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Exxaro Coal Central (Pty) Ltd Dorstfontein West Mine Hydrogeological Investigation

Report

Version - 1

30 March 2020



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EXECUTIVE SUMMARY

Exxaro Coal Central (Pty) Ltd commissioned GCS Water and Environment (Pty) Ltd to undertake a hydrogeological investigation and groundwater numerical model update for their Dorstfontein West Colliery as part of the Environmental Authorisation process required for the site Environmental Impact Assessment.

Dorstfontein West Colliery is an operational coal mine, located near the town of Ga-Nala (Kriel), Mpumalanga Province, which is currently mining the No. 2 Seam and No. 4 Seam with a confirmed life of mine plan until 2045.

Previous hydrogeological investigations and modelling was performed and reviewed for this study and the following mine plans were integrated into this hydrogeological study:

- Mining of the No. 2 Seam up to 2019; and;
- Mining of the No. 4 Seam up to 2045.

The coal reserves located at Dorstfontein Coal Mine forms part of the coal-bearing sandstones and siltstones of the Vryheid Formation which rest either conformably on diamictites and associated glaciogenic sediments of probable Dwyka age, or unconformably on basement rocks of the Lebowa Granite suite, which in turn is underlain by volcanic rocks of the Loskop Formation.

Three principal aquifers are identified in the conceptual geohydrological model for the Mpumalanga coalfields: the weathered aquifer, the fractured Karoo aquifer and the fractured pre-Karoo aquifer. The aquifers that occur in the area are classified as minor aquifers (low yielding) but of high importance. Transmissivity values are between 0.01 and 22.5 m²/day with an average value of 3.3 m²/day and a geometric mean of 0.75 m²/day. These values are typical of the Karoo type aquifers.

The weathered layer has a thickness of approximately 15 m and is comprised of residual soils and weathered shales and sandstone with hydraulic conductivity values in the order of 10⁻² m/d. The underlying fractured units consist of shale, sandstone and coal seams in which groundwater movement is limited to secondary porosity, i.e. fractures. Fracturing mainly occurs in the top of this unit and decreasing with depth. Hydraulic conductivity will therefore decrease with depth and range between 10⁻² m/d in the upper layers and 10⁻⁴ m/d for the lower layers.

Groundwater levels generally follow topography and static groundwater levels are mostly within 5 m below ground level (average of 5.5 m below ground level) with some deeper groundwater levels up to 30 m below ground level. Groundwater in the surrounding area is used for single or several households for domestic use, as a water supply for farm workers and in two cases for small communities of 50 - 100 people. Groundwater quality is generally of good quality when compared to drinking water standards and there are no indications that existing mining activities are impacting on private or third-party groundwater sources.

The discard from the underground mine workings has some net acid potential and the interstitial water in the oxic zone of the discard dump facility will acidify. The material from the mine has a net potential to acidify the mine water. Acid-mine drainage generation in the underground will depend on the oxygen ingress versus time for the mine voids to flood. While oxygen is still present, the underground mine water will reach sulphate concentrations of about 2,000 - 2,300 milligrams per litre over the long-term.

After oxygen is depleted; no more sulphate is generated and because of the low recharge rate, sulphate concentrations will remain fairly constant between 2 000 - 2 300 mg/l for several decades.

The conclusions from the geochemical assessment are in line with the water quality monitoring results. Material from the discard dump and coal stockpile facility / area was found to have the potential to become acidic and cause seepage with elevated sulphate concentrations. Elevated sulphate concentrations were found in boreholes down gradient of the discard dump facility. Seepage from the discard dump, the coal stockpile and plant area are captured in the PCD's; as a result, the water in the PCD's shows elevated sulphate concentrations. Boreholes and surface water sampling points down gradient of the PCD's show elevated sulphate concentrations.

The main potential on-site contamination sources for Dorstfontein West are the underground mine workings and the discard dump facility, and to a lesser extent the PCD's, coal stockpile and plant area. Possible pathways for on-site contaminations are surface water streams and the weathered and fractured Karoo aquifers. Potential receptors are a perennial stream and two ephemeral tributaries of the Steenkoolspruit. No privately-owned boreholes were found down gradient of Dorstfontein West.

Based on the groundwater monitoring results there is a sulphate plume localized down gradient of the discard dump facility. The water quality improves further away from the surface infrastructures at Dorstfontein West and no impact on the surface water quality was found at the time of the investigation. No impact of the current underground mining on groundwater quality has been found, this is however only likely to be relevant for the operational phase.

Numerical modelling was carried out to assess potential groundwater ingress, groundwater drawdown and the potential extent of long-term groundwater contamination. A steady state groundwater flow model was used for calibration. Initial estimates of the hydraulic conductivities for different geological units were obtained from the data collected from site-specific aquifer test results combined with information from other studies in the vicinity of the site and were used for a combination of PEST and manual calibration.

Recharge values were re-estimated as part of the calibration and an effective large-scale annual recharge value of 1% of the mean annual precipitation (± 700 mm) was estimated. The calibration was regarded as sufficient with ME = -0.91 m, MAE = 4.08 m, RMS = 4.83 m and RN = 0.04 (or 4%) and a water balance error of less than 0.002%.

A transient groundwater model was used to simulate the development of the drawdown cone over time. Based on the scenario modelling the water levels could be lowered over a relatively large area around the underground mine. The drawdown scenarios show the dewatering of the underground mines will result in a drawdown cone in the area surrounding all mining areas. As the underground voids increase in size, the cone of drawdown caused by the dewatering of the mine voids increases with a maximum extent in 2045.

Groundwater flow directions will be directed towards the mining areas due to the mine dewatering during the operational phase. Therefore, contamination will be contained within the mining area, and little contamination will be able to migrate away from the mining area as can be confirmed by the good groundwater quality in the areas surrounding Dorstfontein West. However, monitoring boreholes DFGW6 and DFGW15-08 were however affected by contaminants emanating from the PCD's and discard dump facilities. The impact significance is likely to be low during the operational phase.

There are several monitoring (NBH0) and privately-owned (NBH1, NBH1B, NBH2, D3, DFTNH18 and DFTNH28/27) boreholes in the potential affected area that might experience a decline in water levels of 10 m or more. The impact of the current cone of dewatering could not be confirmed due to the monitoring borehole NBH0 being locked at the time of this investigation. Privately-owned boreholes NBH1, NBH1B, D3, DFTNH18 and DFTNH28/27 might be impacted upon from 2029 and NBH2 from 2033 as mining activities advances over time.

Once the mining has ceased, ARD is still likely to form given the unsaturated conditions in the facility and contact of water and oxygen through natural processes including precipitation. The contaminant plume emanating from the underground workings and the discard dump facility will move in a westerly direction towards an unnamed perennial tributary of the Steenkoolspruit.

At Dorstfontein West the potential decant points are located at the lowest topographical sections of the underground mines. The calculations show the time-to-decant ranges between ~56 and ~280 years. Decant volume calculations show discharge rates of between approximately 260 and 1,560 m³/d. The rate of water level recovery in the underground voids should be monitored. The expected significance of the impact from decant is high.

The following recommendations are made:

- A closure water management plan should be developed. This should assess the managed of decant via channelled decant or the management of a critical water level to minimise contamination of the shallow weathered aquifer. The discard dump facility should also be assessed in terms of a remediation action plan should the risk for contaminating on the stream be high. This should all be analysed in a financial model to further inform the most effective closure water management options. The groundwater model should be used as a management tool to inform this process;
- The actions in the groundwater monitoring plan should be adhered to;
- All mining areas should be flooded as soon as possible to restrict oxygen ingress to lower sulphate levels in seepage;
- The rate of water level recovery in the underground voids should be monitored. Stage curves should be developed which would aid in the management of closure phase;
- Treatment options of decant should be investigated for the post-closure phase;
- Water quality sampling of the two tributaries of the Olifants River is essential for the operational and post-closure phase;
- The groundwater monitoring network should be expanded for the operational and post-closure phases at DCMW;
- The numerical model should be updated once every three years or after significant changes in mine schedules or plans by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario.

GLOSSARY

A confined aquifer - a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric pressure.

ABA - Acid Base Accounting

An unconfined, water table or phreatic aquifer - are different terms used for the same aquifer type which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

ANC - Acid Neutralising Capacity

Aquifer - A body of rock, consolidated or unconsolidated, that is sufficiently permeable to conduct groundwater and to yield significant quantities of water to wells and springs.

ARD - Acid Rock Drainage

Bedrock - A general term for the rock that underlies soil or other unconsolidated superficial material.

Cone of depression - A depression in the potentiometric surface of a body of groundwater that has the shape of an inverted cone and develops around a well/mine shaft/open pit mine from which water is being withdrawn.

Drawdown - The decline of the water table or potentiometric surface as a result of withdrawals from wells or excavations.

DCMW/ DCM West - Dorstfontein Coal Mine West / Dorstfontein West

DWS - Department of Water and Sanitation (Used to be DWA and DWAF)

EC - Electrical Conductivity (mS/m)

Effective porosity - is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Fault - A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fe - Iron (mg/l)

Fracture - A crack, joint, fault or other break in rocks caused by mechanical failure.

Groundwater table - is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

Heterogeneous - indicates non-uniformity in a structure.

Hydraulic conductivity (K) - Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow.

Hydraulic gradient - is the rate of change in the total head per unit distance of flow in a given direction.

Hydraulic head - Generally the altitude of the free surface of a body of water above a given datum.

Interflow - The lateral movement of water in the unsaturated zone during and immediately after precipitation. Interflow occurs when the zone above a low permeability horizon becomes saturated and lateral flow is initiated parallel to the barrier.

Joint - A fracture in rock along which there has been no visible movement.

K - Hydraulic Conductivity

LoM - Life of Mine

mamsl - Metres above mean sea level

mbgl - Metres below ground level

Mechanical dispersion - is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

NAG - Net Acid Generation

NGDB - National Groundwater Database

Observation borehole - is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

PCD - Pollution Control Dam

Perched Water Table - The upper surface of a body of unconfined groundwater separated from the main body of groundwater by unsaturated material.

Permeability - the ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time. Permeability is not to be confused with hydraulic conductivity. While similar, permeability considers the properties of the fluid being transmitted.

pH - is a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity.

Piezometric head - is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a piezometric surface, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity - The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.

Pumping tests - are conducted to determine aquifer or borehole characteristics.

Recharge - is the addition of water to the zone of saturation; also, the amount of water added.

S - Storativity

SO₄ - Sulphate (mg/l)

Specific yield - the ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium. Specific yield is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table in an unconfined aquifer.

Static water level - is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity - the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness.

TDS - Total Dissolved Solids (mg/l)

Total dissolved solids (TDS) - is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) - is a measure of the ease with which groundwater flows in the subsurface. It is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated aquifer thickness.

Vadose zone - is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table - is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

CONTENTS PAGE

1	INTRODUCTION	1
1.1	PROSED ACTIVITIES	1
1.2	STUDY OBJECTIVES AND SCOPE OF SERVICE	1
2	METHODOLOGY.....	2
2.1	DATA REVIEW	2
2.2	HYDROCENSUS	3
2.3	GEOCHEMICAL ASSESSMENT UPDATE	4
2.4	SITE CONCEPTUALISATION AND GROUNDWATER NUMERICAL MODELLING	5
2.4.1	<i>Site Conceptualisation.....</i>	<i>5</i>
2.4.2	<i>Numerical Modelling.....</i>	<i>5</i>
2.4.2.1	<i>Model Construction and Calibration</i>	<i>6</i>
2.4.2.2	<i>Scenario Modelling.....</i>	<i>6</i>
2.5	IMPACT ASSESSMENT	6
2.6	GROUNDWATER MANAGEMENT PLAN.....	7
2.6.1	<i>AMD Treatment Plan.....</i>	<i>7</i>
3	GENERAL PHYSIOGRAPHICAL AND GEOLOGICAL DESCRIPTION	7
3.1	LOCALITY	7
3.2	CLIMATE AND SURFACE WATER DRAINAGE	9
3.2.1	<i>Climate.....</i>	<i>9</i>
3.2.2	<i>Catchment.....</i>	<i>10</i>
3.2.3	<i>Drainage.....</i>	<i>10</i>
3.3	GEOLOGICAL SETTING.....	10
3.3.1	<i>Regional Geology.....</i>	<i>10</i>
3.3.2	<i>Local Geology.....</i>	<i>11</i>
4	HYDROGEOLOGICAL DESCRIPTION.....	13
4.1	AQUIFER HYDRAULICS	14
4.2	HYDROCENSUS INVESTIGATION	15
4.2.1	<i>Borehole Status and Use.....</i>	<i>17</i>
4.2.2	<i>Groundwater Use</i>	<i>17</i>
5	MINE INFRASTRUCTURE AND ACTIVITIES.....	17
5.1	DISCARD DUMP EXTENSION	21
6	GROUNDWATER QUALITY	21
6.1	HYDROCENSUS BOREHOLES	21
6.2	MONITORING BOREHOLES	23
6.3	BOX CUT	30
6.4	POLLUTION CONTROL DAMS	30
6.5	DISCARD DUMP	32
6.6	DCM No. 2 SEAM	33
6.7	CONCLUSION SUMMARY	34
7	GROUNDWATER LEVELS.....	34
7.1	HYDROCENSUS BOREHOLES	34
7.2	MONITORING BOREHOLES	35
7.3	GROUNDWATER AND TOPOGRAPHY	37
8	GEOCHEMICAL ASSESSMENT	37
8.1	PREVIOUS GEOCHEMICAL ASSESSMENT SUMMARY.....	37
8.2	MINERALOGY AND TOTAL ELEMENT ANALYSIS	38
8.3	ACID-BASE ACCOUNTING AND NET-ACID GENERATION TESTS	40
8.3.1	<i>Acid-Base Accounting (ABA) Terminology and Screening Methods.....</i>	<i>40</i>
8.3.2	<i>Net-Acid Generation (NAG) Terminology and Screening Methods.....</i>	<i>42</i>

8.3.3	ABA and NAG Test Results	43
8.4	STATIC LEACH TEST RESULTS	44
8.5	KINETIC COLUMN LEACH TEST RESULTS	46
8.6	CONCEPTUAL GEOCHEMICAL MODEL	49
8.6.1	Oxygen and Water Infiltration.....	49
8.6.2	Geochemical Reactions.....	50
8.7	GEOCHEMICAL NUMERICAL MODEL	51
8.7.1	Introduction	51
8.7.2	Modelling Scenarios.....	52
8.7.3	Geochemical Model Results.....	52
8.7.3.1	Model Results	52
8.7.3.2	Predicted Seepage Water Quality Summary	56
8.7.4	Model Limitations.....	58
8.8	GEOCHEMICAL MODELLING CONCLUSIONS.....	58
8.8.1	Geochemical Assessment and Site Water Quality	59
9	HYDROGEOLOGICAL SITE CONCEPTUALISATION	60
9.1	SOURCE	60
9.2	PATHWAY	60
9.3	RECEPTOR.....	61
10	HYDROGEOLOGICAL NUMERICAL MODELLING.....	61
10.1	MODEL CONFIDENCE LEVEL CLASSIFICATION	61
10.2	MODEL LIMITATIONS AND EXCLUSIONS.....	62
10.3	MODEL CODE, DESIGN AND CONSTRUCTION	63
10.3.1	Governing Equations.....	63
10.3.2	Model Software Package.....	63
10.3.3	Boundary Conditions.....	64
10.3.4	Finite Difference Grid.....	66
10.3.5	Vertical Discretisation.....	66
10.3.6	Time Discretisation.....	68
10.3.7	Mine Schedule.....	68
10.3.8	Model Input Parameters.....	68
10.4	CALIBRATION AND SENSITIVITY ANALYSIS	68
10.4.1	Calibration.....	68
10.4.1.1	Calibration Targets	69
10.4.2	Steady-State Calibration.....	69
10.4.2.1	Aquifer Hydraulic Conductivity	73
10.4.2.2	Other Model Parameters.....	73
10.4.3	Sensitivity Analysis	74
11	NEW MINE ACTIVITIES POTENTIAL IMPACTS.....	74
11.1	ENVIRONMENTAL IMPACT SIGNIFICANCE RATING METHODOLOGY.....	74
11.2	OPERATIONAL PHASE	77
11.2.1	Groundwater Quantity (Groundwater Level Drawdown).....	77
11.2.2	Mine Inflow Volumes.....	80
11.2.3	Groundwater Quality (Contamination of Surrounding Aquifer/s)	81
11.2.4	Operational Phase Impact Rating	81
11.3	POST-CLOSURE PHASE.....	83
11.3.1	Groundwater Quality.....	83
11.3.2	Discard Dump.....	85
11.3.3	Mine Water Decant.....	86
11.3.4	Post-Closure Phase Impact Rating	88
12	GROUNDWATER MANAGEMENT PLAN.....	90
12.1	PROPOSED ACTIONS	90
12.1.1	Operational Phase.....	90

12.1.2	Post-Closure Phase.....	91
12.2	AMD TREATMENT PLAN	93
12.2.1	Site Characterisation and Field Work.....	93
12.2.1.1	Test Work	94
12.2.2	Risk-Based AMD Assessment.....	94
12.2.3	Prevention.....	95
12.2.3.1	Landform Design and Final Topography	96
12.2.3.2	Groundwater	97
12.2.3.3	Surface Water	97
12.2.3.4	Climate Change and Vegetation.....	98
12.2.4	Treatment	98
12.2.5	Treatment Options	99
12.2.6	AMD Management Plan	99
12.3	GROUNDWATER MONITORING NETWORK	99
12.3.1	Operational Phase Monitoring	99
12.3.2	Post-Closure Phase Monitoring.....	100
13	CONCLUSIONS AND RECOMMENDATIONS	101
14	REFERENCES.....	103

LIST OF FIGURES

Figure 3-1	DCMW Locality.....	8
Figure 3-2	Precipitation Distribution	9
Figure 3-3	DCMW Regional Surface Geology.....	12
Figure 5-1	DCMW Surface Infrastructure.....	18
Figure 5-2	DCMW No. 2 Seam Mine Plans	19
Figure 5-3	DCMW No. 4 Seam Mine Plans	20
Figure 6-1	Durov Diagram - Hydrocensus Borehole.....	23
Figure 6-2	Manganese Concentration (Box Cut Proximity Boreholes).....	30
Figure 6-3	Sulphate Concentration (PCD's Proximity Monitoring Locations)	31
Figure 6-4	Manganese Concentration (PCD's Proximity Monitoring Locations).....	32
Figure 6-5	Sulphate Concentration (Discard Dump Proximity Monitoring Locations).....	33
Figure 6-6	Sulphate Concentration (DCM No. 2 Seam Proximity Monitoring Locations) ...	34
Figure 7-1	DCM No. 2 Seam Groundwater Levels	36
Figure 7-2	DCMW Groundwater Levels.....	36
Figure 7-3	DCM Surface Elevation - Groundwater Level Correlation.....	37
Figure 8-1	Sample Classification in terms of % S (Below 3%) and NP/AP (Below 10).....	44
Figure 8-2	Discard 1 Sulphate (SO ₄), Electrical Conductivity (EC) and pH.....	47
Figure 8-3	Discard Dump Conceptual Model (Illustrating Oxidic Presence and Anoxic Zone) 50	
Figure 8-4	Scenario A - Changes in pH Values Over Model Time.....	53
Figure 8-5	Scenario A - Changes in SO ₄ Concentration Over Model Time	54
Figure 8-6	Scenario A - Changes in Mineralogy Over Model Time.....	55
Figure 10-1	DCMW Model Boundary Types and Grid	65
Figure 10-2	DCMW Model Cross-Section.....	67
Figure 10-3	Steady State Model Calibration Results (Pre-Mining).....	71
Figure 10-4	Steady State Model Pre-Mining Groundwater Levels.....	72
Figure 10-5	Parameter Sensitivity Summary (Relative Composite)	74
Figure 11-1	Simulated Groundwater Cone of Drawdown Extent.....	79
Figure 11-2	Simulated Groundwater Inflows	80
Figure 11-3	Simulated Sulphate (SO ₄) Contaminant Plume	84
Figure 11-4	Potential Decant Points.....	87
Figure 12-1	Risk-based AMD approach	95

LIST OF TABLES

Table 4-1	Statistics for Results on Packer Tests (WRC Report No 291/1/98)	14
Table 4-2	Transmissivity Values Statistics	15
Table 4-3	Hydrocensus Summary	16
Table 6-1	Water Quality Comparison - SANS 241-1 Drinking Water Standard.....	22
Table 6-2	Monitoring Network Summary	24
Table 6-3	DCM Groundwater Quality Comparison (SANS 241-1:2005 Drinking Water Standard and Resource Quality Limits).....	26
Table 6-4	DCMW Groundwater Quality Comparison (SANS 241-1:2015 Drinking Water Standard)	27
Table 6-5	Wastewater Facility Surface Water Quality Comparison (WUL Requirements)	28
Table 6-6	River and Stream Water Quality Comparison (SANS 241-1:2015 Drinking Water Standard)	29
Table 7-1	Groundwater levels recorded during the February 2019.....	35
Table 8-1	XRF Major Oxide Results (Weight %)	40
Table 8-2	X-ray diffraction results (weight %)	40
Table 8-3	Description of identified minerals	40
Table 8-4	NP:AP Ratio Screening Methods (Price, 1998)	42
Table 8-5	NAG Test Screening Method (Miller et al., 1998)	42
Table 8-6	Acid-Base Accounting (ABA) and Net-Acid Generating (NAG) Results	44
Table 8-7	Peroxide Leachate Physical Parameters and Major Anions	46
Table 8-8	Discard 1 ICP Weekly Leach Results	48
Table 8-9	Geochemical Scenario Model Description	52
Table 8-10	Geochemical Model Scenario Weighted Average %S and NP.....	52
Table 8-11	Discard Dump Estimated pH and SO ₄	57
Table 8-12	Evolution in Acid-Mine Drainage (AMD) (adapted from Fourie 2014) *	58
Table 10-1	Identification of the real-world boundaries and adopted model boundary conditions	64
Table 10-2	Steady State Model Mass Balance (Pre-Mining)	71
Table 10-3	Horizontal and Vertical Calibrated Hydraulic Conductivity Values	73
Table 10-4	Karoo Aquifers Calibrated Transmissivity Values.....	73
Table 11-1	Groundwater Impacts - Operational Phase.....	82
Table 11-2	DCMW Underground Void Volume Calculation Summary.....	88
Table 11-3	DCMW Time-To-Decant Calculation Summary	88
Table 11-4	DCMW Decant Volumes	88
Table 11-5	Groundwater Impacts - Post-Closure Phase.....	89
Table 12-1	Operational, Decommissioning and Post-Closure Phases Groundwater Monitoring Programme	100

LIST OF APPENDICES

APPENDIX A HYDROCENSUS LABORATORY CERTIFICATES.....	105
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1 INTRODUCTION

GCS Water and Environment (Pty) Ltd was appointed by Exxaro Coal Central (Pty) Ltd to undertake a hydrogeological specialist study as part of the Environmental Authorisation process required for the site Environmental Impact Assessment.

Dorstfontein West Mine (Pty) Ltd, also known as Dorstfontein Coal Mine (Pty) Ltd, is an underground mine with both No. 2 and No. 4 Seams operated by Exxaro, located within the jurisdiction of Emalahleni Local Municipality in the Mpumalanga Province.

1.1 Proposed Activities

Exxaro Coal Central (Pty) Ltd (Exxaro) Dorstfontein Coal Mine West (DCMW) is currently mining No. 2 Seam via underground mining methods on the western portion of their mining right area and proposes to mine No. 4 Seam via board and pillar mining method.

Exxaro proposes the following new activities on site:

- Expansion of the existing discard dump which is coming to the end of its life by 2022;
- Mining at No. 4 Seam; and
- The construction of a conveyor belt and associated service road, from DCMW which will be linked to the conveyor systems at DCM East (DCME) to ensure coal is conveyed from DCMW to DCME where the coal will be loaded and transported to Richards Bay Terminal via rail.

1.2 Study Objectives and Scope of Service

The objectives of the study were to:

- Identify any fatal flaws or key issues in terms of site and regional hydrogeology and interaction between surface water and groundwater; and
- Adhere to environmental laws and regulations, and to define any potential recommendations for the site's Integrated Water Use Licence Application (IWULA).

The scope of service for the hydrogeological assessment consisted of the following tasks:

- A desktop review and short baseline hydrogeological description of the site area, including review of:
 - Surface water drainage and its potential impact on groundwater;
 - Geochemical assessment gaps;
 - Groundwater monitoring network;
 - Structural geophysics; and
 - Aquifer parameters.
- Hydrocensus investigation;
- Pollution plumes:

- Determination of the existence and extent of the pollution plume at the site.
- Determination of the source of the pollution plume based on current activities as revealed by the current monitoring network.
- Determine short-term and long-term pollution (post-closure) potential of all the discard dumps and conduct necessary tests for such determination.
- Mine decant:
 - Determine or confirm decant points.
 - Determine the quantity and quality of water that might decant from the underground workings post-closure also the timing of such decant.
 - Determine possible options on the post-closure water treatment based on the predicted decant quantity and quality.
- Determine the quantity and quality of water that might originate from the discard dump in the short-term and post-mine closure.
- Make recommendations:
 - For short term and long-term interventions that can be implemented to prevent or mitigate pollution;
 - For a site Acid Mine Drainage treatment plan; and
 - To further increase the confidence of the modelling work done in future.

2 METHODOLOGY

2.1 Data Review

Data that were reviewed included:

- Published 1:250,000 scale geological data and map (CGS,1986);
- Published hydrogeological data and map Johannesburg 2526 (Barnard, 2000);
- South African Mine Water Atlas (WRC, 2016);
- Public domain climatic and topographic data for the site;
- Exxaro DCMW Water Use License (04/B11B/ACGIJ/506) - and associated amendments;
- Groundwater monitoring data received from the client (2015 - 2019);
- Groundwater monitoring data conducted by GCS (2010 - 2014);
- Received mine plans and schedule.

The following GCS Water and Environment (Pty) Ltd. reports formed part of the review process:

- GCS Water and Environment (Pty) Ltd, 2007. Hydrogeological Study for the Dorstfontein Western Expansion Project (P/N: TCSA.D.07.022);
- GCS Water and Environment (Pty) Ltd, 2008. Dorstfontein 4-seam EMP Study - Hydrogeological Investigation (P/N: TCSA.D07.251);
- GCS Water and Environment (Pty) Ltd, 2009. Geohydrological Study for the Dorstfontein Western Expansion Project (P/N: 08-246);

- GCS Water and Environment (Pty) Ltd, 2009. Hydrogeological Assessment for Total Coal Forzando Mining Sections. Version 1 (P/N: 08-377);
- GCS Water and Environment (Pty) Ltd, 2009. Dorstfontein Eastern Expansion - Water Use License Application Calculations (P/N: 09-303);
- GCS Water and Environment (Pty) Ltd, 2009. Dorstfontein Coal Mine East Mine Expansion Project - Environmental Management Programme (P/N: 10-007);
- GCS Water and Environment (Pty) Ltd, 2011. Hydrogeological Study for the Dorstfontein Western Expansion Project (P/N: 10-007);
- GCS Water and Environment (Pty) Ltd, 2012. Dorstfontein coal mine: west mine expansion project - Revised - Environmental Impact Assessment and Environmental Management Programme (EIA/EMP);
- GCS Water and Environment (Pty) Ltd, 2015a. Dorstfontein West Hydrogeological Investigation; and
- GCS Water and Environment (Pty) Ltd, 2015b. Dorstfontein East Hydrogeological Investigation.

2.2 Hydrocensus

GCS Water and Environment (Pty) Ltd (GCS) conducted a hydrocensus in 2014 with the main purpose to update regional groundwater users and hydrogeological information. The hydrocensus included the following tasks:

- Identify all water users within this surrounding area;
- Obtain GPS locations all production boreholes, monitoring boreholes, and springs;
- Verify the general status of boreholes;
- Update the groundwater user information, including purpose of abstraction, abstraction rates etc.; and
- Take hydrogeological field measurements (static water levels and borehole depths).

An updated hydrocensus investigation was completed by GCS within a ~ 5 km radius from the site between the 17th and 19th of February 2019, during which 22 boreholes were identified and investigated.

The updated hydrocensus will confirm the current groundwater conditions within the hydrocensus area and identify any major changes from the previous 2014 hydrocensus investigation. The following information was recorded (where possible) at each of the identified locations:

- GPS Coordinates (decimal degrees, Geographic WGS84);
- General site conditions;
- Water usage/s;
- Ownership of the feature (where applicable);

- Field parameters (e.g. pH and electric conductivity (EC));
- Water level or flow regime; and
- Equipment installed (where applicable).

Groundwater samples were collected from selected hydrocensus boreholes. The samples were submitted to a South African National Accreditation System (SANAS) accredited laboratory for analyses and the analysis was carried out in accordance with methods prescribed by and obtained from the South African Bureau of Standards (SABS), in terms of the Standards Act, Act 30 of 1982. The results were compared to the South African National Standards (SANS) 241:2015 water quality standards for drinking water. The SANS drinking water standard was used for comparison and not for compliance purposes.

The laboratory analyses included:

- Major anion and cations;
- ICP metal scan; and
- pH, Total Dissolved Solids (TDS), Bicarbonates, Electrical Conductivity (EC), and Total Hardness.

The methodology in the collection and preservation of groundwater samples is important for the reliability of the analysis. Samples were taken and preserved to ensure a correct version of the on-site conditions at the site area. This work was undertaken in accordance to the following publications:

- SABS ISO 5667-11:1993 Guidance on sampling of groundwater
- SABS ISO 5667-1:1980 Guidance on the design of sampling programs
- SABS ISO 5667-2:1991 Guidance on sampling techniques
- SABS ISO 5667-3:1994 Guidance on the preservation and handling of samples

The hydrocensus results are discussed in Section 4.2.

2.3 Geochemical Assessment Update

An environmental geochemical assessment was conducted previously by GCS in 2015 (GCS, 2015a). The main objectives of that assessment were to:

- Determine the geochemical nature of the material for the underground workings, discard dumps and run of mine;
- Determine the long-term net acid generation potential;
- Identify metals that may be present in drainage from the mine; and
- Perform geochemical modelling in order to predict future decant water qualities from the mine.

A total of twenty (15) samples were collected for the 2015 study. To confirm the above objectives and taking into account the proposed activities listed in Section 1.1; an additional 5 samples were collected to undergo geochemical analyses.

Based on the geochemical assessment, mitigation measures will be recommended in order to minimize any impact on drainage quality from the mine.

The geochemical analyses and geochemical model are discussed in Section 8.

2.4 Site Conceptualisation and Groundwater Numerical Modelling

2.4.1 Site Conceptualisation

The existing conceptual model was updated using all available information including the following: hydrocensus, mine plans and schedules, as well as the regional geological and hydrogeological setting. The conceptual model further includes all potential sources of contamination as well as preferential pathways that were identified during site visits. The conceptual model quantifies and describes the interactions between the hydrogeological, geological and hydrological environments.

2.4.2 Numerical Modelling

The existing numerical groundwater flow and contaminant transport model was updated, refined and calibrated using the new data for the mine scenarios. Once the model was calibrated it was used to simulate the expected groundwater inflows, drawdown and contaminant transport associated with the project.

The numerical model for the project was updated using Groundwater Modeling System (GMS) 10.4.5, a pre- and post- processing package for the modelling code MODFLOW-USG and MT3D-USGS.

MODFLOW-USG is based on an underlying control volume finite difference (CVFD) formulation in which a cell can be connected to an arbitrary number of adjacent cells. MODFLOW can perform both steady state and transient analyses and supports a wide variety of boundary conditions and input options.

MT3D-USGS is a 3D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3D-USGS is an update of MT3DMS, which uses a modular structure similar to the structure utilized by MODFLOW and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation. MT3D-USGS includes the following four (4) new packages:

- Contaminant treatment system;
- Unsaturated zone transport;
- Lake transport; and

- Surface flow transport.

The numerical modelling was undertaken in a number of steps, as detailed below.

2.4.2.1 Model Construction and Calibration

Model set-up and calibration involved the following:

- Model construction during which the Model boundaries were identified and quantified, the project sub-catchment was discretised into a model grid, time steps were allocated and error criteria for heads and the water balance was set; and
- Calibration of a flow model refers to a demonstration that the model is capable of reproducing field-measured heads and flows which are the calibration values.

Calibration was achieved when a set of parameters, boundary conditions and stresses are found that produce simulated heads that match field measured data. This is a crucial step in the modelling project, which will aid in ensuring that model results are reliable.

Following calibration, the model was used to simulate various scenarios for future mining and infrastructure development at the site.

2.4.2.2 Scenario Modelling

Scenario modelling is used to run future scenarios on varying changes in the natural environment or anthropogenic inputs. Mine dewatering, rebound of water levels after mining ceased and contaminant transport (potential pollution plumes) were simulated.

The deliverables from the modelling phase of the project include a calibrated groundwater flow and contaminant transport model. The results of the modelling provided:

- The extent of potential dewatering;
- Potential impact on surrounding groundwater users;
- Groundwater inflows and decant positions and volumes; and
- Potential contaminant plumes that may originate from the mining areas or waste storage facilities (discard dump, etc.).

2.5 Impact Assessment

Potential impacts were classified according to standard risk assessment methodology and the most significant impacts were discussed in detail. The impact assessment included the updated mine schedule, extension of the discard dump facility, and a geochemical assessment.

2.6 Groundwater Management Plan

Based on the impact assessment, a groundwater management plan was formulated. An update of the groundwater monitoring programme was also conducted in order to monitor the potential impacts. Furthermore, an Acid Mine Drainage (AMD) treatment plan was included.

2.6.1 AMD Treatment Plan

An approach for an AMD treatment plan for DCMW for the short and long term be given. Treatment will depend on the extent, volume and the make-up of the AMD, as well as the geographical area that it affects. The potential AMD decant volumes and chemistry predicted from the numerical groundwater flow modelling scenarios and pre-treatment methods available will be considered. Thereafter, the best methodology will be selected for the AMD treatment plan.

Note of Importance: The AMD treatment methodology does not include detailed treatment designs or costing.

3 GENERAL PHYSIOGRAPHICAL AND GEOLOGICAL DESCRIPTION

3.1 Locality

DCMW is situated on the farm Dorstfontein 71 IS, directly north-east of the town of Ga-Nala (Kriel), which falls within the Magisterial District of Bethal, under the jurisdiction of the Emalahleni Local Council, Mpumalanga Province.

The current underground mining operations are accessible via the R547 (Ga-Nala - Witbank road). The site locality is given in Figure 3-1 together with the updated mine plans, hydrocensus boreholes and monitoring boreholes.

The hydrocensus and site monitoring is discussed in more detail in Section 4 to Section 7 of this report.

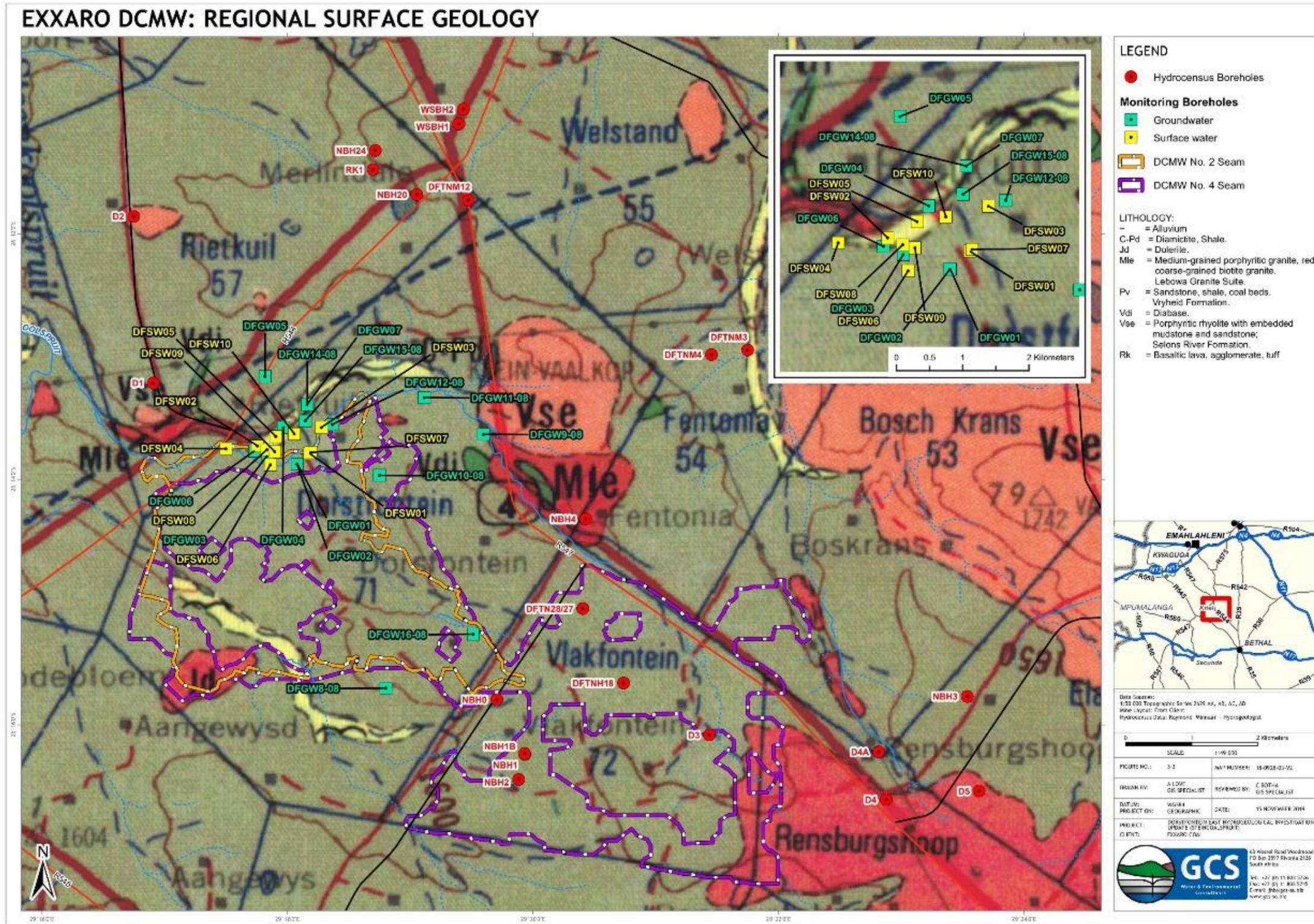


Figure 3-1 DCMW Locality

3.2 Climate and Surface Water Drainage

3.2.1 Climate

Climate Data was obtained from the South African Weather Service and databases of WR2005 during the GCS 2015 hydrogeological study (GCS 2015a). The local climate can be described as semi-arid high-veld conditions, with warm summers and moderate dry winters. Average daily summer temperatures of approximately 27 °C are experienced, while peak temperatures of up to 36 °C do occur. The number of days of heavy frost occurrences are however, limited and freezing of wet soils, frost heave and permafrost do not occur.

Relative humidity ranges from a minimum of 34 % to a maximum of 94 %, with dry atmospheric conditions dominating. The average annual precipitation of ~ 700 mm is considerably less than the average annual A-pan evaporation of ~ 1 840 mm. Evaporation of open surfaces of water (lake evaporation), though less than A-pan values, will be significant (calculated at ~ 1 500 mm per annum) and plant-life in natural local grasslands will be dormant for long periods during the year.

Although local climate change assessments do not indicate significant changes between long-term Mean Annual Precipitation (MAP) and modelled 'now climate', a trend of increased early summer precipitation and decreased late summer precipitation is evident. Normal Dry Weather Conditions (precipitation and runoff values exceeded on average 70 % of time) are used to describe climate change impacts. Trends of change in precipitation are magnified in modelled runoff.

Precipitation (adjusted for the effects of climate change) has a Precipitation Variability Index of 1.7 and is expected to vary as follows:

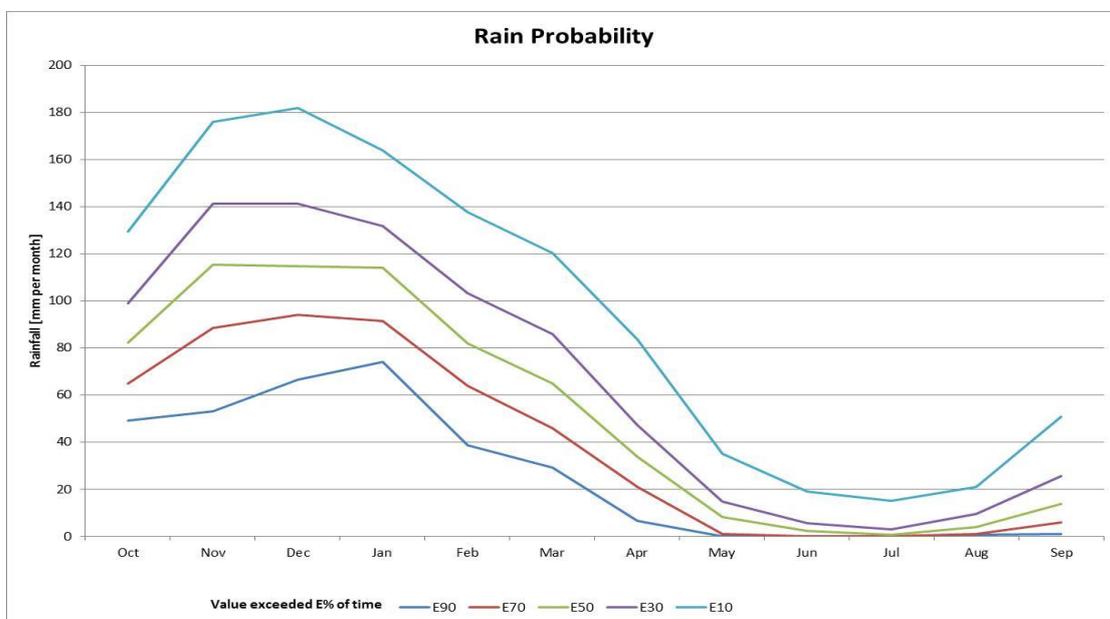


Figure 3-2 Precipitation Distribution

In Figure 3-2 (above) precipitation probability is expressed in terms of how often a value is likely to be exceeded in a given month (example: For December, in 70 % of years in a long-term record, precipitation is likely to exceed 94.2 mm in the month).

3.2.2 Catchment

The extent of the area of investigation is mainly determined by the catchment which is engaged by the mine. DCMW is situated in the B11D quaternary catchment of the Upper Olifants River Water Management Area (WMA). Precipitation that falls within the B11D catchment drains towards the Steenkoolspruit.

3.2.3 Drainage

Recharge to the weathered aquifer from precipitation drains towards regional surface water courses and less than 60 % of the recharge emanates in streams. The remainder is withdrawn through evapotranspiration from the weathered aquifer or drained by other means.

The topography at DCMW, where the current underground mining activities are taking place, differs approximately 50 m in elevation between a higher lying plateau (~1,600 m above mean sea level (m amsl), and two unnamed tributaries of the Steenkoolspruit, which are situated directly to the north and south of the mining area.

3.3 Geological Setting

3.3.1 Regional Geology

The coal reserves located at Dorstfontein forms part of the Highveld Coalfield. The coal in the Highveld Coalfield occurs in the Vryheid Formation of the Ecca Group forming part of the Karoo Supergroup. The area is underlain by coal-bearing sandstones and siltstones of the Vryheid Formation which rest either conformably on diamictites and associated glaciogenic sediments of probable Dwyka age, or unconformably on basement rocks of the Basement Granite. The Ecca sediments overlie the Dwyka Group. Refer to Figure 3-3 for the regional surface geology map.

Pre-Karoo basement rocks outcrop along the eastern section of the farming portion, bordering the Van Dyksdrift-Bethal road, which belong to the Lebowa Granite suite (granite), which in turn is underlain by volcanic rocks of the Loskop Formation.

Five coal seams numbered from bottom to top as No. 1 - 5 are present. Only two of the seams are feasible over most of the area. These are No. 2 and No. 4 coal seams, which are usually separated by sediments of a total thickness in the order of 20 - 30 m. The thickness and distribution of the seams have been controlled by paleotopography, pre- and syndepositional events, and the later destructive effects of dolerite intrusions. The DCM area was unaffected by major fluvial events contemporaneous with peat accumulation, thus modification of seam thicknesses by ancient erosion is minimal.

During late Jurassic times the Karoo strata were invaded by dolerite dykes and sills resulting in the devolatilization of coal proximal to intrusions. The tendency of dolerite sills to migrate to differing stratigraphic levels has caused seam displacement.

3.3.2 Local Geology

The structural nature of the coal seam and the overburden formation has resulted in sub-outcropping occurring in the western portions of the farm Dorstfontein. The seams targeted at DCMW are the No. 2 seam and No. 4 seam. The No. 4 Seam is divided into an Upper and Lower Seam. Both seams are widely developed, but it is the No. 4 Lower Seam that is the prime economic target of this coal field. Dolerite sills and dykes are also common in the Witbank field. Granite outcrops close to the box cut.

The No. 2 coal seam occurs at about 20 - 30 m below the No. 4 coal seam and is also laterally continuous. The thickness of the No. 2 seam varies between approximately 1m and 3 m. Locally the No. 2 coals seam is divided into an upper and lower seam with a parting thickness of up to 0.7 m, based on available data.

From available information the No. 4 Lower Seam is laterally continuous and is economically the most important of the No. 4 Seam. The No. 4 Lower Seam varies from 1.4 to 5.5 m in thickness where it is laterally continuous, but locally in the west and north-east it may be up to 8 m thick. It consists mainly of dull coal. The average thickness of the No. 4 Lower Seam is 4 m. Shale intercalations are common in the upper part of the seam, which consists mainly of dull coal (Snyman, 1998).

The floor elevations of the No. 4 Coal Seam do not indicate any general dipping trend. The coal seam is more or less undulated with anticline elevation at approximately 1,590 m amsl and syncline elevation at approximately 1,510 m amsl. However, the coal seam in the area of western expansion project shows certain dipping trend of angle approximately 0.5° in a south-westerly direction. The sulphur level in the coal varies between 0.8 and 1.4 % with an average of just above 1 %. Generally, the sulphur particles are very small (approximately 50 microns). Approximately 50 % of the sulphur is pyretic and 50 % is organic, which results in a reduction in the sulphur content after beneficiation has taken place.

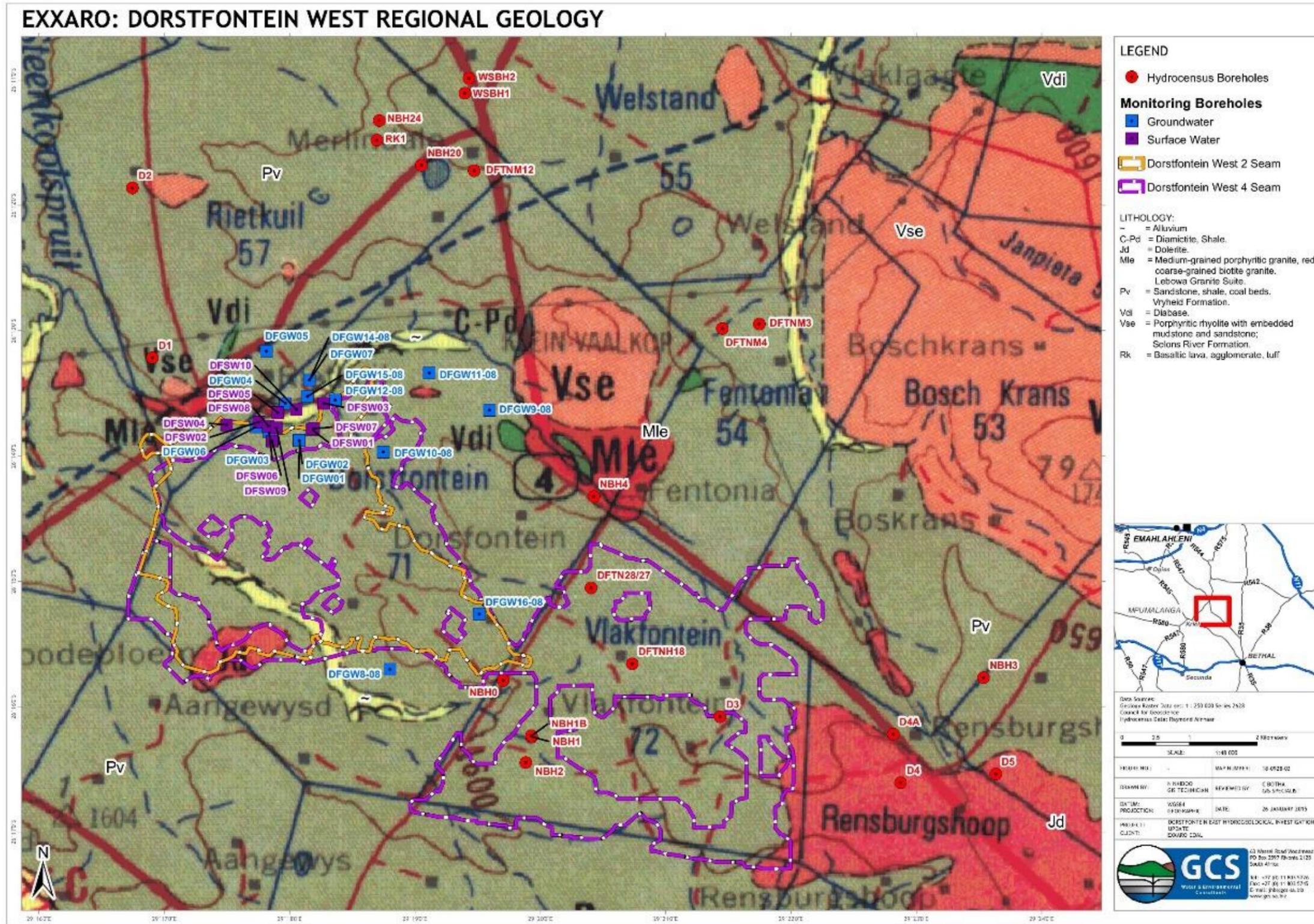


Figure 3-3 DCMW Regional Surface Geology

4 HYDROGEOLOGICAL DESCRIPTION

The hydrogeological site conceptualisation of the area is based on the generally accepted model for the Mpumalanga coalfields. Three principal aquifers are identified: the weathered aquifer; the fractured Karoo aquifer; and the fractured pre-Karoo aquifer (Hodgson & Krantz, 1998). The Karoo rocks are not known for the development of aquifers, but occasional high-yielding boreholes may be present. The aquifers that occur in the area can therefore be classified as minor aquifers (low yielding), but of high importance (Parsons, 1995).

These types of groundwater systems are common to the groundwater regime that characterises a Karoo environment. The systems do not necessarily occur in isolation of one another; more often than not forming a composite groundwater regime that is comprised of one, some, or all of the systems. Good hydraulic connectivity often exists between the two top aquifers and they have consequently been treated as a single unit in the modelling of groundwater flow.

Intrusion-related systems are also often characterised by discrete and / or erratic development. The weathered aquifer is perched and occurs at depths of 0 - 15 m below ground level (m bgl). The lower 5 to 10 m of the perched aquifer is saturated due to the impervious nature of the competent, horizontally stratified lithologies of the underlying Vryheid Formation; which occur at depths of 5 - 15 m bgl. The saturated depth of this aquifer is dependent on precipitation recharge, thus influx of water into a bord and pillar mining operation is also expected to vary seasonally. Highly variable recharge occurs over the area, but generally values are between 1 and 3 % of the MAP (based on work by Kirchner *et al.* (1991) and Bredenkamp (1995) in other parts of the country).

Shallow Weathered Aquifer

Precipitation that infiltrates the weathered rock of the shallow aquifer soon reaches an impermeable layer of shale underlying the weathered zone. The movement of groundwater on top of this shale is lateral and in the direction of the surface slope. This water reappears on surface at fountains where the flow paths are obstructed by a barrier, such as a dolerite dyke, paleo-topographic highs in the bedrock, or where the surface topography cuts into the groundwater level at streams.

The aquifer within the weathered zone is generally low-yielding (range 100 - 2,000 litres per hour (l/h)) because of its insignificant thickness. Few farmers therefore tap this aquifer by borehole. Wells or trenches dug into the upper aquifer are often sufficient to secure a constant water supply of excellent quality.

Fractured Karoo Rock Aquifer

The pores within the Ecca sediments are too well cemented to allow any significant permeation of water. All groundwater movement is therefore along secondary structures, such as fractures, cracks and joints in the sediments. These structures are better developed in competent rocks such as sandstone, hence the better water-yielding properties of the latter rock type.

Of all the un-weathered sediments in the Ecca Group, the coal seams often have elevated hydraulic conductivity. Packer testing of the No. 2 seam and underlying Dwyka tillite (WRC Report No 291/1/98) has the hydraulic conductivity distribution as indicated in Table 4-1.

Table 4-1 Statistics for Results on Packer Tests (WRC Report No 291/1/98)

Statistics	Hydraulic Conductivity	
	No. 2 Seam	Dwyka
[-]	[m/day]	[m/day]
Number of Tests	21	21
Minimum	0.0007	0.0002
Maximum	0.5000	0.0180
Mean	0.1017	0.0034
Median	0.0743	0.0024
Standard Deviation	0.1295	0.0034

Note/s:

- m/day - metres per day

The data listed in Table 4-1 suggest that seepage of water through the No. 2 Seam is possible. Due to its low hydraulic conductivity, the Dwyka tillite may form a hydraulic barrier between the overlying mining activities and the basal floor.

In terms of water quality, the fractured Karoo aquifer always contains higher salt loads than the upper weathered aquifer. These higher concentrations are attributed to the longer contact time between the water and the rock. The occasional high chloride and sodium levels are attributed to boreholes in the vicinity of areas where salts naturally accumulate on surface, such as pans.

4.1 Aquifer Hydraulics

For this study, transmissivity values estimated in earlier reports were reviewed. Transmissivity values were sourced from:

- Eight (8) boreholes at DCMW (prefixed with code DFGW) on which falling head tests were performed;
- Eleven (11) boreholes at DCME (prefixed with code GCS) which were pump tested at a constant rate and allowed to recover;
- Three (3) boreholes at Forzando North (prefixed with code FNGW) which were pump tested at a constant rate and allowed to recover;
- One (1) borehole at Forzando South (prefixed with code FSGW) which was pump tested at a constant rate and allowed to recover; and

- Transmissivity values from Pulles et. al, 1994.

The above results yielded transmissivity values of between 0.01 and 22.5 square metres per day (m^2/d) with an average value of 3.3 m^2/d (Table 4-2).

Table 4-2 Transmissivity Values Statistics

Statistics [-]	Transmissivity [m^2/d]
Number of Observations	36
Minimum	0.01
Maximum	22.25
Average	3.32
Geomean	0.75
Harmonic Mean	0.06

Note/s:

- m^2/d - metres squared per day

Hydraulic conductivities determined from aquifer tests correspond with expected hydraulic parameters for Karoo Aquifers. The values range from 10^{-2} to 10^{-4} metres per day (m/d). The aquifer characteristics can be summarised as follows (GCS, 2009):

- Transmissivity values decreased with depth;
- The No. 4 Seam coal seam is not highly permeable. Some seepage of water from the coal can be expected during mining, and
- Shale and dolerite at depths exceeding 15 m have a hydraulic conductivity between ~ 0.004 and ~ 0.02 m/d .

4.2 Hydrocensus Investigation

Previously, during August and November 2014, GCS conducted a hydrocensus within a ~ 5 km radius of the proposed mining activities where a total of 26 boreholes were visited. During February 2019, GCS conducted another hydrocensus within a ~ 5 km radius of the proposed mining activities. A total of 22 boreholes were visited during February 2019. All the boreholes visited during the February 2019 hydrocensus investigation are illustrated in Figure 3-1 and are summarised in Table 4-3.

Table 4-3 Hydrocensus Summary

Borehole ID	Property Details			Coordinates ¹		Elevation	Static Water Level		Collar Height	Equipment	Primary Use	Sampled	
	Name	Owner	Contacts	Latitude	Longitude		[m amsl]	[m bgl]					[m amsl]
	[-]	[-]	[-]	[DD]	[DD]								
NBH4	Portion RE, Dorstfontein 71 IS	Mr N. Hirschowitz	0826080108	29.340470	26.238700	1621	8.75	1612.25	0.10	Submersible pump	Domestic	Existing Pump System	
DFTNM3	Fentonia	Exxaro	Unknown	29.362470	26.215790	1571	22.50	1548.50	0.12	None	Monitoring BH	Bailer	
DFTNM4	Fentonia	Exxaro	Unknown	29.357560	26.216370	1588	14.35	1573.65	0.16	None	Monitoring BH	Bailer	
DFTNM12	Welstand	Exxaro	Unknown	29.324580	26.195380	1595	8.95	1586.05	0.37	None	Monitoring BH	Bailer	
WSBH2	Welstand	Mr. Swart	0842064476	29.323872	26.183087	1599	56.40	1542.60	0.33	Submersible pump	Domestic	Bailer	
WSBH1	Welstand	Mr. Swart	0842064476	29.323277	26.185065	1598	12.50	1585.50	0.11	Submersible pump	Domestic	Bailer	
NBH24	Portion 2, Rietkuil	Mr I.J.G. De Wet	0823248731	29.311926	26.188684	1612	33.90	1578.10	0.00	Submersible pump	Domestic	Existing Pump System	
RK1	Portion 2, Rietkuil	Mr I.J.G. De Wet	0823248731	29.311639	26.191264	1614	19.10	1594.90	0.06	Submersible pump	Domestic	Existing Pump System	
D4	Portion 2, Boschkrans	Mr E. Muller	0823882139	29.381270	26.276780	1626	10.95	1615.05	0.07	Submersible pump	Domestic	Bailer	
D4A	Portion 2, Boschkrans	Mr E. Muller	0823882139	29.380280	26.270310	1621	2.95	1618.05	0.15	N/A	None	Bailer	
D1	Rietkuil	Municipality	Unknown	29.281769	26.220246	1582	51.10	1530.90	Unknown	Submersible pump	Livestock	Not Sampled	
D2	Rietkuil	Municipality	Unknown	29.279109	26.197638	1598	Not Applicable	Not Applicable	Unknown	None	Destroyed	Not Sampled	
NBH20	Rietkuil	Municipality	Unknown	29.317546	26.194651	1599	Not Applicable	Not Applicable	Unknown	Handpump	Domestic	Not Sampled	
DFTN28/27	Portion 2, Vlakfontein	Mr K. Pieterse	Unknown	29.340110	26.250855	1627	Destroyed	Not Applicable	Unknown	None	Destroyed	Not Sampled	
DFTNH18	Portion 2, Vlakfontein	Mr K. Pieterse	Unknown	29.345609	26.260968	1637	Blocked	Not Applicable	Unknown	Windmill	Domestic	Not Sampled	
NBH0	Portion 1, Dorstfontein	Mr N. Hirschowitz	Unknown	29.328400	26.263197	1626	Locked	Not Applicable	Unknown	None	Monitoring BH	Not Sampled	
NBH1	Portion 2, Vlakfontein	Mr K. Pieterse	Unknown	29.332230	26.270671	1622	20.40	1601.60	Unknown	Windmill	Domestic and livestock	Not Sampled	
NBH1B	Portion 2, Vlakfontein	Mr K. Pieterse	Unknown	29.332190	26.270533	1622	31.60	1590.40	Unknown	Submersible pump	Domestic and livestock	Not Sampled	
NBH2	Portion 1, Vlakfontein	Mr K. Pieterse	Unknown	29.331397	26.274080	1620	24.70	1595.30	Unknown	Submersible pump	Domestic and livestock	Not Sampled	
D3	Portion 2, Vlakfontein	Mr U.G. de Wet	Unknown	29.357274	26.268010	1625	Not Applicable	Not Applicable	Unknown	Unknown	Unknown	Not Sampled	
NBH3	Portion 8, Boschkrans 53 IS	Mr J. Grobler	Unknown	29.392301	26.262788	1658	Not Applicable	Not Applicable	Unknown	Windmill	Unknown	Not Sampled	
D5	Portion 13, Boschkrans	Mr E. Muller	Unknown	29.393906	26.275628	1673	Not Applicable	Not Applicable	Unknown	Windmill	Unknown	Not Sampled	

Notes:

- DD - Decimal Degrees
- m amsl - metres above mean sea level
- m bgl - metres below ground level
- m agl - metres above ground level

¹. Coordinate System - Projection: *Geographic*
- Datum: *WGS84*

4.2.1 Borehole Status and Use

Information pertaining to water use of the 22 boreholes is listed below:

- Twelve (12) boreholes were used for domestic, stock watering and irrigation purposes;
- Four (4) boreholes (three (3) Exxaro owned and one (1) privately owned) are used for environmental monitoring purposes;
- One (1) borehole was not in use;
- Two (2) boreholes were destroyed; and
- The use of three (3) boreholes was unknown.

4.2.2 Groundwater Use

Many of the privately-owned boreholes which were investigated within the immediate study area were either equipped or being pumped which prevented the measurement of static water levels (they are used on a daily basis for domestic water supply to farmers, communities and drinking water for livestock). In many of the instances water is used for single or several households for domestic use, as a water supply for farm workers and in two cases for small communities of ~ 50 - 100 people. Three (3) springs were found as part of the hydrocensus; located on privately owned land and are used for livestock watering.

5 MINE INFRASTRUCTURE AND ACTIVITIES

Exxaro DCMW is an operational coal mine, currently mining No. 2 Seam via underground mining methods on the western portion of their mining right area and proposes to mine No. 4 Seam, thus extending the life of mine to ~ 16-20 years and result in Run of Mine (ROM) production increasing to ~ 150,000 tons per month for the next 15 years.

Subsequently, an additional discard facility is required to accommodate the disposal of the discard and slurry from the proposed No. 4 Seam mining. Further an overland conveyor belt and associated service road/s are required to transport beneficiated coal from DCMW to DCME mine.

There are three (3) pollution control dams (PCD's) situated down-gradient of the plant and a discard dump located behind the offices. The three (3) lined PCD's store contaminated stormwater runoff from the coal stockpile areas, the waste sorting areas and the workshop areas with wash bays. In addition, these PCD's receive seepage from the discard dump.

Figure 5-1 shows the locations of DCMW existing surface infrastructure (i.e. discard dump, the PCD's and the plant area); while the life of mine's (LOM's) No. 2 Seam and No. 4 Seam mine plans are shown in Figure 5-2 and Figure 5-3, respectively.

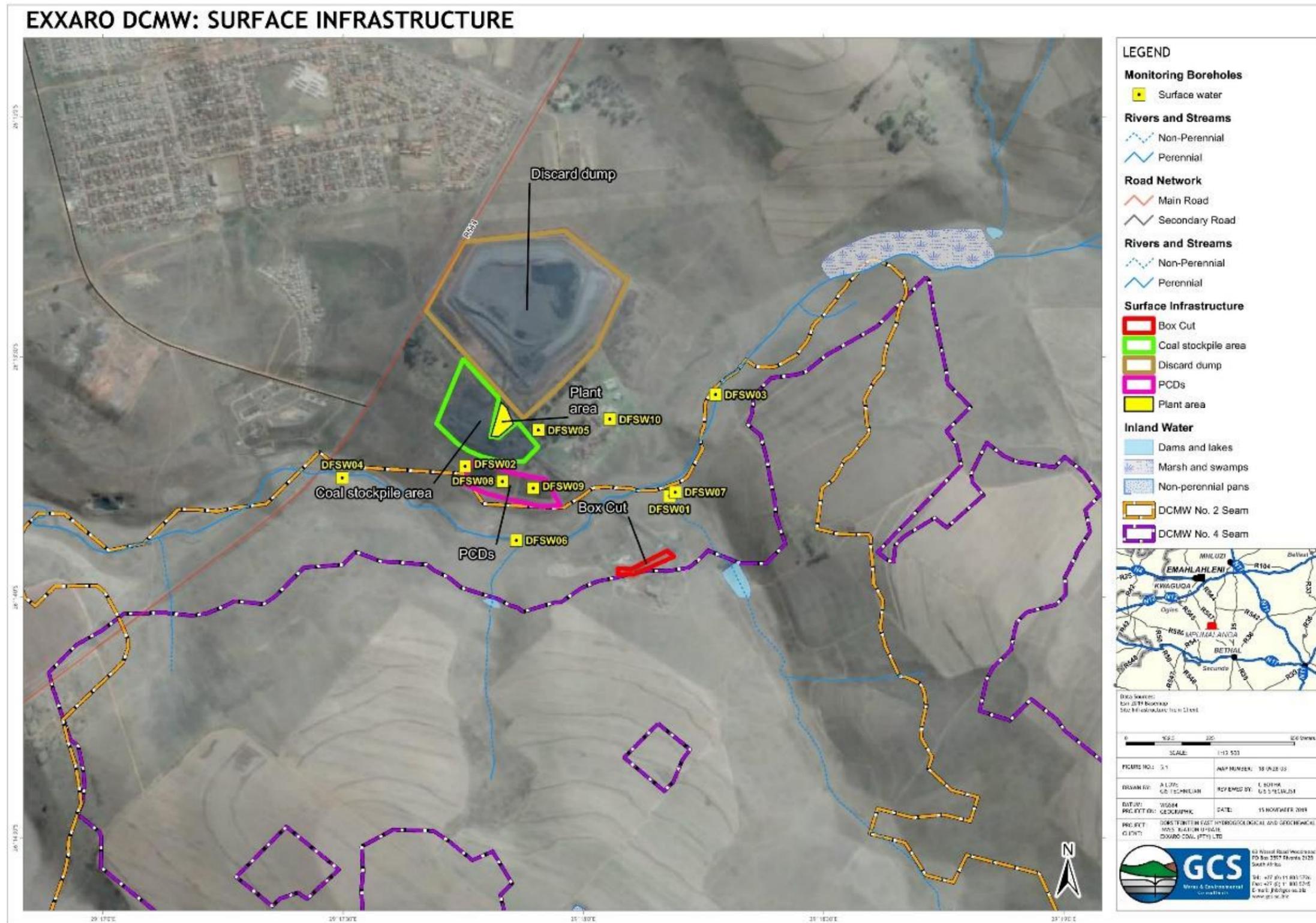


Figure 5-1 DCMW Surface Infrastructure

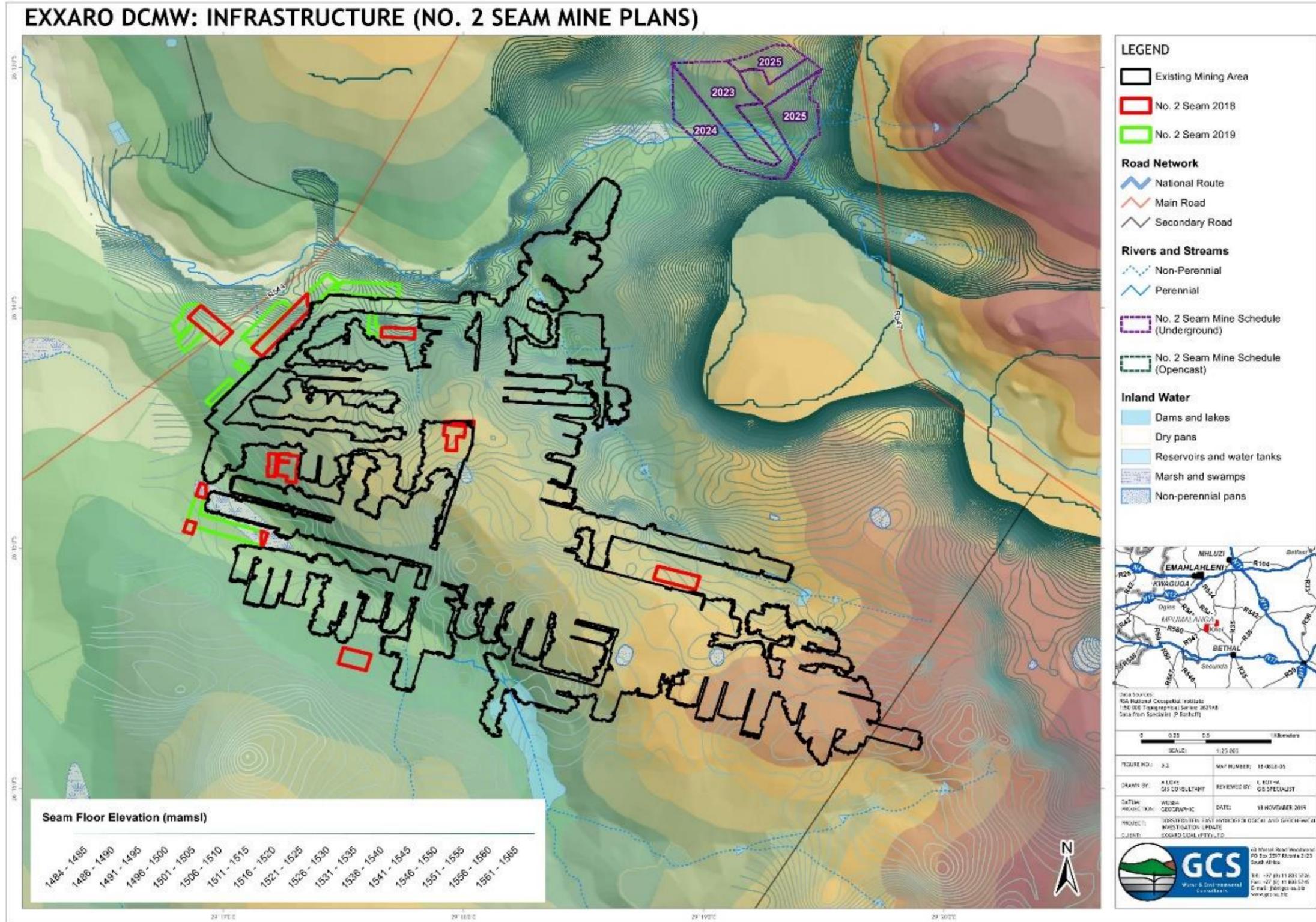


Figure 5-2 DCMW No. 2 Seam Mine Plans

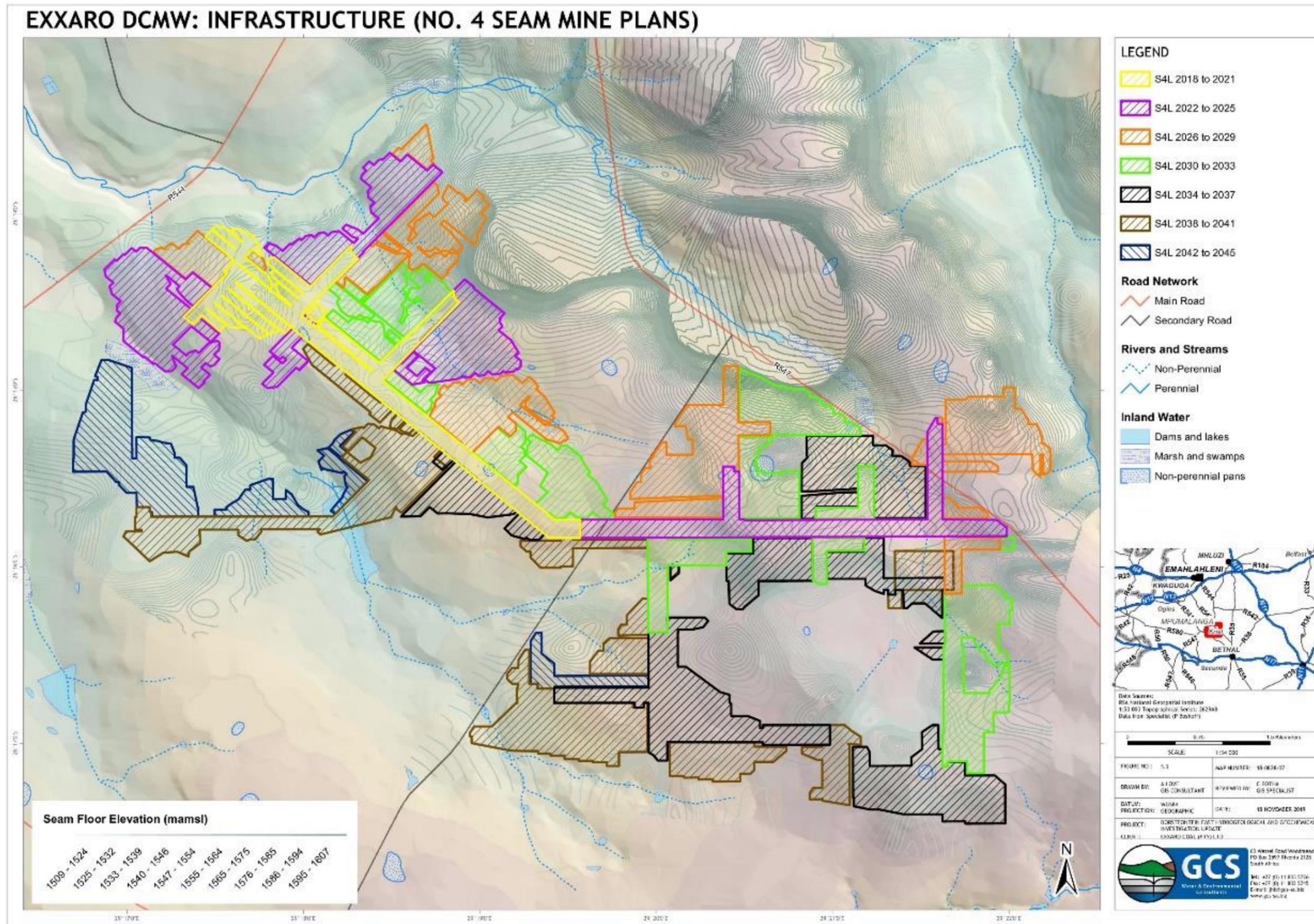


Figure 5-3 DCMW No. 4 Seam Mine Plans

5.1 Discard Dump Extension

According to the Waste Disposal Facility Study Report by Jones & Wagner (2017), the development of the discard dump will entail removal of topsoil within the footprint and stockpiled for use during the rehabilitation phase.

Following the removal of the topsoil, the barrier system will be constructed and will comprise the following layers from excavation level upwards:

- Substrate preparation layer: the substrate will be ripped and re-compacted to 90 % of MOD AASHTO density with a moisture content of - 2 to + 2 % of optimum;
- Primary impermeable layer: two (2) x 150 mm layers of clay compacted to 98 % of Standard Proctor Density at a moisture content of + 1 to + 3 % of optimum moisture content in order to have a permeability (k) of less than 1×10^{-6} cm/s (centimetre per second);
- Primary geomembrane layer: 1.5 mm high-density polyethylene (HDPE) double textured geomembrane layer;
- Protection layer: 200 mm layer of fine sand that will protect the geomembrane against damage from the coarse discard; and
- Leachate collection layer and drains: 400 mm layer of coarse discard with HDPE pipe drainage network.

6 GROUNDWATER QUALITY

6.1 Hydrocensus Boreholes

Groundwater samples were collected from 10 hydrocensus boreholes; refer to Table 6-1 for the groundwater quality results. Sample analyses results were compared to the SANS 241-1:2015 for drinking water standard for comparison purposes only and not for compliance purposes.

The nitrate concentration in borehole WSBH1 (24.7 mg/l as N) exceeded the SANS 241-1 Acute Health Risk Limit of 11 mg/l as N. Adverse health effects (such as Methaemoglobinaemia in infants and mucous membrane irritation in adults) may occur when the nitrate as N concentration exceeds 20 mg/l as N (South African Water Quality Guideline (SAWQG), 1996). Nitrate sources typically include human and animal waste and/or agricultural fertilizer. Nitrate is highly soluble, and if fertilizers and/or human and animal waste come into contact with water, any nitrate present will dissolve.

The remaining boreholes (NBH24, RK1, WSBH2, DFTNM12, NBH4, DFTNM4, DFTNM3, D4 and D4a) had no measured parameters exceeding the SANS 241-1 requirements and it can be concluded that the groundwater quality measured in these boreholes is of good quality. There is no indication that mining activities are impacting on the groundwater quality in these boreholes.

Table 6-1 Water Quality Comparison - SANS 241-1 Drinking Water Standard

Description	Unit	SANS 241-1: 2015 Drinking Water Standard	NBH24	RK1	WSBH2	WSBH1	DFTNM12	NBH4	DFTNM4	DFTNM3	D4	D4a	
			Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19	Feb-19
pH Value	pH	pH Value @ 20 °C	5-9.7 ^o	7.840	7.050	7.430	6.300	7.400	7.630	8.090	7.890	7.450	7.750
Conductivity	EC	mS/m @ 25 °C	170 ^A	38.200	31.700	31.100	46.500	37.200	48.800	34.900	28.700	52.400	38.800
Total Dissolved Solids	TDS	mg/l	1200 ^A	274.000	250.000	257.000	384.000	294.000	365.000	263.000	207.000	408.000	300.000
Calcium	Ca	mg/l	NS	14.300	16.100	27.100	30.600	14.200	22.800	22.900	16.600	64.700	39.600
Magnesium	Mg	mg/l	NS	6.840	9.400	11.000	20.500	10.600	37.600	9.600	11.600	24.600	13.200
Total Hardness	T-Hard	mg/l as CaCO ₃	NS	64.000	79.000	113.000	161.000	79.000	212.000	97.000	89.000	263.000	153.000
Sodium	Na	mg/l	200 ^A	62.600	22.100	27.600	39.700	57.500	7.690	41.700	40.100	27.200	38.000
Potassium	K	mg/l	NS	5.780	9.800	5.840	9.760	5.470	3.240	3.160	2.020	2.570	3.270
Total Alkalinity	T-Alk	mg/l as CaCO ₃	NS	174.000	85.000	69.000	12.000	180.000	110.000	173.000	177.000	234.000	194.000
Bicarbonate	HCO ₃	mg/l	NS	173.000	85.000	69.000	12.000	180.000	109.000	171.000	175.000	233.000	193.000
Chloride	Cl	mg/l	300 ^A	28.500	20.800	64.700	94.300	14.600	17.100	7.430	9.480	21.300	18.000
Sulphate	SO ₄	mg/l	500 ^{AH}	BDL(0.141)	1.570	34.700	22.400	21.700	75.000	16.500	BDL(0.141)	80.100	40.700
Nitrate	NO ₃	mg/l as N	11 ^{AH}	2.480	10.200	0.664	24.700	0.542	12.200	0.345	0.293	0.832	0.352
Nitrite	NO ₂	mg/l as N	0.9 ^{AH}	0.050	0.060	0.070	0.070	0.070	0.060	0.080	0.070	0.070	0.100
Ammonium, NH ₄	NH ₄	mg/l	NS	0.090	0.060	0.020	0.020	0.030	0.070	0.230	0.190	0.030	0.480
Fluoride, F	F	mg/l	1.5 ^{CH}	0.510	BDL(0.263)	0.280	BDL(0.263)	0.400	BDL(0.263)	BDL(0.263)	1.050	BDL(0.263)	0.330
Iron, Fe	Fe	mg/l	2 ^{CH}	BDL(0.004)									
Aluminium, Al	Al	mg/l	0.3 ^o	BDL(0.002)									
Copper, Cu	Cu	mg/l	2 ^{CH}	0.098	BDL(0.002)								
Chromium, Cr	Cr	mg/l	NS	BDL(0.003)									
Orthophosphate	PO ₄	mg/l as PO ₄	NS	BDL(0.005)	0.050	BDL(0.005)	BDL(0.005)	BDL(0.005)	BDL(0.005)	0.013	BDL(0.005)	BDL(0.005)	BDL(0.005)
Lead, Pb	Pb	mg/l	0.01 ^{CH}	0.010	BDL(0.004)								
Arsenic, As	As	mg/l	0.01 ^{CH}	BDL(0.006)									
Selenium, Se	Se	mg/l	0.04 ^{CH}	BDL(0.002)									
Mercury, Hg	Hg	mg/l	0.006 ^{CH}	BDL(0.004)									
Barium, Ba	Ba	mg/l	0.7 ^{CH}	0.201	0.171	0.352	0.476	0.111	0.076	0.385	0.650	0.102	0.099
Antimony, Sb	Sb	mg/l	0.02 ^{CH}	BDL(0.001)									
Nickel, Ni	Ni	mg/l	0.07 ^{CH}	BDL(0.002)									
Manganese, Mn	Mn	mg/l	0.4 ^{CH}	BDL(0.001)									
Cadmium, Cd	Cd	mg/l	0.003 ^{CH}	BDL(0.002)									

SANS 241-1:2015 Keys:

^a	SANS 241-1 Aesthetic Risk Limit
^{CH}	SANS 241-1 Chronic Health Risk Limit
^{AH}	SANS 241-1 Acute Health Risk Limit
^o	SANS 241-1 Operational Risk Limit
NS	No Standard
Red text	SANS 241-1 Exceedance

Notes:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

Illustrated on the Durov Diagram (Figure 6-1), the groundwater sampled during the hydrocensus indicated a pH ranging from 6 to 9 and an electrical conductivity ranging from 20 to 60 mS/m. A chloride enrichment is observed in boreholes WSBH1 and WSBH2 whereas boreholes D4A, NBH24, DFTNM12, DFTNM4, DFTNM3 and RK1 indicate a slight sodium enrichment.

The groundwater quality is mostly likely controlled by the composition of the Karoo Supergroup's Vryheid Formation sandstones that contain, amongst others, calcite, Mica group minerals and feldspars. The minerals of the Vryheid Formation lithology commonly contain chemical elements such as calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg), as well as carbonate species such as bicarbonate (HCO_3^-). The chloride enrichment at levels observed can be indicative of mineralised stagnant water, which is typical of groundwater quality within sedimentary Karoo Supergroup aquifers.

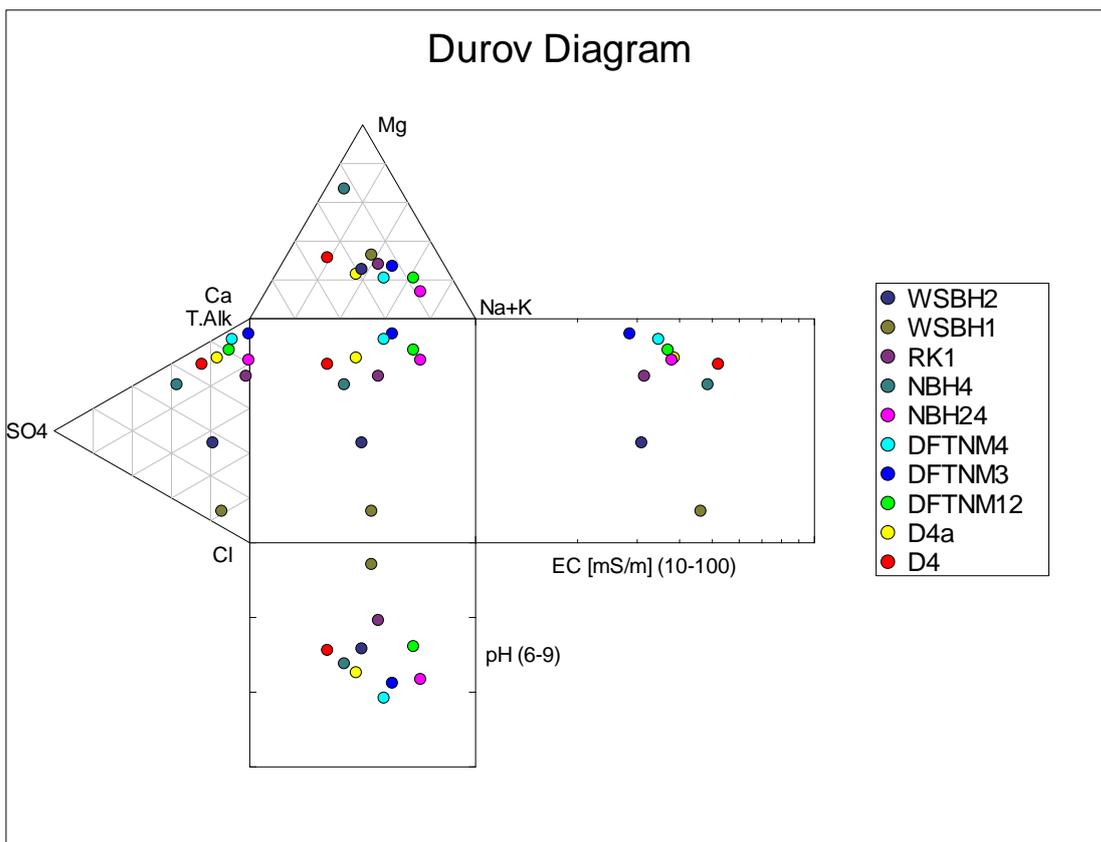


Figure 6-1 Durov Diagram - Hydrocensus Borehole

6.2 Monitoring Boreholes

DCMW has an active monitoring programme with a number of monitoring localities, as described in Table 6-2. Currently 25 monitoring localities (15 boreholes and 10 surface water) exist on the DCMW site. The 2015 - present monitoring data was received directly from Exxaro. GCS conducted monitoring activities on the site up until December 2014 when the mine was owned by Total Coal SA.

Table 6-2 Monitoring Network Summary

Sample Point ID	Coordinates		Monitoring Type	Location Description
	Latitude	Longitude		
[-]	[DD]	[DD]	[-]	[-]
Box Cut				
DFGW01	-26.23121	29.30131	Groundwater	Close to box cut. South of Steenskoolspruit tributary
DFGW02	-26.23123	29.30127	Groundwater	Adjacent to DFGW1
Pollution Control Dams				
DFGW03	-26.23009	29.29725	Groundwater	Down-gradient of pollution dam no. 2
DFGW06	-26.22945	29.29554	Groundwater	Adjacent to pollution control dam 1
DFSW02	-26.22879	29.2959	Surface water	Pollution dam no. 1
DFSW08	-26.22932	29.2972	Surface water	Pollution dam no. 2
DFSW09	-26.22955	29.29826	Surface water	Pollution dam no. 3
Discard Dump				
DFGW04	-26.22629	29.29944	Groundwater	Next to Burger yard. Downstream of discard dump
DFGW05	-26.21934	29.29695	Groundwater	Along R544, adjacent to the cemetery. Up-gradient of discard dump
DFGW07	-26.22318	29.30266	Groundwater	Downstream of discard dump
DFGW11-08	-26.22224	29.31857	Groundwater	Further upstream of DFGW12-08
DFGW12-08	-26.22586	29.30609	Groundwater	Upstream of DFSW3
DFGW14-08	-26.22318	29.30267	Groundwater	Next to DFGW7, down gradient of discard dump
DFGW15-08	-26.22538	29.30240	Groundwater	South of DFGW14-08 and north-east of DFGW5
DFSW05	-26.22753	29.29844	Surface water	Seepage from the discard dump
DCM 2 Seam				
DFGW8-08	-26.26168	29.31335	Groundwater	Far south of DCM 2 Seam
DFGW9-08	-26.22721	29.32659	Groundwater	East of DCM 2 Seam, next to R547
DFGW10-08	-26.23279	29.31249	Groundwater	South-east of DCM 2 Seam
DFGW16-08	-26.25436	29.32522	Groundwater	North-east of DFGW8-08
River/stream				
DFSW01	-26.22981	29.30299	Surface water	Small stream passing through the mine. Steenskoolspruit Tributary
DFSW03	-26.2263	29.30459	Surface water	Upstream in the tributary passing through the mine. Downstream of the discard dump.
DFSW04	-26.22918	29.29163	Surface water	Above the bridge. Downstream of DFSW1
DFSW06	-26.23135	29.29768	Surface water	Downstream of DFSW1 on Steenskoolspruit tributary
DFSW07	-26.22968	29.30319	Surface water	Small stream entering tributary to Steenskoolspruit at DFSW1
Drinking water				
DFSW10	-26.22715	29.30092	Surface water	Potable water from regional office kitchen

Notes:

- DD - Decimal Degrees
- 1. Coordinates - Projection: Geographic
- Datum: WGS84

The groundwater quality in the groundwater monitoring localities (DFGW1, DFGW2, DFGW3, DFGW4, DFGW5, DFGW6 AND DFGW7) for DCMW is compared to the water resource quality limits as stipulated in the Water Use Licence (WUL) (file No: 16/2/7/B100/C60) for compliance purposes and SANS 241-1:2015 for drinking water standard for comparative purposes. The groundwater quality with groundwater monitoring localities within DCMW (DFGW8-08, DFGW9-08, DFGW10-08, DFGW16-08, DFGW11-08, DFGW12-08, DFGW14-08 and DFGW15-08) is only compared to SANS 241-1:2015 for drinking water standard for comparative purposes. The quality of wastewater being disposed into a wastewater facility (DFSW02, DFW08 and DFW09) is compared to the Amended WUL Requirements as stipulated WUL (file No: 16/2/7/B100/C60, amended June 2017) for compliance purposes. The water quality within rivers and streams samples is compared to SANS 241-1:2015 for drinking water standard for comparative purposes. The latest available water quality for 2019, compared to the relevant standards/requirements, is summarised in Table 6-3 to Table 6-6.

The water quality is described in the sections below and is grouped together based on the different mining areas.

Table 6-3 DCM Groundwater Quality Comparison (SANS 241-1:2005 Drinking Water Standard and Resource Quality Limits)

Description	Unit	SANS 241-1: 2015 Drinking Water Standard	Resource Quality Limits	DFGW2	DFGW4	DFGW6	DFGW7	
				Mar-19	Mar-19	Mar-19	Mar-19	
pH Value	pH	pH Value @ 20°C	≤5 to ≤9.7	6.5-8.4	7.400	7.500	7.100	8.000
Conductivity	EC	mS/m @ 25°C	≤170	NS	71.100	32.600	231.000	40.300
Total Dissolved Solids	TDS	mg/l	≤1200	650	522.000	284.000	2238.000	288.000
Calcium	Ca	mg/l	NS	NS	60.000	21.000	182.000	23.000
Calcium Hardness	Ca-Hard	mg/l as CaCO ₃	NS	NS	150.000	52.000	454.000	58.000
Magnesium	Mg	mg/l	NS	NS	37.000	20.000	212.000	28.000
Magnesium Hardness	Mg-Hard	mg/l as CaCO ₃	NS	NS	154.000	82.000	874.000	115.000
Total Hardness	T-Hard	mg/l as CaCO ₃	NS	NS	304.000	134.000	1328.000	172.000
Sodium	No	mg/l	≤200	21.12	31.000	8.000	85.000	9.000
Potassium	K	mg/l	NS	NS	3.500	1.800	2.000	3.500
Total Alkalinity	T-Alk	mg/l as CaCO ₃	NS	NS	136.000	92.000	100.000	120.000
Bicarbonate	HCO ₃	mg/l	NS	NS	136.000	92.000	100.000	120.000
Carbonate	CO ₃	mg/l	NS	NS	BDL(5.000)	BDL(5.000)	BDL(5.000)	BDL(5.000)
Chloride	Cl	mg/l	≤300	25	54.000	16.000	45.000	10.000
Sulphate	SO ₄	mg/l	≤500	400	134.000	60.000	1184.000	70.000
Nitrate	NO ₃	mg/l as NO ₃	NS	NS	BDL(0.440)	4.420	BDL(0.440)	19.470
Nitrate	NO ₃	mg/l as N	≤11	NS	BDL(0.100)	1.000	BDL(0.100)	4.400
Fluoride, F	F	mg/l	≤1.5	NS	0.300	0.200	2.100	BDL(0.2)
Total Suspended Solids	SS	mg/l	NS	NS	133.000	75.000	301.000	4.700
Langelier Saturation Index	LSI	-	<-2 or >2	NS	BDL(0.200)	BDL(0.200)	BDL(0.200)	-
Sodium Absorption Ratio	SAR	-	12	NS	0.800	0.300	1.000	0.300
Aluminium, Al	Al	mg/l	≤ 0.3	0.18	BDL(0.100)	BDL(0.100)	BDL(0.100)	BDL(0.100)
Manganese, Mn	Mn	mg/l	≤ 0.5	0.18	BDL(0.025)	BDL(0.025)	1.150	0.035
Iron, Fe	Fe	mg/l	≤ 2	1.2	0.130	0.062	0.091	BDL(0.025)
Total Chromium	Cr	mg/l	≤ 0.05	NS	0.054	BDL(0.025)	0.049	BDL(0.025)
Phosphorus	PO ₄	mg/l as PO ₄	NS	NS	BDL(0.100)	BDL(0.100)	BDL(0.100)	BDL(0.100)

Standard Limit Keys:

Red text Exceeds both limits or the only available limit
Blue text Exceeds lower limit
NS No Standard

Notes:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

Table 6-4 DCMW Groundwater Quality Comparison (SANS 241-1:2015 Drinking Water Standard)

Description	Unit	SANS 241-1: 2015 Drinking Water Standard	DFGW9-08	DFGW10-08	DFGW11-08	DFGW12-08	DFGW15-08	DFGW16-08
			Mar-19	Mar-19	Mar-19	Mar-19	Mar-19	Mar-19
pH Value	pH	pH Value @ 20°C	8.000	7.500	7.900	8.200	7.100	9.100
Conductivity	EC	mS/m @ 25°C	43.600	41.300	37.800	59.800	308.000	21.300
Total Dissolved Solids	TDS	mg/l	280.000	264.000	246.000	420.000	3118.000	182.000
Calcium	Ca	mg/l	NS	30.000	48.000	25.000	38.000	337.000
Calcium Hardness	Ca-Hard	mg/l as CaCO ₃	NS	74.900	119.900	62.400	94.900	841.600
Magnesium	Mg	mg/l	NS	24.000	16.000	9.000	16.000	316.000
Magnesium Hardness	Mg-Hard	mg/l as CaCO ₃	NS	98.900	65.900	37.100	65.900	1301.600
Total Hardness	T-Hard	mg/l as CaCO ₃	NS	173.770	185.770	99.500	160.800	2143.160
Sodium	No	mg/l	≤200	32.000	19.000	50.000	65.000	21.000
Potassium	K	mg/l	NS	2.400	5.800	2.500	2.500	7.800
Free and Saline Ammonia	NH ₄	mg/l	NS	0.100	0.200	0.300	0.300	0.600
Total Alkalinity	T-Atk	mg/l as CaCO ₃	NS	208.000	220.000	148.000	92.000	392.000
Bicarbonate	HCO ₃	mg/l	NS	251.000	268.000	179.000	110.000	478.000
Carbonate	CO ₃	mg/l	NS	1.000	0.000	1.000	1.000	0.000
Chloride	Cl	mg/l	≤300	14.000	4.000	32.000	11.000	31.000
Sulphate	SO ₄	mg/l	≤500	22.000	BDL (2.000)	2.000	190.000	1785.000
Nitrate	NO ₃	mg/l as NO ₃	NS	0.400	3.100	BDL (0.440)	BDL (0.440)	BDL (0.440)
Nitrate	NO ₃	mg/l as N	≤11	0.100	0.700	BDL (0.100)	BDL (0.100)	BDL (0.100)
Fluoride, F	F	mg/l	≤1.5	0.800	0.300	0.600	2.900	BDL (0.200)
Aluminium, Al	Al	mg/l	≤ 0.3	BDL (0.100)				
Manganese, Mn	Mn	mg/l	≤ 0.5	0.030	0.120	0.117	0.055	BDL (0.025)
Iron, Fe	Fe	mg/l	≤ 2	0.078	0.082	0.113	0.100	0.047

Standard Limit Keys:**Exceeds SANS 241-1: 2015 limit**

NS No Standard

Notes:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

Table 6-5 Wastewater Facility Surface Water Quality Comparison (WUL Requirements)

Description	Unit	Amended WUL	DFSW2	DFSW8	DFSW9	
			Apr-19	Apr-19	Apr-19	
pH Value	pH	pH Value @ 20° C	2-7-9	8.200	8.100	8.200
Conductivity	EC	mS/m @ 25° C	NS	153.000	181.000	96.500
Total Dissolved Solids	TDS	mg/l	3300	1282.000	1646.000	788.000
Calcium	Ca	mg/l	NS	174.000	244.000	116.000
Calcium Hardness	Ca-Hard	mg/l as CaCO ₃	NS	433.000	609.000	290.000
Magnesium	Mg	mg/l	NS	64.000	72.000	29.000
Magnesium Hardness	Mg-Hard	mg/l as CaCO ₃	NS	265.000	295.000	120.000
Total Hardness	T-Hard	mg/l as CaCO ₃	NS	698.000	903.000	410.000
Sodium	No	mg/l	290	90.000	103.000	51.000
Potassium	K	mg/l	NS	10.000	10.900	2.700
Total Alkalinity	T-Alk	mg/l as CaCO ₃	NS	100.000	76.000	116.000
Bicarbonate	HCO ₃	mg/l	NS	100.000	76.000	116.000
Carbonate	CO ₃	mg/l	NS	BDL(5.000)	BDL(5.000)	BDL(5.000)
Chloride	Cl	mg/l	65	31.000	36.000	23.000
Sulphate	SO ₄	mg/l	2530	786.000	1085.000	365.000
Nitrate	NO ₃	mg/l as N	NS	0.400	0.400	BDL(0.100)
Fluoride, F	F	mg/l	NS	3.000	2.600	3.500
Total Suspended Solids	SS	mg/l	NS	329.000	14.000	2.700
Langelier Saturation Index	LSI		NS	0.800	0.800	0.700
Sodium Absorption Ratio	SAR		NS	1.500	1.500	1.100
Aluminium, Al	Al	mg/l	26	BDL(0.1)	BDL(0.1)	BDL(0.1)
Manganese, Mn	Mn	mg/l	21	0.637	1.240	BDL(0.025)
Iron, Fe	Fe	mg/l	60	BDL(0.025)	BDL(0.025)	BDL(0.025)
Total Chromium	Cr	mg/l	NS	BDL(0.025)	BDL(0.025)	BDL(0.025)
Orthophosphate	PO ₄	mg/l as P	NS	BDL(0.100)	BDL(0.100)	BDL(0.100)

Standard Limit Keys:

Exceeds WUL Requirement

NS No Standard

Note/s:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

Table 6-6 River and Stream Water Quality Comparison (SANS 241-1:2015 Drinking Water Standard)

Description	Unit	SANS 241-1: 2015 Drinking Water Standard	DFSW1	DFSW3	DFSW4	DFSW6	DFSW10	
			Mar-19	Mar-19	Feb-19	May-19	May-19	
pH Value	pH	pH Value @ 20 °C	≤5 to ≤9.7	8.000	8.000	8.000	8.000	8.000
Conductivity	EC	mS/m @ 25 °C	≤170	321.000	311.000	85.000	263.000	13.000
Total Dissolved Solids	TDS	mg/l	≤1200	3220.000	3082.000	572.000	2508.000	86.000
Calcium	Ca	mg/l	NS	300.000	324.000	61.000	198.000	11.000
Calcium Hardness	Ca-Hard	mg/l as CaCO ₃	NS	747.000	808.000	152.000	495.000	26.000
Magnesium	Mg	mg/l	NS	375.000	331.000	51.000	272.000	4.000
Magnesium Hardness	Mg-Hard	mg/l as CaCO ₃	NS	1544.000	1360.000	209.000	1121.000	16.000
Total Hardness	T-Hard	mg/l as CaCO ₃	NS	2291.000	2168.000	361.000	1615.000	42.000
Sodium	Na	mg/l	≤200	40.000	32.000	26.000	87.000	6.000
Potassium	K	mg/l	NS	12.000	8.000	7.000	17.000	2.000
Free and Saline Ammonia	NH ₄	mg/l	NS					
Total Alkalinity	T-Alk	mg/l as CaCO ₃	NS	340.000	412.000	252.000	208.000	36.000
Bicarbonate	HCO ₃	mg/l	NS	340.000	412.000	252.000	254.000	36.000
Carbonate	CO ₃	mg/l	NS	BDL(5.000)	BDL(5.000)	BDL(5.000)	BDL(5.000)	BDL(5.000)
Chloride	Cl	mg/l	≤300	73.000	54.000	25.000	88.000	12.000
Sulphate	SO ₄	mg/l	≤500	1895.000	1853.000	169.000	1543.000	11.000
Nitrate	NO ₃	mg/l as NO ₃	NS					
Nitrite	NO ₂	mg/l as N	≤11	BDL(0.100)	BDL(0.100)	BDL(0.100)	BDL(0.100)	0.000
Fluoride, F	F	mg/l	≤1.5	1.000	0.000	0.000	1.000	0.000
Total Suspended Solids	SS	mg/l	NS	49.000	7.000	164.000	9.000	BDL(1.000)
Langelier Saturation Index	LSI		<-2 or >2	1.000	1.000	0.000	1.000	BDL(1.300)
Sodium Absorption Ratio	SAR		12	0.000	0.000	1.000	1.000	0.000
Aluminium, Al	Al	mg/l	≤ 0.3	BDL(0.100)	BDL(0.100)	BDL(0.100)	BDL(0.100)	BDL(0.100)
Manganese, Mn	Mn	mg/l	≤ 0.5	0.000	0.000	1.000	BDL(0.025)	BDL(0.025)
Iron, Fe	Fe	mg/l	≤ 2	0.000	0.000	0.000	BDL(0.025)	BDL(0.025)
Total Chromium	Cr	mg/l	≤ 0.05	0.000	0.000	BDL(0.025)	BDL(0.025)	BDL(0.025)
Orthophosphate	PO ₄	mg/l as P	NS	BDL(0.100)	BDL(0.100)	1.000	BDL(0.100)	BDL(0.100)

Standard Limit Keys:

Exceeds SANS 241-1: 2015 limit

NS No Standard

Notes:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

6.3 Box Cut

Boreholes DFGW01 and DFGW02 are located within proximity to the box cut. Borehole DFGW01 was last sampled in June 2015 and it is assumed this borehole has been blocked since then. Borehole DFGW02 has been continuously sampled on a quarterly basis and the available chemical data indicates that the sodium and chloride concentrations consistently exceed the WUL Limits of 21.12 mg/l and 25 mg/l, respectively. It is important to note that despite exceeding the WUL Limits the sodium and chloride concentrations recorded in borehole DFGW02 are still low and are well below the SANS 241-1:2015 aesthetic limit of 200 mg/l for sodium and 300 mg/l for chloride concentration. The manganese concentration recorded in boreholes DFGW01 and DFGW02 occasionally exceeds the resource quality limits of 0.18 mg/l, a time series graph of the manganese concentration is shown in Figure 6-2.

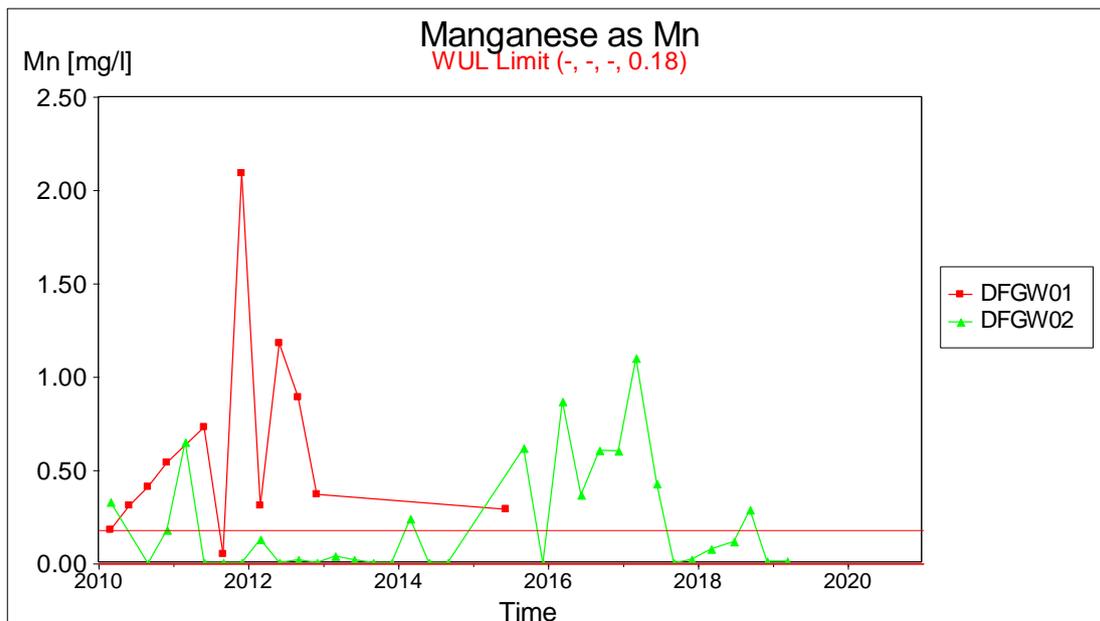


Figure 6-2 Manganese Concentration (Box Cut Proximity Boreholes)

6.4 Pollution Control Dams

There are three PCD's down-gradient of the plant and samples taken at sampling localities DFSW02, DFSW08 and DFSW09 represent samples from PCD no. 1, PCD no. 2 and PCD no. 3 respectively. Borehole DFGW03 is located down-gradient of pollution dam no. 2 and borehole DFGW06 is adjacent to pollution control dam 1. Borehole DFGW03 was last sampled in September 2014. The water quality recorded in the pollution control dams indicates elevated total dissolved solids, sodium, chloride, sulphate and manganese concentrations and occasionally elevated aluminium and iron concentrations. Inflows into PCD's include contaminated stormwater runoff from the coal stockpile areas, the waste sorting areas and the workshop areas with wash bays and seepage from the discard dump. Elevated sulphate and metal concentrations are normally associated with wastewater from coal mining due to the oxidation of pyrite.

Water quality recorded in borehole DFGW06 also indicate elevated total dissolved solids, sodium, chloride, sulphate and manganese concentrations exceeding the relevant resource quality limits.

Time series graph of the sulphate and manganese concentrations within the monitoring localities surrounding the PCD's is shown in Figure 6-3 and Figure 6-4.

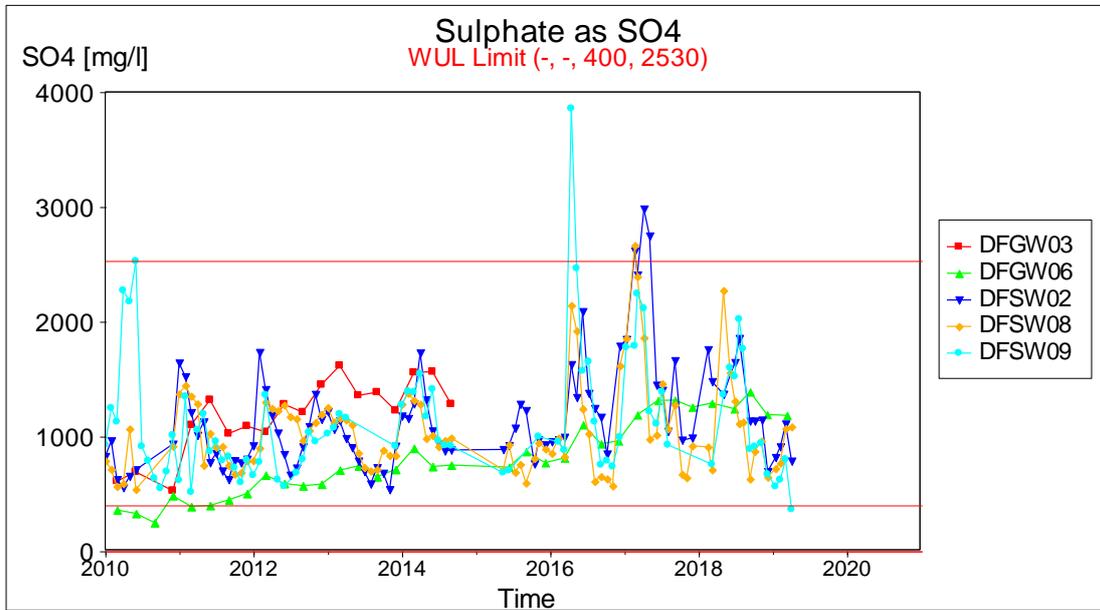


Figure 6-3 Sulphate Concentration (PCD's Proximity Monitoring Locations)

The sulphate concentration within the groundwater is compared to the resource quality limit of 400 mg/l and the wastewater is compared to the Amended WUL Requirement of 2,530 mg/l, Figure 6-3. The sulphate concentration in DFGW06 indicates an increasing trend since 2010, indicating an impact on the groundwater from the PCD's.

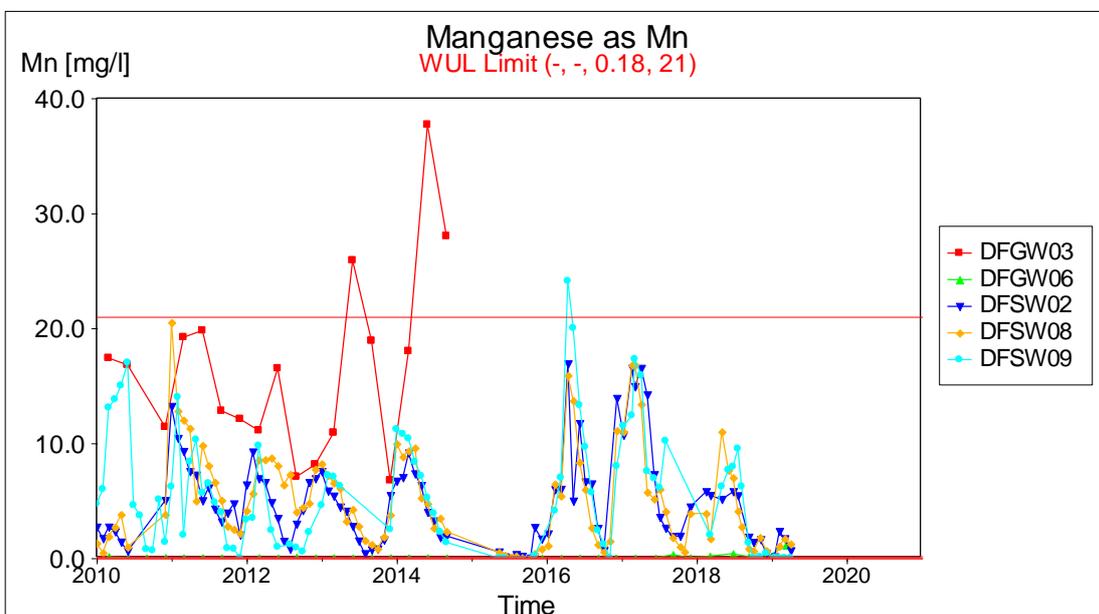


Figure 6-4 Manganese Concentration (PCD's Proximity Monitoring Locations)

The manganese concentration within the groundwater is compared to the resource quality limit of 0.18 mg/l and the wastewater is compared to the Amended WUL Requirement of 21 mg/l, Figure 6-4. The manganese concentration in DFGW06 indicates a slight increase since December 2018. When sampled, DFGW03 indicated very elevated manganese concentrations.

6.5 Discard Dump

Borehole DFGW05 is located upgradient of the discard dump whereas boreholes DFGW04, DFGW07, DFGW14-08, DFGW11-08 and DFGW12-08 are located downgradient of the discard dump. Boreholes DFGW05 and DFGW14-08 were last sampled in September 2014 and June 2015 respectively. Locality DFSW05 represents seepage for the discard dump and borehole DFGW15-08 is located to the north-east of the seepage point.

Seepage from the discard dump indicates elevated total dissolved solids, sulphate and manganese concentrations. Groundwater quality within boreholes DFGW04 and DFGW07 indicated complaint water quality with none of the analysed parameters exceeding the resource quality limits. Borehole DFGW11-08 indicated good water quality with all the analysed parameters remaining below the SANS 241-1: 2015 drinking water standard limits. Borehole DFGW12-08 indicated fluoride concentration exceeding the SANS 241-1: 2015 drinking water standard limit of 1.5 mg/l. Borehole DFGW15-08 indicates elevated electrical conductivity, total dissolved solids and sulphate concentrations exceeding the relevant SANS 241-1: 2015 drinking water standard limits.

Time series graph of the sulphate concentration within the monitoring localities surrounding the discard dump is shown in Figure 6-5.

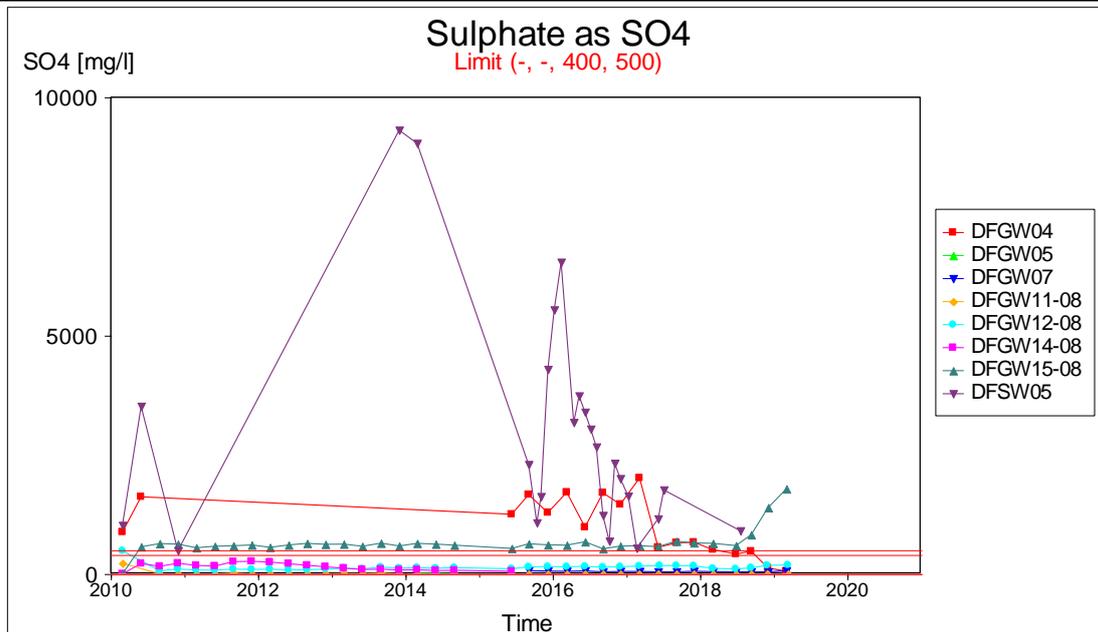


Figure 6-5 Sulphate Concentration (Discard Dump Proximity Monitoring Locations)

The sulphate concentration within DFGW04, DFGW05 and DFGW07 is compared to the resource quality limit of 400 mg/l and the remaining localities are compared to the SANS 241-1 2015 drinking water standard of 500 mg/l, Figure 6-5. The sulphate concentration within the discard dump seepage fluctuates and has indicated a decreasing trend in sulphate concentration since February 2016, but despite the decreasing trend the sulphate concentration within DFGW05 remains elevated. An increasing trend in DFGW15-08 is seen since June 2018 indicating that the seepage from the discard dump is likely impacting on the groundwater. Improved water quality, in terms of sulphate concentration, is seen in borehole DFGW04. DFGW04 indicates a decreasing trend in sulphate concentration since March 2017 and the sulphate concentration is currently below the resource quality limit of 400 mg/l.

6.6 DCM No. 2 Seam

Boreholes DFGW08-08 (far south of DCM No. 2 Seam), DFGW09-08 (east of DCM No. 2 Seam), DFGW10-08 (south-east of DCM 2 Seam) and DFGW16-08 (far south of DCM No. 2 Seam) are located within proximity to DCM 2 Seam mining area. Borehole DFGW8-08 was last sampled in September 2014. Boreholes DFGW9-08, DFGW10-08 and DFGW16-08 indicated good water quality with all the analysed parameters remaining below the SANS 241-1: 2015 drinking water standard limits.

Time series graph of the sulphate concentration within the monitoring localities surrounding the discard dump is shown in Figure 6-6.

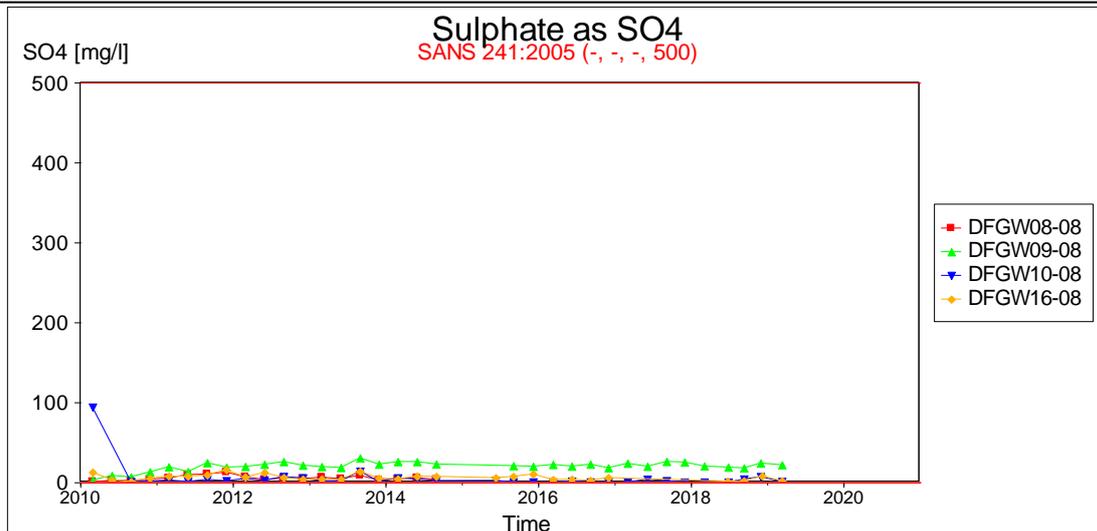


Figure 6-6 Sulphate Concentration (DCM No. 2 Seam Proximity Monitoring Locations)
The sulphate concentrations within boreholes DFGW08-08, DFGW09-08, DFGW10-08 and DFGW16-08 has remained well below the SANS 241-1: 2015 drinking water standard limit of 500 mg/l since 2010.

6.7 Conclusion Summary

The spatial analysis of the monitoring and hydrocensus chemistry data indicates the following:

- Generally, the hydrocensus boreholes sampled had no measured parameters exceeding the SANS 241-1 requirements and it can be concluded that the groundwater quality measured in these boreholes is of good quality. There is no indication that mining activities are impacting on the groundwater quality in these boreholes.
- The manganese concentration recorded in Box-Cut monitoring boreholes DFGW01 and DFGW02 occasionally exceeds the resource quality limits.
- Higher sulphate concentrations seems to be localized to sampling points in close proximity to the discard dump and PCD's.
- Based on these results there is a sulphate plume localized down gradient of the discard dump, coal stockpile area and PCD's.
- No impact of the underground mining on groundwater quality has been found.

7 GROUNDWATER LEVELS

7.1 Hydrocensus Boreholes

Groundwater levels recorded during the hydrocensus, during February 2019, is summarised in Table 7-1. The groundwater levels ranged between 2.9 and 56.4 m bgl, with an average groundwater level of 22.7 m bgl.

Table 7-1 Groundwater levels recorded during the February 2019

Borehole ID	Coordinates ¹		Elevation	Static Water Level	
	Latitude	Longitude		[m bgl]	[m amsl]
	[-]	[DD]			
NBH4	29.340470	26.238700	1621	8.75	1612.25
DFTNM3	29.362470	26.215790	1571	22.50	1548.50
DFTNM4	29.357560	26.216370	1588	14.35	1573.65
DFTNM12	29.324580	26.195380	1595	8.95	1586.05
WSBH2	29.323872	26.183087	1599	56.40	1542.60
WSBH1	29.323277	26.185065	1598	12.50	1585.50
WSWP1	29.322077	26.118508	1599	16.40	1582.60
NBH24	29.311926	26.188684	1612	33.90	1578.10
RK1	29.311639	26.191264	1614	19.10	1594.90
D7	29.390600	26.246470	1633	3.60	1629.40
D4	29.381270	26.276780	1626	10.95	1615.05
D4A	29.380280	26.270310	1621	2.95	1618.05
D1	29.281769	26.220246	1582	51.10	1530.90
D2	29.279109	26.197638	1598	Unknown (Destroyed)	
NBH20	29.317546	26.194651	1599	Unknown (Closed System)	
DFTN28/27	29.340110	26.250855	1627	Unknown (Destroyed)	
DFTNH18	29.345609	26.260968	1637	Unknown (Blocked)	
NBH0	29.328400	26.263197	1626	Unknown (Locked)	
NBH1	29.332230	26.270671	1622	20.40	1601.60
NBH1B	29.332190	26.270533	1622	31.60	1590.40
NBH2	29.331397	26.274080	1620	24.70	1595.30
D3	29.357274	26.268010	1625	Unknown (Closed System)	
NBH3	29.392301	26.262788	1658	Unknown (Closed System)	
D5	29.393906	26.275628	1673	Unknown (Closed System)	

Notes:

- DD - decimal degrees
- m amsl - metres above mean sea level
- m bgl - metres below ground level

1. Coordinates - Projection: *Geographic*
- Datum: *WGS84*

7.2 Monitoring Boreholes

Historical groundwater levels from 2010 to the latest available data for 2019 for the DCM No. 2 Seam area and the DCMW area are shown in Figure 7-1 and Figure 7-2, respectively.

The groundwater levels for DCM No. 2 Seam area indicated minor fluctuations over the monitoring period, excluding boreholes DFGW2 and DFGW6, Figure 7-1. Borehole DFGW2 indicated a relatively large decrease in groundwater level since November 2018 possibly due to dewatering in the surrounding area; while borehole DFGW6 indicates a decreasing trend in groundwater level since groundwater monitoring commenced in March 2010. The majority of the DCM No. 2 Seam site is characterised by shallow, less than 10 m bgl, groundwater levels. The shallow groundwater conditions make the groundwater highly vulnerable to surface pollutions.

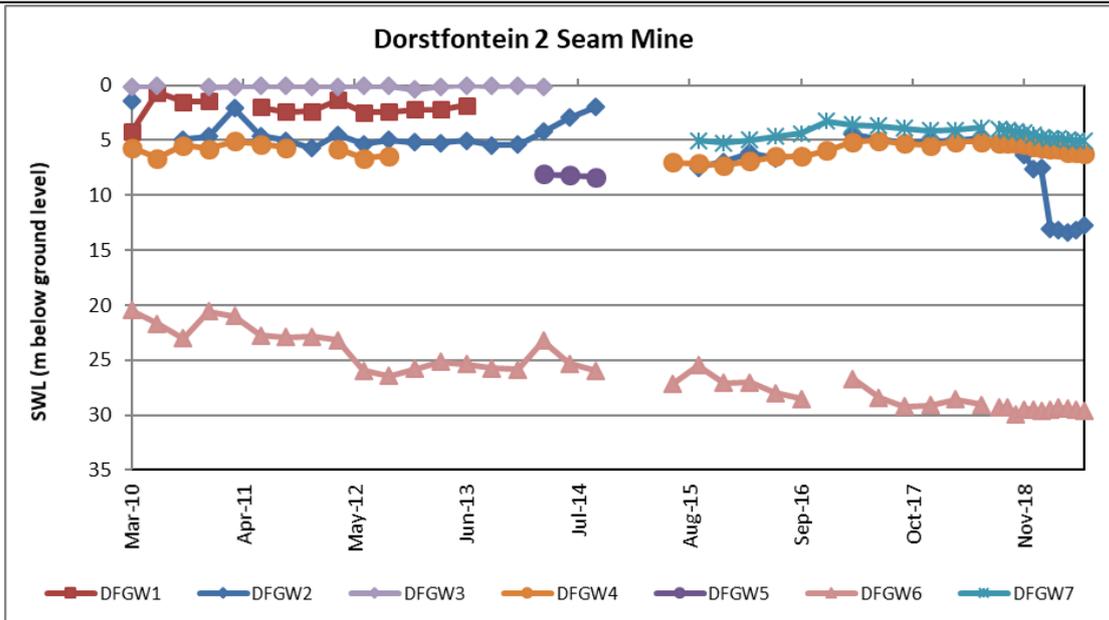


Figure 7-1 DCM No. 2 Seam Groundwater Levels

The majority of groundwater levels for DCMW indicate minor fluctuations over the monitoring period, excluding boreholes DFGW11-08 and DFGW10-08, Figure 7-2. Borehole DFGW11-08 indicates erratic change in groundwater level between 2010 and 2012 but has shown stable groundwater condition since September 2012. Borehole DFGW10-08 indicated a relatively large decrease in groundwater level between June 2014 and September 2016 after which groundwater levels increased and stabilized during the third quarter of 2018. The majority of groundwater levels are within 5 m bgl although some boreholes indicate deeper groundwater levels between 8 and 30 m below ground level.

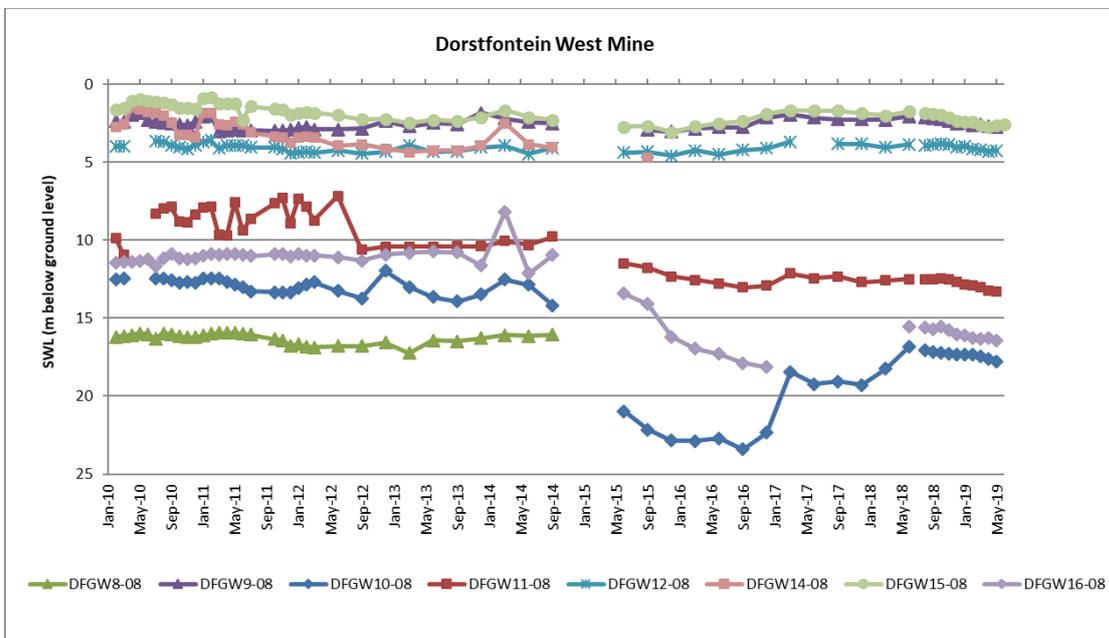


Figure 7-2 DCMW Groundwater Levels

7.3 Groundwater and Topography

All available water levels of boreholes in the surrounding area were used to compare groundwater levels with existing topography and used as input into the numerical groundwater model. The available groundwater levels were sourced from the hydrocensus carried out in 2014 and 2019 and the quarterly sampling rounds carried out at the DCMW and DCME sites.

A linear correlation was observed between groundwater levels and surface topography elevations. As evident in Figure 7-3, a good correlation of groundwater levels in the DCM area was found ($R^2 = 85\%$). The correlation of groundwater levels versus surface topography is good and suggests that the groundwater levels for the area generally mimics the topography.

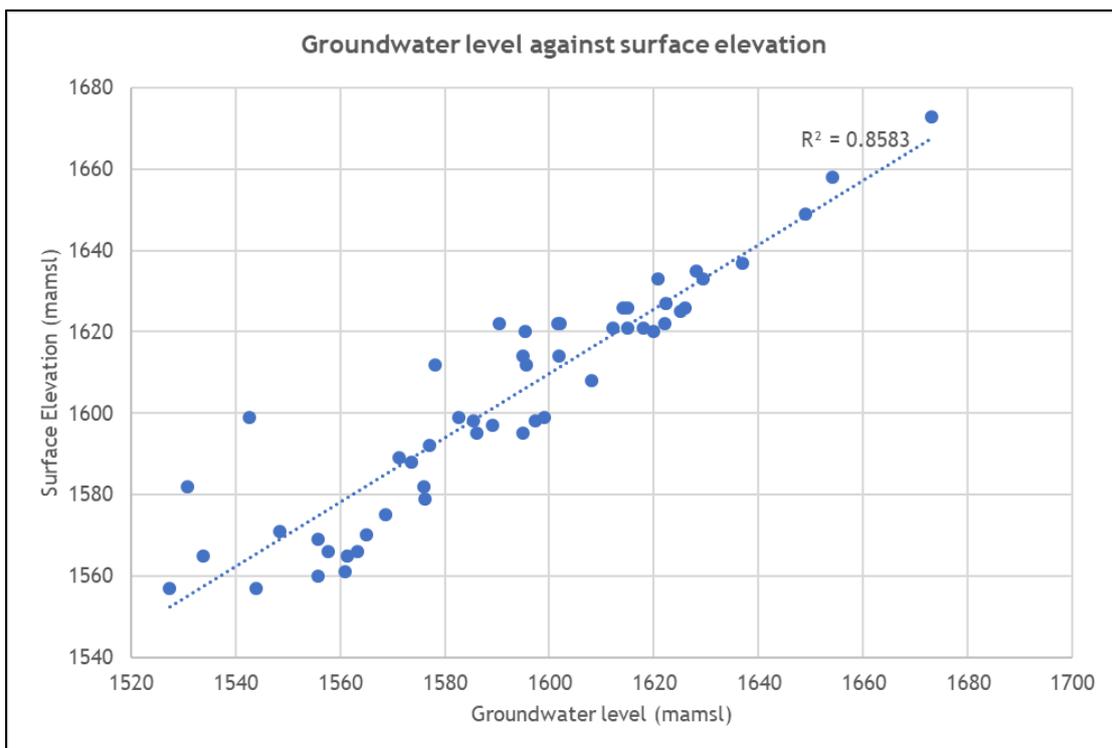


Figure 7-3 DCM Surface Elevation - Groundwater Level Correlation

8 GEOCHEMICAL ASSESSMENT

8.1 Previous Geochemical Assessment Summary

A total of 15 samples were collected in 2015 for geochemical testing (GCS, 2015a), comprising of the following samples:

- One (1) mixture of inter-bedded sandstone, shale and some coal sample;
- One (1) mixture of coarse sand and coal slurry sample;
- One (1) ROM coal samples;
- One (1) coal slurry samples;
- Three (3) coal discard samples;
- Three (3) coal product samples; and

- Five (5) coal samples.

Based on the results of the 2015 geochemical assessment, the following conclusions were previously made:

- Pyrite was the only sulphide detected in the samples. Pyrite is generally elevated in coal with respect to clastic rocks due to formation under reducing conditions. In general, oxidation of pyrite is a major source of acid-mine drainage generation;
- Carbonate minerals detected include calcite, dolomite and siderite. Calcite and dolomite are important minerals in the neutralization of acidity produced by pyrite oxidation in AMD and frequently occurs in Karoo sedimentary rocks. Siderite does not contribute to the neutralization of AMD as it only neutralizes the acid generated by the oxidation of its own iron (Fe);
- Discard dump: Most discard will form hot-spot material and will acidify over the long-term if placed. Hot-spot interburden material will have a sulfate (SO_4) concentration of probably up to 6 000 mg/l; although it will vary over the dump (even up to 10 000 mg/l in high %S discard).
- The discard has some net acid potential and the interstitial water in the oxic zone will acidify to a pH of ~ 3.5 - 4.5 in the unsaturated zone within less than 20 years of placement. The saturated zone will be near neutral and the pH at the contact between the unsaturated and saturated zone will have a pH less than 6 reaching pH 4.5 over time.
- Underground: AMD generation in the underground will depend on the oxygen ingress versus time for the mine to flood. While oxygen is still present, the underground mine water will reach sulphate concentrations of ~ 2,000 - 2,300 mg/l for the higher (4% of MAP) and lower recharge rates (2% of MAP). After oxygen is depleted no more sulphate is generated and the mine water will slowly be flushed with infiltrating groundwater. The recharge on the underground mine is however low thus sulphate will remain at a fairly constant concentration of ~ 2,000 - 2,300 mg/l for several decades.
- Although the material in the underground mine has a net potential to acidify the mine water, oxygen will be depleted with the result that sulphide oxidation will be inhibited and no acidification will occur.
- It is not foreseen that metals will significantly be present in neutral drainage. Al, Fe and Mn will be present at elevated concentrations in acidic mine drainage. Other metals that may leach in acidic drainage include Ni, Co and Pb.

8.2 Mineralogy and Total Element Analysis

The XRF and XRD results are reported in Table 8-1 and Table 8-2, respectively; while the descriptions of the minerals present in the samples are listed in Table 8-3.

The mineralogy of discard 1, discard 3 and discard 5 is dominated by oxide combinations of SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 and K_2O with small amounts of MnO , P_2O_5 , Na_2O , V_2O_5 , BaO , SrO , ZrO_2 , Cr_2O_3 , MgO , Mn_3O_4 , SO_3 and CaO forming the oxide series that combines to form chain silicates and sheet silicate minerals. The oxide results subsequently predict the main mineralogical environment of the sandstones and siltstones of the Vryheid Formation with which the coal is associated. In most cases the chain silicates and sheet silicates formed from the anion and cation rich oxides can act as neutralising minerals under their normal dissolution and weathering reactions. A high percentage of ash was observed in all three samples, indicating high organic carbon content.

Phyllosilicates and tectosilicates are formed through the combination of these oxides. The high phyllosilicates and tectosilicates along with CaO , MgO and Na_2O indicate that the material does have a potential neutralising capacity and acid generation might be naturally buffered to a degree until chemical equilibrium within the aqueous system is reached and precipitation of sulphate and salt minerals can occur under saturated conditions.

Sulphide minerals

- Pyrite was detected in all three samples as trace minerals, and it's associated with the depositional environment in which the sandstone and siltstone formation occurred and is commonly a trace mineral deposited along with coal. Pyrite is generally elevated in coal with respect to clastic rocks due to formation under reducing conditions and can form during or very shortly after peat accumulation (autigenic) or as veins later in the coal's burial history (epigenetic). The presence of pyrite may lead to ARD formation and thus the discard material should be managed and monitored to minimise seepage and runoff of leachate;

Silicate minerals

- Quartz is present in all the samples as a major mineral. The quartz grains generally have a detrital origin and originate from the felsic mother rock;
- Phyllosilicate minerals include mainly kaolinite and muscovite. Kaolinite is present as a major mineral in all three samples and muscovite as a minor to trace mineral in all the samples. Muscovite may also be further altered to Sericite (fine grained muscovite); and
- Microcline is present as a minor mineral in samples discard 3 and discard 5. Microcline (K-feldspar) is typically present in rocks that also have a high quartz content. Generally, K-feldspar occurs frequently in both coal and clastic rocks of the Vryheid Formation, although it is generally slightly more frequent in clastic rocks.

Table 8-1 XRF Major Oxide Results (Weight %)

Oxide	Discard 1	Discard 3	Discard 5
SiO ₂	63.8913	68.54029	70.17039
Al ₂ O ₃	22.56314	20.20843	21.67035
K ₂ O	1.71129	2.06742	2.55834
P ₂ O ₅	0.05267	0.05773	0.04243
Mn ₃ O ₄	0.02254	0.01992	<0.010
CaO	0.97195	0.94016	0.45062
MgO	0.23169	0.22601	0.17977
TiO ₂	1.19558	1.02803	1.03942
Na ₂ O	0.2043	0.21492	0.21111
V ₂ O ₅	0.02524	0.02218	0.01997
BaO	0.05207	0.05607	0.07412
Fe ₂ O ₃	8.47969	5.8446	3.05482
Cr ₂ O ₃	0.04364	0.04842	0.04308
SrO	0.01459	0.01366	0.01377
ZrO ₂	0.05869	0.05681	0.05833
MnO	0.02096	0.01853	0.00727
SO ₃	0.92615	1.08755	0.50496
Total (XRF)	100.44	100.43	100.09
Ash	61.53	65.53	70.75

Note/s:

- None

Table 8-2 X-ray diffraction results (weight %)

Mineral	Discard 1	Discard 3	Discard 5
Quartz	42	47.2	51.8
Pyrite	3.8	1.8	0.8
Kaolinite	49.9	39.6	37.1
Muscovite	4.3	0.5	1.7
Microcline	0	10.9	8.5

Note/s:

- None

Table 8-3 Description of identified minerals

Mineral	Formula	Mineral type/group	Sub-group
Quartz	Al ₂ Si ₂ O ₅ (OH) ₄	Phyllosilicate 1:1 layer	Kaolinite group
Pyrite	KAlSi ₃ O ₈	Tectosilicate	K-feldspar subgroup
Kaolinite	KAl ₂ (AlSi ₅ O ₁₀)(OH,F) ₂	Phyllosilicate 2:1 layer	Mica group (Muscovite subgroup)
Muscovite	FeS ₂	Sulphides	Pyrite group
Microcline	SiO ₂	Tectosilicate	Tectosilicate

Keys:

- Yellow text - Sulphides and Sulphates
- Red text - Phyllosilicates
- Green text - Tectosilicates

Note/s:

- None

8.3 Acid-Base Accounting and Net-Acid Generation Tests**8.3.1 Acid-Base Accounting (ABA) Terminology and Screening Methods**

Acid-base accounting (ABA) is a static test where the net potential of the rock to produce acidic drainage is determined. The percentage sulphur (%S), the acid potential (AP), the neutralization potential (NP) and the net neutralization potential (NNP) of the rock material are determined in this test, as an important first order assessment of the potential leachate that could be expected from the rock material. A description of the different ABA components is given below:

- If pyrite is the only sulphide in the rock the AP (acid potential) is determined by multiplying the percentage sulphur (%S) with a factor of 31.25. The unit of AP is kg

CaCO₃/t rock and indicates the theoretical amount of calcite neutralized by the acid produced;

- The NP (Neutralization Potential) is determined by treating a sample with a known excess of standardized hydrochloric or sulphuric acid (the sample and acid are heated to insure reaction completion). The paste is then back titrated with standardized sodium hydroxide in order to determine the amount of unconsumed acid. NP is also expressed as kg CaCO₃/t rock as to represent the amount of calcite theoretically available to neutralize the acidic drainage; and
- NNP is determined by subtracting AP from NP;
- For the material to be classified in terms of their acid-mine drainage (AMD) potential, the ABA results could be screened in terms of its NNP, %S and NP:AP ratio as follows:
 - A rock with NNP < 0 kg CaCO₃/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg CaCO₃/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg CaCO₃/t to 20 kg CaCO₃/t exists that is defined as a “grey” area in determining the net acid generation or neutralization potential of a rock. Material with a NNP above this range is classified as Rock Type IV - No Potential for Acid Generation, and material with a NNP below this range as Rock Type I - Likely Acid Generating;

Further screening criteria could be used that attempts to classify the rock in terms of its net potential for acid production or neutralization. The following screening methods given in Table 8-4 below, as proposed by Price (1998), use the NP:AP ratio to classify the rock in terms of its potential for acid generation; and

- Soregaroli and Lawrence (1998) further states that samples with less than 0.3% sulphide sulphur are regarded as having insufficient oxidisable sulphides to sustain long term acid generation. Material with a %S below 0.3% is therefore classified as Rock Type IV - No Potential for Acid Generation, and material with a %S of above 0.3%, as Rock Type I - Likely Acid Generating.

Table 8-4 NP:AP Ratio Screening Methods (Price, 1998)

Acid Generation Potential	Type	NP: AP screening criteria	Comments
Rock Type I (Likely Acid Generating)	Potentially Acid Forming	Total S (%) > 0.3% and NP:AP ratio 1:1 or less	Likely AMD generating.
Rock Type II (Possibly Acid Generating)	Intermediate	Total S (%) > 0.3% and NP:AP ratio 1:1 - 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides.
Rock Type III (Low Potential for Acid Generation)	Low Potential Acid Forming	Total S (%) < 0.3% and NP:AP ratio 2:1 - 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficient reactive NP.
Rock Type IV (No Potential for Acid Generation)	Non-Acid Forming	Total S (%) < 0.3% and NP:AP ratio 4:1 or greater	No further AMD testing required unless materials are to be used as a source of alkalinity.

Note/s:

- None

8.3.2 Net-Acid Generation (NAG) Terminology and Screening Methods

In the Net-acid Generating (NAG) test hydrogen peroxide (H₂O₂) is used to oxidize sulfide minerals in order to predict the acid generation potential of the sample.

The NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure (to a strong oxidant) and weathering. The test can be used to refine the results of the ABA predictions.

In general, the static NAG test involves the addition of 25 ml of 30% H₂O₂ to 0.25 g of sample in a 250 ml wide mouth conical flask, or equivalent. The sample is covered with a watch glass and placed in a fume hood or well-ventilated area. Once "boiling" or effervescing ceases, the solution is allowed to cool to room temperature and the final pH (NAG pH) is determined. A quantitative estimation of the amount of net acidity remaining (the NAG capacity) in the sample is determined by titrating it with sodium hydroxide (NaOH) to pH 4.5 (and/or pH 7.0) to obtain the NAG Value.

In order to determine the acid generation potential of a sample, the screening method of Miller et al. (1998) is used. See Table 8-5 below:

Table 8-5 NAG Test Screening Method (Miller et al., 1998)

Rock Type	NAG pH	NAG value	NNP
[-]	[-]	[H ₂ SO ₄ kg/t]	[CaCO ₃ kg/t]
Rock Type Ib High Capacity Acid Forming	< 4	> 10	Negative
Rock Type Ib Lower Capacity Acid Forming	≥ 4	≤ 10	
Uncertain, possibly Ib	< 4	> 10	Positive
Uncertain	≥ 4	0	Negative (Reassess mineralogy ¹)
Rock Type IV Non-Acid Forming	≥ 4	0	Positive

Note/s:

- kg/t kilogram per tonne
1. If low acid forming sulphides is dominant then Rock Type IV

8.3.3 ABA and NAG Test Results

ABA and NAG test results were performed by *Aquatico Laboratory*, Pretoria. The test results are presented as follows:

- The ABA results are presented in Table 8-6 below. The results were screened as discussed in above as *Rock Type I to IV*; and
- The classification of the rock samples in terms of %S and NP/AP is depicted in Figure 8-1.

From the ABA and NAG test results the following observations could be made:

- The NP/AP indicates the potential for the rock to generate acid drainage, whereas the %S indicated whether this drainage will be over the long term. In Figure 8-1 the red lines therefore assess the long-term acid generation potential, while the horizontal yellow line assesses the long-term acid generation potential;
- The sulphide %S and total %S (determined by infrared (IR) detector after heating the sample to 1 000°C and ±2 000°C respectively in an Eltra Furnace) was used to determine the acid potential of the rock. Therefore, the acid potential of the samples was not overestimated;
- The total %S (determined at ±2 000°C) is slightly higher than the %S at 1 000°C. The S at 1 000°C are more representative of the sulphide sulphur as almost only sulphides are ignited at that temperature. The total S (determined at ±2 000°C) represents both sulphide and sulphate sulphur. For most samples there was however not a significant difference in terms of net acid potential using either sulphur to determine the acid potential;
- Pyrite was the only sulphide detected in the rock through means of XRD. It was assumed that oxidation of pyrite will be the only contributor to acidity;
- All the discard samples have a %S higher than 0.3% guideline value of Lawrence and Segragoli (1998). Indicating that enough oxidisable sulphides is present to sustain long term acid generation. The neutralization potential is also very low compared to the acid potential of the samples and although these samples show an uncertain (possibly acid forming) NAG classification, all the samples indicate a significant potential to generate acid mine drainage. Hence, they can all be classified as rock type I (likely acid generating);

Overall, it could be concluded that all the samples have to some degree of potential to generate acid mine drainage/seepage.

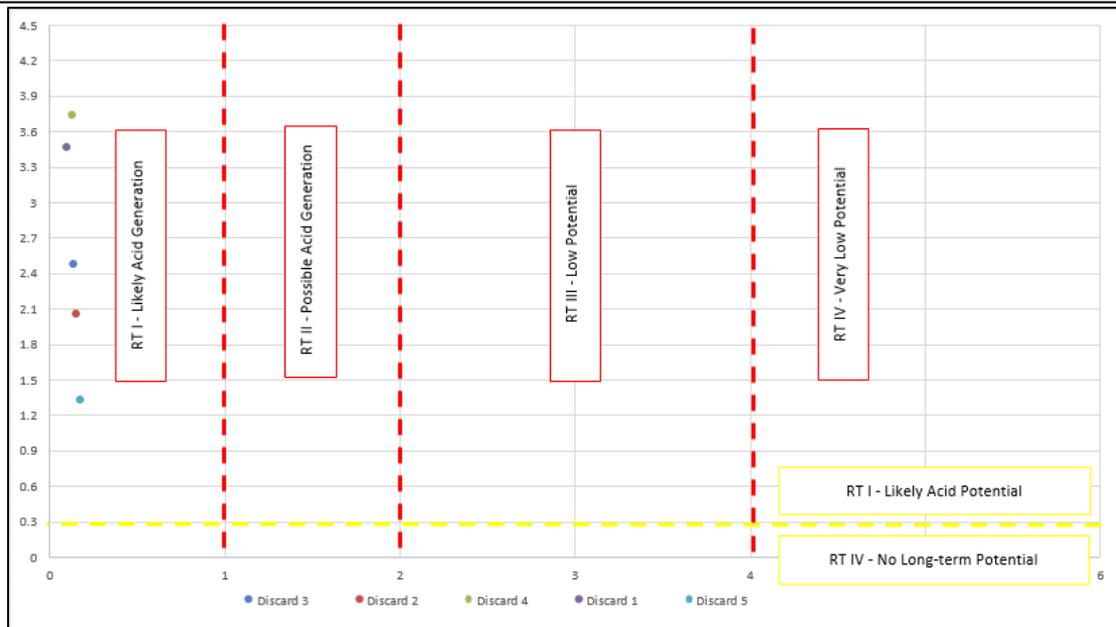


Figure 8-1 Sample Classification in terms of % S (Below 3%) and NP/AP (Below 10)

Table 8-6 Acid-Base Accounting (ABA) and Net-Acid Generating (NAG) Results

Acid - Base Accounting Modified Sobek (EPA-600)	Sample Identification				
	Discard 1	Discard 2	Discard 3	Discard 4	Discard 5
Paste pH	7	7.2	7.14	7.25	8.03
NAG CaCO ₃ kg/t	76.9	42.6	47.3	75.2	30.7
NAG pH	1.52	1.64	1.62	1.71	1.59
Total Sulphur (%) (LECO)	3.46	2.06	2.48	3.74	1.33
Sulphide Sulphur (%) (LECO)	3.18	1.98	2.25	3.5	1.19
Sulphate Sulphur (%) (LECO)	0.274	0.074	0.229	0.237	0.14
Acid Potential (AP) (CaCO ₃ kg/t) TS	108	64.3	77.4	117	41.5
Acid Potential (AP) (CaCO ₃ kg/t) SS	99.5	62	70.3	109	37.1
Neutralization Potential (NP) CaCO ₃ kg/t	10.2	9.9	10.4	14.6	7.1
Nett Neutralization Potential (NNP) CaCO ₃ kg/t	-89.3	-52.1	-59.85	-94.78	-30.03
Neutralising Potential Ratio (NP : AP) TS	0.094	0.154	0.134	0.125	0.171
Neutralising Potential Ratio (NP : AP) SS	0.103	0.16	0.148	0.133	0.191
Rock Type NNP					
Rock Type % S					
Rock Type NP/AP					
Rock Type NAG	Uncertain, possibly Ib				
Final Verdict					

Note/s:
• None

8.4 Static Leach Test Results

Samples were leached with 15% hydrogen peroxide for 24 hours. For the hydrogen leach a 10:1 ratio (500 ml water: 5 g rock) were used. System parameters and major anions of the extractions are listed in Table 8-7 below.

From Table 8-7 the following observations could be made:

- It is important to note that the measured sulphate values can only be used as a qualitative measure of the sulphate that can be leached from the rocks. It does not represent the actual drainage quality from the rocks but rather gives an indication of which rocks produce more sulphate than other;
- It is evident that samples with a lower NP: AP content (a higher net Acid Potential) have a higher acidic drainage as shown by the lowered pH in especially the hydrogen peroxide leachate. More sulphate is also present in the leach from rock samples with a lower NP:AP ratio. Ca in the leachate has a strong correlation with sulphate because of the generation of acid upon oxidation of the sulphide and the associated dissolution of carbonates; and
- In discard 1, discard 2 and discard 3 sulphate reaches values of up to 221 mg/l, 140 mg/l and 116 mg/l respectively, which are all within the acceptable limits.

Table 8-7 Peroxide Leachate Physical Parameters and Major Anions

SPLP Results (Physical Parameters and Anions)							
Parameter	Unit	SANS 241:2011			Discard 1	Discard 3	Discard 5
		Class I	Class II	Class III			
20 - pH	pH	6-8.4	5-6; 8.4-9.7	<5; >9.7	7.56	7.53	7.8
20 - EC	mS/m	<85	85-170	>170	66.6	47.9	36.8
01 - Alk	mg CaCO ₃ /l	NS	NS	NS	162	152	83.9
02 - Cl	mg/l	<150	150-300	>300	52.3	28.8	11.1
03 - SO ₄	mg/l	<250	250-500	>500	221	140	116
04 - PO ₄	mg/l	NS	NS	NS	BDL(0.005)	BDL(0.005)	0.125
06 - NO ₃	mg/l	<5.5	5.5-11	>11	BDL(0.194)	BDL(0.194)	BDL(0.194)
30 - Ca	mg/l	NS	NS	NS	129	90.3	51.2
30 - Mg	mg/l	NS	NS	NS	11.5	9.71	5.18
30 - K	mg/l	NS	NS	NS	12.1	11.5	11.6
31 - Al	mg/l	<0.15	0.15-0.3	>0.3	BDL(0.002)	BDL(0.002)	BDL(0.002)
31 - Fe	mg/l	<1	1.0-2.0	>2	BDL(0.004)	BDL(0.004)	BDL(0.004)
31 - Mn	mg/l	<0.25	0.25-0.5	>0.5	0.507	0.361	0.027
31 - Cd	mg/l	<0.0015	0.0015-0.003	>0.003	BDL(0.002)	BDL(0.002)	BDL(0.002)
31 - Co	mg/l	<0.25	0.25-0.5	>0.5	0.005	0.003	BDL(0.003)
31 - Cr	mg/l	<0.025	0.025-0.05	>0.05	BDL(0.003)	BDL(0.003)	BDL(0.003)
31 - Cu	mg/l	<1	1.0-2.0	>2	BDL(0.002)	BDL(0.002)	BDL(0.002)
31 - Ni	mg/l	<0.035	0.035-0.07	>0.07	0.008	0.007	BDL(0.002)
31 - Pb	mg/l	<0.005	0.005-0.01	>0.01	BDL(0.004)	BDL(0.004)	BDL(0.004)
31 - Zn	mg/l	<2.5	2.5-5.0	>5	BDL(0.002)	BDL(0.002)	BDL(0.002)
33 - B	mg/l	NS	NS	NS	0.175	0.156	0.133
33 - Ba	mg/l	NS	NS	NS	0.085	0.116	0.134
33 - Be	mg/l	NS	NS	NS	BDL(0.005)	BDL(0.005)	BDL(0.005)
33 - V	mg/l	<0.1	0.1-0.2	>0.2	0.001	BDL(0.001)	0.004
32 - Bi	mg/l	NS	NS	NS	0.004	0.004	BDL(0.004)
32 - Ag	mg/l	NS	NS	NS	BDL(0.001)	BDL(0.001)	BDL(0.001)
32 - Ga	mg/l	NS	NS	NS	0.009	0.008	0.006
32 - Li	mg/l	NS	NS	NS	0.09	0.079	0.056
33 - Mo	mg/l	NS	NS	NS	0.2	0.604	0.514
32 - Rb	mg/l	NS	NS	NS	0.078	0.074	0.053
33 - Sr	mg/l	NS	NS	NS	1.57	1.33	0.942
32 - Te	mg/l	NS	NS	NS	BDL(0.001)	BDL(0.001)	BDL(0.001)
32 - Tl	mg/l	NS	NS	NS	BDL(0.037)	BDL(0.037)	BDL(0.037)
33 - As	mg/l	NS	NS	NS	BDL(0.006)	BDL(0.006)	BDL(0.006)
34 - Sb	mg/l	NS	NS	NS	BDL(0.001)	BDL(0.001)	BDL(0.001)
35 - Se	mg/l	NS	NS	NS	BDL(0.002)	BDL(0.002)	BDL(0.002)

SANS 241-1:2011 Keys:

Yellow text Exceedance of SANS 241-1:2011 Class I
 Red text Exceedance of SANS 241-1:2011 Class II
 NS No Standard

Note/s:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

8.5 Kinetic Column Leach Test Results

Column leach testing was performed on one sample (Discard 1). For the leaching columns a 1:2 water to rock ratio (1 kg: 2 kg rock) were used. The rock material was leached over a 10-week period, the leachate was analysed for several parameters. The test results are listed in Table 8-8. The measured pH, EC and SO₄ in the leachate is also depicted in Figure 8-2.

From the kinetic leaching test results the following observations could be made:

- It is important to note that the leach test results do not represent the actual drainage quality from the rocks but rather gives an indication of the typical chemical parameters that leach from the rocks as well as the rate at which these chemicals are leached under the specific test conditions;
- All the EC measures was above 25 mS/m. The average to high EC values is due to the high reactivity of the tested material and especially the sulphide oxidation rate;
- From Discard 1 a high sulphide load is present during the first few weeks. This is because the material is highly reactive hence pyrite oxidation kicks off rapidly then gradually slows down as the material reaches equilibrium; and
- Overall the kinetic leach test results show that the material is fast reacting and that in most cases sulphate is released but eventually sulphide oxidation proceeds very slowly.

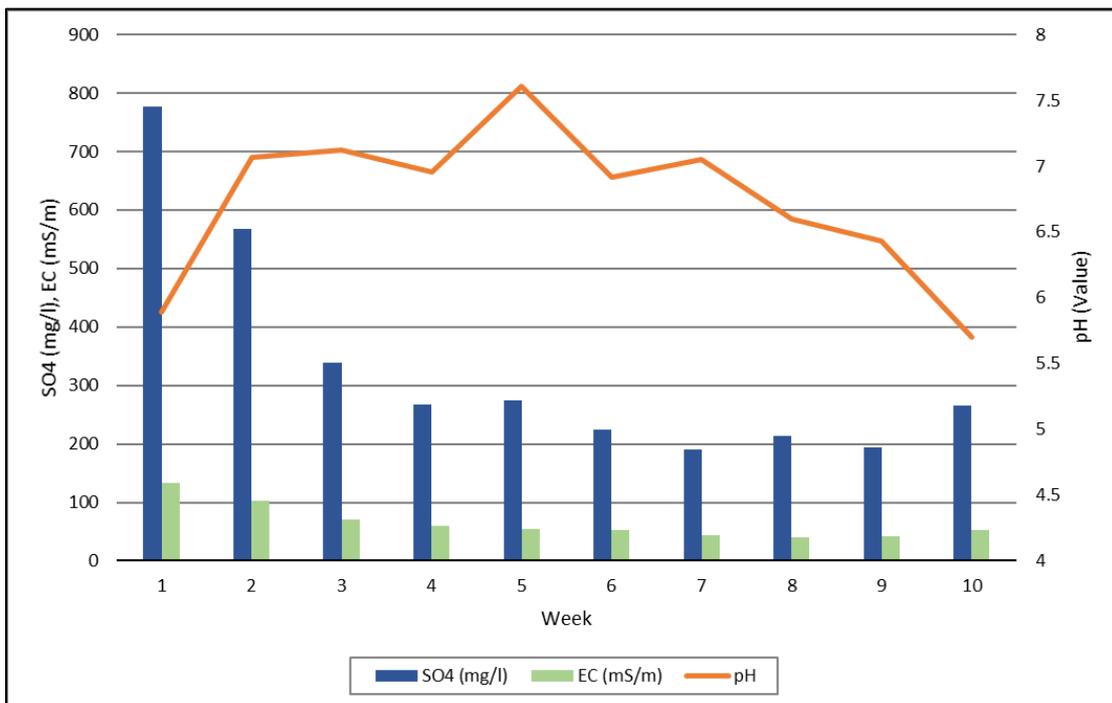


Figure 8-2 Discard 1 Sulphate (SO₄), Electrical Conductivity (EC) and pH

Table 8-8 Discard 1 ICP Weekly Leach Results

Week	pH	EC	SO ₄	Ca	Mg	Na	K	Al	Fe	Mn	
	[pH Value]	[mS/m]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	
1	5.89	133	776	147	23.8	94.3	9.31	0.139	29.8	1.54	
2	7.07	102	568	142	24.4	66.3	7.7	BDL(0.002)	0.243	1.11	
3	7.12	70.5	338	92.6	15.4	33.7	7.01	BDL(0.002)	BDL(0.004)	0.731	
4	6.96	59	268	-	-	-	-	-	-	-	
5	7.61	54.4	274	79.4	13.4	11.6	4.42	BDL(0.002)	BDL(0.004)	0.803	
6	6.92	52	224	77.7	10.5	6.57	3.82	0.015	BDL(0.004)	0.753	
7	7.05	42.9	191	76.9	9.79	3.76	3.29	0.024	BDL(0.004)	0.741	
8	6.6	40	213	-	-	-	-	-	-	-	
9	6.43	42.5	194	69.5	8.22	2.29	2.78	0.123	0.095	0.64	
10	5.7	52.2	265	91.8	10.7	3.47	3.41	0.136	BDL(0.004)	0.907	
SANS 241:2011	0-50% of limit	6 - 8.4	<85	<250	-	-	<100	-	<0.15	<1	<0.25
	50-100% of limit	5-6; 8.4-9.7	85-170	250-500	NS	NS	100-200	NS	0.15-0.3	1-2	0.25-0.5
	Above limit	<5; >9.7	>170	>500	NS	NS	>200	NS	>0.3	>2	>0.5

SANS 241-1:2011 Keys:

Yellow text - Exceedance of SANS 241-1:2011's 0-50% limit

Red text - Exceedance of SANS 241-1:2011's 50-100% limit

NS - No Standard

Note/s:

- mS/m - milli Siemens per metre
- mg/l - milligrams per litre
- BDL - below laboratory instrument detection limit

8.6 Conceptual Geochemical Model

8.6.1 Oxygen and Water Infiltration

The following comments relate to acid mine drainage in general:

- The impact on drainage from a mine or mining waste depends on the interaction between the solid, water and air phase;
- The degree of acid-mine drainage will depend on the minerals present in order to generate or neutralize acidic drainage, as well as the interaction of the minerals with the oxygen and water;
- Without any of these three phases no acid mine drainage will be possible. For instance, if the mine is sealed off from the atmosphere then no oxygen ingress is possible with no resultant oxidation of sulphides; and
- If oxygen is present, but no sulphides, then mine drainage will most likely not be acidic. However, some metals may still leach at near-neutral conditions from the material but at a much lower concentration than in acidic drainage.

A conceptual model of the presence of the oxic and anoxic zone in the discard dump is depicted in Figure 8-3:

- The unsaturated zone will comprise of an outer oxic and deeper anoxic zone depending on the depth of oxygen infiltration into the residue dump as illustrated in Figure 8-3 below; and
- Pyrite oxidation will only take place in the oxic zone and the interstitial water in the upper part of the unsaturated zone will have a much higher sulphate concentration than the saturated water deeper in the dump.

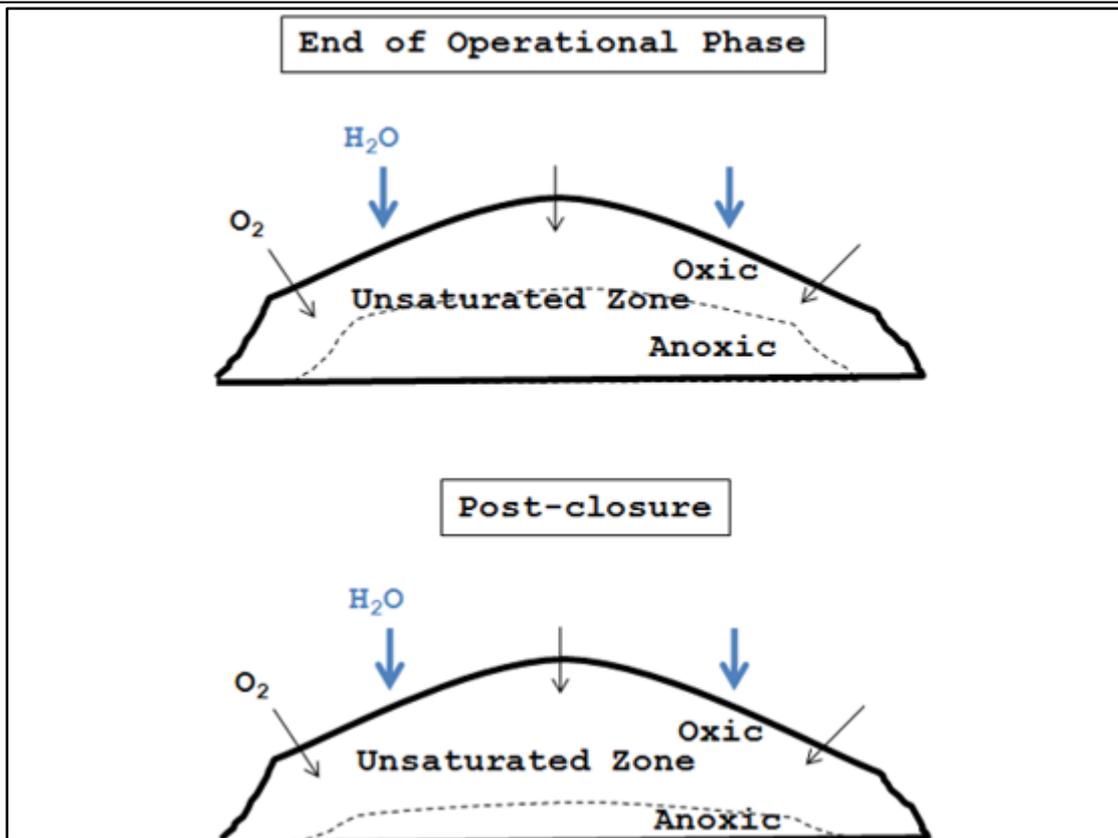
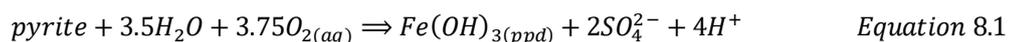


Figure 8-3 Discard Dump Conceptual Model (Illustrating Oxic Presence and Anoxic Zone)

8.6.2 Geochemical Reactions

The following observations relate to the geochemical reactions in the mine material:

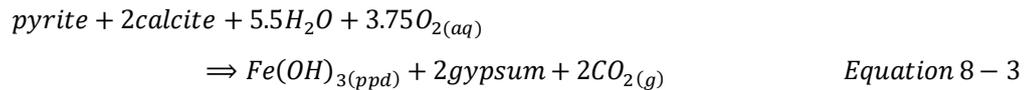
- The mine material will consist of a solid, water and gas phase. Without one of these phases no Acid-mine Drainage (AMD) production and drainage are possible. The waste rock material (solid phase) are the reactive part of the three phases and contains sulphide minerals that reacts spontaneously with oxygen and water;
- Upon oxidation, pyrite will react with the infiltrating oxygen and water to produce Fe^{3+} , SO_4^{2-} and acidity:



- Water serves as the transport medium for the products of AMD as it percolates through the waste material. The water phase also serves as the medium in which dissolution of neutralizing minerals can take place. The acid produced by the pyrite will be consumed by calcite (and/or dolomite) if present in the rock:



- Together with SO_4 the Ca^{2+} produced will form gypsum and the above equations could be rewritten as follows:



- If all the carbonate minerals (generally, calcite and dolomite in the Vryheid Formation) are depleted then the seepage from the dumped material becomes acidic. Silicate minerals can also consume some of the acidity. However, silicate minerals react too slowly to prevent acidification in material with a significant potential to generate acidic drainage;
- In acidic seepage, metals will also be leached out at elevated concentrations and the final stage of AMD would have been reached;
- An important aspect in the environmental geochemical modelling of a mine is therefore to determine whether enough neutralization minerals exists and if not, when it will become depleted. It is not possible to determine the time scale for these mineral reactions from the laboratory tests. Even with leach tests neutralization minerals are often not depleted and more important, the tests also do not have the same rock/water/gas ratio than the backfilled material. Numerical kinetic modelling provides the only possible means to model the rock, water and gas phases and to add a time scale to the problem.

8.7 Geochemical Numerical Model

8.7.1 Introduction

The objective of the geochemical modelling was to estimate the seepage quality at the discard dump at Dorstfontein Colliery. The modelling results will also aid in the planning of future water management measures at the mine.

Analytical results cannot be used directly to establish the changes in the leachate quality from a mine over time. Due to the complexity in the interaction between the solid, water and gas phases, geochemical numerical modelling was used to predict the Acid Mine Drainage (AMD) from the discard dump.

The oxygen diffusion into the residue mine waste was modelled using a MATLAB version of PYROX. The code models the diffusion of oxygen through the unsaturated zone, the oxygen consumed by mineral oxidation, and the subsequent sulphate, iron and acidity production.

The interaction between the mineral, water and the gas phase were modelled using Geochemist's Workbench Professional. This model solves the hydro-chemical and mineral reactions with the equilibrium model and the kinetic rate law for mineral dissolution. The Geochemist's Workbench is a set of interactive software tools for solving problems in aqueous geochemistry.

8.7.2 Modelling Scenarios

One model scenario was compiled to model the seepage water quality from the discard dump as summarised in Table 8-9.

The %S and NP of the waste rock used for the model is given in detail in Table 8-10. The following comments relate to the model input and assumptions:

- Sample representativeness:
 - The samples were assumed to be representative of the discard dump; and
 - In the modelling it is assumed that the modelled rock is saturated;
- Pyrite and carbonate mineral content:
 - The average %S and NP used for the numerical modelling are summarised in Table 8-10;
 - The carbonate mineral content was calculated from the measured NP values; and
 - The pyrite content was calculated from the weighted sulphide sulphur %S, assuming all sulphide sulphur is present as pyrite.

Table 8-9 Geochemical Scenario Model Description

Model Scenario	Site	Description
Model A	Discard	%S = 2.42 An 'average' composition of the discard was assumed.

Table 8-10 Geochemical Model Scenario Weighted Average %S and NP

Model Scenario	Site	Sulphide Sulphur (%S)	AP CaCO ₃ (kg/t)	NP CaCO ₃ (kg/t)	NNP CaCO ₃ (kg/t)	NP/AP	Rock Type NNP	Rock Type (%S)	Rock Type NP/AP
Model A	Discard Dump	2.42	75.58	10.44	-65.14	0.13	I	I	I

8.7.3 Geochemical Model Results

8.7.3.1 Model Results

The change in the modelled water quality is depicted as follows:

The change in the modelled water quality is depicted as follows:

- Figure 8-4: Changes in pH concentration over model time;
- Figure 8-5: Changes in SO₄ concentration over model time; and
- Figure 8-6: Changes in mineralogy over model time.

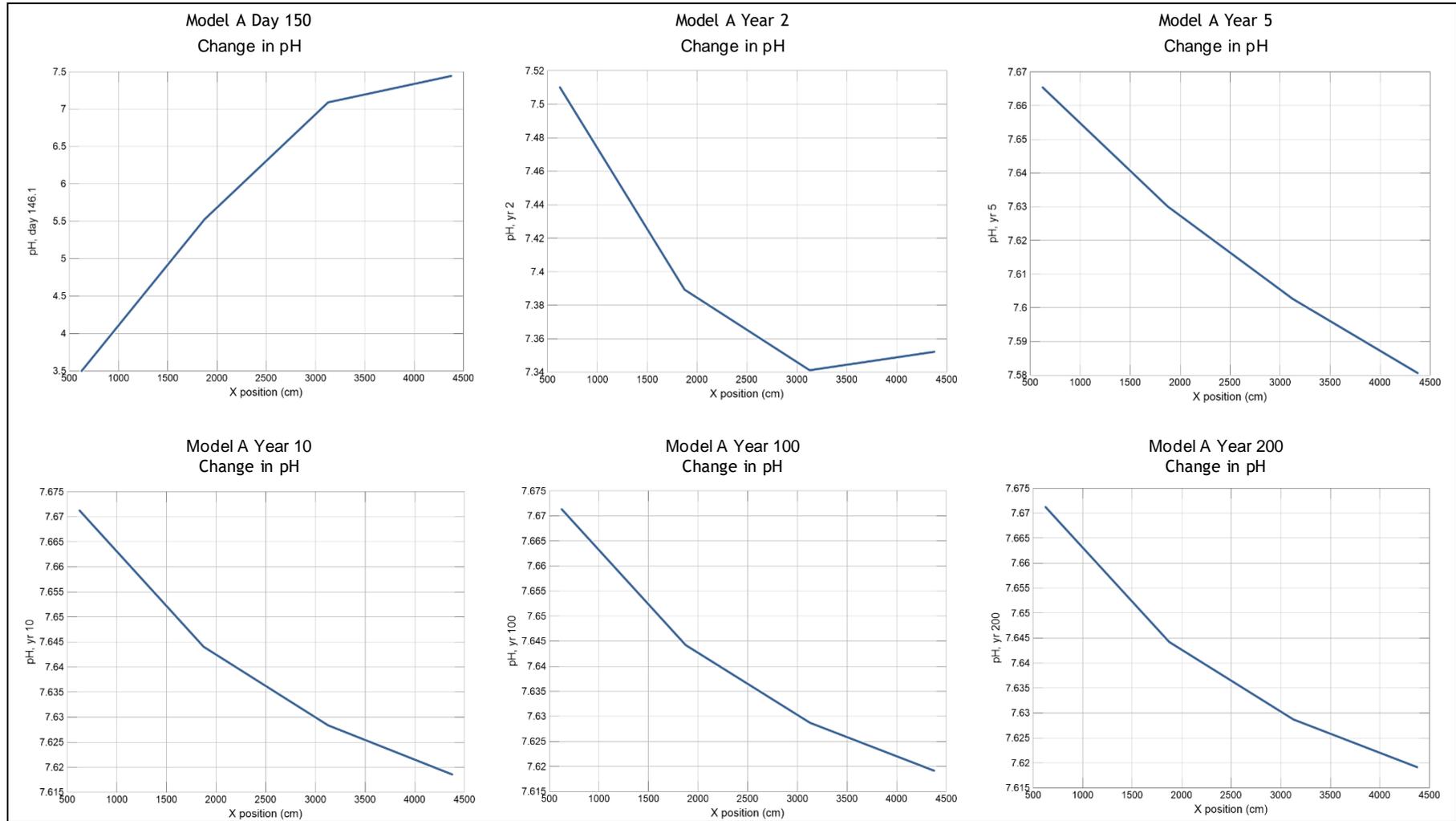


Figure 8-4 Scenario A - Changes in pH Values Over Model Time

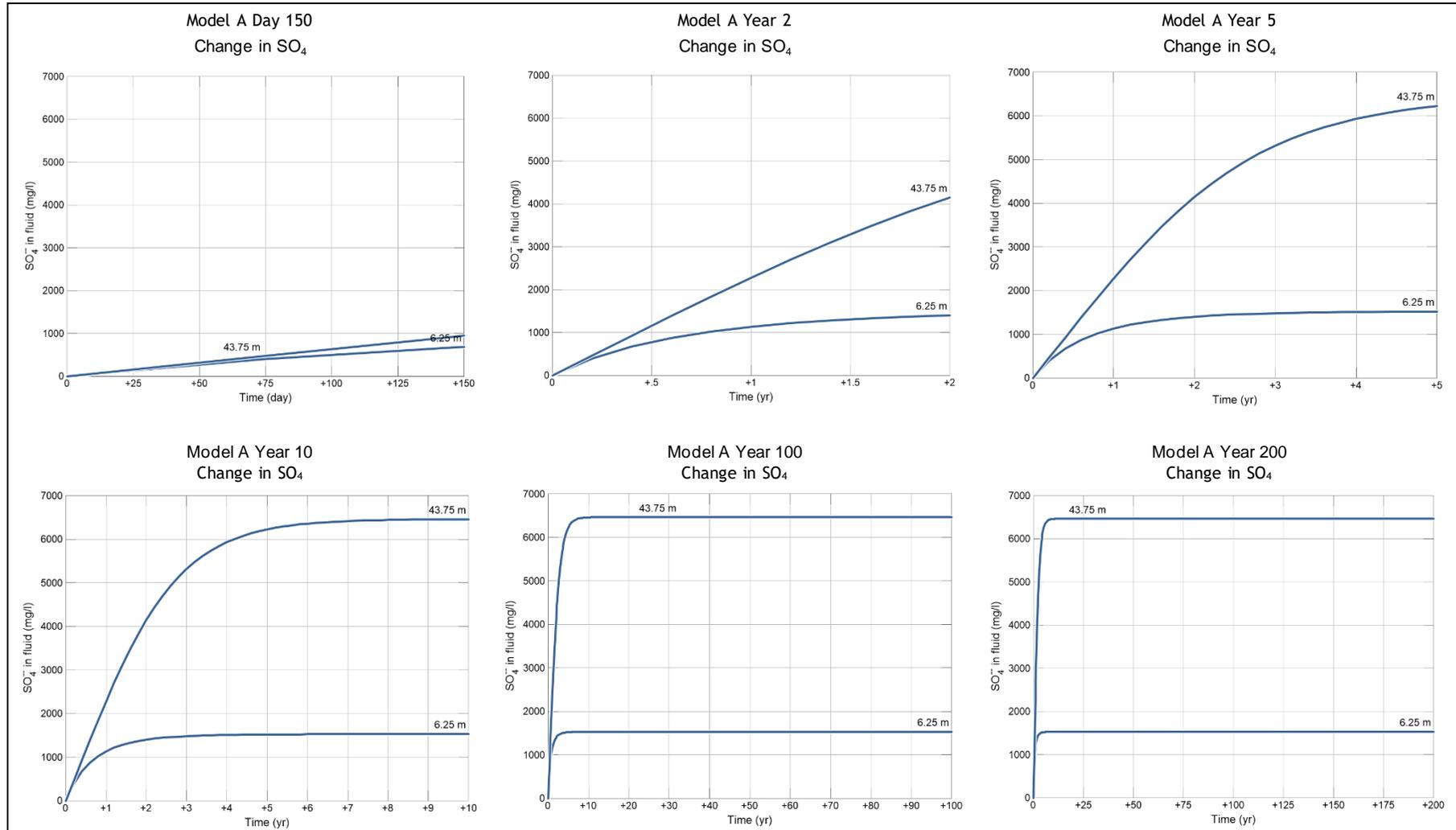


Figure 8-5 Scenario A - Changes in SO_4 Concentration Over Model Time

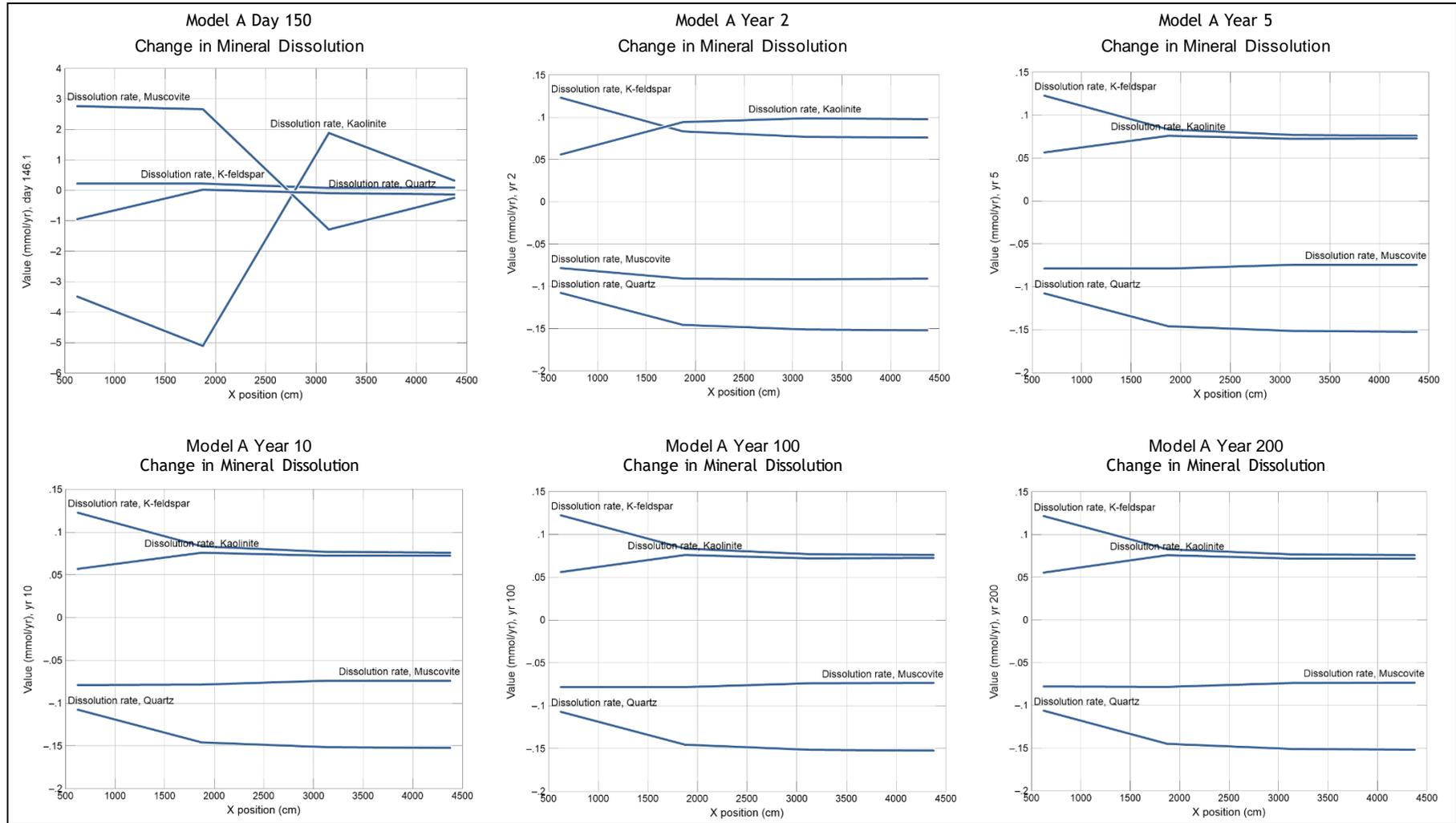


Figure 8-6 Scenario A - Changes in Mineralogy Over Model Time

8.7.3.2 Predicted Seepage Water Quality Summary

Based on the geochemical model results, the water quality for mining is summarized as follows:

- The pH and SO₄ for the different model stages are summarized in Table 8-11; and
- The evolution in acid-mine drainage in terms of the mineral dissolution and the mine water quality is summarized in Table 8-12.

From the model results the following conclusions could be made:

Depth of oxidation

- The oxygen concentration will decrease downwards in the unsaturated zone because of consumption by pyrite and physical retardation of the porous media. The oxygen infiltration will eventually reach a pseudo-steady state; and
- The oxic zone will migrate downwards in the discard dump over time.

Changes in major ions

- Alkalinity is the dominant anion in the recharge water in the unsaturated zone but is quickly replaced by sulphate;
- Sulphate then becomes the major anion as it is a direct product of the sulphide oxidation. The major cations that will be present in seepage will predominantly originate from the reaction of the neutralization minerals; and
- Seepage from the discard dump will have a sulphate value of up to 6 500 mg/l in the unsaturated zone and will vary over the dump to a value of up to 1500 mg/l in the saturated zone of the discard dump.

Changes in pH conditions

- Discard dump: The discard has some net acid potential and the interstitial water at the bottom of the discard will acidify to a pH of 3.5 - 4.5 in the saturated zone within less than 150 days. The unsaturated zone will be near neutral (pH 7.5) and the pH at the contact between the unsaturated and saturated zone will have a pH less than 6.5 reaching pH 5.5 over time; and
- As the material in the discard reaches equilibrium by year 5 the pH in the unsaturated and saturated zone of the discard dump will be near neutral (between pH 7.67 and 7.58).

Metals in mine water

- It is not foreseen that any metals except Al, Fe and Mn will be present in *neutral seepage* from the mine. These elements will mostly be present at concentrations of <1 mg/l in the mine water at near-neutral conditions;
- Over the long-term Al will likely become more dominant as it is released from the silicate mineralogy. Metal concentrations under acidic conditions can however be expected to be very erratic and will change significantly between each monitoring run; and

- The metal concentrations in the upper part of the saturated zone might be slightly elevated (e.g. Al, Fe, Mn at <5 mg/l) but deeper down the saturated zone metal concentrations will significantly decline (e.g. Al, Fe, Mn at <1 mg/l).

Mineral dissolution in mine water

- By day 150, In the saturated zone both muscovite and k-feldspar will precipitate while quartz and kaolinite will dissolve in solution. In the unsaturated zone kaolinite and k-feldspar will precipitate while muscovite and quartz will dissolve;
- By model year 2, both k-feldspar and kaolinite will precipitate in the saturated and unsaturated zone while muscovite and quartz will dissolve in solution in both the saturated and unsaturated zone; and
- By model year 5 when the system starts reaching equilibrium, both k-feldspar and kaolinite will precipitate in the saturated and unsaturated zone while muscovite and quartz will remain dissolved in solution in both the saturated and unsaturated zone. This will be maintained till the end of year 200.

It can therefore be concluded that, overall, the mine material will have a net neutralization potential. The average discard material has a potential to generate AMD and a hot-spot will form in the early stages in the saturated zone but as equilibrium is attained the acid is neutralized by the presence of phyllosilicates and tectosilicates along with CaO, MgO and Na₂O which makes up the discard material.

Table 8-11 Discard Dump Estimated pH and SO₄

Backfill Material	Coal Discard in the Unsaturated Zone			Coal Discard in the Saturated Zone		
	Short Term: 0-10 Years	Medium Term: 10 - 100 Years	Long Term: 100-200 Years	Short Term: 0-10 Years	Medium Term: 10 - 100 Years	Long Term: 100-200 Years
AMD Stage	Stage 1	Stage 1	Stage 1	Stage 2&3	Stage 1	Stage 1
No Selective Mining: pH	7.34 - 7.61	7.61 - 7.63	7.61 - 7.63	3.5 - 7.67	7.64 - 7.67	7.64 - 7.67
No Selective Mining: SO ₄ (mg/l)	1000 - 6500	6500	6 500	800 - 1500	1500	1500

Table 8-12 Evolution in Acid-Mine Drainage (AMD) (adapted from Fourie 2014) *

Component	AMD Stage 1	AMD Stage 2	AMD Stage 3
Mineralogical reactions and products			
Pyrite	Oxidation	Oxidation. SO ₄ reaches maximum concentration in interstitial water.	Depleted in upper oxidation zone. SO ₄ decrease from maximum.
Calcite and dolomite	Dissolution	Depleted in upper oxidation zone.	Depleted in upper oxidation zone.
Gypsum	Precipitation, controls SO ₄	Dissolution	Depleted in upper oxidation zone.
Fe-sulphates	None	Precipitation	Some dissolute while other keeps precipitating
Metals Al, Fe, Mn	Precipitate/adsorp	Elevated, reaches maximum value	Decrease from maximum
Traces Ni, Co, Pb, Cu	Precipitate/adsorp	Elevated, reaches maximum value	Decrease from maximum
pH	Neutral	Acidic in seepage from unsaturated zone	Acidic in seepage from unsaturated zone
Water quality changes			
pH	6.5 - 7.5	6.5 down to <4.5	3.5 - 4.5
Alkalinity (as CaCO ₃)	50 - 450	0	0
Ca	100 up to 750	750 down to 300	500 - 300
Mg	50 up to 350	250 - 450 (700)	150 - 350
Na	50 - 150	150 up to 250	150 - 250
SO ₄	1 500 - 2 500 mg/l	> 2 500 mg/l	> 2 500 mg/l
Al	< 1	< 100 (up to 1 000)	< 100 (up to 1 000)
Fe	< 1	< 100 (up to 1 000)	< 100 (up to 1 000)
Mn	<1	< 100	< 100

* Values in brackets are for highly carbonaceous material.

8.7.4 Model Limitations

The following important comments relate to the validation of the geochemical model:

Mineral kinetics

- The pyrite oxidation rate was determined from kinetic column test performed. The calibrated surface area was in good agreement with literature values;
- No attempt was made to model any microbial activity. It is assumed that microbial activity could be ignored during near neutral conditions. The modelled concentrations were however in good agreement with mine water measurement at similar mines;

Predicted water quality

- The geochemical modelling results were in good agreement with mine water measurements at similar mines; and
- It is recommended that the geochemical model is updated during the life of the mine in order to calibrate and validate its results and to construct an effective closure plan.

8.8 Geochemical Modelling Conclusions

Based on the results of the geochemical assessment, the following conclusions could be made:

- Pyrite was the only sulphide detected in the samples and it's associated with the depositional environment in which the sandstone and siltstone formation occurred and is commonly a trace mineral deposited along with coal. Pyrite is generally elevated in coal with respect to clastic rocks due to formation under reducing conditions and can form during or very shortly after peat accumulation (authigenic) or as veins later in the coal's burial history (epigenetic). The presence of pyrite may lead to ARD formation and thus the discard material should be managed and monitored to minimize seepage and runoff of leachate;
- Seepage from the discard dump will have a sulphate value of up to 6 500 mg/l in the unsaturated zone, and will vary over the dump to a value of up to 1500 mg/l in the saturated zone of the discard dump;
- The discard has some net acid potential and the interstitial water in the oxic zone will acidify to a pH of 3.5 in the saturated zone within less than 150 days of placement. The unsaturated zone will be near neutral (pH 7.5) and the pH at the contact between the unsaturated and saturated zone will have a pH less than 6.5 reaching pH 5.5 over time. As the material in the discard reaches equilibrium by year 5 the pH in the unsaturated and saturated zone of the discard dump will be near neutral (between pH 7.67 and 7.58); and
- It is not foreseen that metals will significantly be present in neutral drainage. However, in the long-term, Al will likely become more dominant as it is released from the silicate mineralogy. Metal concentrations under acidic conditions can however be expected to be very erratic and will change significantly between each monitoring run.

8.8.1 Geochemical Assessment and Site Water Quality

The conclusions from the geochemical assessment are in line with the water quality monitoring results:

- Material on the discard dump and the coal stockpile area have the potential to become acidic and cause seepage with elevated sulphate concentrations; elevated sulphate concentrations were found in boreholes and surface water samples down gradient of the discard dump;
- Seepage from the discard dump, the coal stockpile and plant area are captured in the PCD's; as a result, the water in the PCD's shows elevated sulphate concentrations; boreholes and surface water sampling points down gradient of the PCD's show elevated sulphate concentrations.

9 HYDROGEOLOGICAL SITE CONCEPTUALISATION

The conceptual model describes the hydrogeological environment and is used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system. The conditions should be chosen in view of the specific objective of the modelling and might not be relevant for other modelling objectives. The conceptual model is based on the source-pathway-receptor principle.

9.1 Source

The main potential on - site contamination sources for DCMW are:

- The underground mine workings;
- The slurry and discard dump (discard dump);
- The Pollution Control Dams (PCD's); and
- The coal stockpile area.

9.2 Pathway

From the reviewed information the conceptual Model consists of three hydrogeological units:

- Weathered and highly fractured Karoo;
- Moderately fractured Karoo; and
- Slightly fractured Karoo.

According to Hodgson & Krantz (1998) recharge ranges between 1 and 3 % of MAP. The weathered layer has a thickness of approximately 15 m and is comprised of residual soils and weathered shales and sandstone. Groundwater levels generally following topography and hydrocensus groundwater levels range between 2.9 and 56.4 m bgl, with an average groundwater level of 22.7 m bgl. Hydraulic conductivity values are estimated to be in the order of 10^{-2} m/d.

The underlying fractured units consist of shale, sandstone and coal seams. The pores within the Ecca sediments are too well cemented to allow any significant permeation of water which is therefore limited to fractures. Fracturing mainly occurs in the top of this unit and decreases with depth. Hydraulic conductivity typically decreases with depth and is estimated to range between 10^{-2} m/d in the upper layers and 10^{-4} m/d for the lower layers.

Along the eastern section of the farming portion where Pre-Karoo basement rocks outcrop the conceptual model consist of two hydrogeological units:

- Weathered pre-Karoo basement;
- Fractured pre-Karoo basement.

The pre-Karoo basement unit consist of granite. Boreholes drilled in the granite were dry. Hydraulic conductivities for the weathered pre-Karoo unit will therefore be low, in the order of 10^{-3} m/d, and groundwater flow in the (limited) fractured granite will be minimal or absent.

Based on the conceptual model, possible pathways for on-site contaminations are:

- The surface water streams; and
- The weathered and fractured Karoo aquifers.

9.3 Receptor

Potential receptors as seen in Figure 3-1 are:

Streams:

- One perennial stream (a tributary of the Steenkoolspruit) running along the northern boundary of DCMW; and
- Two ephemeral streams (tributaries of the Steenkoolspruit) running over and along the southern boundary of DCMW.

Springs:

- No spring sources were found down gradient of DCMW;

Privately owned boreholes:

- No privately-owned boreholes were found down gradient of DCMW; one borehole (NBH0) was found at the western most end of DCMW but was not in use.

10 HYDROGEOLOGICAL NUMERICAL MODELLING

10.1 Model Confidence Level Classification

An Australian Guideline Class 1 model classification was pursued and was evaluated from a semi-quantitative assessment of the available data on which the model was based, the manner in which the model was calibrated and how the predictions were formulated. The level of confidence depended upon the available data for the conceptualisation, design and construction of the model. This model could be classified Class 2 after the input of additional aquifer testing with multiple groundwater level monitoring in the weathered and fractured aquifers, correlation with existing mine inflows and measured flow and head stages of the rivers used for model boundaries.

Consideration was given to the spatial and temporal coverage of the available datasets in order to characterise the aquifer and the historic groundwater behaviour that was useful in model calibration. Factors that may affect the model confidence level during the calibration procedure were considered and included the types and quality of data that was incorporated in the calibration, the degree to which the model was able to reproduce observations, and whether the model was able to represent present-day hydrogeological conditions. The time frame and level of stresses applied in the predictive models were consistent to that of the model calibration process.

10.2 Model Limitations and Exclusions

Groundwater flow models are inherently simplified mathematical representations of complex aquifer systems. The simplification limits the accuracy with which groundwater systems can be simulated in general. There are numerous sources of error and uncertainty in groundwater flow models. Model error commonly stems from practical limitations of grid spacing, time discretisation, parameter structure, insufficient calibration data, and the effects of processes not simulated by the model. These factors, alongside unavoidable error in field observations and measurements, result in uncertainty in the model predictions.

The calibration of the model developed for DCMW was mainly based on available groundwater levels focussing on the Eccca Group deposits in which the DCME site is situated. Assumed is a homogenous rock matrix for the Eccca aquifers. The calculated inflows represent the correct order of magnitude, and the most likely range of inflow variation based on the uncertainties of the model used will be presented.

Transmissivity, hydraulic conductivity and storage values were estimated from site-specific aquifer test results combined with information from other studies in the vicinity of the site. Additional aquifer testing with multiple-level monitoring in the weathered and fractured aquifers on the site would increase the confidence of the hydrogeological parameters used as input for the numerical modelling.

Contaminant transport has been included in this model was based on geochemical modelling and seepage rates have been based on rehabilitation plans for the underground mine in combination with ranges from studies for similar infrastructures. It is recommended that seepage rates from the facilities be determined using unsaturated flow modelling based on the final designs. Detailed engineering designs should be provided for further investigations.

10.3 Model Code, Design and Construction

10.3.1 Governing Equations

The numerical model used in this modelling study was based on the conceptual model developed from the findings of the desktop and the baseline investigations. The simulation model simulates groundwater flow based on a three-dimensional cell-centred grid and may be described by the following partial differential equation:

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) \pm W = S_s \frac{\partial h}{\partial t} \quad \text{Equation 10.1}$$

where

- K_{xx} , K_{yy} , K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);
- h is the potentiometric head (L);
- W is a volumetric flux per unit volume representing sources and/or sinks of water, with:
 - $W < 0.0$ for flow out of; and
 - $W > 0.0$ for flow in the groundwater system (T-1).
- S_s is the specific storage of the porous material (L-1); and
- t is time (T).

Equation 10.1, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions (Harbaugh et al. 2000).

10.3.2 Model Software Package

The numerical model for the project was constructed using GMS 10.4.5, a pre- and post-processing package for the modelling code MODFLOW. MODFLOW is a modular three-dimensional groundwater flow model developed by the United States Geological Survey (Harbaugh et al., 2000). MODFLOW uses 3D finite difference discretisation and flow codes to solve the governing equations of groundwater flow. MODFLOW NWT (Niswonger et al., 2011) was used in the simulation of the groundwater flow model. Both are widely used simulation codes and are well documented.

10.3.3 Boundary Conditions

Boundary conditions express the way in which the considered domain interacts with its environment. In other words, they express the conditions of known water flux, or known variables, such as the hydraulic head. Different boundary conditions result in different solutions, hence the importance of stating the correct boundary conditions. Boundary condition options in MODFLOW can be specified either as:

- Specified head or Dirichlet; or
- Specified flux or Neumann; or
- Mixed or Cauchy boundary conditions.

From the conceptual point of view, it was essential to meet two criteria to the maximum extent possible:

- The modelled area should be defined by natural geological and hydrogeological boundary conditions, i.e. the model domain should preferably encompass entire hydrogeological structures; and
- The mesh size of model grid has to correspond to the nature of the problem being addressed with the model.

Local hydraulic boundaries were identified for model boundaries. They were represented by local watershed boundaries and topographical highs and delineated the entire model domain. These hydraulic boundaries were selected far enough from the area of investigation to not influence the numerical model behaviour in an artificial manner. The model boundaries and model grid are shown in Figure 10-1; Table 10-1 while provides a summary of the boundaries, boundary descriptions and boundary conditions specified in the hydrogeological model.

Table 10-1 Identification of the real-world boundaries and adopted model boundary conditions

Boundary	Boundary Description	Boundary Condition
Top	Top surface of water table	Mixed type: River cells for rivers; drains for non-perennial streams. Recharge is constant for the model area. Recharge flux is applied to the highest active cell.
North	River boundary condition	Olifants River
East	River and no-flow boundary condition	Viskuil tributary and topographical high
South	River boundary condition	Steenkoolspruit River
West	River boundary condition	Steenkoolspruit River

Note/s:

- None

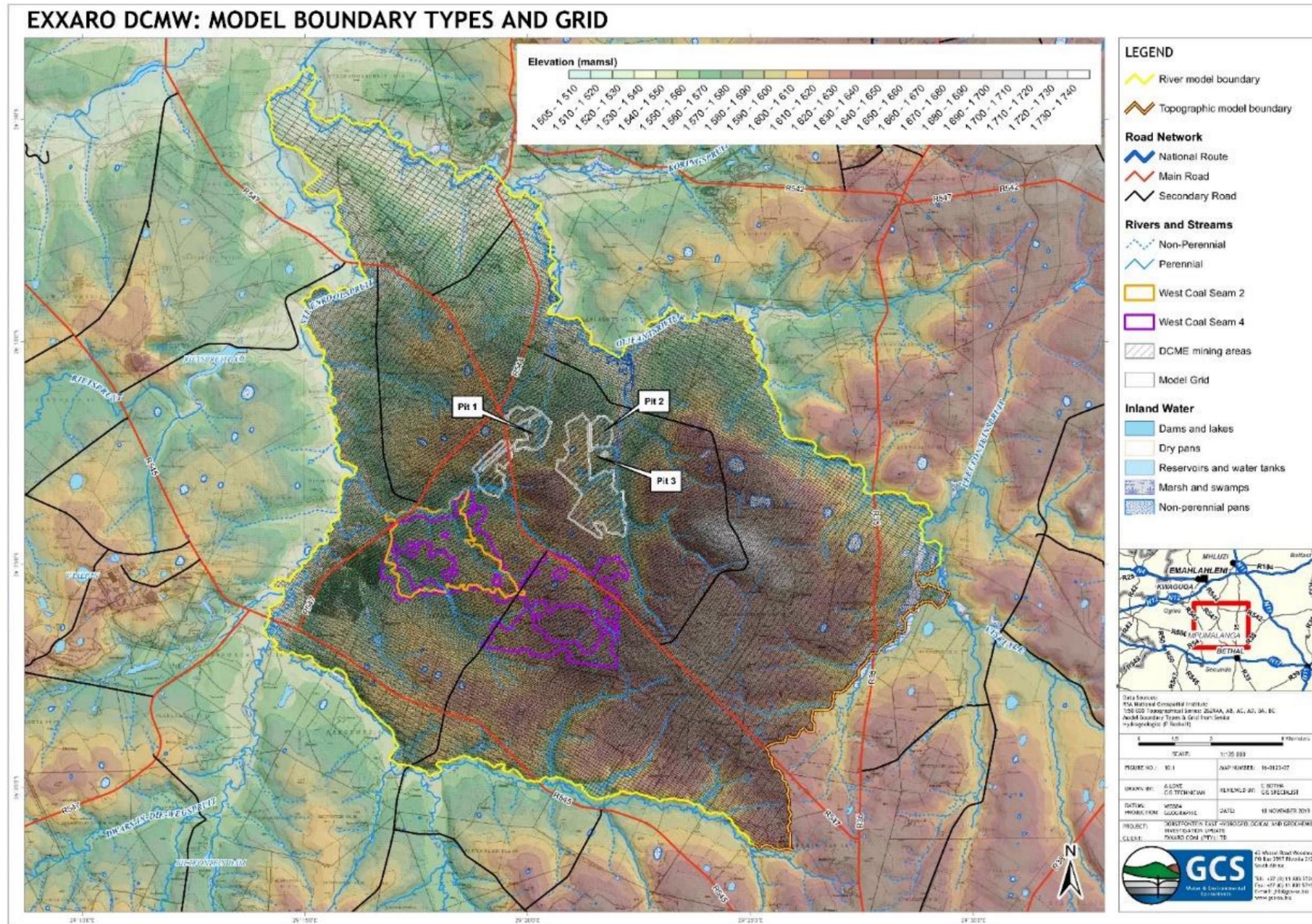


Figure 10-1 DCMW Model Boundary Types and Grid

10.3.4 Finite Difference Grid

Compilation of the finite difference grid using the GMS 10.4.5 graphic user interface facilitated the construction of a rectangular horizontal grid, as well as vertical geometry provided for each of the layers. The grid consists of 3 layers. The positions of the different geological boundaries are incorporated in the modelling grid. A grid refinement of 50 m x 50 m cells around the DCMW mining area with gradually coarser grid cell sizes away from the mining areas (Figure 10-1). This is standard practise and does not influence the accuracy of the results obtained.

10.3.5 Vertical Discretisation

Along the vertical direction, the steady state hydrogeological model is structured in 3 model layers (Figure 10-2). The layer positions were selected to best incorporate the conceptual model and to allow for accurate horizontal and vertical groundwater flow in the model. The following layers were defined:

- Weathered Karoo layer (~ 20 m thickness);
- Fractured Karoo:
 - Upper fractured Karoo layer with coal seams (~ 60 m thickness); and
 - Lower fractured bedrock (~ 40 m thickness).

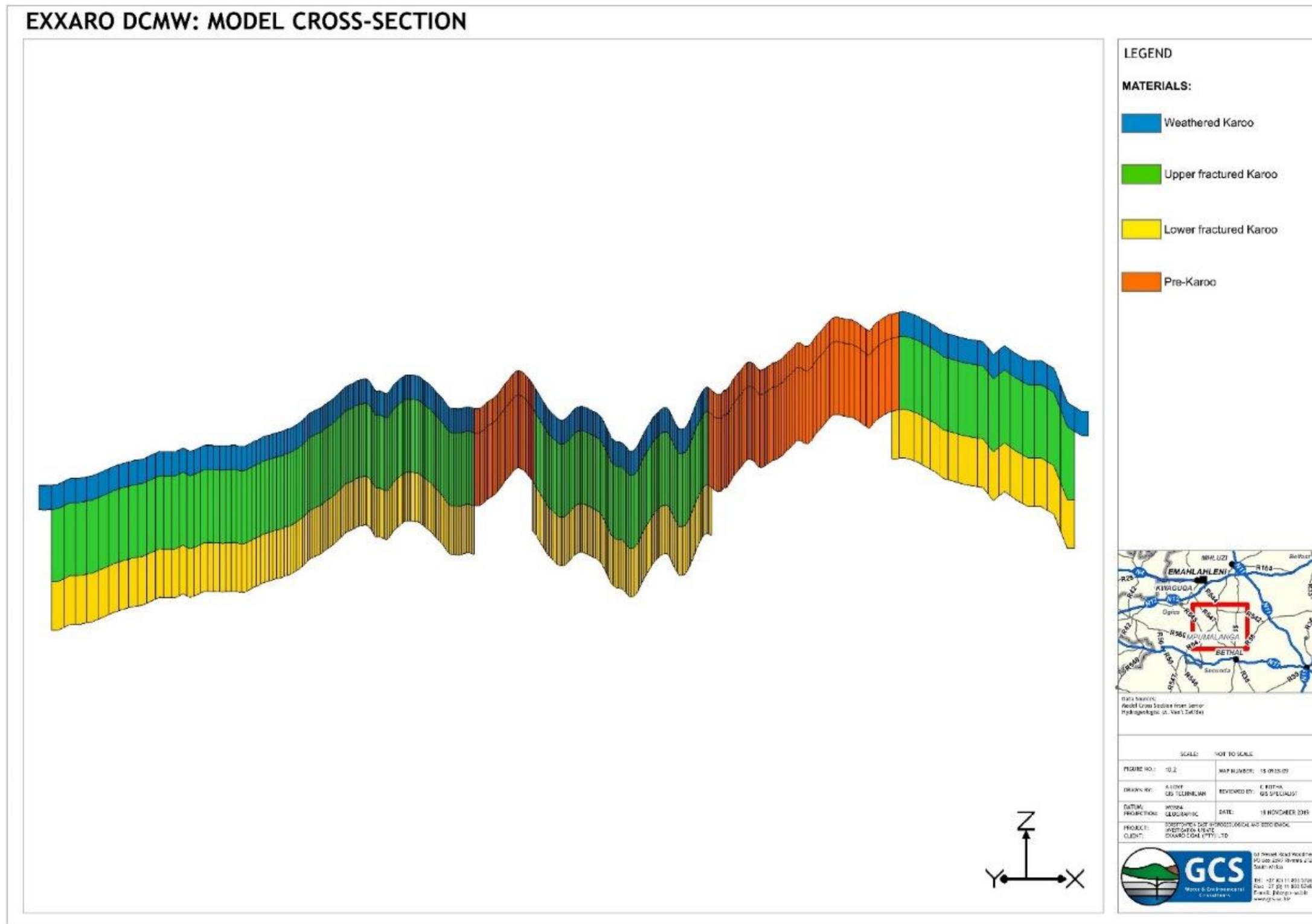


Figure 10-2 DCMW Model Cross-Section

10.3.6 Time Discretisation

Time parameters are relevant when modelling transient (time-dependent) conditions. They include time unit, the length and number of time periods and the number of time steps within each time period. All model parameters associated with boundary conditions and various stresses remain constant during one time period. Having more time periods allows these parameters to change in time more often (Kresic, 2007).

For the purpose of simulation of groundwater inflows into the mine, the transient simulation was discretized into stress periods of 1 year in length. Each stress period was then divided into 10-time steps. Incremental time steps (Time Step Multiplier: 1.2) from a few days to several months were used for mine inflow simulation.

10.3.7 Mine Schedule

The mine schedules for the No. 2 and No. 4 seams (as discussed in Section 5) were updated and used as input for the model. The underground mining operations were simulated by means of drain cells which were assigned to the correct model layers based on the anticipated depth of mining.

10.3.8 Model Input Parameters

Model input parameters for this flow model are divided into two groups:

- Hydrogeological parameters; and
- Initial conditions.

The initial estimates for hydraulic properties were assigned based on the site-specific aquifer test results combined with information from other studies in the vicinity of the site. The initial head conditions, specified in the steady state model, were estimated from topography. Initial transient model heads were derived from the steady state model results.

One percent (1 %) recharge of MAP was applied, which is ~ 6.5 mm per annum (mm/a). Due to the homogeneous nature of the geology in the study area, similar parameter values were assigned to the entire model domain, except for the co-disposal facility at DCME and discard dump at DCMW which was given a recharge value of 8 % of annual precipitation.

10.4 Calibration and Sensitivity Analysis

10.4.1 Calibration

Calibration is the process of finding a set of boundary conditions, stresses and hydrogeological parameters that produce result that most closely matches field measurements of hydraulic heads and flows. In a regional groundwater flow model, a difference between calculated and measured heads of up to several meters can be tolerated and is usually expressed as a function of the total range of observations.

A scaled absolute mean value of below 10 % (*RN*, see equations below) is generally regarded as acceptable for a regional model. This calibration was done under steady state conditions. When calibrated, the model can be used to predict the influence of various management scenarios. Limitations in terms of the model that was set up were the fact that there are current mining activities already taking place which had to be taken into consideration.

10.4.1.1 Calibration Targets

The groundwater levels of on-site monitoring boreholes for the period 2010 - 2016 and hydrocensus data from investigations carried out in 2014 - 2016 and 2019 and were available for model calibration.

For calibration of a pre-mining steady state, the most recent groundwater levels for hydrocensus locations were used. For selected monitoring boreholes groundwater levels from 2010 were used to exclude any impacts of current mining activities on the calibration process of the pre-mining conditions.

10.4.2 Steady-State Calibration

For steady state conditions the groundwater flow Equation 10.1 reduces to the following equation:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) \pm W = 0 \quad \text{Equation 10.2}$$

The numerical model calculated head distribution ($h_{x,y,z}$) is dependent upon the recharge, hydraulic conductivity and boundary conditions. For a given set of boundary conditions, the head distribution across the aquifer can be obtained for a given set of hydraulic conductivity values and specified recharge values. This simulated head distribution can then be compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

Steady state calibration of the DCMW model area was accomplished by refining the vertical and horizontal hydraulic conductivity relative to average recharge values until a reasonable resemblance between the measured piezometric levels and the simulated piezometric levels were obtained.

For the DCMW model area this was done by a combination of manual calibration and PEST using aquifer zone properties for all model layers. The success rate of the calibration process is usually assessed by the following statistical quantities:

- Mean Error

$$ME = \frac{1}{n} \sum_{i=1}^n (h_m - h_s)_i \quad \text{Equation 10.3}$$

- Mean Absolute Error

$$MAE = \frac{1}{n} \sum_{i=1}^n |h_m - h_s|_i \quad \text{Equation 10.4}$$

- Root Mean Square

$$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^n (h_m - h_s)_i^2} \quad \text{Equation 10.5}$$

- Normalized RMS

$$RN = \frac{RMS}{H_{max} - H_{min}} \quad \text{Equation 10.6}$$

Where:

- h_m represents measured head;
- h_s represents simulated head;
- n is the number of calibration targets;
- H_{max} represents maximum measured head; and
- H_{min} represents minimum measured head.

The steady state calibration was regarded as sufficient at ME= -0.91 m, MAE = 4.08 m, RMS = 4.83 m and RN = 0.04 (or 4%). This is an improvement when compared to the results from the previous model version of 2015 where the RMS was 7.9. This is due to the input of updated groundwater level observations, data selection and slight adjustments in aquifer hydraulic conductivity.

Figure 10-3 shows the relation between measured and simulated head at the end of steady state calibration process. In case of absolute conformity, the points should create a line. As it can be seen, the level of conformity is tolerable especially when uncertainty in spatial variation of hydraulic properties is taken into account.

A water balance error (all flows into the model minus all flows out of the model) of less than 0.5 % is regarded as an accurate balance calculation. The steady state mass balance for entire model domain, presented in Table 10-2, achieved a water balance error of less than 0.002%.

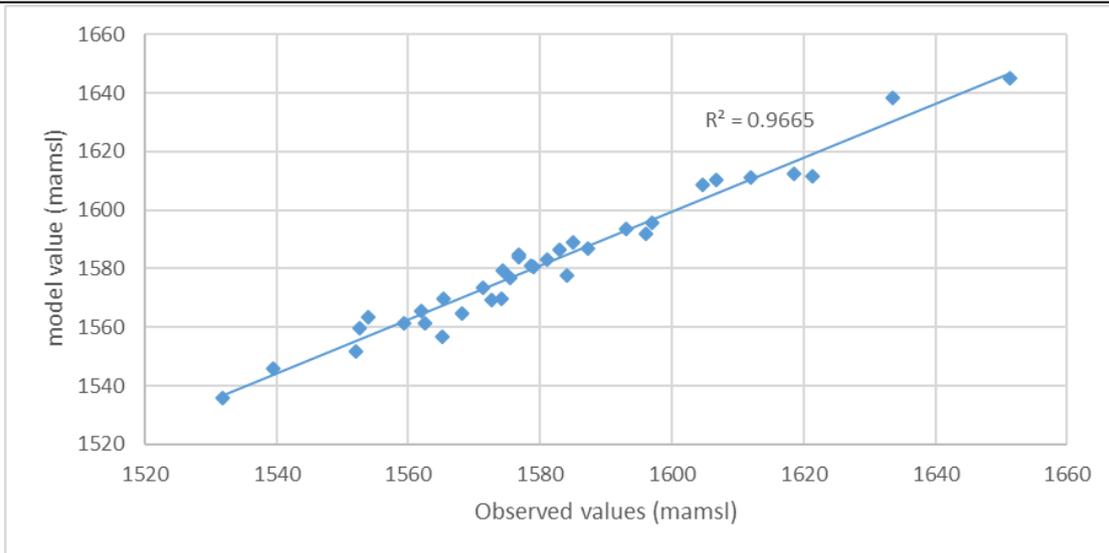


Figure 10-3 Steady State Model Calibration Results (Pre-Mining)

Table 10-2 Steady State Model Mass Balance (Pre-Mining)

Description	Flow In	Flow Out
[-]	[m ³ /d]	[m ³ /d]
Sources / Sinks		
Mine Inflow	0	0
River Leakage	2,352	- 2,962
Recharge	8,519	- 0
Drains	0	- 7,909
TOTAL FLOW	10,871	- 10,871
Summary		
Total	In-Out	Percentage (%) Difference
	- 0.21	- 0.0019

Notes:

- m³/d - cubic metres per day

Figure 10-4 shows the steady-state (pre-mining) groundwater levels across the DCMW area.

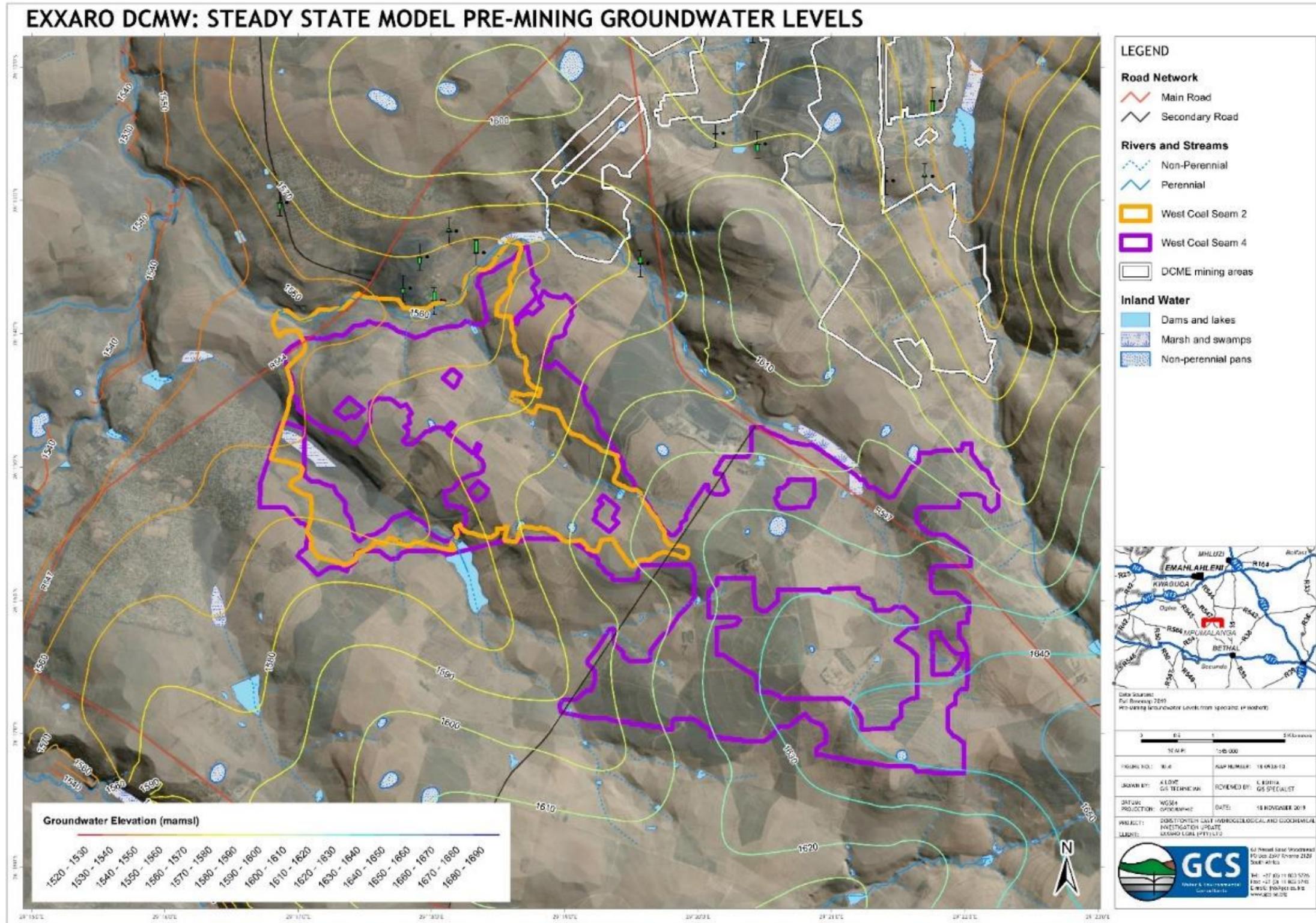


Figure 10-4 Steady State Model Pre-Mining Groundwater Levels

10.4.2.1 Aquifer Hydraulic Conductivity

Initial estimates of the hydraulic conductivity for the different geological units were obtained from site-specific aquifer test data. These hydraulic conductivity values were assigned to geologic layers in the model area. The initial estimates were used for a combination of PEST and manual calibration. The resulting calibrated hydraulic conductivity and transmissivity values for each layer as summarised in Table 10-3 and Table 10-4 respectively. The transmissivity value of the model is in the same order of magnitude as the average transmissivity determined from the site-specific aquifer test results.

Table 10-3 Horizontal and Vertical Calibrated Hydraulic Conductivity Values

Model Layer Number [-]	Zone Description [-]	Hydraulic Conductivity	
		Horizontal [m/d]	Vertical [m/d]
1	Weathered Karoo (Ecca)	3.2×10^{-1}	3.2×10^{-3}
2	Upper fractured Karoo (Ecca)	1.0×10^{-2}	1.0×10^{-3}
3	Lower fractured Karoo (Ecca and Dwyka)	5.0×10^{-3}	5.0×10^{-4}
1	Granite (Lebowa)	5.0×10^{-3}	5.0×10^{-4}
2	Granite (Lebowa)	5.0×10^{-3}	5.0×10^{-4}
3	Granite (Lebowa)	00×10^0	00×10^0

Note/s:

- - - not applicable
- m/d - metres per day

Table 10-4 Karoo Aquifers Calibrated Transmissivity Values

Model Layer Number [-]	Thickness [m]	Lithology [-]	Transmissivity Values [m ² /d]
1	20	Weathered Karoo	1.0
2	60	Upper fractured Karoo	0.6
3	40	Lower fractured Karoo	0.2

Note/s:

- - - not applicable
- m - metres
- m²/d - metres squared per day

10.4.2.2 Other Model Parameters

Recharge values were re-estimated as part of the steady state flow model calibration. An effective large-scale annual recharge value of 1 % of the MAP (~ 700 mm) was estimated for the DCMW model. The model was assigned a recharge value of 7 mm/a for the entire model area.

Other model parameters used in the calibrated model were as follows:

- Specific yield (S_y) for the unconfined weathered layers: 0.03 (unitless);
- Specific storage (S_s) for the confined fractured layers: 1.67×10^{-6} to 1.67×10^{-7} (unitless);
- Rivers:
 - Head stage at surface level;
 - Bottom elevation at 2 m below surface level;
 - Conductance river bottom of 0.86 metres squared per day per metres squared (m²/d/m²);
- Drains:
 - Drain level at 2 m below surface level;

- Drain conductance of $0.86 \text{ m}^2/\text{d}/\text{m}^2$;

10.4.3 Sensitivity Analysis

A sensitivity analysis was carried out on the calibrated model. The purpose of the sensitivity analysis was to quantify the uncertainty in the calibrated model caused by the uncertainty in the estimates of aquifer parameters. During the sensitivity analysis horizontal and vertical hydraulic conductivity and recharge were assessed. The parameter sensitivities can be seen in **Error! Reference source not found.**

Results of the sensitivity analysis indicate that the water levels in the model are mainly sensitive to changes in recharge and to a lesser extent to the conductivity of layer 2 (upper fractured bedrock) and layer 1 (weathered rock). Based on these results it is recommended that the mine should consider a groundwater monitoring programme to provide improved data regarding the parameters for these aquifer units. Time series of groundwater level data will benefit future model updates the most.

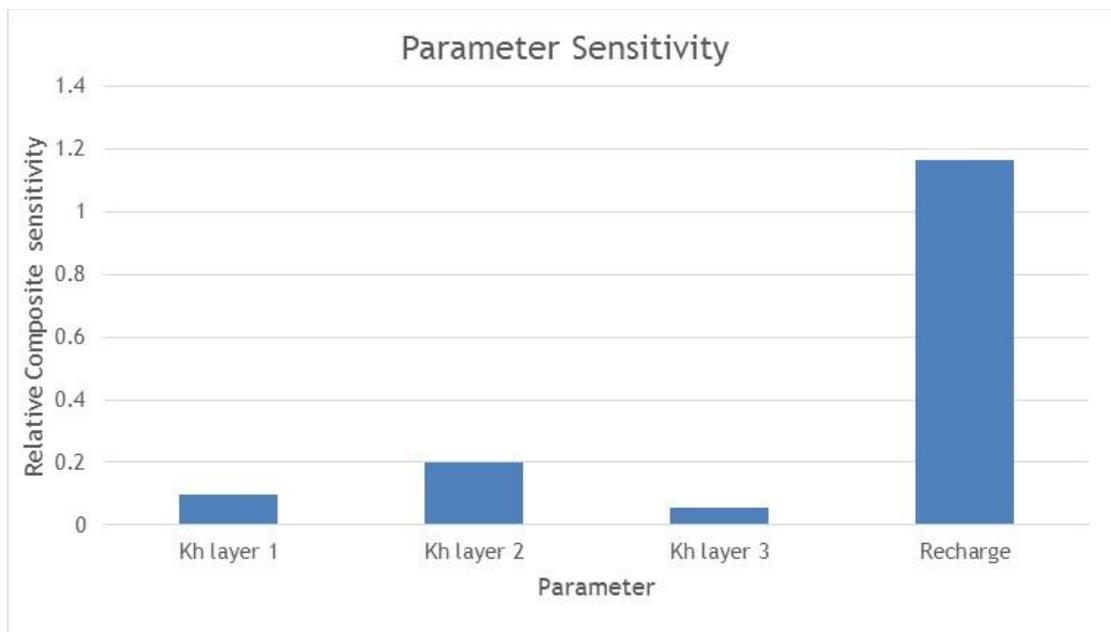


Figure 10-5 Parameter Sensitivity Summary (Relative Composite)

11 NEW MINE ACTIVITIES POTENTIAL IMPACTS

11.1 Environmental Impact Significance Rating Methodology

To ensure uniformity, the assessment of potential impacts has been addressed in a standard manner so that a wide range of impacts are comparable. The methodology utilised is from the South African Department of Environmental Affairs and Tourism guideline document on EIA Regulations (April 1998). The following descriptive value-added evaluation method will be used to determine the significance of the impacts.

Extent (Spatial Scale)

Extent is an indication of the physical and spatial scale of the impact.

Low (1)	Low/Medium (2)	Medium (3)	Medium/High (4)	High (5)
Impact is localised within the site boundary: Site only	Impact is beyond the site boundary: Local	Impacts felt within adjacent biophysical and social environments: Regional	Impact widespread far beyond site boundary: Regional	Impact extend National or over international boundaries

Consideration to be given to:

- Access to resources;
- Amenity;
- Threats to lifestyles, traditions and values; and
- Cumulative impacts, including possible changes to land uses around the site.

Duration

Duration refers to the time frame over which the impact is expected to occur, measured in relation to the lifetime of the proposed project.

Low (1)	Low/Medium (2)	Medium (3)	Medium/High (4)	High (5)
Immediate mitigating measures, immediate progress	Impact is quickly reversible, short term impacts (0-5 years)	Reversible over time; medium term (5-15 years)	Impact is long-term	Long term; beyond closure; permanent; irreplaceable or irretrievable commitment of resources

Consideration to be given to:

- Cost-benefit economical and socially (e.g. long- or short-term costs / benefits)

Intensity of magnitude / severity

Intensity refers to the degree or magnitude to which the impact alters the functioning of an element of the environment. The magnitude of alteration can either be positive or negative, as were also taken into consideration during the assessment of severity.

Type of Criteria	Negative				
	H-(10)	M/H-(8)	M-(6)	M/L-(4)	L-(2)
Qualitative	Very high deterioration, high quantity of deaths, injury of illness / total loss of habitat, total alteration of ecological processes, extinction of rare species	Substantial deterioration, death, illness or injury, loss of habitat / diversity or resource, severe alteration or disturbance of important processes	Moderate deterioration, discomfort, partial loss of habitat / biodiversity or resource, moderate alteration	Low deterioration, slight noticeable alteration in habitat and biodiversity. Little loss in species numbers	Minor deterioration, nuisance or irritation, minor change in species / habitat / diversity or resource, no or very little quality deterioration.
Quantitative	Level of deterioration is so high that the level thereof is not always measurable	Measurable deterioration. Recommended level will occasionally be violated.	Measurable deterioration. Recommended level will occasionally be violated	Rare violation of recommended level. Very slight measurable deterioration.	No measurable change. Recommended level will never be violated.

Consideration to be given to:

- Cost-benefit economically and socially (e.g. high net cost = substantial deterioration); and
- Impacts on future management (e.g. easy / practical to manage with change or recommendation).

Probability of occurrence

Probability describes the likelihood of the impacts actually occurring. This determination is based on previous experience with similar projects and/or based on professional judgment.

Low (1)	Low/Medium (2)	Medium (3)	Medium/High (4)	High (5)
Improbable; low likelihood; seldom. No known risk or vulnerability to natural or induced hazards.	Likely to occur from time to time. Low risk or vulnerability to natural or induced hazards	Possible, distinct possibility, frequent. Low to medium risk or vulnerability to natural or induced hazards.	Probable if mitigating measures are not implemented. Medium risk of vulnerability to natural or induced hazards.	Definite (regardless of preventative measures), highly likely, continuous. High risk or vulnerability to natural or induced hazards.

Significance

Significance is determined through a synthesis of the above impact characteristics and is an indication of the overall importance of the impact. The significance of the impact “without mitigation:” is the prime determinant of the nature and degree of mitigation required. For this assessment, the significance of the risk without prescribed mitigation actions was measured.

The significance of the identified impacts on components of the affected environment were determined as significance points (SP) = (magnitude + duration + spatial scale) x probability. The maximum value per aspect is 100 SP. Environmental effects were rated as high, moderate or low significance, based on the following:

- more than 60 significance points indicated high (H) environmental significance;
- between 30 and 60 significance points indicated moderate (M) environmental significance; and
- less than 30 significance points indicated low (L) environmental significance.

11.2 Operational Phase

11.2.1 Groundwater Quantity (Groundwater Level Drawdown)

During the operational phase, it is expected that the main impact on the groundwater environment will be the dewatering of the surrounding aquifer /s.

With the No. 2 Seam and No. 4 Seam floor elevations generally below the groundwater level, the underground voids will have to be actively dewatered to ensure a safe and dry working environment. This will cause groundwater to seep into the mining areas from the surrounding aquifers. Pumping of this groundwater from the mining areas to surface will cause dewatering of the surrounding aquifers and an associated decrease in groundwater levels within the zone of influence.

The zone of influence of the dewatering cone depends on several factors including the depth of mining below the regional groundwater level, recharge from precipitation to the aquifer /s, the size of the mining area, and the aquifer transmissivity amongst others. The numerical groundwater flow model was used to simulate the development of the drawdown cone as mining advance over time (refer to Section 5 regarding the current and future mine plans and schedules for both No. 2 Seam and No. 4 Seam). The minimum drawdown used for the impact assessment was the 5 m drawdown contour, which corresponds to the achieved model RMSE value of 4.8.

Measured groundwater levels (refer to Section 7) over the monitoring period shows minor fluctuations, indicating no / limited influence from the existing mining activities, except for boreholes DFGW11-08 and DFGW10-08. Generally, the groundwater levels are less than 5 m bgl with some deeper groundwater levels up to ~ 30 m bgl.

The numerical groundwater flow model results show the dewatering of the underground mine workings will create a drawdown cone surrounding the mine out areas and will increase in size as mining activities for the No. 2 Seam and No. 4 Seam advances over time; with a maximum extent of between ~ 400 and ~ 1,200 m from the mining areas at life of mine (2045, based on the 5 m minimum drawdown contour).

Figure 11-1 shows the simulated cone of dewatering as mining activities for the No. 2 Seam and No. 4 Seam advances over time.

The following deductions can be made:

-
- After 2019; the cone of drawdown is only influenced by the dewatering for the No. 4 Seam mining activities, as the No. 2 Seam underground mine voids are allowed to flood.
 - There are several monitoring and privately-owned boreholes in the potential affected area that might experience a decline in water levels of 10 m or more:
 - Monitoring borehole NBH0 is located at the east south-eastern perimeter of the No. 2 Seam underground workings. The current cone of dewatering impact on this monitoring borehole could not be confirmed at the time of this investigation due to the borehole being locked.
 - Private-owned boreholes NBH1, NBH1B, NBH2, D3, DFTNH18 and DFTNH28/27 is used for domestic and / or irrigation purposes and is located south-east of the existing No. 2 Seam underground void and within the No. 4 Seam underground mining area.

Based on the simulated cone of dewatering, these boreholes are likely to be impacted by lowering of water levels:

- Boreholes NBH1, NBH1B, D3, DFTNH18 and DFTNH28/27 from year 2029; and
- Borehole NBH2 from year 2033.

Base flow to the tributaries on the site may be reduced during the operational phase due to lowering of groundwater levels. Flow in the tributaries should be monitored on a regular basis.

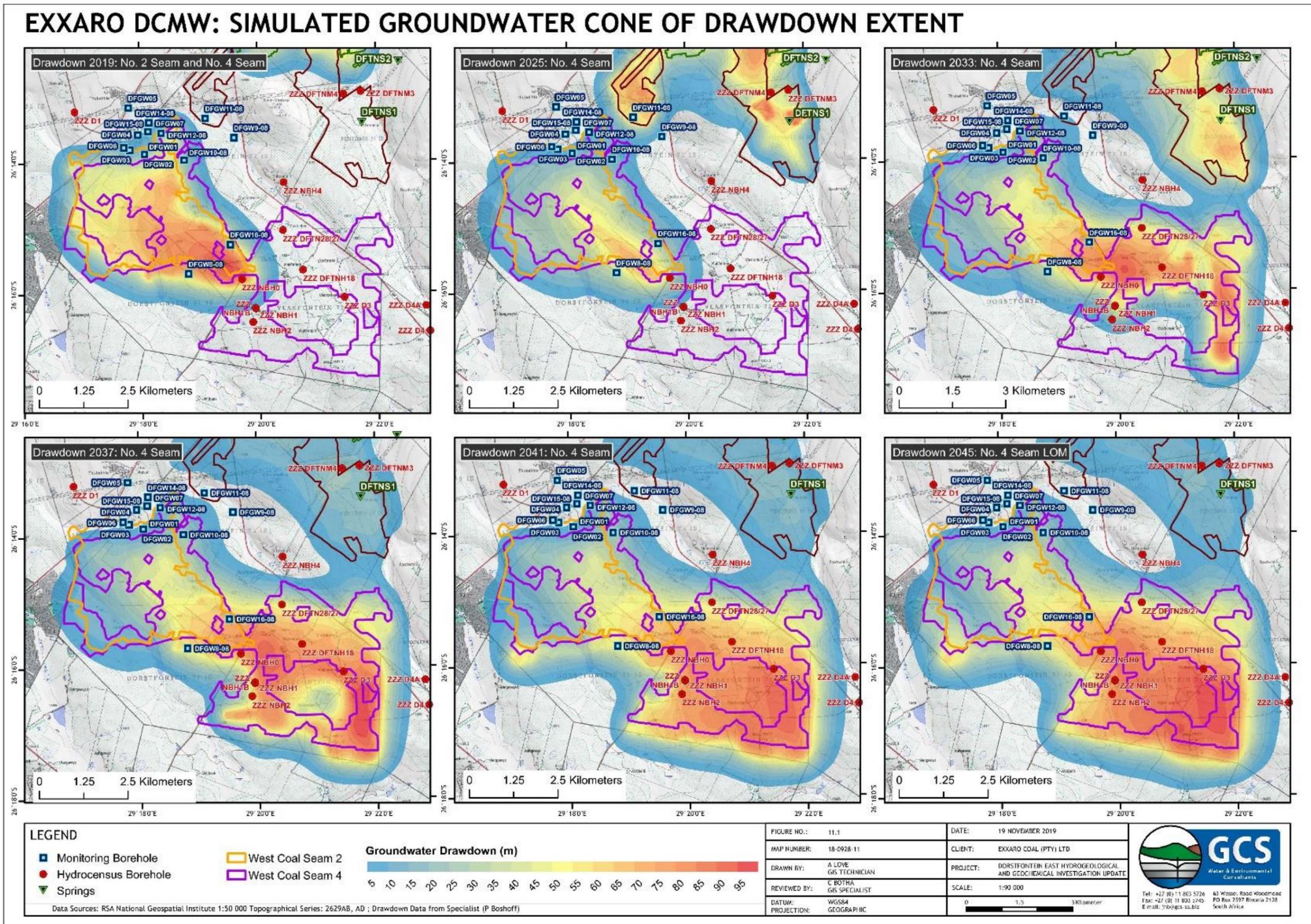


Figure 11-1 Simulated Groundwater Cone of Drawdown Extent

11.2.2 Mine Inflow Volumes

The numerical groundwater flow model was used for the prediction of groundwater inflows into the underground mine workings as mining advance over time. The mine inflow volumes were calculated for the No. 2 Seam and No. 4 Seam mine schedules obtained from the client (refer to Section 5 regarding the mine plans and schedules) and is shown in Figure 11-2.

The predicted groundwater inflows into the underground mine fluctuates between ~ 800 and ~ 2,500 m³/d:

- The decrease in inflows (~ 1,330 cubic metres per day (m³/d)) up to 2025 is due to reduction in mining activities associated with No. 2 Seam and the shallower mining depth of the No. 4 Seam mining operations;
- Groundwater inflows increases from 2025 to LOM (2045) to ~ 2,500 m³/d as the No. 4 Seam mining activities advances; and
- The inflows during mining of the No. 2 Seam (up to 2019) is between ~ 1,330 and ~ 1,800 m³/d.

It must be noted that these calculations have been performed using simplifying assumptions for homogeneous aquifer conditions. In reality groundwater inflows could deviate substantially from this. The inflows represent the correct order of magnitude, and the most likely range of inflow variation based on the uncertainties of the model used has been indicated in Figure 11-2.

Note of importance: The inflows shown in Figure 11-2 have been averaged over a four (4) year mine schedules received for the No. 4 Seam from the client at the time of the investigation (refer to Section 5).

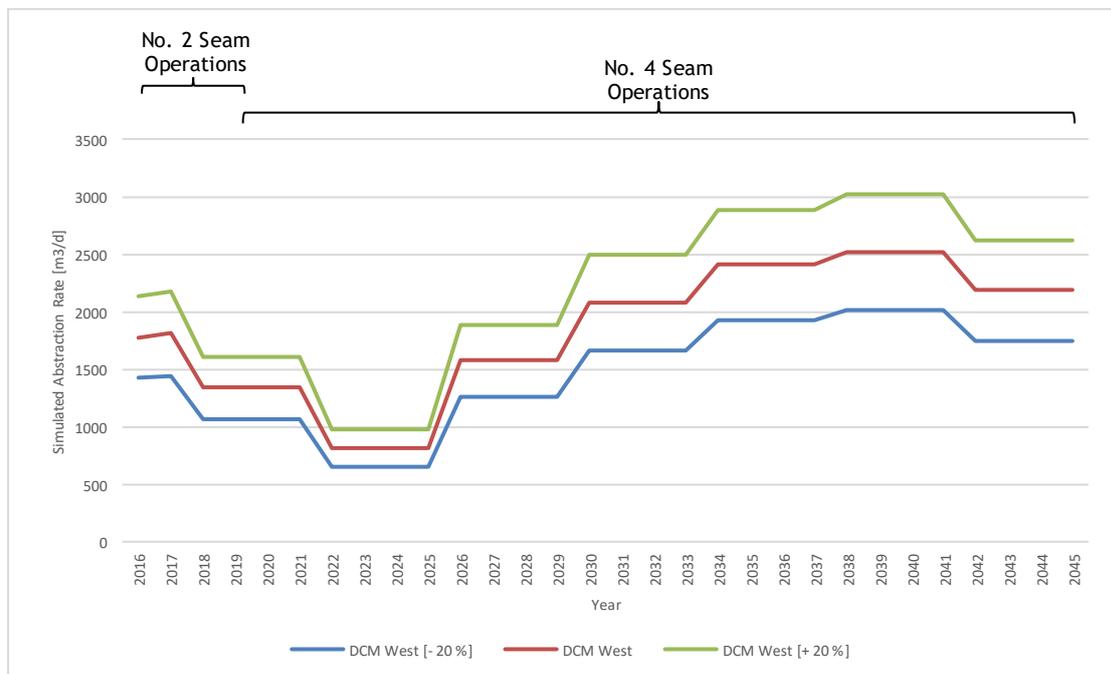


Figure 11-2 Simulated Groundwater Inflows

11.2.3 Groundwater Quality (Contamination of Surrounding Aquifer/s)

The life of mine for the existing and proposed mining activities is planned up to 2045. This allows sufficient time for chemical reactions to take place in the mined-out areas, overburden dumps and other potential pollution sources to provide ARD conditions. Groundwater flow directions will be directed towards the mining areas due to the mine dewatering.

Therefore, potential contaminated groundwater will be contained within the mining area, and little contamination will be able to migrate away from the mining area. The pollution control dams (PCD's) are lined, thereby preventing contamination of the underlying aquifers. The mine residue from the underground mine is stored in a discard dump. Seepage from the discard dump is intercepted by cut-off trenches / drains, located down gradient of the discard dump and transferred to the PDC's.

Contamination from the mining areas is generally contained within the mining areas. It is furthermore evident that selected boreholes have been impacted by contaminants at the plant area. Boreholes DFGW4 and DWGW15-08 located down gradient of the discard dump are impacted by mining related contaminants. Boreholes DFGW6 and DWGF3 are located down gradient of the PCD's which are also impacted by mining related contaminants (seepage from these dams). These impacted monitoring boreholes are mostly affected by contaminants emanating from surface related contaminant sources.

11.2.4 Operational Phase Impact Rating

The potential impacts on the groundwater during the operational phase is summarised in Table 11-1.

Table 11-1 Groundwater Impacts - Operational Phase

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	AREA APPLICABLE	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION							RECOMMENDED MITIGATION MEASURES	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION						
			M	D	S	P	TOTAL	STATUS	SP		M	D	S	P	TOTAL	STATUS	SP
Matters pertaining to HYDROGEOLOGY																	
WATER QUANTITY																	
Underground mining will result in groundwater inflows into the workings which need to be pumped out for mine safety and the resultant dewatering (water level decrease) of the groundwater system in the immediate vicinity of the workings. One spring source could be impacted upon, and base flow to the tributaries may be reduced.	Underground Mining	Mining areas and surroundings	4	3	2	4	36	-	M	Keeping the workings dry is necessary for mining and mitigation is not possible. No users are currently likely to be affected. Long term groundwater level monitoring is proposed to compare measured groundwater levels to modelling results. Should it be proven that the mining activities impact on any boreholes an alternative water supply will need to be provided.	4	3	2	4	36	-	M
WATER QUALITY																	
Analyses showed that acid mine drainage (AMD) formation is expected and poor-quality leachate can occur based on the leach potential of the material. This can influence the water quality in the surrounding aquifers. However, groundwater flow directions will be directed towards the underground voids and contaminant migration away from the mining areas will be limited during active mining.	Underground Mining	Mining areas and surroundings	4	4	1	3	27	-	L	There is nothing that can be done to mitigate contamination from the underground areas. However, the area surrounding the mine will not be affected during the operational stage. Long-term groundwater quality monitoring is proposed. If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.	4	4	1	3	27	-	L
The discard dump receives coal containing materials from the underground workings being exposed to water and oxygen, resulting in ARD. Contamination of the groundwater system occurs through seepage from the discard dump.	Discard dump	Discard dump and surroundings	4	5	2	4	44	-	M	A discard dump is needed to store the discard materials from the underground workings. Clean water and rainwater need to be diverted away from the discard dump as much as possible to reduce seepage to groundwater.	4	5	2	4	44	-	M
Stockpiling of coal will expose coal to water and oxygen, resulting in ARD from stockpiles and from down gradient PCD's, which are lined. Contamination of the groundwater system occurs from these sites.	Coal stockpiling and PCD's	Coal stockpile, PCD's and surroundings							M	Clean water needs to be kept away from the stockpiling area and the underlying material compacted to minimise water infiltrating from the site. Keep stockpiles as small as possible to minimise their footprint.							M
Handling of waste and transport of materials can cause various types of spills (domestic waste, sewage water, hydrocarbons) which can infiltrate and cause contamination of the groundwater system.	Waste Handling	Plant							L	Waste needs to be discarded and spills cleaned up immediately according to the WULA conditions. The DWA should be notified in the event of a spill.							L

11.3 Post-Closure Phase

11.3.1 Groundwater Quality

Once the mining has ceased, ARD is still likely to form given the unsaturated conditions in the mining areas and contact of water and oxygen through natural processes including precipitation. Therefore, groundwater contaminant plumes are likely to migrate from the mining areas once the water level in the underground voids have reached long term steady state conditions.

The contaminant plumes emanating from the underground voids will have a cumulative impact on the groundwater quality as seen in the post mining simulations (Figure 11-3). The migration of contaminated water from the underground mine has been simulated for 50 and 100 years after colliery closure.

The contaminant plume emanating from the underground workings and the discard dump facility will move in a westerly direction towards the unnamed perennial tributary of the Steenkoolspruit; with a maximum distance from the mining areas of ~400 m. The contaminant concentration is likely to increase over time as the plume develops.

Shallow contaminated seepage may impact on the unnamed perennial tributary to the Steenkoolspruit. This impact is however likely to be moderate due to the expected contaminant movement calculated for 100 years post-closure.

Continuous water quality measurements for both tributaries of the Olifants River should be part of the post-closure plan. If contamination of the surface water is indicated then mitigation measures, i.e. ensuring surface water quality remains within standards prior to flowing into the Olifants River, should be implemented.

There are several monitoring (DFGW8-08, DFGW10-08, DFGW11-08, DFGW12-08, DFGW16-08, DFGW01 and DFGW02) and privately-owned (NBH0, NBH1, NBH1B, NBH2, DFTN18 and DFTN28/27) boreholes located in the fractured Karoo aquifer is likely to be impacted upon based on the impact simulations.

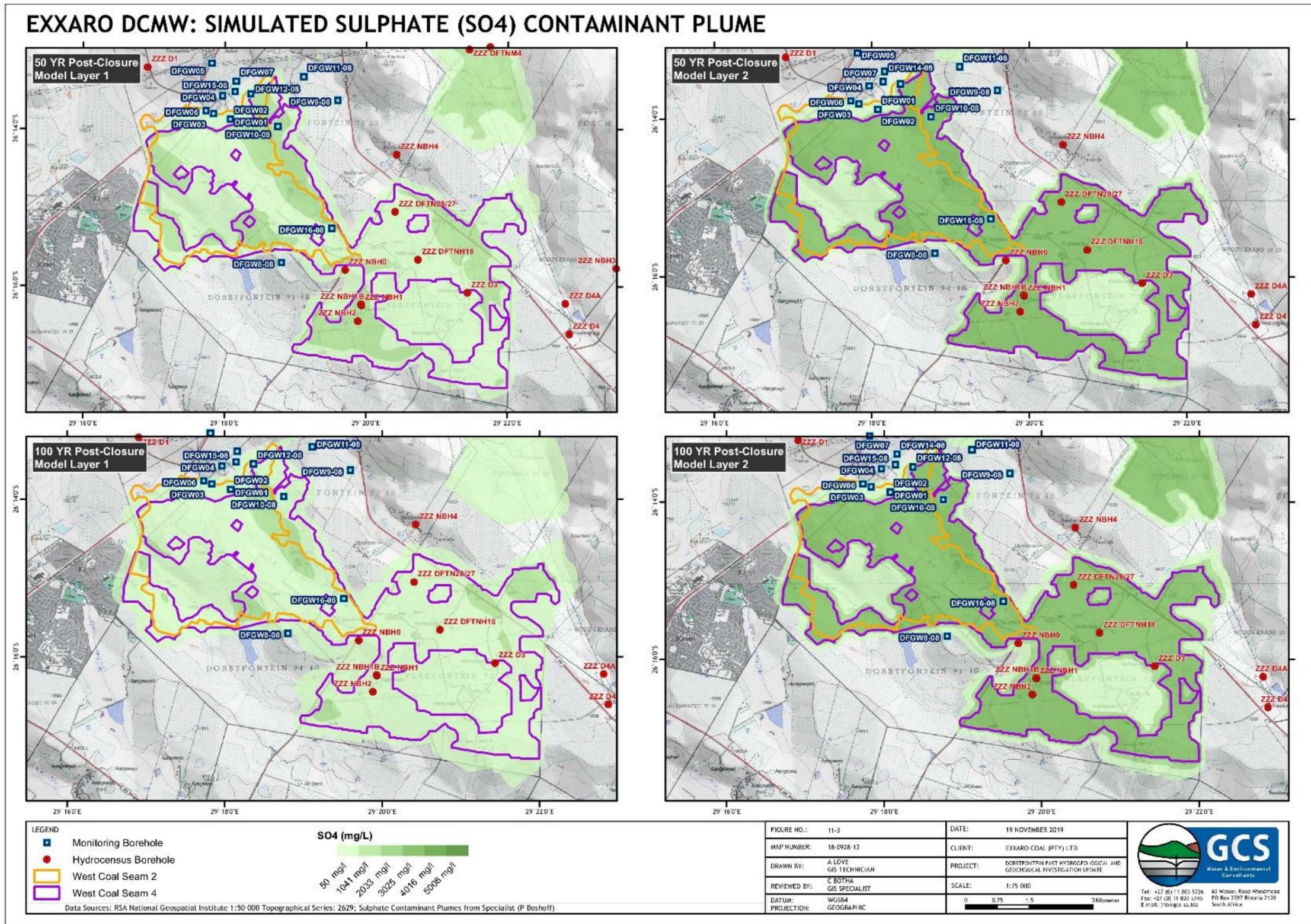


Figure 11-3 Simulated Sulphate (SO4) Contaminant Plume

11.3.2 Discard Dump

The discard dump at DCMW needs to be closed and rehabilitated to ensure that any potentially acid forming (PAF) waste is encapsulated within non-acid forming (NAF) standards.

One method of reducing the contamination load is to restrict water from infiltrating the waste material by providing it with a cover (DCM's preferred method of rehabilitation of the discard dump post-closure¹). Three classes of cover system are identified, namely, low permeability barriers, store and release systems and capillary barriers. Low permeability barriers typically comprise an infiltration barrier, which limits water infiltration into the wastes. Store and release systems rely on evapotranspiration potential to remove water from the soils before it enters the mine waste. Capillary barriers consist of a capillary layer, an unsaturated drainage layer and a capillary break that are designed to drain water from the UDL before breakthrough occurs in the capillary break.

Final cover systems can also be constructed to impede oxygen ingress into the coal discard or to introduce buffering agents to neutralise acidic water.

The main objective of low permeability barriers is to restrict precipitation water infiltrating into the waste. The low-permeability barrier typically comprises the following components: (1) Topsoil layer, (2) Protection layer, (3) Drainage layer, (4) Infiltration barrier, and (5) Capillary break.

Two distinct closure scenarios should be considered for the DCMW discard dump to ensure chemical stability for groundwater management purposes. As mentioned above the objective is to reduce infiltration and seepage and therefore long-term risks and environmental liabilities. To achieve this the two options, or a combination of the two, must be implemented:

- Reclamation of the dump for use in the energy sector. It is recommended that a feasibility assessment be planned and commissioned as soon as possible to identify the viability of reworking the discard dump. Such a rehabilitation program has the benefit of cash inflow and waste minimization. Capital can then be re-invested in further rehabilitation programs.
- Total cover of the dump with an impermeable cover or a combination of the systems mentioned above. It is recommended that a detail cover design is determined for the dump which will include additional site work and laboratory testing with a final cover design system. It is documented in the WRC Document (The evaluation of soil covers used in the rehabilitation of coal mines, WRC Report No. 1002/1/04 Water Research) that cover layers of at least 1m in thickness shows proper reduction in oxygen and water ingress. Natural recharge, over the long post closure phase, must be at least <1 % of MAP.

¹ DCM's current closure financial provision makes provision for 300 mm thick engineered soil cover

11.3.3 Mine Water Decant

When the active dewatering of the mining area has ceased, groundwater levels will rebound. As the underground voids flood, decant will occur when the groundwater level recovers / rebound to levels above the lowest surface elevation.

Surface decanting refers to direct discharge of mine water to surface through backfilled material, voids, shafts, adits and other direct paths. For underground mining, the decant point can be established as the locations with access to the underground voids from surface, such as (backfilled) shafts and box cuts, or at lowest topographical points if mining is relatively shallow. This can occur long after the end of life of mine and is referred to as the time-to-decant.

At DCMW, the potential decant points are located at the No. 2 Seam existing box-cut and the lowest topographical point of the underground mine (No. 2 Seam and No. 4 Seam). A summary of the decant time and volume for the underground mine workings is provided in Table 11-2 to Table 11-4. The expected significance of the impact is high (Table 11-5).

The calculations for the DCMW underground mine voids show that the time-to-decant, range between ~ 56 and ~ 280 years with a discharge rate of between ~ 260 and ~ 1,560 m³/d; and is based on an extraction rate of the underground mine of 50 and 60 % to exclude the volumes of the pillars and recharge values similar to the current recharge as well as to literature values (Hodgson & Krantz, 1998 and Vermeulen & Hodgson, 2005).

Subsidence of mined out areas could cause preferential pathways. The possible effects of subsidence were not included in the decant calculations. It is suggested that the subsidence be assessed with geotechnical experts.

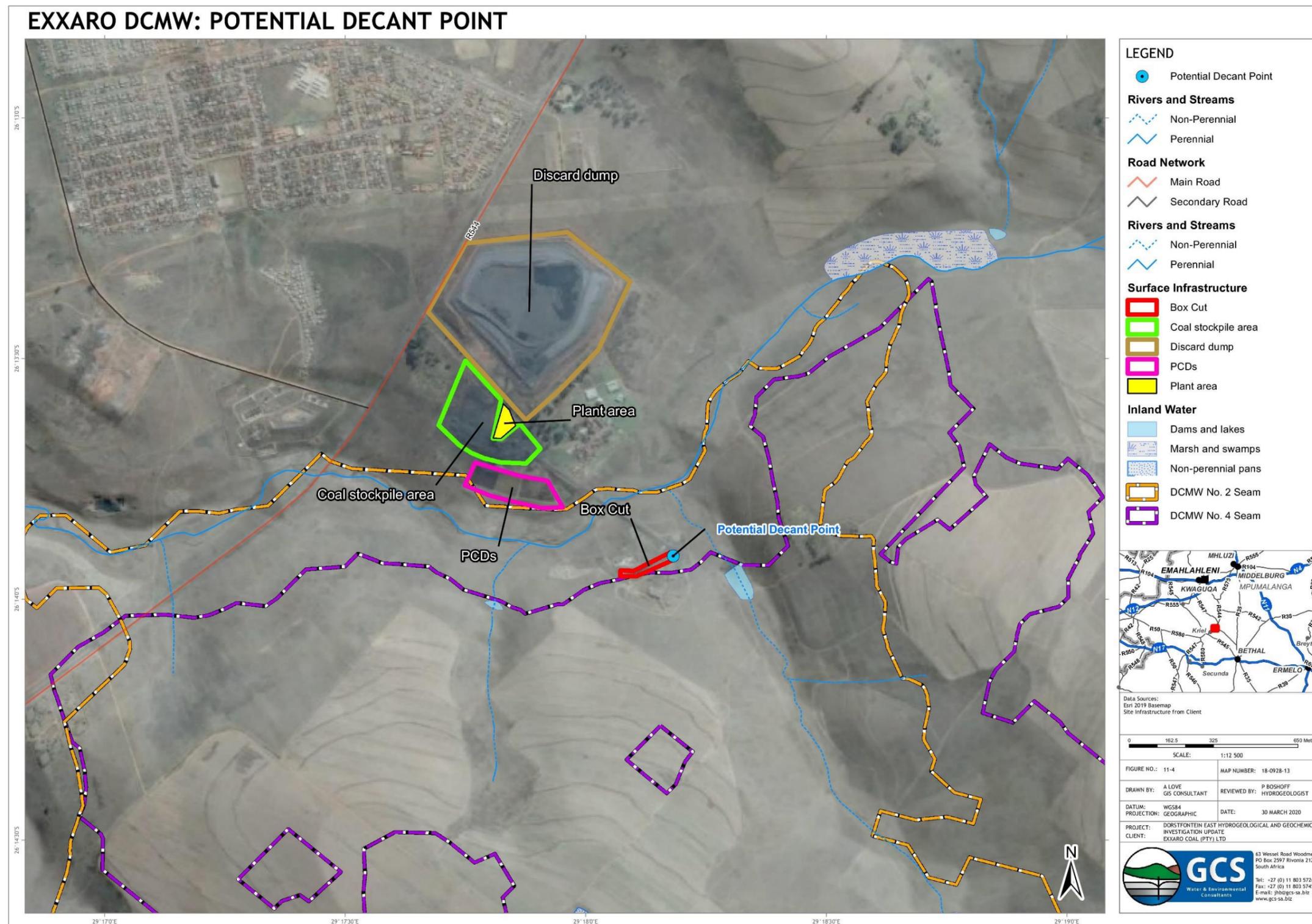


Figure 11-4 Potential Decant Points

Table 11-2 DCMW Underground Void Volume Calculation Summary

Description	Total Underground Mine Void Volume ¹		
	Total	50 % Extraction	60 % Extraction
[-]	[m ³]	[m ³]	[m ³]
No. 2. Seam Void	15,462,698	7,731,349	9,277,619
No. 4 Seam Void	37,774,150	18,887,075	22,664,490
Total (No. 2 Seam and No. 4 Seam)	53,236,848	26,618,424	31,942,109

Note/s:

- m³ - cubic metre
1. Void volume was calculated based on mine plans and an average height of 2 m for both No. 2 Seam and No. 4 Seam

Table 11-3 DCMW Time-To-Decant Calculation Summary

Description	Worst Case Scenario	Best Case Scenario
	Recharge 1 %	Recharge 5 %
[-]	[years]	[years]
DCMW Underground	281	56

Note/s:

- None

Table 11-4 DCMW Decant Volumes

Description	Recharge 1 %	Recharge 5 %
[-]	[m ³ /d]	[m ³ /d]
DCMW Underground	260	1,560

Note/s:

- m³ - cubic metre

11.3.4 Post-Closure Phase Impact Rating

The potential impacts on the groundwater during the post-closure phase is summarised in Table 11-5.

Table 11-5 Groundwater Impacts - Post-Closure Phase

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	AREA APPLICABLE	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION							RECOMMENDED MITIGATION MEASURES	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION						
			M	D	S	P	TOTAL	STATUS	SP		M	D	S	P	TOTAL	STATUS	SP
Matters pertaining to HYDROGEOLOGY																	
WATER QUALITY																	
Contaminated groundwater seepage to streams (salt load)	Rehabilitated mining areas	Mining areas and surroundings	8	4	2	4	56	-	M	Groundwater levels in the underground mine will recover. Pollution plumes may migrate to surface water bodies such as the two tributaries of the Olifants River. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. Surface water monitoring of the streams will be essential. Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure. The drilling of boreholes into mining areas is recommended so that recovery of water in mining areas can be monitored. Intercepting decant by a downstream trench or subsurface drains is an option to investigate. The impacts of the mitigation measures should be assessed by water and wetland specialists. If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.	6	4	2	4	48	-	M
Groundwater contaminant plume	Rehabilitated mining areas	Mining areas and surroundings	8	4	2	4	56	-	M	Groundwater levels in the underground mine will recover. Pollution plumes may migrate to down gradient areas. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. Surface water monitoring of the streams will be essential. Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure. The drilling of boreholes into mining areas is recommended so that recovery of water in mining areas can be monitored.	6	4	2	4	48	-	M
Mine decant and water quality deterioration	Underground mining areas	Underground mines and down gradient areas	8	5	3	4	64	-	H	It is very difficult to mitigate against AMD. In order to manage AMD, it is important that a detailed water balance be calculated for the mine and that the expected decant points and decant qualities are determined. Water influx into the mining areas should be kept to the absolute minimum possible. In this regard the fracturing of the overlying strata due to blasting or surface subsidence should be avoided at all cost, so as to prevent increased infiltration of surface water into the mine workings. Based on DCM's current closure financial provision, the preferred method of managing post closure decant is by means of a pump and treat system. The level to which the water is treated depends on the use of the water after treatment but should be determined in consultation with the DWA. As a minimum, treated water should meet the standards for use for livestock watering and irrigation. Hodgson et al. (WRC Report 1263/1/07; 2007) recommend the following measures for management of mine water and the feasibility and effectiveness of employing these measures at DCM should be investigated: 1) Select the mining method based on environmental considerations; 2) Mine from deep to shallow; 3) Flood the mine workings as soon as possible; 4) Flush the mines after flooding. If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.	8	5	2	4	60	-	M
Deterioration in water quality	Discard Dump facility	Discard dump facility and surroundings	8	5	3	4	64	-	H	DCM's current closure financial provision accounts for the capping of the discard dump with a 300 mm thick engineered soil cover. This will reduce the amount of seepage coming from the facility and will reduce oxygen influx. Mitigation measures should be maintained until such a time as seepage water from the discard dump facility conforms to the relevant standards for aquatic ecosystems. If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.	8	5	2	4	60	-	M

12 GROUNDWATER MANAGEMENT PLAN

12.1 Proposed Actions

Based on the groundwater impact assessments and proposed mitigation measures (refer to Section 11), the groundwater management plan should entail the actions as described below or the operational and post-closure phases.

12.1.1 Operational Phase

General:

- Static groundwater levels should be monitored to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time;
- Interpretation of the monitoring results and auditing of the monitoring network must be conducted annually by a qualified hydrogeologist to ensure compliance with regulations.
- A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWA Best Practice Guidelines. The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioned phase;
- A closure water management plan should be developed. This should assess the management of decant via channelled decant or the management of a critical water level to minimise contamination of the shallow weathered aquifer. The discard dump facility should also be assessed in terms of a remediation action plan should the risk for contaminating on the stream be high. This should all be analysed in a financial model to further inform the most effective closure water management options. The groundwater model should be used as a management tool to inform this process;
- The numerical model should be updated once every three (3) years or after significant changes in mine schedules or plans by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario. Updates to the model should be carried out more frequently if significant changes are made to the mine schedule or plan.
- It is recommended that the geochemical assessment is updated during the life of the mine in order to calibrate and validate its results and to construct an effective closure plan.
- All monitoring boreholes which are to be mined out and / or are not operational should be grouted and sealed to prevent cross contamination of aquifers;
- If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, compensation of affected parties should be considered. This may be done through the installation of additional boreholes for water supply purposes, or providing an alternative water supply; and

- Should it be proven that the mining activities impact on any boreholes, an alternative water supply will need to be provided.

Site Water Management

- A proper storm water management should be implemented and maintained. Berms should also be implemented to ensure separation of clean water and dirty water areas;
- During the operational phase, the mine water should be used or pumped to dirty water dams or pollution control facilities in order to avoid deterioration of the mine water. The longer the mine water resides in the underground mine workings the higher its TDS will be. It is not foreseen that mine water in contact with the underground material will acidify during the operational phase of the proposed mining but will depend on operational water management;
- Poor quality runoff from dirty areas should be contained and diverted to the pollution control dams for re-use; and
- The footprint of dirty water areas like the pollution control dams, water return dam, workshops and oil and diesel storage areas should be minimised.

Mining Areas

- As much as possible coal must be removed from the underground mine during the operational phase;
- Keeping the workings dry is necessary for mining and mitigation is not possible. Monitoring boreholes for long term groundwater level monitoring should be maintained over the life of mine to compare measured groundwater levels to calculated impacts;
- Fracturing of the overlying strata due to blasting or surface subsidence should be avoided so as to prevent increased infiltration of surface water into the mine workings; and
- If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.

Discard Dump Facility and Other Infrastructure

- Clean water needs to be diverted away from the discard dump facility as much as possible to reduce seepage to groundwater. Groundwater quality monitoring is proposed;
- Sewage effluent emanating from latrines or ablution blocks, if any, should be treated to acceptable levels before discharge into the environment.

12.1.2 Post-Closure Phase

General

- Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine;

-
- The closure water management measures should be implemented which may include a decant management system and water treatment plant.
 - All old exploration boreholes must be sealed off after closure;
 - The drilling of boreholes into mining areas is recommended so that recovery of water can be monitored.
 - Multiple-level monitoring boreholes should be constructed to monitor base-flow quality within sensitive zones;
 - The results of the monitoring programme should be used to confirm/validate the predicted impacts on groundwater availability and quality after closure;
 - Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure.
 - The monitoring network should be audited annually by a qualified hydrogeologist;
 - The existing predictive tools should be updated to verify long-term impacts on groundwater, if required;
 - Surface water monitoring of the tributaries will be essential;
 - The feasibility and effectiveness of the following measures (*Hodgson et al. 2007*) at DCMW could be investigated:
 - Select the mining method based on environmental considerations;
 - Mine from deep to shallow;
 - Flood the mine workings as soon as possible; and
 - Flush the mines after flooding.

Mining Areas

- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite;
- Intercepting decant by a downstream trench at each decant point is an option to investigate for the DCMW site;
- Treating of decanting mine water to acceptable water quality levels can be achieved by the installation of a treatment plant. Investigations must continue to establish the most effective way to treat water on site if needed at the end of LoM. The installation of a RO plant should be seen as a last option.
- The level to which the decant water is treated depends on the use of the water after treatment, but should be determined in consultation with the DWA;
- If a risk of impact on the surface water bodies is established, a remediation action plan should be developed to negate the potential impact.

Discard Dump Facility and Other Infrastructure

- Rehabilitation of the discard dump facility should be undertaken to limit the infiltration of precipitation water into the facility;
- Precipitation water and runoff should be diverted away from the discard dump facility as much as possible;

-
- The use of an engineered soil cover should be investigated and implemented if feasible to reduce the infiltration rate of precipitation water falling on the facility
 - Mitigation measures should be maintained until such a time as seepage water from the discard dump facility conforms to the relevant standards for aquatic ecosystems.
 - The Pollution control dams could be used to intercept polluted seepage water. This should be considered if it is found that streams are indeed negatively affected by pollution.

12.2 AMD Treatment Plan

AMD also known as acid rock drainage (ARD) is a well-defined process where sulphide minerals (mainly pyrite) are oxidized to produce acidic leachate. This reaction is a two-step process where the first reaction result in sulphuric acid and ferrous sulphate, then with further oxidation ferric hydroxide and more sulphuric acid is formed. Pyrite is a common minor constituent in many mineral deposits, such as coal.

In the natural environment this reaction takes place at a very slow rate and as a result naturalization almost always removes the acidity. Mining activities disturb the in-situ rocks and expose pyrite, which accelerates the oxidation reaction.

The most effective and economical method of controlling acid drainage is to prevent its formation. Once established, acid drainage is often difficult and costly to treat. Because most metal ions are increasingly soluble with decreasing pH, acid drainage frequently results in a heavy metals problem. Management by prevention requires characterisation of overburden or waste material and knowledge of the hydrology of the site so that the likely occurrence of acid drainage can be predicted and potentially acid-producing material selectively handled and isolated.

Where the potential for acid drainage exists, provision in the planning stage to prevent acid drainage is essential.

12.2.1 Site Characterisation and Field Work

An AMD management strategy should consist of the following actions:

- Development of a site-specific conceptual model. This model will describe the following:
 - Conceptualize the source - Identify all geological units that are disturbed during mining? Determine which of these units are potential acid forming?
 - Conceptualize the pathway - What is the most likely pathway for contaminants to migrate off site and reach potential receptors (surface or groundwater)
 - Identify the receptors - identify all potential current and future receptors

-
- Sample selection. Based on the conceptual model a sample plan should be developed to get information of the disturbed geological units (geochemical analyses) as well as the surface and groundwater quality. The sample plan will determine which materials and locations needs to be sampled; and
 - Test work (as described below).

12.2.1.1 Test Work

Geochemical test work to predict AMD consists of the following:

- Static testing, such as Acid Base Accounting (ABA). Static test gives an indication of the overall potential that a rock sample will generate acidic leachate. It determines the balance of acid generating and acid neutralizing capacity of a sample. This is a relatively low-cost procedure which can be done in a matter of hours to a few days.
- Kinetic testing, such as humidity cell tests attempt to predict the quality of the leachate over time. Rocks / samples with a net acid generating potential will be subjected to kinetic test. Kinetic test is defined as a group of test work procedure wherein acid generation and metal mobilization from a sample is measured over time. These procedures could take up to 26 weeks to complete.
- Field trails are set up as large-scale column leach tests on the sites - under actual field conditions. Laboratory tests need to be converted to field conditions and the best way of “calibrating” the lab results are with field trails.

12.2.2 Risk-Based AMD Assessment

With increased geochemical information and knowledge, the process could be integrated into the operational plan which will enhance the closure processes (Figure 12-1). The information will also inform the decision-making process on how to manage mine void management.

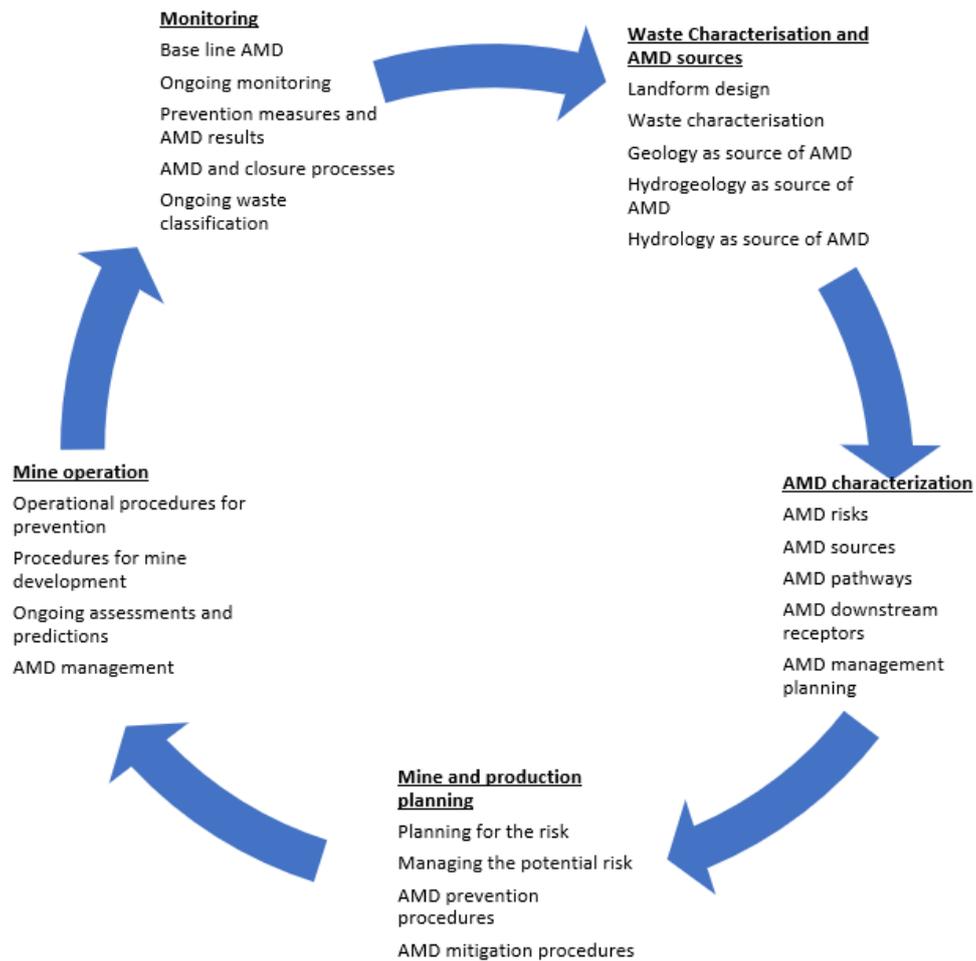


Figure 12-1 Risk-based AMD approach

12.2.3 Prevention

Oxygen and water are necessary to initiate acid formation and prevention methods aim to exclude either reactant from the pyritic material. This involves controlled placement of acid forming materials and appropriate water management strategies.

Prevention is dependent on identifying the pyritic material before mining in order to:

- Adopt mining procedures that can selectively handle acid forming materials for placement within the waste dump. If calcareous strata or other alkaline material, which can neutralise and acidity generated, are available, mining methods and dump construction should enable blending of material within the dump.
- Control the hydrology of the site to prevent water from contacting pyritic material by diverting surface water away from pyritic material and preventing ponding and subsequent infiltration.

- Isolate the pyritic material from water by placing it above the water table and capping with clay or other impermeable materials. The cap can then be covered with soil and vegetation established. This technique reduces infiltration and leaching. Unlike tailings storage areas, waste dumps are unlikely to have an impermeable or semi-impermeable base or sides. The task of reshaping and encapsulation is consequently greater and costlier.
- Submerge the acid-forming material; this can be an effective strategy where enough water is available. It has been suggested that a water cover enough to maintain the partial pressure of oxygen below 1% is necessary to inhibit pyrite oxidation.

12.2.3.1 Landform Design and Final Topography

Landform redesign is required to include, place and move all new overburden spoils to create a final topography that coincides with all the surface drainage areas of the site. The best result of a final topography can be achieved when the landform is designed during the early stages of the operation.

Key elements of a successful landform design include:

- The comprehensive characterisation of the properties of soils, overburden and mineral processing wastes to determine their potential erodibility, capacity to support plant growth and potential to have adverse impacts on water quality (AMD).
- The segregation and selective placement of those materials to ensure the creation of a favourable medium for plant growth and the protection of water resources.
- The incorporation of surface water management into the design.

Some of the key aspects that require management throughout the mine operation include:

- During the planning stages of an operation a final landform design should have been developed.
- In the client's case the final landform design will benefit the mine as it would influence numerous aspects including the placement of tailings, waste rock dumps, topsoil and taking the final water management requirements into account.
- Each deposit on the mine site requires a specific management plan to ensure that volumes, angles, drainage lines and waterways, are developed in the final landform, and are adhered to during the operational cycle of the mine.
- The drainage topography for the overall site must be planned as part of the overall landscaping. Drainage areas of adjacent land areas will provide a guide to site requirements, but the mine area will often need to be higher on the post mining landform.

-
- The slopes from overburden, waste rock and tailings, will require slopes of more than 1:3 to reduce the velocity of run-off in order to prevent excessive erosion and to allow vegetation to establish enough root growth. Straight ridges and sharp angles need to be avoided.
 - The volume and velocity of the runoff water must be controlled entering the watercourses in surrounding areas. An increase of water could result in erosion in downstream areas of the catchment.
 - Areas with small variable elevation could influence the soil moisture and the type of vegetation in the area. Elevation is required to take water into surrounding drainage areas.
 - Side slopes of the rehabilitation area are to be covered by topsoil sourced from the topsoil stockpiles which were created during the clearing of specific areas. The layer of topsoil on the side slopes and other areas should be at least 300 mm thick (after compaction) to aid plant growth and assist in re-generation of indigenous plants.
 - A change management procedure is required when the mine plan changes and the final landform is influenced by these changes.
 - An integrated approach is required to ensure that all aspects of the rehabilitation process is considered during the changes on the mine.

12.2.3.2 Groundwater

Hydrogeological conceptual and predictive modelling is required to inform the AMD potential of water sources. Groundwater flow modelling is undertaken to predict the range of possible outcomes for underground mine voids, which guides further technical studies and site-specific closure plans to focus on key uncertainties. Groundwater flow models provide predictions for water level recovery rates and equilibrium levels for the mine void options available at closure. The outputs from this work guides AMD strategies, provide input to hydrogeochemical assessments and inform environmental impact assessments using the source, pathway, receptor approach.

12.2.3.3 Surface Water

The design of the surface water management works will include consideration of AMD requirements.

The management of surface water may be addressed with:

- Maintaining AMD water with store and release cover systems.
- Designing of slopes to drain surface water to surrounding water networks.

Considerations include fate of the captured water, potential for surface water recharge of the groundwater system and stability of the impacted landforms to changes in surface water flows. The selection and design of these alternatives will be made over the life of mine with consideration of on material, geochemistry, environmental values and hydrology.

12.2.3.4 Climate Change and Vegetation

The climate change predictions will consider the most appropriate rehabilitation revegetation approach to designed landforms and selected native species based on the current climatic conditions. If there were to be an effect on landforms and revegetation from climate change, those changes would reasonably be expected to be gradual and would be experienced across the entire region, including adjoining unmined areas. By revegetating based on the current climatic conditions the mine will blend in with the surrounding vegetation, regardless of the effect of climate change. Major differences will be managed by ensuring enough diversity of species within mining areas and that the natural adjustments to a changing climate will be accommodated within the local species gene pool.

12.2.4 Treatment

Treatment procedures for dealing with acid leachates will vary according to site conditions. Treatment methods previously adopted or under trial include the following:

- Incorporation of lime or other neutralising materials into the surface of waste dumps. Neutralising capacity of the available material and the “lime demand” of the dump should be tested to determine feasibility.
- Channelling run-off from the dump to selected recharge areas i.e. ditches filled with alkaline material or areas of the dump where selected material with high neutralising capacity has been placed.
- Injection of neutralising fluids e.g. sodium carbonate, anhydrous ammonia or caustic soda into mine dumps to intercept flow paths of acid drainage.
- Collection of acid drainage downstream for chemical treatment or inline aeration.
- Directing acid drainage to artificial wetlands where biological production of bicarbonate neutralises the acidic drainage. Metals are removed through hydrolysis and biological formation of insoluble sulphides and carbonates.
- In areas where evaporation consistently exceeds precipitation, disposal by evaporation may be feasible. Safe disposal of sludge with elevated levels of heavy metals and salts is then required.

12.2.5 Treatment Options

This report acts as an AMD background document that will assist engineering consultants in the final design of areas; including the topography surrounding the dumps and stockpiles, vegetation, water management plans and treatment of water. Landform design will be key to channel AMD to a centralised setting where treatment options can be considered prior to the release into the environment.

12.2.6 AMD Management Plan

The following AMD management plan will be developed for DCMW:

- Review of geological units that are disturbed during mining. The geological database will be used to develop conceptual geochemical units of all the disturbed lithologies;
- Each geochemical unit will be sampled and submitted for static test work;
- The samples that are potentially acid forming will be submitted for kinetic test work;
- Field trials will be set up on the mine with potentially acid forming samples;
- Review all surface and groundwater chemical data with reference to acidic leachate; and
- Once the test results are available a geochemical report will be produced which will make proposals for the handling and disposal of potentially acidic materials. This report will also inform closure scenario selections for the various mining voids.

12.3 Groundwater Monitoring Network

The groundwater monitoring network design should comply with the risk-based source-pathway -receptor principle. A groundwater-monitoring network should contain monitoring positions which can assess the groundwater status at certain areas.

Both the impact on water quality and water quantity should be catered for in the monitoring system. The boreholes in the network should cover the following:

- Contaminant sources,
- Receptors and
- Potential contaminant plumes.

Furthermore, monitoring of the background water quality and levels is also required.

12.3.1 Operational Phase Monitoring

Groundwater monitoring should be conducted to assess the following:

- The impact of mine dewatering on the surrounding aquifers. This will be achieved through monitoring of groundwater levels in the monitoring boreholes. If private

boreholes are identified within the zone of impact on groundwater levels, these should be included in the monitoring programme;

- Groundwater inflow into the mine workings. This will be achieved through monitoring of groundwater levels in the monitoring boreholes as well as measuring water volumes pumped from mining areas;
- Groundwater quality trends. This will be achieved through sampling of the groundwater in the boreholes at the prescribed frequency; and
- The rate of groundwater recovery and the potential for decant after mining ceases. This can be achieved through drilling of additional boreholes into the underground workings for monitoring purposes. These boreholes should be drilled in the deepest sections of the mine. Stage curves should be drawn to assess the inflow into defunct workings.

Groundwater Monitoring should be undertaken to SANS and DWA requirement according to the schedule presented in Table 12-1. In addition to the existing operational monitoring boreholes, the following recommendations are made:

- Boreholes associated with the No. 4 Seam should be drilled to monitor the possible impact of these potential sources;
- Boreholes should be drilled into the underground mine areas post-closure to measure the rate of groundwater recovery and flooding of the underground mine areas.

It is envisaged that the frequency of monitoring remains on a quarterly basis.

Table 12-1 Operational, Decommissioning and Post-Closure Phases Groundwater Monitoring Programme

Monitoring Position	Sampling Interval	Analysis	Water Quality Standard/s
All monitoring boreholes	Quarterly measuring the depth of groundwater levels	Groundwater levels since 2010	Not applicable
All monitoring boreholes	Quarterly sampling for water quality analysis	Full analysis in April and October	South African Water Quality Guidelines: Domestic Use
Precipitation	Daily at the mine	Precipitation data provided since 2012	Not applicable

12.3.2 Post-Closure Phase Monitoring

Regarding post-closure monitoring points in the underground voids, exact locations can be targeted towards the end of life of mine based on the following criteria:

- The monitoring points can only be installed after mining activities have been completed;
- For DCMW the following number of monitoring points are proposed;
 - Three (3) borehole for No. 2 Seam, and
 - Three (3) borehole for No. 4 Seam;
- As the aim is to measure recovering groundwater levels these points should be installed at the deepest points for each seam.

Installation and exact location of the monitoring points needs to be done accurately in order to prevent groundwater flow from the one seam into the other; if underground voids for No. 2 Seam and No. 4 Seam overlap at the monitoring location, the monitoring point for No. 2 Seam must be drilled through a pillar, not a void, in No. 4 Seam.

13 CONCLUSIONS AND RECOMMENDATIONS

Three distinct superimposed groundwater systems are present in the Dorstfontein area. They can be classified as:

- The upper weathered Ecca aquifer;
- The fractured aquifers within the Ecca sediments; and
- The aquifer below the Ecca sediments (deeper aquifer formed by fracturing of the Karoo sediments and dolerite intrusions).

The weathered Karoo layer has a thickness of approximately 15 m and is comprised of residual soils and weathered shales and sandstone. The underlying fractured units consist of shale, sandstone and coal seams and are too well cemented to allow any significant permeation of water which is therefore limited to fractures. Fracturing mainly occurs in the top of this unit decreasing with depth.

Groundwater in the Dorstfontein area is mainly used for domestic supply, small scale irrigation (gardens) and / or livestock watering. The groundwater quality in the area is generally good. Groundwater levels generally following topography and static groundwater levels are on average approximately 5.5 mbgl.

Hydraulic conductivity values for the weathered layer are in the order of 10^{-2} m/d. Hydraulic conductivity of the fractured Karoo unit decreases with depth and will range between 10^{-2} m/d in the upper layers and 10^{-3} m/d for the lower layers. These values are typical of Karoo type aquifers.

While oxygen is still present, the underground mine water will reach sulphate concentrations of about 2 000 - 2 300 mg. After oxygen is depleted no more sulphate is generated. Because of the low recharge rate sulphate concentrations will remain fairly constant between 2 000 - 2 300 mg/l for several decades.

DCMW is an existing operation and as a result there are contaminant sources already present, i.e. operational underground workings, discard dump facility, pollution control and return water dams and a plant area.

Monitoring boreholes DFGW6 (adjacent to the PCD 1) and DFGW15-08 (down gradient of the discard dump facility) indicate elevated sulphate concentrations. Based on these results there is a small sulfate plume localized near both PCD 1 and discard dump facilities.

Groundwater monitoring shows minor fluctuations and most groundwater levels are less than 5 m bgl. However, some boreholes show deeper groundwater levels up to approximately 30 m bgl; indicating possible impact from the mining activities.

As a result of dewatering groundwater levels could be lowered over relatively large area around the underground mine. Calculated groundwater inflow volumes are between approximately 800 and 2,500 m³/d.

Groundwater flow directions will be directed towards the mining areas due to the mine dewatering during the operational phase. Therefore, contamination will be contained within the mining area, and little contamination will be able to migrate away from the mining area as can be confirmed by the good groundwater quality in the areas surrounding DCMW. However, monitoring boreholes DFGW6 and DFGW15-08 were however affected by contaminants emanating from the PCD's and discard dump facilities. The impact significance is likely to be low during the operational phase.

There are several monitoring (NBH0) and privately-owned (NBH1, NBH1B, NBH2, D3, DFTNH18 and DFTNH28/27) boreholes in the potential affected area that might experience a decline in water levels of 10 m or more. The impact of the current cone of dewatering could not be confirmed due to the monitoring borehole NBH0 being locked at the time of this investigation. Privately-owned boreholes NBH1, NBH1B, D3, DFTNH18 and DFTNH28/27 might be impacted upon from 2029 and NBH2 from 2033 as mining activities advances over time.

Once the mining has ceased, ARD is still likely to form given the unsaturated conditions in the facility and contact of water and oxygen through natural processes including precipitation. The contaminant plume emanating from the underground workings and the discard dump facility will move in a westerly direction towards an unnamed perennial tributary of the Steenkoolspruit.

Shallow contaminated seepage may impact on the unnamed perennial tributaries to the Olifants River. This impact is however likely to be moderate. Surface water quality sampling is proposed to continue during the operational and post-closure phases. No privately-owned boreholes located in the fractured Karoo aquifer are likely to be impacted upon based on the impact simulations.

Two (2) potential decant points have been determined for the DCMW post-closure mining areas. The decant calculations show that with varying recharge rates the time-to-decant ranges between ~ 56 and ~ 280 years and the discharge rate ranges between approximately 260 and 1,560 m³/d. The impact of decant on surface water is likely to be high and is proposed to treat the water emanating for the underground workings to increase the decant water quality.

The following recommendations are made:

- A closure water management plan should be developed. This should assess the managed of decant via channelled decant or the management of a critical water level to minimise contamination of the shallow weathered aquifer. The discard dump facility should also be assessed in terms of a remediation action plan should the risk for contaminating on the stream be high. This should all be analysed in a financial model to further inform the most effective closure water management options. The groundwater model should be used as a management tool to inform this process;
- The actions in the groundwater monitoring plan should be adhered to;
- All mining areas should be flooded as soon as possible to restrict oxygen ingress to lower sulphate levels in seepage;
- The rate of water level recovery in the underground voids should be monitored. Stage curves should be developed which would aid in the management of closure phase;
- Treatment options of decant should be investigated for the post-closure phase;
- Water quality sampling of the two tributaries of the Olifants River is essential for the operational and post-closure phase;
- The groundwater monitoring network should be expanded for the operational and post-closure phases at DCMW;
- The numerical model should be updated once every three years or after significant changes in mine schedules or plans by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario.

14 REFERENCES

BARNARD, 2000. Department of Water Affairs and Forestry, South Africa, 2000: An Explanation of the 1:500 000 General Hydrogeological Map - Johannesburg 2526. Government Printers Pretoria.

BREDENKAMP DB, BOTHA LJ, VAN TONDER GJ AND VAN RENSBURG HJ (1995) Manual on Quantitative Estimation of Groundwater Recharge and Aquifer Storativity. WRC Report No TT 73/95.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1996). The groundwater harvest potential of the Republic of South Africa. (1996). Department of Water Affairs and Forestry, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1998). Minimum Requirements for water monitoring at waste management facilities (1998). Department of Water Affairs & Forestry, Waste Management Series, 1998).

HODGSON, F.D.I., KRANTZ, R.M., (1995). Investigation into groundwater quality deterioration in the Olifants River catchment above the Loskop Dam with specialized investigation in the Witbank Dam sub-catchment. Institute for Groundwater Studies, University of the Orange Free State. WRC Report No. 291/1/95

HODGSON, FDI AND KRANTZ, RM, (1998). Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam Sub-catchment. WRC Report No.29/1/98

INSTITUTE OF GROUNDWATER STUDIES FOR THE WATER RESEARCH COMMISSION (1998) Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam sub-catchment. WRC Report No 291/1/98.

KIRCHNER R, VAN TONDER GJ and LUKAS E (1991) Exploitation Potential of Karoo Aquifers. WRC Report No. 170/1/91.

NSOVO ENVIRONMENTAL CONSULTANTS (2019). DRAFT SCOPING REPORT FOR THE PROPOSED DEVELOPMENT OF EXXARO DORSTFONTEIN WEST DISCARD DUMP FACILITY, PILLAR EXTRACTION MINING AT 4 SEAM AND A CONVEYOR BELT FROM DCM WEST TO DCM EAST WITHIN THE JURISDICTION OF EMALAHLENI LOCAL MUNICIPALITY, MPUMALANGA PROVINCE

PARSONS, R. (1995). A South African Aquifer System Management Classification. Water Research Commission Report No. KV 77/95.

SOUTH AFRICAN NATIONAL STANDARD FOR DRINKING WATER (SANS 241-1: 2011). Part 1: Microbiological, physical, aesthetic and chemical determinants.

SOUTH AFRICAN WATER QUALITY GUIDELINES FOR AGRICULTURAL WATER USE, (1996). Volume 4, Second Edition, Department of Water Affairs & Forestry.

SOUTH AFRICAN WATER QUALITY GUIDELINES FOR DOMESTIC USE, (1996). Volume 1, Second Edition, Department of Water Affairs & Forestry.

WRC (1996). The groundwater resources of the Republic of South Africa, sheets 1 and 2. (1996). Water Research Commission and Department of Water Affairs & Forestry.

VERMEULEN, P.D. AND HODGSON, F.D.I., (2005). Recharge in South African Collieries.

APPENDIX A HYDROCENSUS LABORATORY CERTIFICATES

Test Report

Page 1 of 4

Client: Groundwater Consulting Services
Address: 63 Wessel Road, Woodmead, 2191
Report no: 63616
Project: GCS

Date of certificate: 04 March 2019
Date accepted: 19 February 2019
Date completed: 01 March 2019
Revision: 0

Lab no:			92278	92279	92280	92281	92282	92283	92284
Date sampled:			15-Feb-2019						
Aquatico sampled:			No						
Sample type:			Water						
Locality description:			NBH24	RK1	WSBH2	WSBH1	DFTNM12	NBH4	DFTNM4
Analyses	Unit	Method							
	A pH @ 25°C	pH	ALM 20	7.84	7.05	7.43	6.30	7.40	7.63
A Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	38.2	31.7	31.1	46.5	37.2	48.8	34.9
A Total dissolved solids (TDS)	mg/l	ALM 26	274	250	257	384	294	365	263
A Total alkalinity	mg CaCO ₃ /l	ALM 01	174	85.1	68.9	11.5	180	110	173
A Chloride (Cl)	mg/l	ALM 02	28.5	20.8	64.7	94.3	14.6	17.1	7.43
A Sulphate (SO ₄)	mg/l	ALM 03	<0.141	1.57	34.7	22.4	21.7	75.0	16.5
A Nitrate (NO ₃) as N	mg/l	ALM 06	2.48	10.2	0.664	24.7	0.542	12.2	0.345
A Nitrite (NO ₂) as N	mg/l	ALM 07	0.051	0.064	0.066	0.068	0.071	0.063	0.077
A Ammonium (NH ₄) as N	mg/l	ALM 05	0.088	0.057	0.022	0.024	0.030	0.073	0.228
A Orthophosphate (PO ₄) as P	mg/l	ALM 04	<0.005	0.050	<0.005	<0.005	<0.005	<0.005	0.013
A Fluoride (F)	mg/l	ALM 08	0.513	<0.263	0.284	<0.263	0.399	<0.263	<0.263
A Calcium (Ca)	mg/l	ALM 30	14.3	16.1	27.1	30.6	14.2	22.8	22.9
A Magnesium (Mg)	mg/l	ALM 30	6.84	9.40	11.0	20.5	10.6	37.6	9.60
A Sodium (Na)	mg/l	ALM 30	62.6	22.1	27.6	39.7	57.5	7.69	41.7
A Potassium (K)	mg/l	ALM 30	5.78	9.80	5.84	9.76	5.47	3.24	3.16
A Aluminium (Al)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A Iron (Fe)	mg/l	ALM 31	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
A Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A Chromium (Cr)	mg/l	ALM 31	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
A Copper (Cu)	mg/l	ALM 31	0.098	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A Nickel (Ni)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A Cadmium (Cd)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A Lead (Pb)	mg/l	ALM 31	0.010	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
A Arsenic (As)	mg/l	ALM 34	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A Selenium (Se)	mg/l	ALM 34	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
N Mercury (Hg)	mg/l	ALM 35	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
A Barium (Ba)	mg/l	ALM 33	0.201	0.171	0.352	0.476	0.111	0.076	0.385
A Bicarbonate alkalinity	mg CaCO ₃ /l	ALM 26	173	85.0	68.7	11.5	180	109	171

A = Accredited N = Non accredited O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report ; The results relates only to the test item tested; Results reported against the limit of detection; Results marked 'Not SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory; Uncertainty of measurement available on request for all methods included in the SANAS Schedule of Accreditation; The report shall not be reproduced except in full without approval of the laboratory
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Lab no:	92278	92279	92280	92281	92282	92283	92284
Date sampled:	15-Feb-2019	15-Feb-2019	15-Feb-2019	15-Feb-2019	15-Feb-2019	15-Feb-2019	15-Feb-2019
Aquatico sampled:	No	No	No	No	No	No	No
Sample type:	Water	Water	Water	Water	Water	Water	Water
Locality description:	NBH24	RK1	WSBH2	WSBH1	DFTNM12	NBH4	DFTNM4
Analyses							
	Unit	Method					
N Antimony (Sb)	mg/l	ALM 36	<0.001	<0.001	<0.001	<0.001	<0.001

A = Accredited N = Non accredited O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report ; The results relates only to the test item tested; Results reported against the limit of detection; Results marked 'Not SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory; Uncertainty of measurement available on request for all methods included in the SANAS Schedule of Accreditation; The report shall not be reproduced except in full without approval of the laboratory
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Test Report

Page 3 of 4

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Lab no:			92285	92286	92287
Date sampled:			15-Feb-2019	15-Feb-2019	15-Feb-2019
Aquatico sampled:			No	No	No
Sample type:			Water	Water	Water
Locality description:			DFTNM3	D4	D4a
Analyses	Unit	Method			
A pH @ 25°C	pH	ALM 20	7.89	7.45	7.75
A Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	28.7	52.4	38.8
A Total dissolved solids (TDS)	mg/l	ALM 26	207	408	300
A Total alkalinity	mg CaCO ₃ /l	ALM 01	177	234	194
A Chloride (Cl)	mg/l	ALM 02	9.48	21.3	18.0
A Sulphate (SO ₄)	mg/l	ALM 03	<0.141	80.1	40.7
A Nitrate (NO ₃) as N	mg/l	ALM 06	0.293	0.832	0.352
A Nitrite (NO ₂) as N	mg/l	ALM 07	0.066	0.065	0.099
A Ammonium (NH ₄) as N	mg/l	ALM 05	0.194	0.025	0.481
A Orthophosphate (PO ₄) as P	mg/l	ALM 04	<0.005	<0.005	<0.005
A Fluoride (F)	mg/l	ALM 08	1.05	<0.263	0.330
A Calcium (Ca)	mg/l	ALM 30	16.6	64.7	39.6
A Magnesium (Mg)	mg/l	ALM 30	11.6	24.6	13.2
A Sodium (Na)	mg/l	ALM 30	40.1	27.2	38.0
A Potassium (K)	mg/l	ALM 30	2.02	2.57	3.27
A Aluminium (Al)	mg/l	ALM 31	<0.002	<0.002	<0.002
A Iron (Fe)	mg/l	ALM 31	<0.004	<0.004	<0.004
A Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001	<0.001
A Chromium (Cr)	mg/l	ALM 31	<0.003	<0.003	<0.003
A Copper (Cu)	mg/l	ALM 31	<0.002	<0.002	<0.002
A Nickel (Ni)	mg/l	ALM 31	<0.002	<0.002	<0.002
A Cadmium (Cd)	mg/l	ALM 31	<0.002	<0.002	<0.002
A Lead (Pb)	mg/l	ALM 31	<0.004	<0.004	<0.004
A Arsenic (As)	mg/l	ALM 34	<0.006	<0.006	<0.006
A Selenium (Se)	mg/l	ALM 34	<0.002	<0.002	<0.002
N Mercury (Hg)	mg/l	ALM 35	<0.004	<0.004	<0.004
A Barium (Ba)	mg/l	ALM 33	0.650	0.102	0.099
A Bicarbonate alkalinity	mg CaCO ₃ /l	ALM 26	175	233	193

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Lab no:	92285	92286	92287
Date sampled:	15-Feb-2019	15-Feb-2019	15-Feb-2019
Aquatico sampled:	No	No	No
Sample type:	Water	Water	Water
Locality description:	DFTNM3	D4	D4a
Analyses			
	Unit	Method	
N Antimony (Sb)	mg/l	ALM 36	<0.001

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