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Dorstfontein East Hydrogeological Investigation Report

Version - 1.2

18 August 2015

Total Coal South Africa

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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that has the shape of an inverted cone and develops around a well/mine shaft/open pit mine from which water is being withdrawn.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.

DWA - Department of Water Affairs (Used to be 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.

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

sulphate - 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.

EXECUTIVE SUMMARY

Total Coal South Africa (TCSA) appointed GCS (Pty) Ltd (GCS) to undertake a hydrogeological investigation and numerical model update for Dorstfontein East (also referred to as DCME) to reflect updated mine schedules and groundwater level monitoring. The following mine plans were considered for this groundwater study:

Mining of the opencasts up to 2020, with:

- opencast 1 (western pit): mining from 2012 to 2016;
- opencast 2 (north-eastern pit): mining from 2012 to 2019;
- opencast 3 (south-eastern pit): mining from 2016 to 2020.

Mining of the underground blocks up to 2032, with:

- Block A and B: mining from 2017 to 2032;
- Block C: mining from 2021 to 2027.

The coal reserves located at Dorstfontein 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 uncomformably 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 m^2/day with an average value of 3.3 m^2/day and a geometric mean of 0.75 m^2/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. Hydraulic conductivity values are 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 fractures. Fracturing mainly occurs in the top of this unit decreasing with depth. Hydraulic conductivity will therefore decrease with depth and will 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 are mostly within 5 m below ground level (average of 5.5 mbgl) with some deeper groundwater levels down to 26 mbgl. 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 has some net acid potential and the interstitial water in the oxic zone of the co-disposal facility will acidify. The material from the mine has a net potential to acidify the mine water.

The sulphate in seepage from the opencast will be about 3 500 mg/l over the long-term as inadequate neutralisation potential is present in the material sampled. 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 around 2 000 - 2 300 mg/l for several decades. It is not foreseen that metals will significantly be present in neutral drainage. Al, Fe and Mn will however be present at elevated concentrations in acidic mine drainage.

The conclusions from the geochemical assessment are in line with the water quality monitoring results. Material from the co-disposal facility 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 co-disposal facility.

The main potential on –site contamination sources for Dorstfontein East are the opencast and underground mine workings and the co-disposal 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 the Olifants River and its tributaries on the site. One privately owned borehole was found down gradient of DCME. NBH6 is an old windmill located to the north of pit 2 but was not in use during the hydrocensus.

Based on the groundwater monitoring results there is a sulphate plume localized down gradient of the co-disposal facility. The water quality improves further away from the surface infrastructures at Dorstfontein East and no impact on the surface water quality in the Olifants River was found at the time of the investigation. No impact of the current opencast 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 as part of this investigation 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 (±700mm) was estimated. The calibration was regarded as sufficient at ME= --0.03 m, MAE = 5.3 m and RMS = 7.0 m and with a water balance error of less than 0.001%.

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 opencast and underground mine. The drawdown scenarios show the dewatering of the opencasts and underground mines will result in a drawdown cone in the area surrounding all mining areas. As the pits and the underground voids increase in size, the cone of drawdown caused by the dewatering of the pits increases with a maximum extent in 2027 as can be seen in Figure 13.1. As the mined out underground voids and opencasts start filling with water after 2032 the groundwater levels in the area will rebound. Groundwater levels are simulated to recover to pre-mining conditions within ~35 years after the end of life (2032) of the Dorstfontein East mine.

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 DCME. However, monitoring boreholes DFTNM10 and DFTNH1 were however affected by contaminants emanating from the Co-disposal facility. The impact significance is likely to be low during the operational phase.

There are several monitoring boreholes in the potential affected area that might experience a decline in water levels of 5m or more. Two privately owned boreholes are in close proximity of the mine, namely NBH6 and NBH20. NBH6 is an old windpump and is not in use. NBH20 is in use as a communal well but has been dry since the beginning of 2014 according to locals. Monitoring boreholes DFTNM11 and DFTNM12 are located close to NBH20 but show no impact on groundwater levels. Therefore it is not likely that NBH20 is impacted upon by the dewatering at Dorstfontein East. It is not expected that the dewatering activities will impact negatively on existing privately owned boreholes.

Once the mining has ceased, ARD is still likely to form given the unsaturated conditions in the Co-disposal facility and contact of water and oxygen through natural processes including rainfall. The contaminant plume emanating from the underground workings and the co-disposal facility will move in a westerly direction towards an unnamed perennial tributary of the Steenkoolspruit. Shallow contaminated seepage may impact on the unnamed perennial tributary to the Olifants River. This impact is however likely to be moderate.

No privately owned boreholes located in the fractured Karoo aquifer are likely to be impacted upon based on the impact simulations, except borehole NBH6 which is located within the simulated contaminant plume. However this is a borehole which is not in use at present.

At Dorstfontein East the potential decant points are located at the lowest topographical sections of the opencast mines. The calculations show the time-to-decant ranges between 25 and 154 years depending on porosity (15 to 25%) and recharge rate (6.5 % according to rehabilitation info and 16% as a maximum from other studies). Decant volume calculations show discharge rates of between approximately 91 and 585 m^3/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:

- The groundwater monitoring network should be expanded for the existing and future mining activities at Dorstfontein East.
- 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.
- 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. Updates to the model should be carried out more frequently if significant changes are made to the mine schedule or plan.

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1 INTRODUCTION

Total Coal South Africa (TCSA) appointed GCS (Pty) Ltd (GCS) to undertake a hydrogeological investigation and numerical model update for Dorstfontein East, also referred to as DCME, near the town of Ga-Nala (Kriel), Mpumalanga Province. Previous hydrogeological investigations and modelling was performed and reviewed for this study.

The current mining operation at DCME is opencast since 2011 and will include both opencast and underground mining in future.

2 SCOPE OF WORK

The following tasks were completed during the hydrogeological investigation:

- Data collection;
- Hydrocensus;
- Assess monitoring network and gap analysis;
- 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 the co-disposal facility;
- Mine decant:
  - determine or confirm decant points;
  - determine the quantity and quality of water that might decant from the underground workings post-closure and 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 co-disposal facility in the short-term and post-mine closure;
- Conduct necessary best practice scientific tests as required to ensure credible data and information is obtained as part of this hydrogeological study (e.g. acid base accounting);
- Make recommendations:
  - for short term and long-term interventions that can be implemented to prevent or mitigate pollution; and
  - to further increase the confidence of the modelling work done in future.

3 METHODOLOGICAL APPROACH

3.1 Data and information review

All relevant public domain information was reviewed including, but not limited to geological, hydrogeological and climatic information. Data obtained from the client included proposed mine plans, coal floor elevations, site infrastructure plans and surface topography contour data. Previous reports from other groundwater studies conducted in the area by GCS were also reviewed. The following GCS reports formed part of the review process:

- GCS (Pty) Ltd. 2007. Hydrogeological Study for the Dorstfontein Western Expansion Project. GCS Project number: TCSA.D.07.022
- GCS (Pty) Ltd. 2008. Dorstfontein 4-seam EMP Study – Hydrogeological Investigation. GCS Project Number: TCSA.D07.251.
- GCS (Pty) Ltd. 2009. Geohydrological Study for the Dorstfontein Western Expansion Project. GCS Project Number: 08-246.
- GCS (Pty) Ltd. 2009. Hydrogeological Assessment for Total Coal Forzando Mining Sections. Version 1. GCS Project Number: 08-377.
- GCS (Pty) Ltd. 2009. Dorstfontein Eastern Expansion - Water Use License Application Calculations. GCS Project Number: 09-303.
- GCS (Pty) Ltd. 2009. Dorstfontein Coal Mine East Mine Expansion Project - Environmental Management Programme (EMP). GCS Project Number: 10-007.
- GCS (Pty) Ltd. 2011. Hydrogeological Study for the Dorstfontein Western Expansion Project. GCS Project Number: 10-007.
- GCS (Pty) Ltd. 2012. Dorstfontein coal mine: west mine expansion project - Revised - Environmental Impact Assessment and Environmental Management Programme (EIA/EMP).

3.2 Hydrocensus

A hydrocensus was conducted within a ~5 km radius of the Dorstfontein West and East workings. A total of 26 boreholes were visited.

The purpose of the hydrocensus was to update regional groundwater users and hydrogeological information. The scope of this task included the following:

- Identify/update 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).

All of the data collected during both of the hydrocensus investigations were captured and analysed. The results of the hydrocensus are presented in Section 7.2 and borehole localities are shown in Figure 7.1.

3.3 Sampling

3.3.1 Groundwater

Groundwater samples were collected from selected hydrocensus boreholes. The samples were submitted to a SANAS (South African National Accreditation System) 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 SANS (South African National Standards) 241:2011 Class 1 water quality standards for drinking water.

The laboratory analyses included:

- Major anion and cations;
- ICP metal scan; and
- pH, Total Dissolved Solids (TDS), , 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

3.3.2 Geochemical Sampling and Testing

An environmental geochemical assessment at DCME was conducted. The primary objectives of the assessment were as follows:

- to determine the geochemical nature of the material from the opencast mines, the underground workings, the co-disposal facility and the run of mine;
- to determine the long-term net acid generation potential;

- to identify metals that may be present in drainage from the mine; and,
- perform geochemical model in order to predict future decant water qualities from the mine.

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 were conducted by Geostratum Pty Ltd, Vanderbijlpark. A total of twenty (15) samples were collected and the findings are discussed in Section 10.

3.4 Monitoring network review and gap analysis

Based on the data review and hydrocensus a gap analyses will be formulated to assess the adequacy of the current monitoring network.

3.5 Modelling

3.5.1 Conceptual Modelling

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.

3.5.2 Numerical Modelling

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

The updated model was constructed using GMS 10.0.5, a pre- and post-processing package. GMS uses the well-established MODFLOW-2005 (Harbaugh et al, 2005) and MT3DMS (Zheng & Wang, 1999) numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and supports a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and updated several times since.

MT3DMS is a 3D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS 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. The numerical modelling was undertaken in a number of steps, as detailed below.

3.5.2.1 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 discretized 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.

3.5.2.2 Scenario modelling

Scenario modelling is typically 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) will be simulated.

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

- The extent of potential dewatering;
- Potential impact on surrounding groundwater users;
- Groundwater inflows and decant positions and volumes;

- Potential contaminant plumes that may originate from the mining areas or waste storage facilities (co-disposal facility, etc.).

4 TOPOGRAPHIC ENVIRONMENT

4.1 Location

DCME is situated on portions of the farms Boschkrans 53IS, Fentonia 54 IS, Rietkuil 57IS and Welstand 55IS, located within the Magisterial District of Bethal, under the jurisdiction of the Emalahleni Local Council, Mpumalanga.

4.2 Climate and Surface Water Drainage

4.2.1 Climate

Climate Data was obtained from the South African Weather Service and databases of WR2005. 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. Average daily winter temperatures are approximately 4°C, with minimum temperatures reaching around -4°C. The number of days when heavy frost occurs is 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 rainfall of 700 mm is considerably less than the average annual A-pan evaporation of 1840 mm. Evaporation off open surfaces of water (lake evaporation), though less than A-pan values, will be significant (calculated at 1500 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 and modelled 'now climate', a trend of increased early summer rainfall and decreased late summer rainfall is evident. Normal Dry Weather Conditions (rainfall and runoff values exceeded on average 70% of time) are used to describe climate change impacts. Trends of change in rainfall are magnified in modelled runoff. Changes in rainfall patterns are shown in Figure 4.1.

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

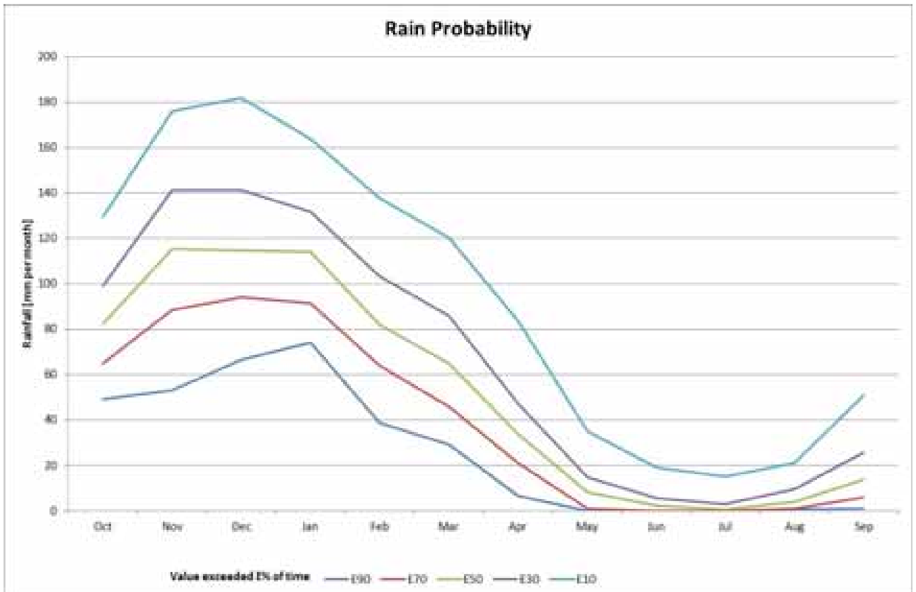


Figure 4.1: Rainfall Distribution

In Figure 4.1 (above) rainfall 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, rain is likely to exceed 94.2 mm in the month). Figure 4.2 reflects how climate change has affected rainfall and compares record values to simulated values for a current climate (where past records have been adjusted to represent current climate).

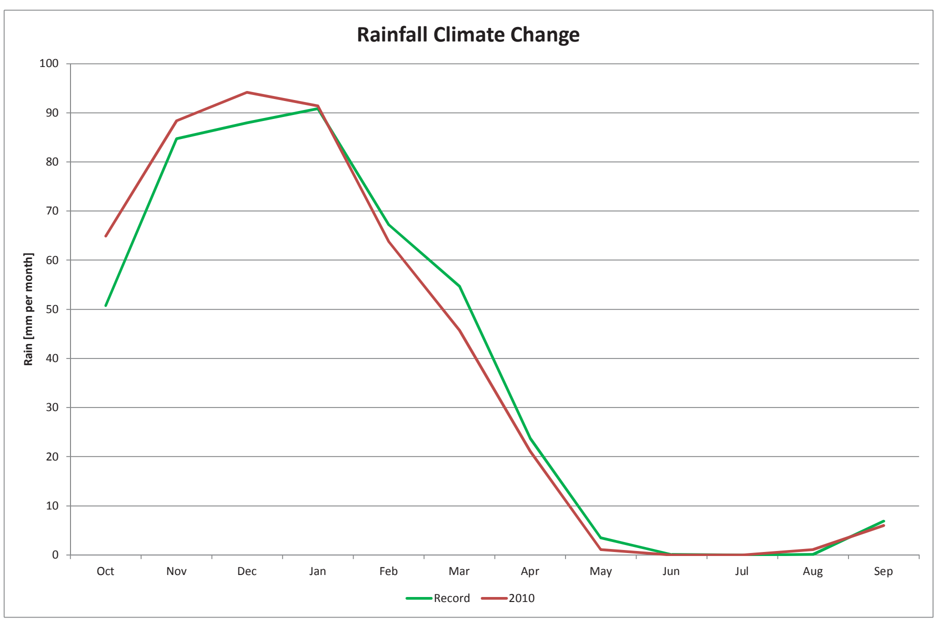


Figure 4.2: Changes in Rain Patterns

4.2.2 Catchment

The extent of the area of investigation is mainly determined by the catchment which is engaged by the mine. DCME is situated in the B11B quaternary catchment in the Upper Olifants River catchment. Rain that falls within the B11B catchment drains towards the Olifants River.

4.2.3 Drainage

Recharge to the weathered aquifer from rainfall 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 DCME where the current underground mining activities are taking place differs approximately 50 meters in elevation between Klein Vaalkop south of the mining activities (approximately 1670 meters above mean sea level (mamsl), and the Olifants River, which borders the proposed mining area to the north.

Three unnamed tributaries of the Olifants River drain in a northerly direction. Two tributaries overly the western limb of the reserve and the eastern tributary overlying the eastern limb. The confluence of the three tributaries is situated on the farm Vlaklaagte 45 IS, just north of the mining concession area. A locality map can be seen in Figure 4.3.

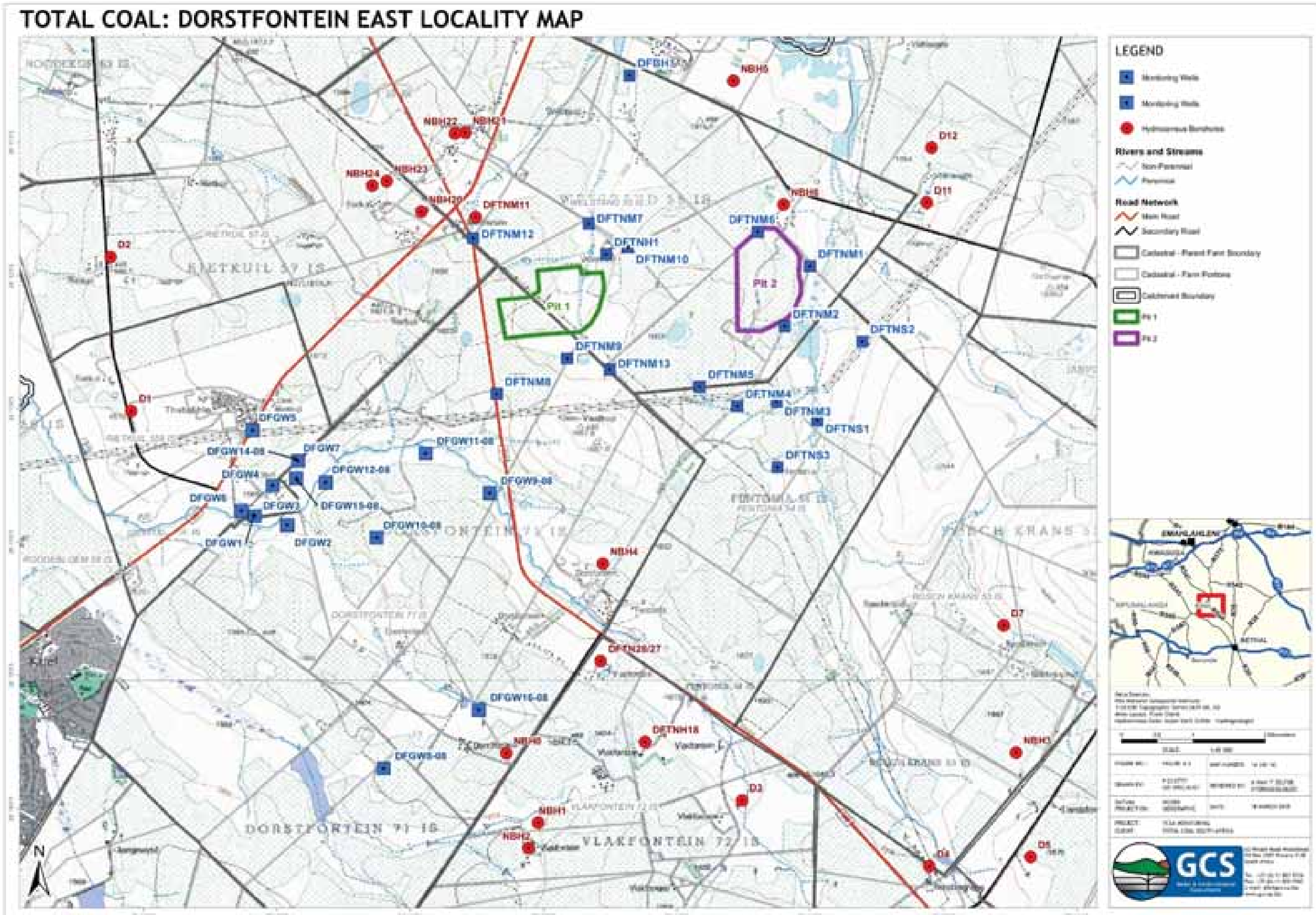


Figure 4.3: Dorstfontein Locality Map With Current Mine Extent

5 MINE INFRASTRUCTURE AND ACTIVITIES

Dorstfontein East's surface operations are situated approximately 3.5 km to the northeast of Dorstfontein West's underground operations. Currently mining activities at Dorstfontein East are open pit (No. 2 and No. 4 coal seams). Mining activity in the open pits at Dorstfontein East started in 2012.

There are extensive No.4 seam coal reserves overlying the No.2 Seam in the eastern portion of the DCM mineral rights area. Dorstfontein East includes mining of the extensive No. 4 coal seam overlying the No. 2 coal seam, which was identified as the preferred resource. In addition to this the No. 1, 3 and 5 coal seams are mined. All resources less than 40m deep are accessed via the opencast operations, whereas the deeper lying coal will be accessed via underground mining operations.

Coal production started in 2012 from two opencast operations at the East Mine. Mining of a third opencast will commence in 2016. Underground production will commence from the opencast high walls on No. 4 and No. 2 seams on the East Mine. RoM from the opencast pits are transported via conveyors to the plant. Discard is conveyed from the plant to a co-disposal facility by conveyor for the coarse fraction and by pipeline for the slurry fraction. The project will ensure a LoM in excess of 25 years.

Mine schedules for the Dorstfontein East site were obtained from the client. After discussion with the client the following mine plans were used as input for this study:

- Opencast: mining of the 4 seam and 2 seam as obtained from the client in December 2014; File references:
  - TC_dfe_4sl
  - TC_dfe_2s;

- Underground: mining of the 4 seam and 2 seam as obtained from the client in 2008. File references:
  - Block A B and 2 Seam Mining Plan 401-002-000-00-000-05-A
  - Block A B and 4 Seam Mining Plan 401-002-000-00-000-04-A
  - Block C 2 and 4 Seams Mining Plan 401-002-000-00-000-06-A

The mine plans include three opencast mines with mining activities between 2011 and 2020 for the No. 2 and No. 4 seams and underground blocks A, B and C with mining activities between 2017 and 2032 for the No. 2 and No. 4 seams. Refer to Figure 5.2 and Figure 5.3 for the mine schedules.

DCM East Mine comprises of the following infrastructure (Figure 5.1):

- Opencast workings;
- Underground workings;
- New processing plant;
- Co-disposal facility;
- Pollution control dams with water return dam;
- Stockpiles;
- Access and haul roads;
- Ancillary infrastructure;
- Existing access road to railloop area; and
- Clean and dirty water management systems.

Figure 5.1 shows the locations of the current extent of the pits, the Co-disposal facility, the PCDs, the coal stockpiles, the overburden storage area and the plant area.

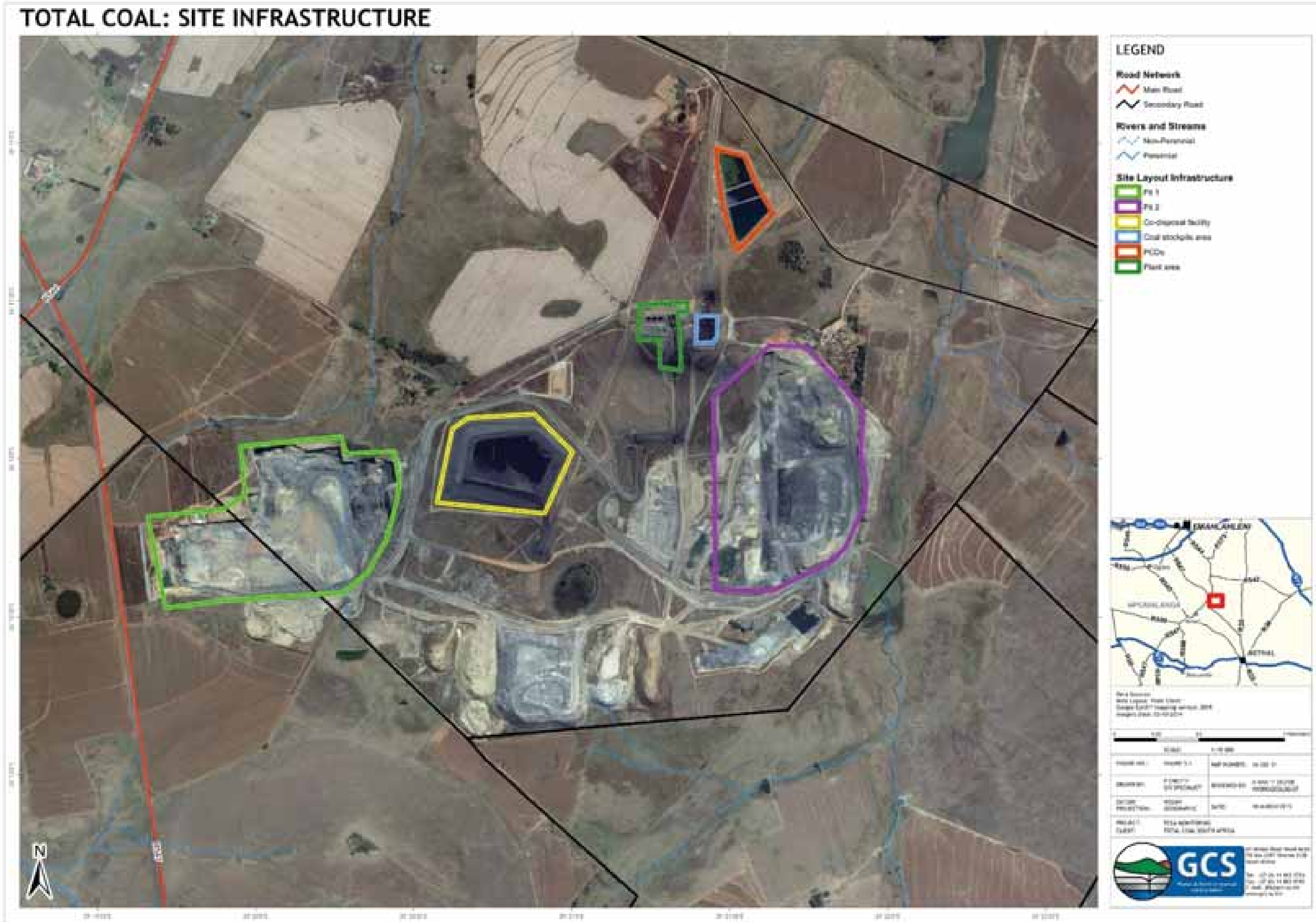


Figure 5.1: Site infrastructure

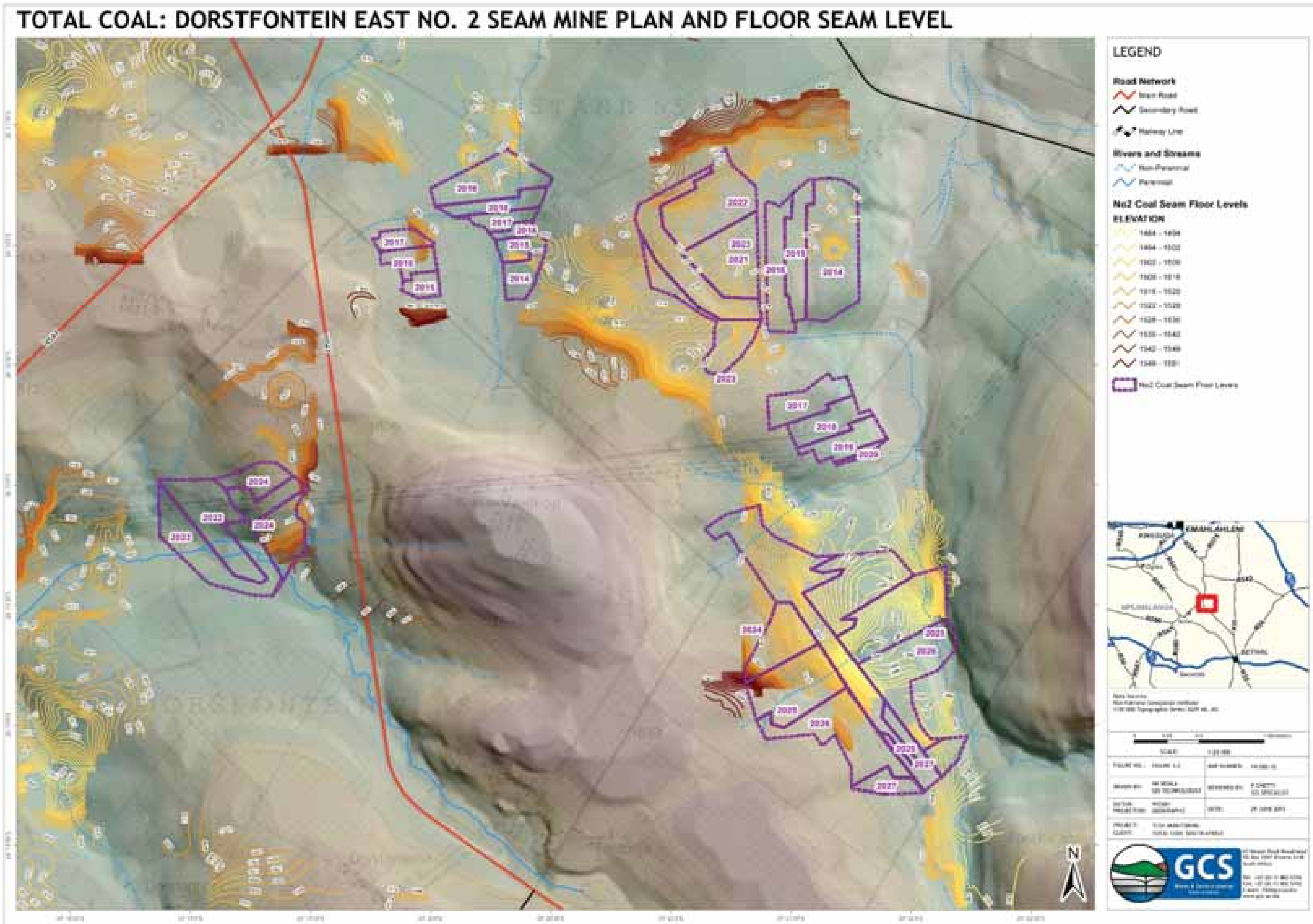


Figure 5.2: Dorstfontein East No. 2 Seam mine plan

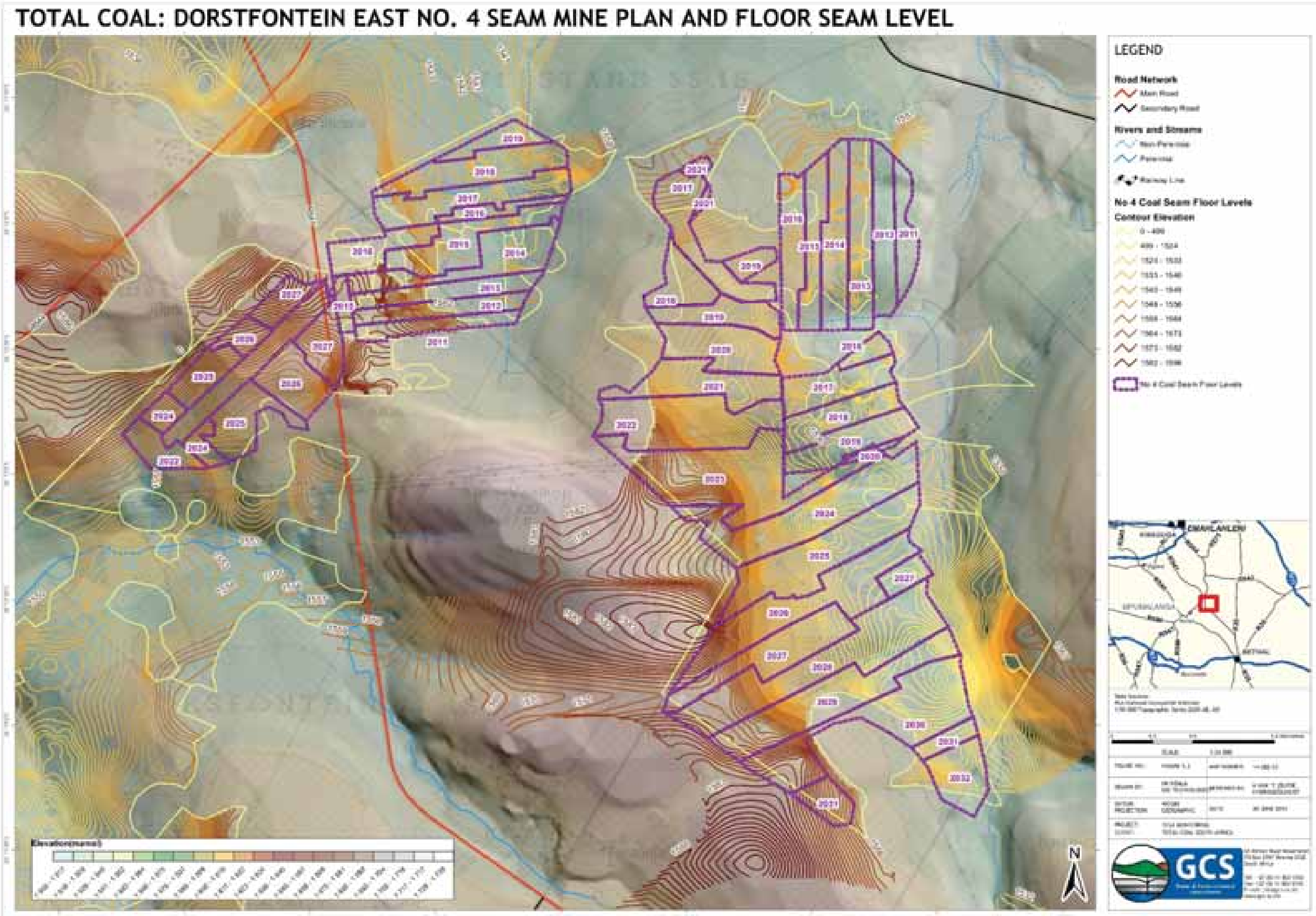


Figure 5.3: Dorstfontein East No. 4 Seam mine plan

6 GEOLOGICAL SETTING

6.1 Regional geology

The Karoo Supergroup in the Olifants Catchment compromises the Ecca Group and Vryheid Formation. The total thickness of these sediments ranges from 0 – 100 m. 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 uncomformably on basement rocks of the Basement Granite. The Ecca sediments overlie the Dwyka Group. Refer to Figure 6.1 for the regional geology map.

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

The area of investigation is situated within the Highveld coal seam. 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 seam 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 dykes and sills resulting in the devolatilization of coal proximal to intrusions. The tendency of sills to migrate to differing stratigraphic levels has caused seam displacement.

6.2 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 DCME are mainly the No. 2 seam and No. 4 seam. In addition, The No. 1, 3 and 5 seams will be targeted in the opencast mines. 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 coalfield.

6.2.1 Coal Seam Dimensions

The No. 2 coal seam occurs at about 20 – 30m below the No. 4 coal seam and is also laterally continuous. The thickness of the No. 2 seam varies between approximately 1m and 3m. Locally the No. 2 coals seam is divided into an upper and lower seam with a parting thickness of up to 0.7m, 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 1.4m to 5.5m in thickness where it is laterally continuous, but locally in the west and north-east it may be up to 8m thick. It consists mainly of dull coal. The average thickness of the No. 4 Lower Seam is 4m. 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 1590 mamsl and syncline elevation at approximately 1510 mamsl. 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. Shale intercalations are common in the upper part of the seam, which consists mainly of dull coal (Snyman, 1998). 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.

Refer to Figure 5.2 and Figure 5.3 for seam floor elevations at DCM. A detailed geological map obtained from the DCM indicated the occurrence of several dolerite dykes that criss-cross the study area. A geophysics investigation that was undertaken did not reveal any significant anomalies any significant anomalies that could be indicative of such structures (GCS, 2011).

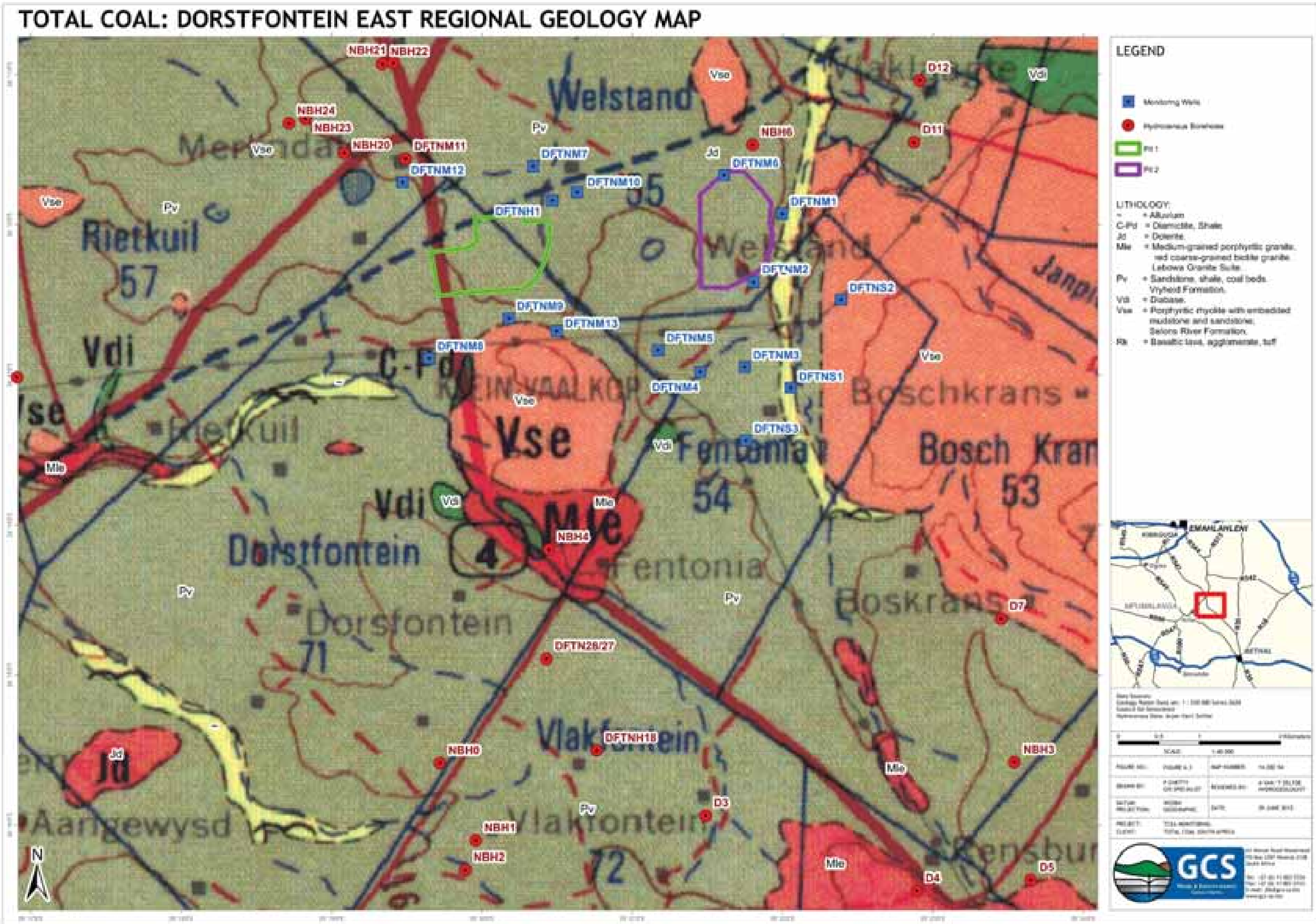


Figure 6.1: Regional Geology Map

7 HYDROGEOLOGICAL BASELINE INFORMATION

7.1 General Aquifer Description

The conceptual geohydrological model of the area is based on the generally accepted model for the Mpumalanga coal fields. 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).

According to WRC report 291/1/98, three distinct superimposed groundwater systems are present within the Olifants River Catchment. They can be classified as:

- The upper weathered Ecca aquifer (shallow aquifer formed in the weathered zone of the Karoo sediments and which is locally perched on the fresh bedrock);
- The fractured aquifers within the unweathered Ecca sediments; and
- The aquifer below the Ecca sediments (deeper aquifer formed by fracturing of the Karoo sediments and dolerite intrusions).

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.-related systems are also often characterised by discrete and/or erratic development.

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 metres below ground level (mbgl). The lower 5 to 10 meters 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 mbgl. The saturated depth of this aquifer is dependent on rainfall recharge, thus influx of water into a bord and pillar or opencast 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 Mean Annual precipitation (MAP) based on work by Kirchner *et al.* (1991) and Bredenkamp (1978) in other parts of the country

7.1.1 Shallow Weathered Aquifer

The Ecca sediments consist of *in-situ* weathered material and transported material with a thickness which varies between 5 to 15 meters below surface in the area surrounding the DCM. The upper aquifer is associated with this weathered zone and water is often found within a few meters below surface. This aquifer is recharged by rainfall.

Rainfall that infiltrates the weathered rock 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 – 2000 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.

7.1.2 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, the coal seams often have the highest 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 7.1.

Table 7.1: Statistics for Results on Packer Tests (WRC Report No 291/1/98)

Statistics	No. 2 Seam – K (m/day)	Dwyka – K (m/day)
Mean (m/d)	0.1017	0.0034
Median (m/d)	0.0743	0.0024
Standard deviation (m/d)	0.1295	0.0034
Min (m/d)	0.0007	0.0002
Max (m/d)	0.5	0.018
Number of tests	21	21

The data listed in Table 2-2 suggest that seepage of water through the No 2 seam is possible. Due to its low hydraulic conductivity, the Dwyka tillite forms 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 and some of the fountains.

7.1.3 Aquifer Hydraulics

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

- eight boreholes at DCMW (starting with code DFGW) on which falling head tests were performed;
- eleven boreholes at DCME (starting with code GCS) which were pump tested at a constant rate and allowed to recover;
- three boreholes at Forzando North (starting with code FNGW) which were pump tested at a constant rate and allowed to recover;
- one borehole at Forzando South (starting with code FSGW) which was pump tested at a constant rate and allowed to recover;
- transmissivity values form Pulles et. al, 1994.

The above results yielded transmissivity values of between 0.01 and 22.5 m^2/day with an average value of 3.3 m^2/day.

Table 7.2: Statistics for transmissivity

number of observations	36
minimum	0.01
maximum	22.25
average	3.32
geometric mean	0.75
harmonic mean	0.06

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

- Transmissivity values decreased with depth.
- The sandstone between the No 4 upper and No 4 lower coal seam has a permeability significantly lower than that of fractures within the Vryheid Formation sediments.
- The No 4 coal seam is not highly permeable. Some seepage of water from the coal can be expected during mining.

- Shale and dolerite at depths exceeding 15 m have a hydraulic conductivity between 0.004 and 0.02 m/day.
- It is fair to assume that the alluvial sands along the streams having higher permeability values.

7.2 Hydrocensus

GCS conducted a hydrocensus in the project area during August and November 2014 within a 5 km radius of the proposed mining activities. A total of twenty-six (26) boreholes were visited. No boreholes of the monitoring network at Dorstfontein East were visited as all monitoring data is held and maintained by GCS. Figure 7.1 presents all of the boreholes visited during GCS 2014 hydrocensus investigations and shows the locations of the boreholes visited.

7.2.1 Borehole status

Information pertaining to water use of the 26 boreholes is shown below:

- 21 boreholes were used for domestic, stock watering purposes and irrigation;
- 3 boreholes were dormant/not in use;
- 2 boreholes, owned by Total Coal and BHP Billiton respectively, are used for monitoring purposes; the borehole owned by Total coal is still part of the current monitoring network.

7.2.2 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. Most of the farmers have to filter the water before it is used for drinking water for the salt content of groundwater is very high.

Three springs were found as part of the hydrocensus. All three springs are on privately owned land and are used for livestock.

Table 7.3: Summary of Hydrocensus Boreholes

ID	Farm Name	Farm Owner	Contact Details	Description	X (m in WGS 84 LO 29)	Y (m in WGS 84 LO29)	Alt (mamsl)	WL (mbgl)	Collar Height (m)	Equipment	Use	Sampled
NBH0	Portion 1, Dorsfontein.	N. Hirschowitz	082 608 0108	Newly drilled borehole. Seeled and under lock and key. No Water Access.	32835.19013	-2905656.365	1626			Collar with locked cap	Not known	No
DFTN28/27	Portion 2, Vlakfontein.	Kobus Pieterse	082 555 0666	Windpump. No Water Access.	34018.32218	-2904378.195	1627	4.65	0.13	Windpump	Stock watering	No
NBH1	Portion 2, Vlakfontein.	Kobus Pieterse	082 555 0666	Windpump. Approx 35 m deep.	33230.53239	-2906608.432	1622	20	0.17	Windpump	Domestic use and drinking water	Yes
NBH2	Portion 2, Vlakfontein.	Kobus Pieterse	082 555 0666	Windpump. No dipmeter Access.	33111.06134	-2906961.338	1620			Windpump	Drinking and livestock watering	Yes
NBH3	Portion 8,Bosch Krans 53 IS.	J Gobler	083 272 1503	Windpump. Well maintained. No Water Access.	39198.97786	-2905663.877	1658	3.8	0.44	Windpump	Livestock watering	No
DFTNH18	Portion 2, Vlakfontein.	Kobus Pieterse	082 555 0666	Windpump. No dipmeter Access.	34570.38982	-2905506.102	1637			Windpump	Drinking water	Yes
NBH4	Portion RE, Dorsfontein 71 IS.	N Hirschowitz.	082 608 0108	Borehole with pump installed. Jo-Jo tank constructed above the borehole. No Water Access.	34048.14407	-2903028.58	1621	6.02	0.17	Submersible pump	Drinking water and livestock watering	No
DFTNM11	Total Coal.	Total Coal	Unknown	Monitoring borehole.	32471.31707	-2898215.654	1597	7.829	0.34	Collar with locked cap	Monitoring	Yes
NBH5	BHP Billiton.	BHP Billiton	Unknown	Open borehole North of DCME. No Water Access.	35694.28531	-2896338.301	1566	8.235	0.43	Collar with locked cap	Monitoring	No
NBH6	Total Coal	Total Coal	Unknown	Old Windpump. No attached pump, and rock covers hole.	36318.38769	-2898054.447	1565	31.11	0.4	Windpump	Dorment	Yes
NBH20	Emalahleni Local Municipality. Rietkuil.	Emalahleni Local Municipality. Rietkuil.	Unknown	Pump in community. No water. Has been dry since beginning of year according to locals.	31792.8116	-2898142.735	1599			Hand pump	Drinking water	No
NBH21	Portion 6, Welstand.	Mr. Swart	084 064 17121	Borehole on Mr. Swart's farm. Submersible pump installed. Used for house. No one available to give a sample.	32341.19107	-2897046.131	1592	14.857	0	Submersible pump	Drinking water	No
NBH22	Portion 6, Welstand.	Mr. Swart	084 064 17121	Windpump on Mr. Swart's farm. Used for livestock. No dipmeter access.	32215.11525	-2897055.456	1595			Windpump	Livestock watering	Yes
NBH23	Portion 2, Rietkuil.	IJG de Wet	082 870 6611	Submersible pump borehole on Mr. de Wet's farm. Used for drinking water. No dip meter access. No Water Access borehole decoupled.	31363.23322	-2897719.016	1608			Submersible pump	Drinking water	No
NBH24	Portion 2, Rietkuil.	IJG de Wet	082 870 6611	Windpump on Mr. de Wet's farm. No sample for it is sealed and water is pumped to other parts of the farm.	31179.37466	-2897776.185	1614	12.24	0	Windpump	Livestock and crop watering	No
D1	RE, Rietkuil.	Emalahleni Local Municipality	Unknown	Borehole near township. North from DCMW co-disposal facility. Used for livestock watering.	28162.20752	-2900898.636	1582	5.98	0.4	Submersible pump	Livestock and crop watering	No
D2	RE, Rietkuil.	Emalahleni Local Municipality	Unknown	Old monitoring borehole. Sealed with a stainless steel cap.	27905.98509	-2898758.672	1598	0.65	0.31	Monitoring Borehole	Not in use	No
D3	Portion 1, Vlakfontein.	IJG de Wet	082 870 6611	Windpump near dry stream area.	35775.13148	-2906309.755	1625		0.24	Windpump	Livestock and crop watering	No
D4	Portion 14, Bosch Krans.	E Muller	823 882 139	Submercible pump located in pump house. Appears to be used for livestock watering and drinking water.	38111.89124	-2907227.16	1626	11.88	0.04	Submersible pump	Livestock and crop watering	No

ID	Farm Name	Farm Owner	Contact Details	Description	X (m in WGS 84 LO 29)	Y (m in WGS 84 LO29)	Alt (mamsl)	WL (mbgl)	Collar Height (m)	Equipment	Use	Sampled
D5	Portion 13, Bosch Krans.	E Muller	823 882 139	Old windpump. Sealed with no water level access.	39376.81576	-2907101.318	1673			Windpump	Livestock and crop watering	No
D7	Portion 2, Bosch Krans.	E Muller	823 882 139	Submersible pump located some distance from a stream. This borehole is used for livestock watering and pumpe to various parts of the farm.	39052.84828	-2903901.687	1633	12.155	0.095	Submersible pump	Livestock and crop watering	No
D8	Portion 1, Bosch Krans.	E Muller	823 882 139	Windpump. Completely sealed with no dip meter access.	40969.19906	-2901352.678	1622			Windpump	Livestock and crop watering	No
D9	Portion 1, Bosch Krans.	E Muller	823 882 139	Windpump. Completely sealed with no dip meter access.	41307.59643	-2901467.87	1649			Windpump	Livestock and crop watering	No
D10	Portion 1, Bosch Krans.	E Muller	823 882 139	Submersible pump located directly nect to farm house. Used for drinking water.	40314.42954	-2900782.25	1635	6.92	0.02	Submersible pump	Domestic watering and house water	No
D11	Total Coal, Vlaklaagte.	Unknown	Unknown	Handpump. Completely sealed with yes dip meter access.	38105.96388	-2898028.991	1561			Hand pump	Was used for drinking water, however salt load is to high to drink.	Yes
D12	BHP Billiton, Vlaklaagte.	Unknown	Unknown	Windpump located some distance from a stream. This borehole is used for livestock watering and pumped to various parts of the farm.	38170.16327	-2897271.351	1565	3.529	0.031	Windpump	Livestock and crop watering	No

*WL – Static Water Level

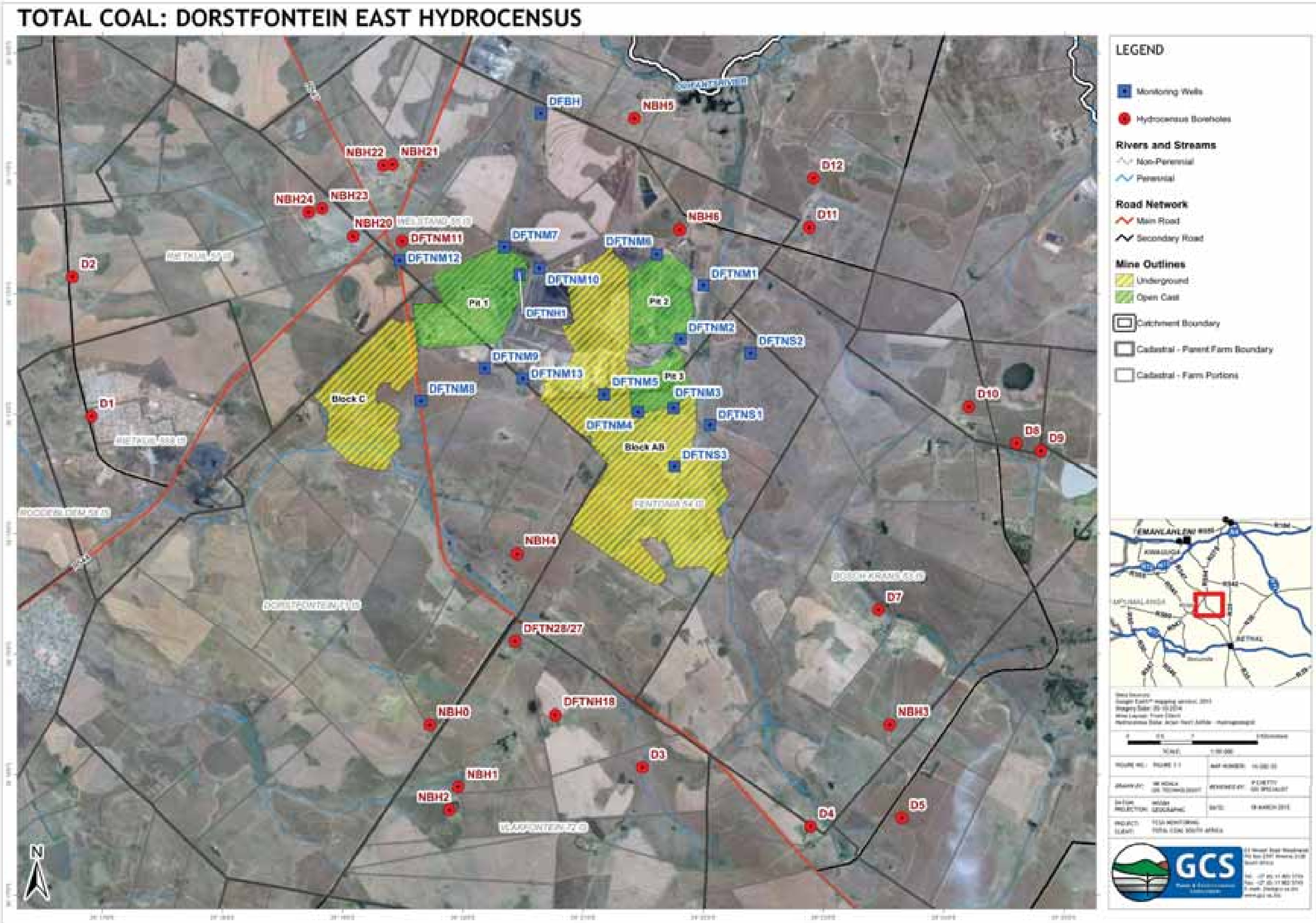


Figure 7.1: Hydrocensus boreholes

8 WATER QUALITY

8.1 Hydrocensus boreholes

Groundwater samples were collected from six hydrocensus boreholes. Refer to Table 8.1 for the groundwater quality results. Sample analyses results were compared to the South African National Standard (SANS) 241:2011 Class 1 water quality standards for drinking water.

No measured parameters exceeded the SANS standards. In DTNM18 the nitrate concentration of 8.03 mg/l was slightly elevated, exceeding 50% of the SANS standard of 11 mg/l.

It can be concluded that the groundwater quality measured in third party boreholes is of good quality when compared to drinking water standards. There is no indication that mining activities are impacting on the groundwater quality in these boreholes.

Table 8.1: Groundwater quality parameters and anions.

Parameters (mg/l)	NBH1	NBH2	NBH6	NBH22	DFTNM11	DFTNM18	SANS 241:2011		
							0-50% of limit	50%-100% of limit	Above limit
pH (Value)	8.06	7.96	7.98	8.36	7.7	7.1	6 - 8.4	5-6; 8.4-9.7	<5 ; >9.7
EC (mS/m)	63.8	63.3	20.6	40.8	48.2	44.5	<85	85-170	>170
Al	<0.02	<0.02	<0.02	0.022	<0.02	<0.02	<0.15	0.15-0.3	>0.3
As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Ba	0.21	0.285	0.076	0.137	0.086	0.276	-	-	-
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-
Ca	15	57.4	8	9.84	16.4	42.7	-	-	-
Cd	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.0015	0.0015-0.003	>0.003
Co	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.25	0.25-0.5	>0.5
Cr	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.025	0.025-0.05	>0.05
Cu	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
Fe	0.495	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
K	3.33	9.3	2.37	3.61	4.81	6.21	-	-	-
Mg	5.62	14.3	2.44	4.83	10.1	6.98	-	-	-
Mn	<0.02	<0.02	<0.02	<0.02	0.036	<0.02	<0.25	0.25-0.5	>0.5
Na	91.9	31.6	25.8	72.2	60	20.7	-	-	-
Ni	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.035	0.035-0.07	>0.07
Pb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Se	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-
Sr	0.364	0.343	0.117	0.148	0.171	0.17	-	-	-
V	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.1	0.1-0.2	>0.2
Zn	0.094	0.033	0.16	0.485	0.332	0.051	<2.5	2.5-5.0	>5
SO_4 (mg/l)	20.4	34.3	26.5	14.8	30.7	43.3	<250	250-500	>500
Total Alkalinity (mg/l)	239	166.3	65.6	187.9	179	97.7	-	-	-
Cl (mg/l)	14.6	30.5	<5	16.9	11.4	14.5	<150	150-300	>300
PO_4 as P(mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	0.11	-	-	-
Nitrate as N (mg/l)	0.22	4.95	<0.1	0.94	0.23	8.03	<5.5	5.5-11	>11
Ammonia as N (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.75	0.75 - 1.5	>1.5
F (mg/l)	1	0.27	5.3	0.82	<0.1	<0.1	-	-	-

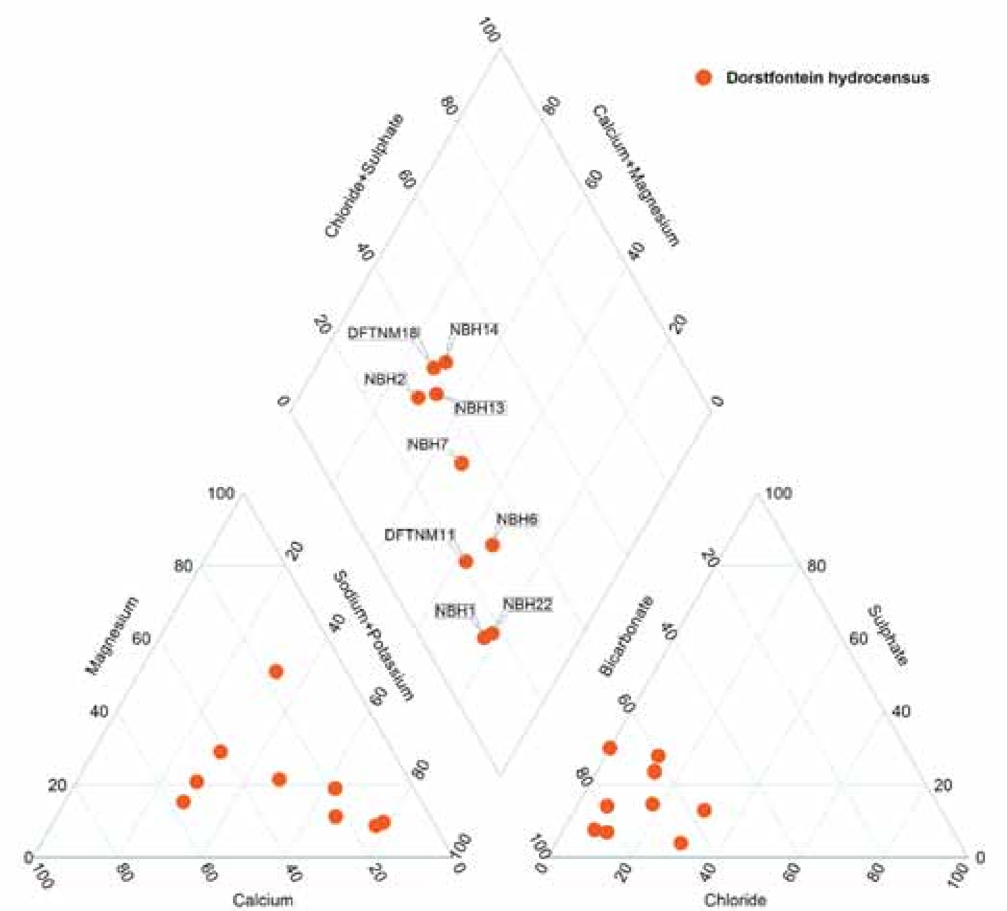


Figure 8.1: Hydrocensus Piper Plot

The piper plot in Figure 8.1 indicates that calcium concentrations are generally higher than magnesium concentrations and bicarbonate concentrations are consistently high. Sulphate concentrations, an indication of pollution from coal mines, are very low, as are chloride concentrations. The results indicate that naturally occurring chemical weathering (water and host rock interactions) takes place. There are no signs of sulphate pollution at any sampled hydrocensus boreholes, indicating no third boreholes are impacted upon by the current mining activities at DCME.

8.2 Monitoring Boreholes

Dorstfontein East has an active groundwater monitoring programme, with a number of monitoring boreholes involved including the boreholes described in Table 8.2. The associated water level data and quality analyses were discussed in quarterly monitoring reports, compiled by GCS, from 2010 up to the present.

Fourteen (14) groundwater monitoring sites exist on the Dorstfontein East site of which two are inaccessible due to being covered with soil and two boreholes are damaged or destroyed. All boreholes are sampled quarterly and water levels are taken monthly.

8.2.1 Quality Standard Compliance

The existing groundwater monitoring boreholes exceeded the following compliance objectives:

- At *DFTNM10* the sulphate concentration has increased since March 2014 and exceeds the SANS limit of 500 mg/l in the last quarter of 2014 (Figure 8.2);
- Nitrate was previously elevated at *DFTNH1* as well as sulphate, although sulphate was still compliant;
- at *DFTNM7* only fluoride was elevated.
- Borehole *DFBH* indicated significant spikes in conductivity, total dissolved solids, sulphate and manganese in March 2011 and December 2013. As borehole in DFBH is drilled into the old TNC underground workings contamination in this borehole could be related to the old underground mine.

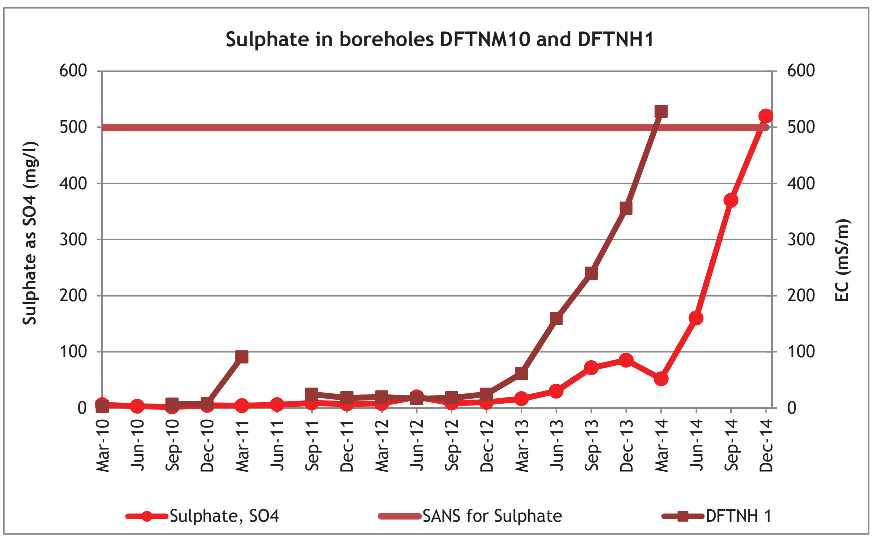


Figure 8.2: Sulphate time series graph for boreholes *DFTNM10* and *DFTNH1*

Table 8.2: Existing Dorstfontein East Boreholes (status in fourth quarter 2014)

Points	Latitude (S)	Longitude (E)	Groundwater Locations	Monitoring Status	Monitoring Frequency
DFTNM1	-26.19881	29.36662	West of Olifants River Tributary, south of DCM7	Boreholes covered with soil. Boreholes not to be re-drilled due to the haul road that has been constructed.	Levels MONTHLY Samples QUARTERLY
DFTNM2	-26.20636	29.36346			
DFTNM3	-26.21579	29.36246		Level recorded. Sampled Sep. Water clear.	
DFTNM4	-26.21636	29.35753			
DFTNM5	-26.21392	29.35284			
DFTNM6	-26.19451	29.36015			
DFTNM7	-26.19347	29.339	West of Olifants River tributary		
DFTNM8	-26.21484	29.32747	South of DFTNM12 along Bethal / Witbank Road R554		
DFTNM9	-26.21038	29.3363			
DFTNM10	-26.19641	29.34386	East of Olifants River tributary		
DFTNM12	-26.1953	29.32454	North of DFTNM8 along Bethal / Witbank Road R554		
DFTNM13	-26.21178	29.3416		Borehole damaged in Jun 2012.	
DFTNH1	-26.19731	29.34116	South of DFTNM9 and DFTNM7	Destroyed June 2014.	
DFBH	-26.17492	29.34407	Underground workings water	Level recorded. Sampled Sep. Water clear.	

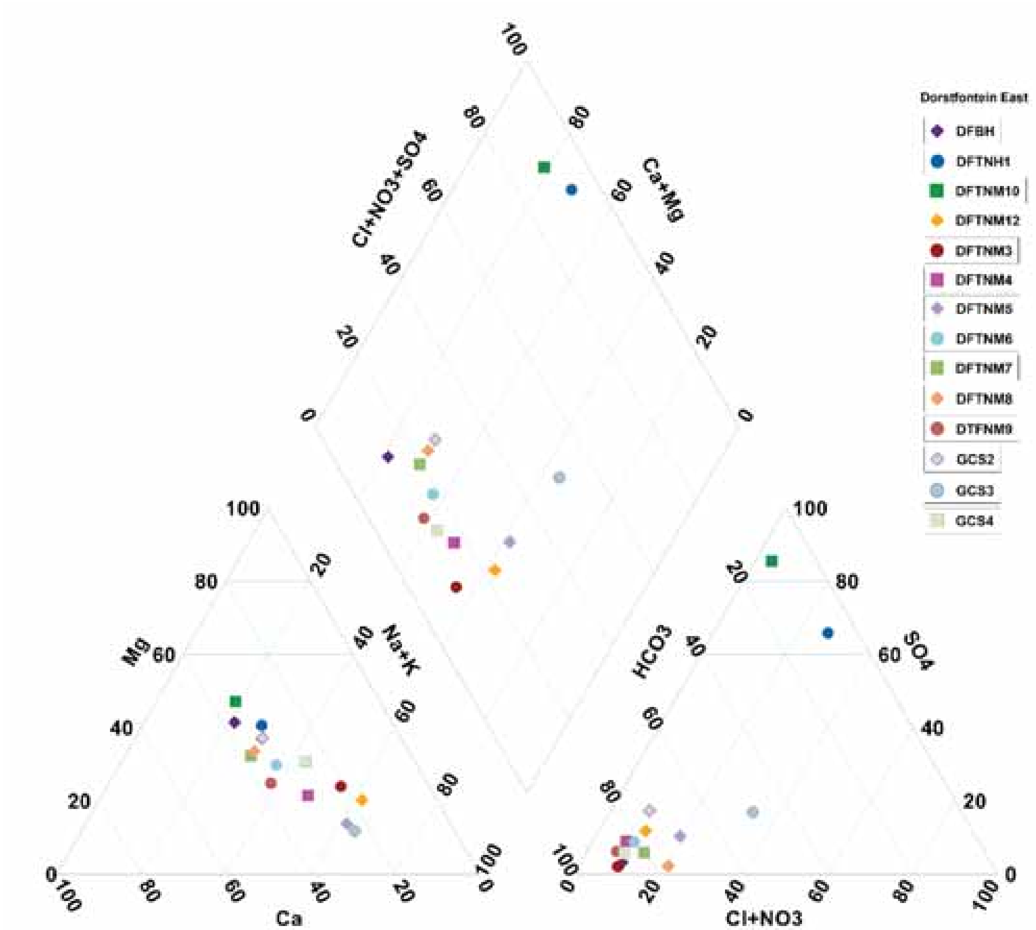


Figure 8.3: Existing Monitoring Boreholes Piper Plot

The above piper plot shows a snapshot of the monitoring network water quality results of the last quarter in 2014. Calcium concentrations are fairly similar for all samples; in some samples magnesium concentrations are dominant, in others sodium concentrations. Bicarbonate is high for most samples but some samples show increased sulphate concentrations. DFTNH1 and DFTNM10 plot closer to the sulphate concentration apex. This could indicate these points are impacted upon by a nearby contamination source. All samples, however, indicate neutral pH which means that no AMD is currently taking place on site. The stiff diagrams produced for the sampled boreholes confirm the piper plot findings indicating sulphate pollution at DFTNH1 and DFTNM10.

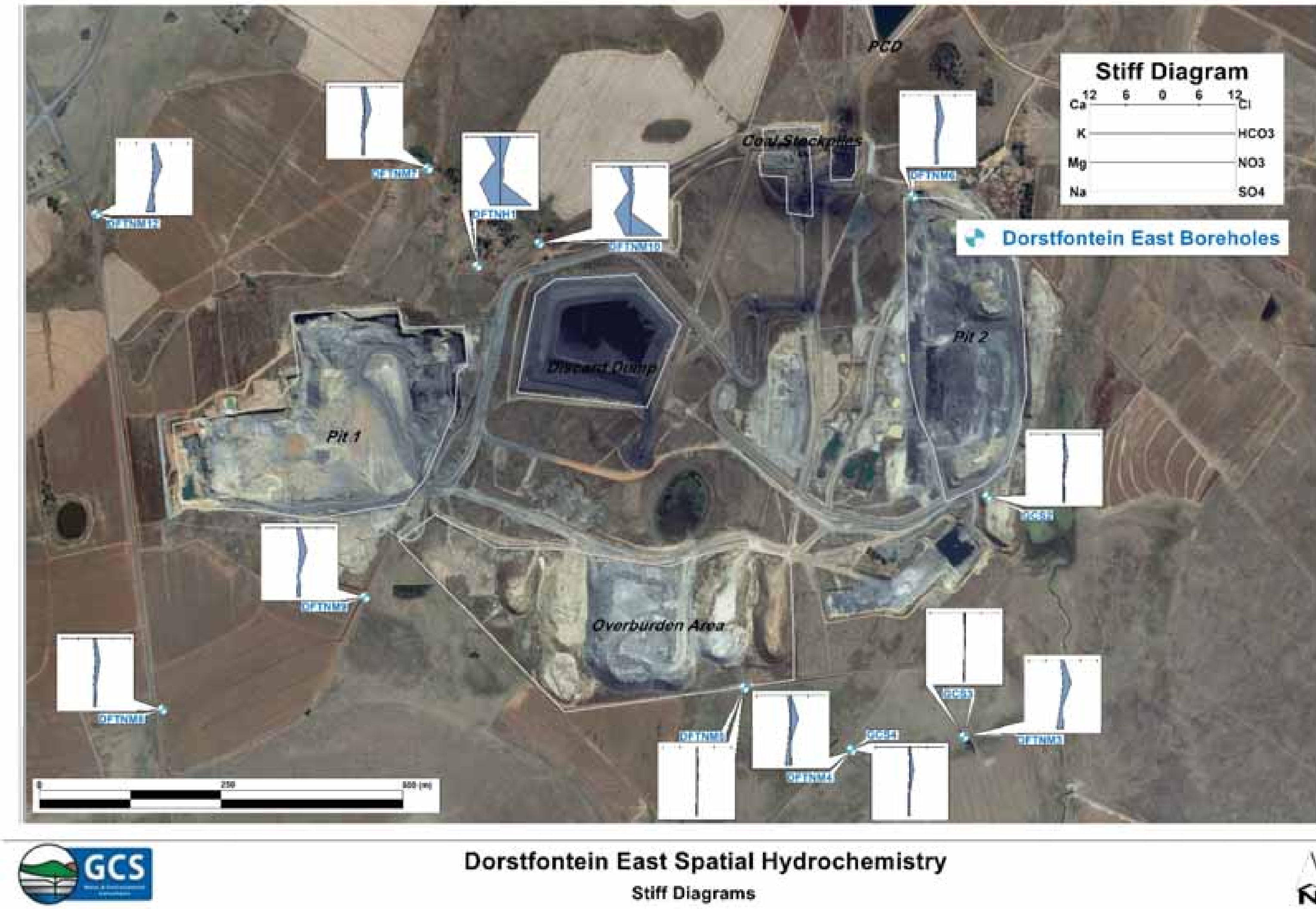


Figure 8.4: Stiff Diagrams for the Existing Monitoring Boreholes

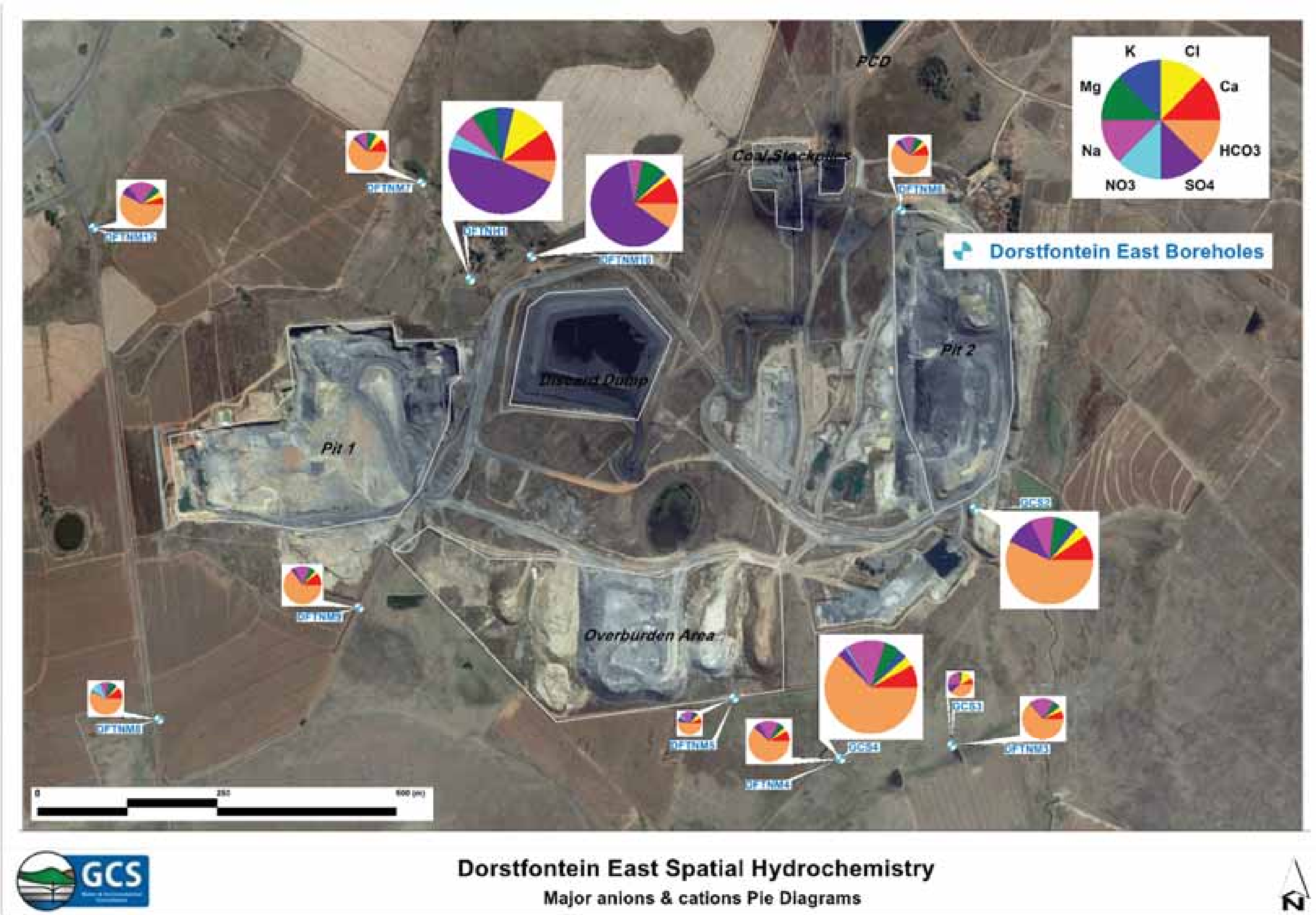


Figure 8.5: Pie Diagrams for the Existing Monitoring Boreholes

8.3 Surface Water quality

Flow from the Dorstfontein east site is towards the Olifants River which flows to the north of the mining area. Sample locations MP3, MP4, MP5 and MP6 are located on the Olifants River. MP6 is upstream of mining activities (Figure 8.6). Samples MP1 and MP2 are located on the western tributary of the Olifants River and samples DCM6 and DCM7 are located on the eastern tributary of the Olifants River.

Olifants River Monitoring Points

The water quality of the Olifants River remained good and complied with SANS limits in the throughout 2014. Aluminium was occasionally slightly elevated. Sulphate concentrations followed a seasonal increasing trend during 2014, but remained below the SANS limit, see Figure 8.7. The elevated sulphate might be an indication of mining activities impacting on the Olifants River.

Western Tributary Monitoring Points

MP1 and *MP2* had mostly compliant water quality, but *MP1* had elevated manganese during 2014.

Sulphate concentrations in *MP2* spiked to the highest recorded concentration in December 2014 and exceeded the SANS limit, see Figure 8.6. *MP2* was dry from August to October 2014 and it is therefore not clear whether the elevated sulphate is due to mining activities or concentration through evaporation.

Eastern Tributary Monitoring Points

Sample points *DCM6* (upstream) and *DCM7* (downstream) monitor the impact of DCM East Mine on the small eastern tributary flowing to the east of the mine (Figure 8.6).

Both sample sites continued to have good water quality in term of compliance to SANS limits in 2014. DCM6 and DCM7 occasionally had slightly elevated aluminium. Sulphate show erratic fluctuations at *DCM7* possibly related to the lack of water flow at the sampling point.

The stream profile for the Olifants River and tributaries is presented as Figure 8.7. The profile for December 2014 showed an elevated sulphate concentration at MP2. As stated previously this is probably due to a lack of flow in the tributary as this sampling location was dry from August to October 2014. The sulphate concentration at MP5 and M6 were similar to those measured downstream at MP3.

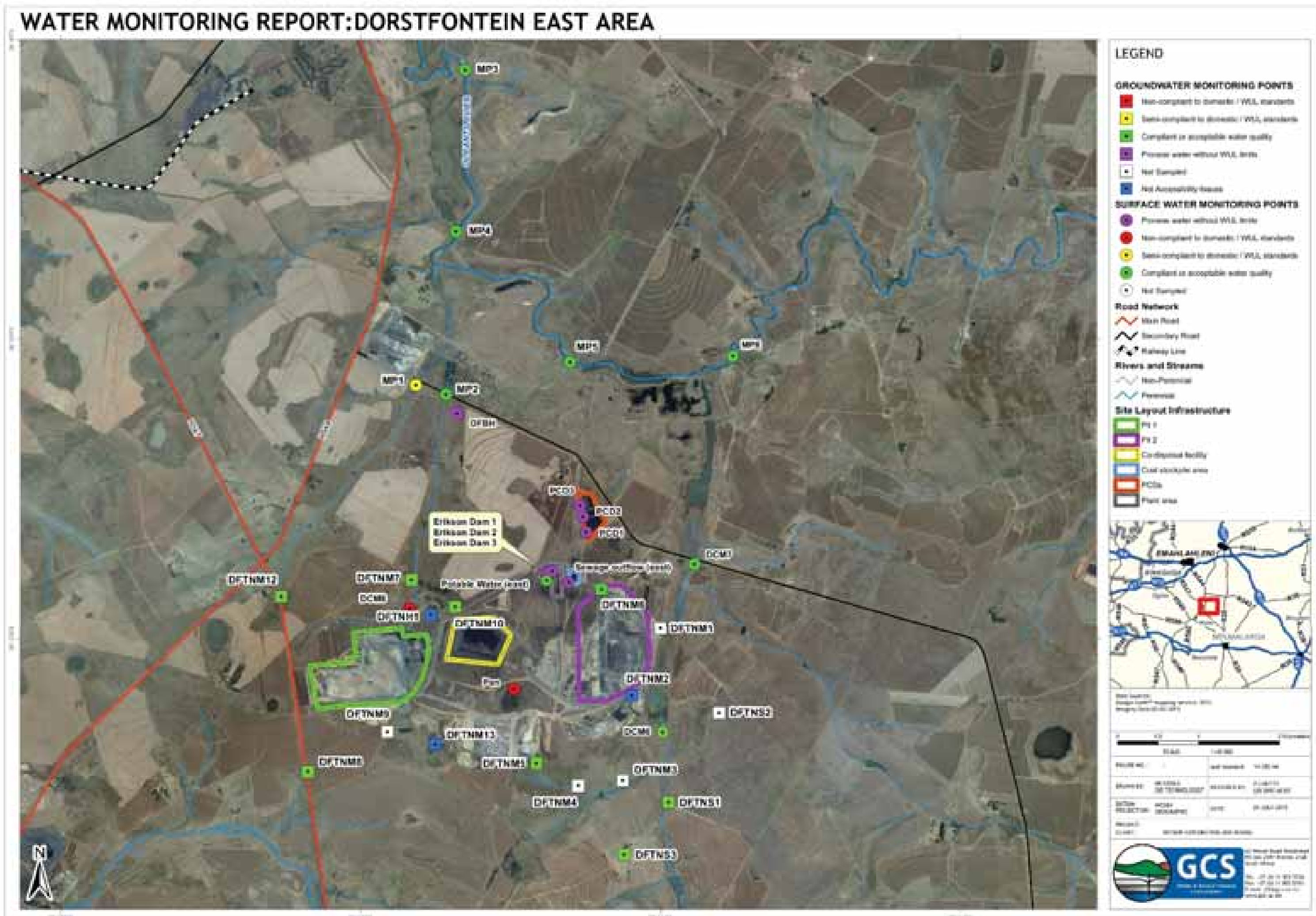


Figure 8.6: DCM East Mine monitoring points

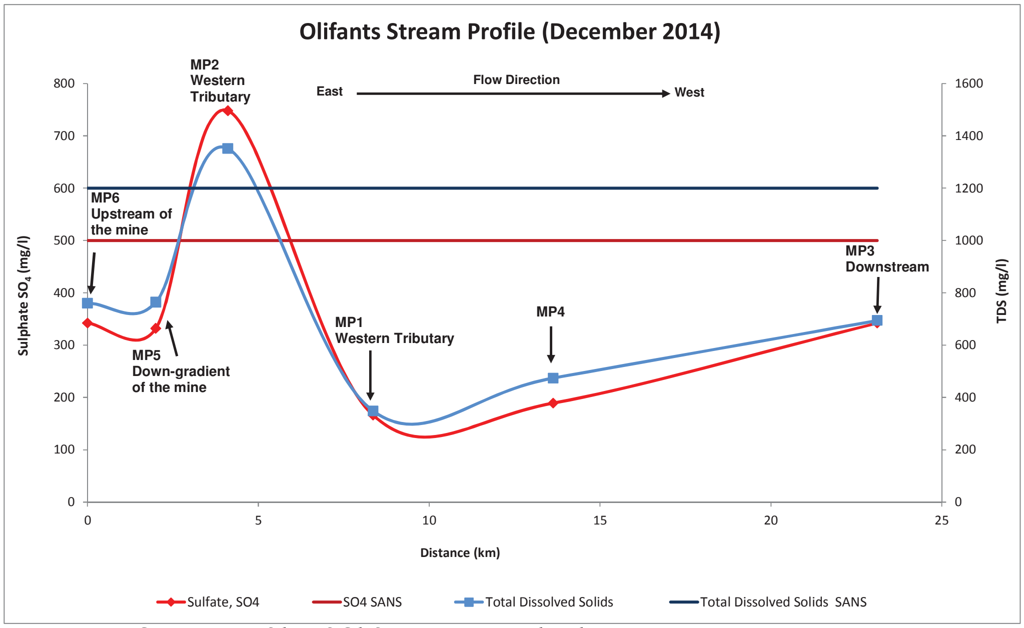


Figure 8.7: Stream profile of Olifants River and tributary

8.4 Spatial Analysis

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

- Higher sulphate concentrations seems to be localized to sampling points in close proximity to the co-disposal facility;
- Monitoring boreholes DFTNH1 and DFTNM10 (down gradient of the Co-disposal facility) indicate elevated sulphate concentrations;
- Based on these results there is a small sulphate plume localized near the co-disposal facility; The water quality improves further away from the surface infrastructures at Dorstfontein East;
- With the current monitoring network it cannot be established if there is any potential contamination down gradient of the coal stockpile and process area, the Erikson dams and the PCD's;

It is recommended that:

- additional monitoring boreholes are installed down gradient of the Co-disposal facility, the plant area and the PCD's;
- surface water management plans for these areas should be carried out properly to reduce the impact;
- The collective piper plot for all 2014 samples collected is shown in Figure 8.3. Stiff and pie charts are shown in Figure 8.4 and Figure 8.5;
- No impact of the current opencast mining on groundwater quality has been found.

9 GROUNDWATER LEVELS

9.1 Monitoring Boreholes

Historical groundwater levels for the Dorstfontein East area are shown in Figure 9.1. For Dorstfontein East Most of the boreholes show an overall decreasing trend since the beginning of 2010 indicating a zone of influence due to dewatering of the open pit mines. A decrease in water level of more than 10 m was noted in boreholes *DFTNM3, DFTNM7, DFTNM10* and *DFTNH1* where boreholes *DFTNM8, DFTNM9, DFTNM12* and *DFBH* showed minor decreases in water levels. At borehole *DFTNH1* intermittent pumping has been taking place which explains the periods of recovery in the overall decreasing trend.

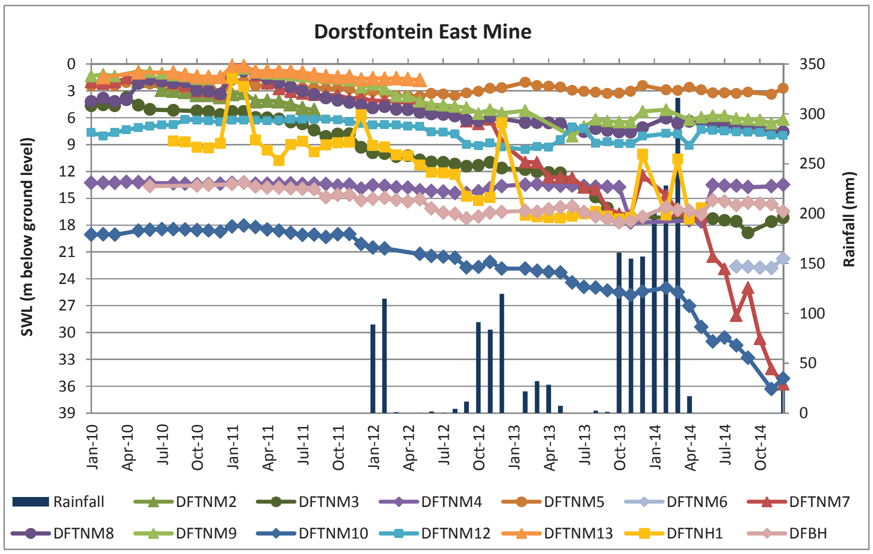


Figure 9.1: Historical groundwater level data for Dorstfontein East.

9.2 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 the quarterly sampling rounds carried out at the Dorstfontein East and West sites. For the boreholes at Dorstfontein East water levels from the first quarterly sampling round in 2010 as these were not impacted upon by mining activities. For the boreholes at Dorstfontein West average groundwater levels of all quarterly sampling rounds were used.

A linear correlation was observed between groundwater levels and surface topography elevations. As evident in Figure 9.2, a good correlation of groundwater levels in the Dorstfontein area was found (R^2 = 92%). The correlation of groundwater levels versus surface topography is good and suggests that the groundwater levels for the area generally follow topography. It has to be noted that groundwater levels from boreholes close to the mining areas may be impacted upon by the mining activities.

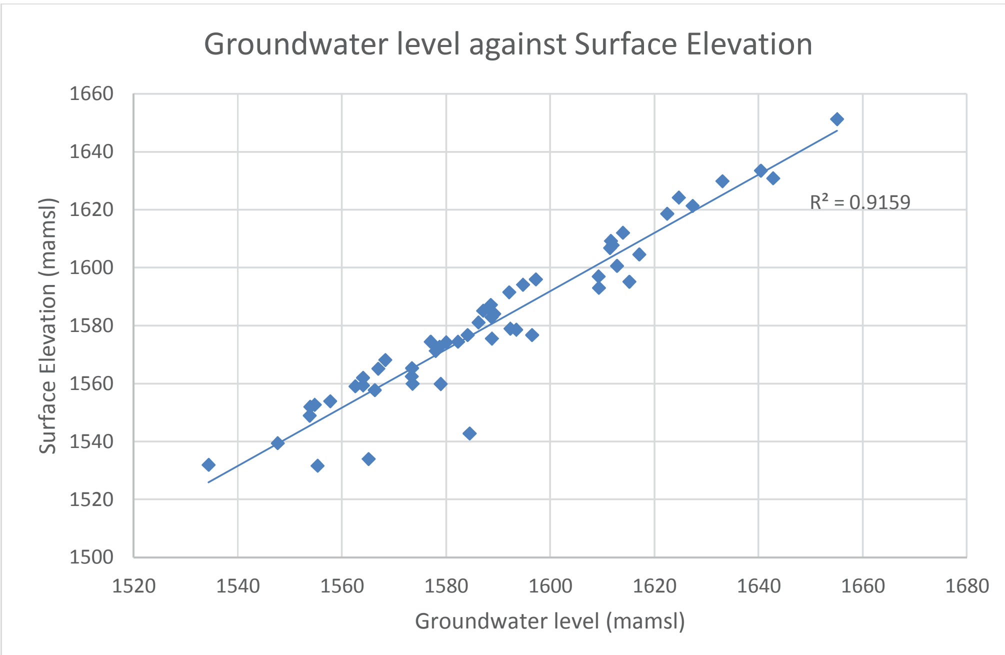


Figure 9.2: Correlation between surface elevation and groundwater level

10 GEOCHEMICAL ASSESSMENT

A total of 15 samples were collected for geochemical testing. Seven of these samples were taken on the adjacent site of Dorstfontein West, to the southwest of Dorstfontein East. However, the sampling results of these samples are included in this report as these results will add to the insight into the chemical composition of the coal of the No. 2 and No. 4 seams, the coal discard and the coal product. A description of the samples are given in Table 10.1. The following lithologies were sampled:

- 1 mixture of inter-bedded sandstone, shale and some coal sample;
- 1 mixture of coarse sand and coal slurry sample;
- 1 ROM coal sample;
- 1 coal slurry sample;
- 3 coal discard samples;
- 3 coal product samples; and
- 5 coal samples.

Table 10.1: Description of samples.

Sample	*	Rock Type	Description
DCMW UG Floor		Coal	RAW coal from underground workings. Floor sample.
DCMW UG Roof		Coal	RAW coal from underground workings. Roof sample.
DCMW Conveyer fresh		Coal discard	This is a fresh discard sample which is loaded via conveyor onto trucks before it is dumped. Consisted of mainly coal discard and waste rock.
DCMW Product Duff	P	Coal product	Finer coal product stockpiled on surface.
DCMW Co-disposed slurry		Coal slurry	This sample composes of discard (larger) and slurry (finer) particles which are co-disposed. Slurry is dominant.
DCMW Toe seepage Matrix		Mixture of coarse sand and coal slurry	This was collected at the toe of one of the co-disposal facilitys. A combination of sand and slurry seepage. Dark black material which may show signs of AMD.
DCMW Product Main	P	Coal product	Coal product stockpiled on surface.
DCME Pit 1 Seam 4 high wall	4	No. 4 coal	RAW coal from high wall of coal seam 4.
DCME Pit 1 Seam 4 low wall	4	No. 4 coal	RAW coal from the low wall of coal seam 4.
DCME Pit 2 Seam 2 Overburden		Mixture of inter bedded sandstone, shale and some coal.	The upper most part of rock before one reaches coal seam 2. The rock sampled apeared to be a mixture of sandstone, shale and some coal.
DCME Pit 2 Seam 2	2	No. 2 coal	Coal form exposed seam 2 in opencast pit. Recently blasted.
DCME ROM		ROM coal	Coal from the UG workings stockpiled before sent to plants.
DCME Fresh Discard		Coal discard (fresh)	Discard sample which was recently dumped at DCME.
DCME Old Discard, near topo low		Coal discard (old)	Discard sample which was dumped years ago at DCME. Sample taken near places where leaching occurs.
DCME Product Stockpile	P	Coal product	

*** Black = Coal (Coal seams and product), Dark Grey = Coal Discard, Light Grey = Coal Slurry, Red = Sand and coal slurry, Brown = Sandstone, shale and coal, Blue = ROM.**

10.1 Mineralogy and total element analyses

The mineralogical composition of the samples were determined by means of X-ray Diffraction (XRD). The XRD was performed by *XRD Analytical and Consulting,* Pretoria. The total element analyses were performed by means of X-ray fluorescence (XRF) at the *Metron Laboratory,* Vanderbijlpark. The results are reported below as follows:

- A simplified classification of the identified minerals are listed in Table 10.2; and
- The XRD and XRF results are presented in Table 10.3 to Table 10.5.

The following pertains to the XRD method used:

- The samples were prepared for XRD analysis using a back loading preparation method. They were analysed with a PANalytical Empyrean diffractometer with PIXcel detector and fixed receiving slits with Fe filtered Co-K radiation. The phases were identified using X'Pert Highscore plus software;
- Amorphous phases were not taken into account in the quantification;
- Trace minerals at concentrations below ± 1% are often not detected by means of XRD testing on whole rock samples as the error might become larger than the analyses reported; and
- The weight percentages of the minerals were determined using the Rietveld method (Autoquan Program).

The following pertains to the XRF method used:

- Samples were analysed using pressed powder pellets; and
- Analyses were done with a Rigaku Supermini 200 with SC and F-PC detectors and fixed receiving slits with Zr of Al filtered Pd-K radiation. The elements were identified using ZSX software.

With regard to the mineralogy and total element composition of the samples the following are noted:

- Graphite is present in all the samples as a dominant to major mineral, except for the overburden sample, graphite is present as a minor mineral. Graphite is a relatively common constituent in regional and contact metamorphic rocks such as marble, skarn deposits and is usually present in deposits that originally contained carbonates or organic material. Graphite may form inclusions in sphalerite, pyrite, magnetite and pyrrhotite in some hydrothermal deposits;
- Hematite was detected in 8 of the 10 samples as a trace mineral. Hematite is one of several iron oxides and clay-sized hematite crystals and also occur as a secondary mineral formed by weathering processes in soil;

- Kaolinite is present in all of the samples as a minor to major mineral. Generally a good correlation between the ash and kaolinite content in the coal present in the Vryheid Formation coal. Kaolinite is generally precipitated by authigenic processes during the coal formation;
- Microcline was detected in 2 of the 10 samples as a minor mineral and accessory mineral in 1 coal sample. Microcline (K-feldspar) is typically elevated in the same 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. K-feldspar forms an incomplete solution series with albite, and K-feldspar will often contain small amount of Na. K-feldspar has a detrital origin and originate from the felsic mother rock;
- Muscovite was detected in all of the samples as an accessory to trace mineral and as a minor mineral in the overburden sample. If muscovite is glauconitic, it is evident of marine transgressions. Glauconite characteristically forms small rounded pellets in clastic sediments deposited under marine conditions where the presence of the glauconite also colour the sediments green;
- Plumbogummite was detected in only 1 coal sample as a trace mineral and is a rare secondary lead phosphate mineral and is found in the oxidized zones of lead-bearing deposits;
- Quartz is present in all of the samples. In 6 of the 10 samples quartz was detected as an accessory to trace mineral and as a minor mineral in the other 4 samples. The quartz grains generally have a detrital origin and originate from the felsic mother rock;
- Rutile was detected as a trace mineral in 4 of the 10 samples. Naturally rutile may contain up to 10% iron and is the most common natural from of TiO_2;
- Smectite (Montmorillonite) was detected in only 1 coal sample as a minor mineral. Smectite can form slowly in solutions of aluminosillicates. High HCO_3 concentrations and long periods of time can aid in the formation. Smectite typically forms from the weathering of micas, feldspars and other silicates (especially more dark minerals present in intermediate to mafic rocks);
- Sulphide and sulfate minerals
  - Pyrite is present in all of the samples as a trace to accessory mineral. Pyrite is the only Fe-sulphide (with the extremely rare exception of marcasite) in South African coal. Pyrite is generally elevated in coal with respect to clastic rocks due to formation under reducing conditions and can forms during or very shortly after peat accumulation (autigenic) or as veins later in the coal's burial history (epigenetic).
- Carbonate minerals
  - Calcite and dolomite are important minerals in the neutralization of acidity produced by pyrite oxidation in acid-mine drainage (AMD). Dolomite and calcite are present as trace to accessory minerals in all of the samples except for 1 sample;

   - Siderite is present in 5 of the 10 samples and was detected as a trace mineral in 4 samples and minor mineral in the overburden sample. Siderite may contribute to the Mn in the mine water as Mn often replaces some of the Fe in the siderite. Siderite does not contribute to the neutralization of AMD as it only neutralizes the acid generated by the oxidation of its own Fe;
- Secondary minerals
   - Gypsum was detected in all of the samples except 1 as an accessory to trace mineral. Gypsum is a secondary mineral that form from the precipitation of sulphate and Ca which is typical products of pyrite oxidation and carbonate mineral dissolution respectively;

The following comments could be made with regard to the elemental composition of the rock material:

- No major elements (expressed as oxides) are significantly elevated in the samples above the average upper crust of the Rudnick and Gao (2003);
- Al_2O_3, CaO and TiO_2 are slightly elevated above the AUC;
- A few trace elements are significantly elevated (more than 5 times) above the AUC, these elements include: As, Nb, Pb and U; and
- Elevation above the average upper crust is however not an indication of the leachability of these trace elements and metals. The leachability was assess through leaching test in Section 2.4.

Table 10.2: Description of identified minerals.

Mineral	*	Formula	Mineral type/group	Sub-group
Calcite	Blue	$CaCO_3$	Anhydrous Carbonates	Calcite group
Dolomite	Blue	$CaMg(CO_3)_2$	Anhydrous Carbonates	Dolomite group
Graphite	Brown	C	Native Elements	Carbon Polymorph
Gypsum	Yellow	Ca(sulphate)$\cdot 2H_2O$	Hydrated Sulfates	Gypsum
Hematite	Grey	Fe_2O_3	Simple Oxides	Corundum-Hematite Group
Kaolinite	Red	$Al_2Si_2O_5(OH)_4$	Phyllosilicate 1:1 layer	Kaolonite group
Microcline	Green	$KAlSi_3O_8$	Tectosilicate	K(Na,Ba) feldspar subgroup
Muscovite	Red	$KAl_2(AlSi_3O_{10})(OH,F)_2$	Phyllosilicate 2:1 layer	Mica group (Muscovite subgroup)
Pyrite	Yellow	FeS_2	Sulfides	Pyrite group
Plumbogummite	Red	$PbAl_3(PO_4)_2(OH)_5\cdot(H_2O)$	Hydrated Phosphate	Alunite Supergroup
Quartz	Green	SiO_2	Tectosilicate	Tectosilicate
Rutile	Grey	TiO_2	Simple Oxides	Rutile group
Siderite	Blue	$FeCO_3$	Anhydrous Carbonate	Calcite group
Smectite	Red	$(Na,Ca)O,\ 3(Al,\ Mg)_2Si_4O_{10}(OH)_2\cdot n(H_2O)$	Phyllosilicate	Smectite group

*** Mineral Type:** Grey = Fe/Al/Ti-Oxides and hydroxides Blue = Carbonates and Chlorides, Yellow = Sulphides and Sulphates, Red = Phyllosilicates, Green = Ino-, Tecto- and Cyclosilicates

Table 10.3: X-ray diffraction results (weight %).

Sample ID	DCMW UG Floor	DCMW UG Roof	DCMW Conveyer Fresh	DCMW Product Duff	DCMW Product Main	DCME Pit 1 High Wall Seam 4	DCME Pit 1 Low Wall Seam 4	DCME Pit 2 Overburden Seam 2	DCME Pit 2 Seam 2	DCME Discard Fresh
Description/ Rock Type										
Calcite	0.92	1.21	3.41	1.12	0.91	0.04	0.27	0.14	-	0.36
(Error)	0.17	0.21	0.36	0.18	0.17	0.12	0.10	0.13	-	0.07
Dolomite	0.26	0.14	0.08	0.10	0.21	0.29	0.36	0.35	0.92	0.46
(Error)	0.15	0.09	0.10	0.10	0.11	0.14	0.13	0.22	0.24	0.20
Graphite	78.38	81.38	47.30	82.83	84.50	57.60	61.17	28.80	78.02	81.28
(Error)	1.41	0.78	3.60	0.63	6.60	3.00	2.04	6.30	1.05	0.75
Gypsum	2.85	1.51	2.01	-	1.10	1.86	0.43	0.72	0.42	1.27
(Error)	0.90	0.45	0.57	-	7.80	0.33	0.16	0.33	0.23	0.33
Hematite	-	0.19	0.47	0.17	-	0.26	0.13	0.27	0.36	0.15
(Error)	-	0.10	0.17	0.11	-	0.13	0.10	0.29	0.11	0.09
Kaolinite	15.03	12.88	19.23	11.69	11.25	25.35	7.42	36.20	11.46	10.36
(Error)	0.90	0.57	1.26	0.48	0.99	1.89	0.54	3.30	0.54	0.45
Microcline	-	-	6.60	-	-	-	2.20	8.69	-	-
(Error)	-	-	0.78	-	-	-	0.33	0.93	-	-
Muscovite	1.22	0.94	3.17	1.04	0.86	1.92	2.79	7.57	1.85	2.43
(Error)	0.24	0.25	0.42	0.17	0.23	0.23	0.30	0.81	0.28	0.28
Pyrite	0.18	0.99	4.84	0.29	0.23	0.33	0.14	0.78	2.47	0.30
(Error)	0.08	0.10	0.36	0.08	0.06	0.10	0.07	0.23	0.15	0.10
Plumbogummite	-	-	-	-	-	-	-	-	1.21	-
(Error)	-	-	-	-	-	-	-	-	0.09	-

Sample ID	DCMW UG Floor	DCMW UG Roof	DCMW Conveyer Fresh	DCMW Product Duff	DCMW Product Main	DCME Pit 1 High Wall Seam 4	DCME Pit 1 Low Wall Seam 4	DCME Pit 2 Overburden Seam 2	DCME Pit 2 Seam 2	DCME Discard Fresh
Description/ Rock Type										
Quartz	1.17	0.79	12.81	1.74	0.95	12.18	6.72	7.79	2.15	3.29
(Error)	0.11	0.10	0.87	0.14	0.12	0.93	0.39	0.75	0.14	0.16
Rutile	-	-	-	0.02	-	0.18	-	-	0.16	0.07
(Error)	-	-	-	0.04	-	0.11	-	-	0.08	0.05
Siderite	-	-	0.80	-	-	-	0.08	8.72	0.98	0.03
(Error)	-	-	0.80	-	-	-	0.07	0.90	0.23	0.04
Smectite	-	-	-	-	-	-	18.30	-	-	-
(Error)	-	-	-	-	-	-	1.17	-	-	-

*** Black = Coal (Coal seams and product), Dark Grey = Coal Discard,** Light Grey = Coal Slurry **Brown = Sand and coal slurry, Orange = Sandstone, shale and coal, Blue = ROM.**

Table 10.4: XRF major oxide results (weight %).

Sample		LOI	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	S	SiO_2	TiO_2
DCMW UG Floor		81%	6.23	1.46	<0.02	0.47	0.11	0.19	<0.02	0.05	0.02	**0.38**	9.74	0.58
DCMW UG Roof		83%	**26.35**	**10.18**	0.02	6.93	0.33	0.90	0.09	0.21	0.09	**3.26**	37.71	**1.72**
DCMW UG Conveyer Fresh		37%	**16.66**	**4.54**	<0.02	7.88	0.92	0.45	0.02	0.03	0.04	**2.55**	32.32	**0.94**
DCMW UG Product Duff		82%	6.02	1.38	0.04	0.68	0.10	0.13	<0.02	0.03	0.02	**0.35**	9.44	0.51
DCMW UG Toe seepage		77%	7.38	0.80	0.04	4.12	0.31	0.36	<0.02	0.03	0.03	**0.28**	9.84	0.60
DCME Pit 1 Seam 4 high wall		53%	**15.57**	0.38	0.02	0.72	0.26	0.25	<0.02	<0.02	0.03	**0.10**	32.26	**0.96**
DCME Pit 1 Seam 4 low wall		51%	14.30	1.72	<0.02	0.98	1.05	0.70	<0.02	0.16	0.07	**0.29**	29.23	**0.90**
DCME Pit 2 Seam 2 overburden		35%	**22.15**	1.93	<0.02	7.37	1.34	0.80	**0.12**	0.07	**0.88**	**0.25**	33.74	**1.43**
DCME Fresh Discard		72%	8.42	0.86	0.03	0.49	0.34	0.49	<0.02	0.17	0.02	0.03	16.36	**0.91**
DCME Product Stockpile		41%	**17.66**	3.58	0.05	2.28	0.62	1.23	<0.02	0.16	**0.21**	**0.94**	33.09	**1.42**
*AUC	AUC		15.40	3.59	See trace	11.20	2.80	2.48	0.10	3.27	0.15	0.06	66.60	0.64
	3-5 times higher		46.2	10.77	See trace	33.6	8.4	7.44	0.3	9.81	0.45	0.18	199.8	1.92
	> 5 times higher		77	17.95	See trace	56	14	12.4	0.5	16.35	0.75	0.3	333	3.2

*** Black = Coal (Coal seams and product), Dark Grey = Coal Discard, Light Grey = Coal Slurry Brown = Sand and coal slurry, Orange = Sandstone, shale and coal, Blue = ROM.**

* *Average Upper Crust, Rudnick and Gao (2003).*

Table 10.5: XRF trace elements results (ppm).

Sample ID	LOI	As	Ba	Cl	Co	Cr	Cu	F	Ga	Nb	Nd	Ni	Pb	Rb	Sr	Th	U	V	Y	Yb	Zn	Zr
DCMW UG Floor	81%	36	142	<20	<20	50	23	100	9	103	<20	21	45	<20	224	<20	<20	109	<30	4	<20	124
DCMW UG Roof	83%	145	622	75	117	34	99	655	47	314	<20	146	281	22	1282	22	71	266	61	13	<20	360
DCMW UG Conveyer Fresh	37%	107	222	47	55	125	41	617	32	213	<20	109	196	28	160	<20	95	130	<30	4	94	151
DCMW UG Product Duff	82%	35	107	<20	<20	61	<20	<50	11	77	21	30	41	<20	161	<20	<20	113	<30	4	20	133
DCMW UG Toe seepage	77%	21	199	21	27	83	43	205	18	78	<20	53	25	<20	124	<20	38	147	<30	2	33	68
DCME Pit 1 Seam 4 high wall	53%	128	198	31	<20	151	34	<50	16	321	25	35	40	26	122	38	48	152	34	12	31	381
DCME Pit 1 Seam 4 low wall	51%	101	472	38	<20	57	33	252	18	256	23	38	58	50	361	30	28	118	47	9	41	298
DCME Pit 2 Seam 2 overburden	35%	90	932	74	54	107	83	565	36	220	44	75	44	38	1244	26	<20	261	<30	7	134	217
DCME Fresh Discard	72%	50	320	20	<20	75	21	<50	11	87	<20	21	<20	<20	233	<20	20	166	<30	6	<20	260
DCME Product Stockpile	41%	58	538	41	54	448	69	149	29	124	45	81	117	32	897	31	<20	253	52	10	50	524
*AUC	Above Limit	4.8	628	294	17.3	92	28	557	17.5	12	27	47	17	82	320	10.5	2.7	97	21	2	67	193
	3-5 times higher	14.4	1884	882	51.9	276	84	1671	52.5	36	81	141	51	246	960	31.5	8.1	291	63	6	201	579
	> 5 times higher	24	3140	1470	86.5	460	140	2785	87.5	60	135	235	85	410	1600	52.5	13.5	485	105	10	335	965

*** Black = Coal (Coal seams and product), Dark Grey = Coal Discard, Light Grey = Coal Slurry Brown = Sand and coal slurry, Orange = Sandstone, shale and coal, Blue = ROM.**

** Average Upper Crust, Rudnick and Gao (2003).*

10.2 Acid-base Accounting and Net-acid generation tests

10.2.1 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 are 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 $CaCO_3$/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 sulfuric acid (the sample and acid are heated to ensure 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 $CaCO_3$/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;

In order 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 $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg $CaCO_3$/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 actually be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg $CaCO_3$/t to 20 kg $CaCO_3$/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 10.6 below, as proposed by Price (1997), 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 10.6: Screening methods using the NP:AP ratio (Price, 1997).

Potential for acid generation	NP:AP screening criteria	Comments
Rock Type I. Likely Acid Generating.	< 1:1	Likely AMD generating.
Rock Type II. Possibly Acid Generating.	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.	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.	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity.

10.2.2 Net-acid generation (NAG) terminology and screening methods

In the Net-acid Generating (NAG) test hydrogen peroxide (H_2O_2) 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% H_2O_2 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 fumehood 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. (1997) is used. See Table 10.7 below:

Table 10.7: NAG test screening method (edited from Miller et al., 1997).

Rock Type	NAG pH	NAG Value (H_2sulphate kg/t)	NNP ($CaCO_3$ kg/t)
Rock Type Ia. High Capacity Acid Forming.	< 4.5	> 10	Negative
Rock Type Ib. Lower Capacity Acid Forming.	< 4.5	≤ 10	-
Uncertain, possibly Ib.	< 4.5	> 10	Positive
Uncertain.	≥ 4.5	0	Negative (Reassess mineralogy)*
Rock Type IV. Non-acid Forming.	≥ 4.5	0	Positive

** If low acid forming sulphides is dominant then Rock Type IV.*

10.2.3 ABA and NAG test results

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

- The ABA results are presented in Table 10.8 below. The results were screened as discussed in Section 2.3.1 above as *Rock Type I to IV*;
- A summary of the ABA results for the various lithologies is presented in Table 10.9;
- The potential risk of the samples to generate AMD is presented in Table 10.10 below;
- The NAG test results are presented in Table 10.11. The results above were screened as discussed in Section 2.3.2 above as *Rock Type I to IV*;
- The classification of the rock samples in terms of %S and NP/AP is depicted in Figure 10.1.
- The correlation between the NAG pH and %S is depicted in Figure 10.2; and
- The correlation between the NAG pH and NAG value is depicted in Figure 10.3.

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 10.1 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 bu 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 coal samples have a %S higher than 0.3%, 1 sample 2.65%. The neutralization potential is very low compared to the acid potential of the samples and all of the samples have a significant potential to generate acid mine drainage. 3 samples acidified during the NAG test and 2 are classified as Uncertain ;
- Coal product samples all have a high %S higher than 0.3%. With a high acid potential and very low neutralization potential, the samples have the potential to generate acid mine drainage. The product samples are all classified as uncertain during the NAG test;
- 2 of the 3 discard samples have a %S higher than 0.3%, 1 one sample with a 6.05%. The samples have a relative low neutralization potential compared to the acid potential and are most likely to generate acid mine drainage. 1 discard sample acidified during the NAG test and the other 2 samples were classified as non-acid forming;
- The slurry sample have a %S of 0.75%. The samples have a high acid potential and low neutralization potential and are most likely to generate acid mine drainage, but did acidify during the NAG test. The slurry and sand mixture sample has a high %S. With no to very low neutralization potential, the sample has potential to generate acid drainage. The sample acidified during the NAG test;
- The run of mine sample have a %S of 0.66. The neutralization potential is relatively high compared to the acid potential of the sample, but the sample may have potential to generate acid mine drainage;
- The sand, shale and coal mixture sample has a high %S. With no to very low neutralization potential, the sample has potential to generate acid drainage. The sample acidified during the NAG test;
- Overall, it could be concluded that all of the samples have to some degree the potential to generate acid mine drainage/seepage.

Table 10.8: Acid-base accounting (ABA) results.

Sample ID	*	Lithology	Paste pH	Sulphide %S	Total %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
DCMW UG Floor		Coal	8.30	0.72	0.60	18.84	10.17	-8.67	0.54	Uncertain	I	I
DCMW UG Roof		Coal	7.52	1.71	1.67	52.34	18.64	-33.70	0.36	I	I	I
DCMW Conveyer fresh		Discard	7.05	5.37	6.03	188.47	38.02	-150.45	0.20	I	I	I
DCMW Product Duff	P	Product	7.50	0.78	0.93	29.22	11.04	-18.18	0.38	Uncertain	I	I
DCMW Co-disposed slurry		Slurry	8.18	0.76	0.75	23.54	3.89	-19.65	0.17	Uncertain	I	I
DCMW Toe seepage Matrix		Mix sand and slurry	3.81	1.57	1.56	48.70	0.00	-48.70	0.00	I	I	I
DCMW Product Main	P	Product	8.07	0.57	0.46	14.37	1.78	-12.59	0.12	Uncertain	I	I
DCME Pit 1 Seam 4 high wall	4	No. 4 coal	7.31	0.72	0.72	22.55	0.00	-22.55	0.00	I	I	I
DCME Pit 1 Seam 4 low wall	4	No. 4 coal	8.31	0.37	0.40	12.49	4.72	-7.77	0.38	Uncertain	I	I
DCME Pit 2 Seam 2 Overburden		Mix sand, shale and coal	7.75	0.62	0.69	21.64	6.36	-15.27	0.29	Uncertain	I	I
DCME Pit 2 Seam 2	2	No. 2 coal	5.21	3.11	2.65	82.69	0.00	-82.69	0.00	I	I	I
DCME ROM		ROM	7.91	0.64	0.66	20.62	22.79	2.17	1.11	Uncertain	I	II
DCME Fresh Discard		Discard (F)	8.60	0.13	0.18	5.76	17.41	11.65	3.02	Uncertain	IV	III
DCME Old Discard, near topo low		Discard (O)	6.82	0.54	0.67	20.94	42.03	21.09	2.01	IV	I	III
DCME Product Stockpile	P	Product	8.12	0.62	0.50	15.64	4.96	-10.68	0.32	Uncertain	I	I

* Black = Coal (Coal seams and product), Dark Grey = Coal Discard, Light Grey = Coal Slurry Brown = Sand and coal slurry, Orange = Sandstone, shale and coal, Blue = ROM.

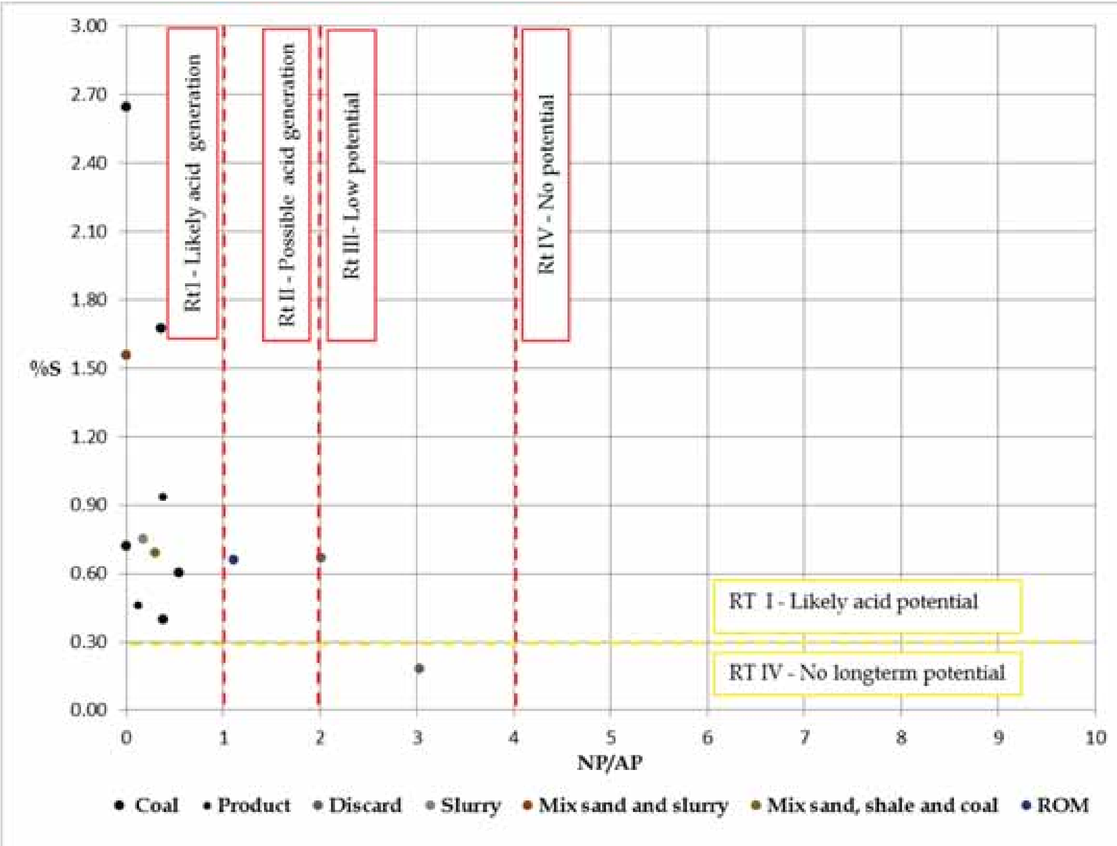


Figure 10.1: Classification of samples in terms of %S (samples below 3%) and NP/AP (samples below 10).

Table 10.9: Acid-base accounting (ABA) results average for different lithologies.

Lithology	Number of samples	Paste pH	Sulphide %S	Total %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
Coal	5	7.33	1.33	1.21	37.78	6.71	-31.07	0.25	I	I	I
Coal Product	2	7.79	0.68	0.70	21.79	6.41	-15.38	0.25	Uncer-tain	I	I
Discard	3	7.94	2.01	2.30	71.72	32.49	-39.23	1.74	I	I	II
Slurry	1	8.18	0.76	0.75	23.54	3.89	-19.65	0.17	Uncer-tain	I	I
ROM	1	7.91	0.64	0.66	20.62	22.79	2.17	1.11	Uncer-tain	I	II
Sand and slurry	1	3.81	1.57	1.56	48.70	0.00	-48.70	0.00	I	I	I
Sandstone, shale and coal	1	7.75	0.62	0.69	21.64	6.36	-15.27	0.29	Uncer-tain	I	II

Table 10.10: Potential for various lithologies to generate acidic drainage.

Criteria	Number of samples	Type (%S) Type (NP/AP) I or II	Type (%S) I Type (NP/AP) III or IV	%S 0.1 - 0.3 Type (NP/AP) I or II	%S 0.1 - 0.3 Type (NP/AP) III or IV	%S <0.1 Type (NP/AP) I or II	%S <0.1 Type (NP/AP) III or IV
Coal	5	100	0	0	0	0	0
Coal Product	2	100	0	0	0	0	0
Discard	3	33.33	33.33	0	0	0	33.33
Slurry	1	100	0	0	0	0	0
ROM	1	100	0	0	0	0	0
Sand and Slurry	1	100	0	0	0	0	0
Sandstone, shale and coal	1	100	0	0	0	0	0
Potential for acid mine drainage		Likely/possibly acid generating. High salt load.	Low to medium potential for acid generation. Medium salt load.	Low potential for acid generation. Low to medium salt load.	Very low potential for acid generation. Very low to low salt load.	No potential for acidic drainage. Very low/no salt load.	No potential for acidic drainage. Very low/no salt load.

Table 10.11: Net acid generation (NAG) test results.

Sample ID	Description/ Rock Type	*	NAG pH: (H_2O_2)	NAG (kg H_2sulphate/t)	NNP ($CaCO_3$ kg/t)	Rock Type
DCMW UG Floor	Coal		6.57	0.00	-8.67	Uncertain
DCMW UG Roof	Coal		2.43	50.00	-33.70	Rock Type Ia. High Capacity Acid Forming
DCMW Conveyer fresh	Coal discard		2.32	182.60	-150.45	Rock Type Ia. High Capacity Acid Forming
DCMW Product Duff	Coal product	P	5.65	0.00	-18.18	Uncertain
DCMW Co-disposed slurry	Coal slurry		6.32	0.00	-19.65	Uncertain
DCMW Toe seepage Matrix	Mixture of coarse sand and coal slurry		2.23	61.40	-48.70	Rock Type Ia. High Capacity Acid Forming
DCMW Product Main	Coal product	P	6.50	0.00	-12.59	Uncertain
DCME Pit 1 Seam 4 high wall	No. 4 coal	4	2.18	59.40	-22.55	Rock Type Ia. High Capacity Acid Forming
DCME Pit 1 Seam 4 low wall	No. 4 coal	4	6.48	0.00	-7.77	Uncertain
DCME Pit 2 Seam 2 Overburden	Mixture of inter bedded sandstone, shale and some coal.		3.47	15.00	-15.27	Rock Type Ia. High Capacity Acid Forming
DCME Pit 2 Seam 2	No. 2 coal	2	2.23	144.10	-82.69	Rock Type Ia. High Capacity Acid Forming
DCME ROM	ROM coal		6.36	0.00	2.17	Rock Type IV. Non-acid Forming
DCME Fresh Discard	Coal discard (fresh)		6.61	0.00	11.65	Rock Type IV. Non-acid Forming
DCME Old Discard, near topo low	Coal discard (old)		6.87	0.00	21.09	Rock Type IV. Non-acid Forming
DCME Product Stockpile	Coal product	P	6.31	0.00	-10.68	Uncertain

*** Black = Coal (Coal seams and product), Dark Grey = Coal Discard, Light Grey = Coal Slurry Brown = Sand and coal slurry, Orange = Sandstone, shale and coal, Blue = ROM.**

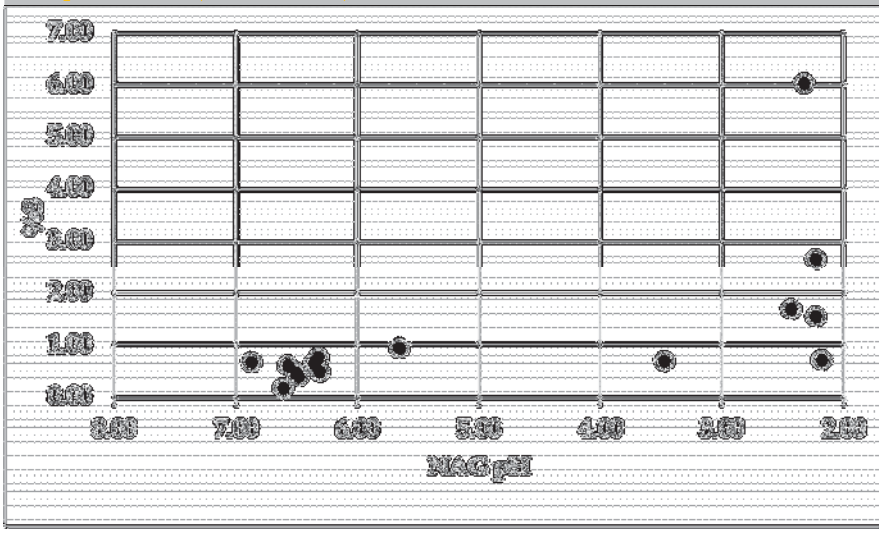


Figure 10.2: NAG pH versus %S.

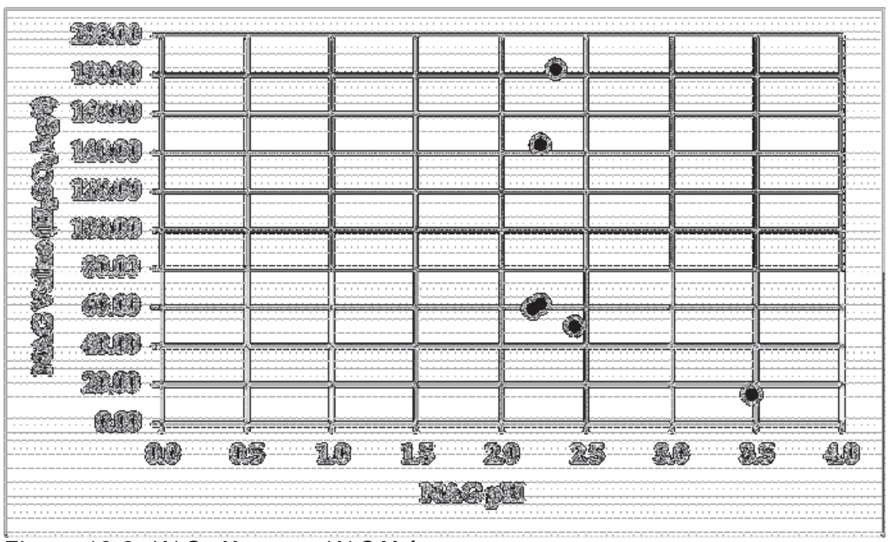


Figure 10.3: NAG pH versus NAG Value.

10.3 Kinetic column leaching test

Column leach testing was performed on a number of samples. The results are presented as follows:

- ICP- OES results are listed in Table 10.12 to Table 10.14;

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

- Kinetic column leaching test indicate the chemicals that will leach out from the rock material over time as well as the oxidation rate of the sulphide minerals in the material.

- Samples were subjected to kinetic leach testing. A rock/water ratio of 1:2 was used where 1 kg of samples was leached with 500ml distilled water weekly. The leachate was analysed for several parameters.
- The %S and NP of the samples were measured as follows before leaching:

Sample	DCMW UG Floor	DCMW UG Roof	DCME Old Discard
Paste pH	8.30	7.52	6.82
% S	0.60	1.67	0.67
AP	18.84	52.34	20.94
NP	10.17	18.64	42.03
NNP	-8.67	-33.70	21.09
NP/AP	0.54	0.36	2.01

- Several metals leached at significant concentrations from samples. Metals and trace elements leached from the samples including Ni.

Table 10.12: ICP results of weekly leach (DCMW UG Floor).

Parameters (mg/l)	DCMW UG Floor					SANS 241:2011		
Leach	0	1	2	3	6	0-50% of limit	50%-100% of limit	Above limit
Al	<0.02	0.026	<0.02	<0.02	<0.02	<0.15	0.15-0.3	>0.3
As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Ba	0.132	0.106	0.106	0.101	0.072	-	-	-
Be	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-
Ca	14.5	16.5	17.9	15.5	13.3	-	-	-
Cd	<0.02	<0.02	<0.02	<0.02	<0.02	<0.0015	0.0015-0.003	>0.003
Co	<0.02	<0.02	<0.02	<0.02	<0.02	<0.25	0.25-0.5	>0.5
Cr	<0.02	<0.02	<0.02	<0.02	<0.02	<0.025	0.025-0.05	>0.05
Cu	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
Fe	0.046	0.024	<0.02	<0.02	<0.02	<1	1-2	>2
K	2.20	2.53	2.47	2.47	2.21	-	-	-
Mg	1.93	3.39	3.17	2.76	2.34	-	-	-
Mn	0.095	0.047	0.051	0.032	<0.02	<0.25	0.25-0.5	>0.5
Na	18.3	33.6	27.9	22.8	8.75	-	-	-
Ni	<0.02	<0.02	<0.02	<0.02	<0.02	<0.035	0.035-0.07	>0.07
Pb	<0.02	<0.02	0.024	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Se	<0.02	<0.02	<0.02	<0.02	<0.02	<0.045	0.045-0.09	>0.09
Sr	0.559	0.657	0.649	0.581	0.538	-	-	-
V	<0.02	<0.02	<0.02	<0.02	<0.02	<0.1	0.1-0.2	>0.2
Zn	<0.02	<0.02	<0.02	<0.02	<0.02	<2.5	2.5-5.0	>5

Table 10.13: ICP results of weekly leach (DCMW UG Roof).

Parameters (mg/l)	DCMW UG Roof					SANS 241:2011		
						0-50% of limit	50%-100% of limit	Above limit
Leach	0	1	2	3	6			
Al	<0.02	<0.02	0.038	<0.02	<0.02	<0.15	0.15-0.3	>0.3
As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Ba	0.118	0.089	0.086	0.101	0.069	-	-	-
Be	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-
Ca	57.9	49.6	34.2	28.8	39.0	-	-	-
Cd	<0.02	<0.02	<0.02	<0.02	<0.02	<0.0015	0.0015-0.003	>0.003
Co	<0.02	<0.02	<0.02	<0.02	<0.02	<0.25	0.25-0.5	>0.5
Cr	<0.02	<0.02	<0.02	<0.02	<0.02	<0.025	0.025-0.05	>0.05
Cu	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
Fe	0.310	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
K	3.24	2.66	2.33	2.05	2.06	-	-	-
Mg	8.00	6.28	3.72	3.10	3.27	-	-	-
Mn	0.271	0.196	0.139	0.118	0.137	<0.25	0.25-0.5	>0.5
Na	35.7	21.5	9.42	5.75	2.72	-	-	-
Ni	0.388	0.157	0.120	0.077	0.094	<0.035	0.035-0.07	>0.07
Pb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Se	<0.02	<0.02	<0.02	<0.02	<0.02	<0.045	0.045-0.09	>0.09
Sr	1.47	1.24	0.883	0.768	0.909	-	-	-
V	<0.02	<0.02	<0.02	<0.02	<0.02	<0.1	0.1-0.2	>0.2
Zn	0.710	0.299	0.113	0.071	0.117	<2.5	2.5-5.0	>5

Table 10.14: ICP results of weekly leach (DCME Old Discard).

Parameters (mg/l)	DCME Old Discard					SANS 241:2011		
Leach	0	1	2	3	6	0-50% of limit	50%-100% of limit	Above limit
Al	<0.02	<0.02	<0.02	<0.02	<0.02	<0.15	0.15-0.3	>0.3
As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Ba	0.030	0.037	0.059	0.064	0.021	-	-	-
Be	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-
Ca	468	400	359	325	250	-	-	-
Cd	<0.02	<0.02	<0.02	<0.02	<0.02	<0.0015	0.0015-0.003	>0.003
Co	<0.02	<0.02	<0.02	<0.02	<0.02	<0.25	0.25-0.5	>0.5
Cr	<0.02	<0.02	<0.02	<0.02	<0.02	<0.025	0.025-0.05	>0.05
Cu	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
Fe	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
K	4.34	3.11	2.77	2.61	2.31	-	-	-
Mg	141	135	86.7	55.8	27.0	-	-	-
Mn	0.100	0.128	0.117	0.088	0.048	<0.25	0.25-0.5	>0.5
Na	3.67	3.21	2.65	2.05	1.42	-	-	-
Ni	<0.02	<0.02	<0.02	<0.02	<0.02	<0.035	0.035-0.07	>0.07
Pb	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005	0.005-0.01	>0.01
Se	0.049	0.024	<0.02	<0.02	<0.02	<0.045	0.045-0.09	>0.09
Sr	4.45	3.93	3.19	2.87	2.25	-	-	-
V	<0.02	<0.02	<0.02	<0.02	<0.02	<0.1	0.1-0.2	>0.2
Zn	0.099	0.103	0.091	0.055	0.195	<2.5	2.5-5.0	>5

10.4 Conceptual Geochemical Model

10.4.1 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 1) solid, 2) water and 3) 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 to 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 material but at a much lower concentration than in acidic drainage.

The following comments relate to the opencast:

- During the operational phase, water is pumped from the opencast pit in order to keep the pit dry. The pumped-out water has a low residence time in the pit (short contact period with rock) and no significant increase in the salt load will occur in the pit water;
- After closure the mine water level will rise as a result of inflowing water and because water is not pumped out from the pit;
- In the opencast the waste rock above the long-term pit water elevation will be unsaturated. Pyrite oxidation will occur in the unsaturated zone as a result of oxygen infiltration.
- A conceptual model of the physic-chemical processes that occur in mining waste in contact with atmosphere is depicted in
- Figure 10.4 below;
    - Consumption of oxygen will lead to a gradient in oxygen fugacity in the backfill material that initiates oxygen diffusion (flow from high concentration to low concentration). The oxygen concentration will be at its highest in material directly in contact with the atmosphere, and due to its consumption, the oxygen concentration will gradually become depleted within only a few meters; and
    - Initially only the upper part of the material will be situated in the oxidation zone. The oxidation zone will shift deeper into the material as sulphide minerals are depleted. The temperature in the material will eventually rise due to the

oxidation of sulphides. Temperature differences will result in differences in gas pressure that initiate the process of oxygen advection.

The following comments relate to the underground mine:

- The following sources of oxygen will exist in the unflooded underground mine:
  - Oxygen is present in the mine before flooding. The oxygen will however be soon depleted if the air phase is not in direct contact with the atmosphere through open adits of shafts;
  - Oxygen in infiltrating water;
- Both of the above processes are fairly ineffective mechanisms of oxygen migration, the first is only localized (point sources of oxygen, e.g. adits or shafts) while the second delivers an extremely small load of oxygen; and
- If the underground mine is situated below the decant elevation, sulphide oxidation will be limited in the underground mine workings.

A conceptual model of the presence of the oxic and anoxic zone in the co-disposal facility is depicted in Figure 10.5:

- 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 10.5 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;

From the above discussion the following conclusion could be made:

- If the underground mine is flooded and situated below the decant elevation, oxygen infiltration, sulphide oxidation and subsequent acid-mine drainage generation will be limited. However, additional site specific conditions (mine depth, potential decant points etc.) still have to be considered in order to determine the actual risk of the underground;
- Open pits and co-disposal facilities will be more in contact with the atmosphere and subsequent oxygen infiltration. Acid mine drainage is likely to take place at these facilities. Mitigation measures will have to be implemented in order to minimize the impact on water resources. However, additional site specific conditions (mine layouts, potential decant/seepage etc.) still have to be considered in order to determine the actual risk of each facility; and

- 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.

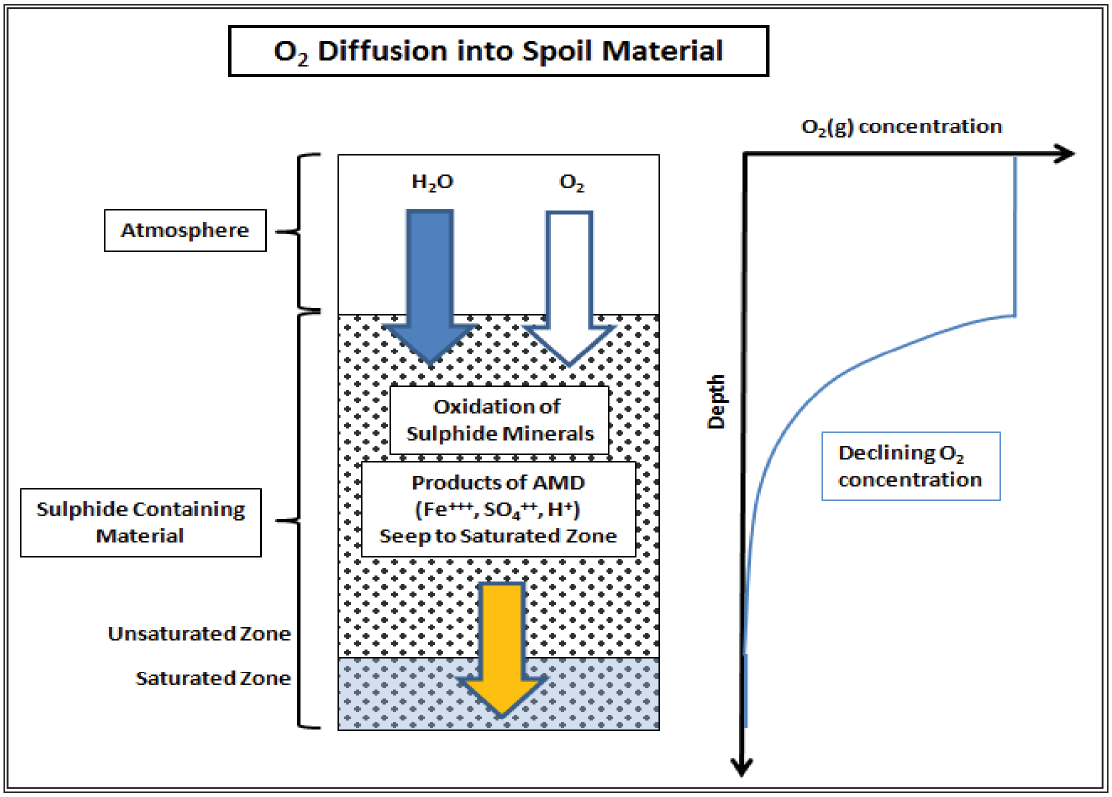


Figure 10.4: Conceptual model of the physico-chemical processes in mine backfill.

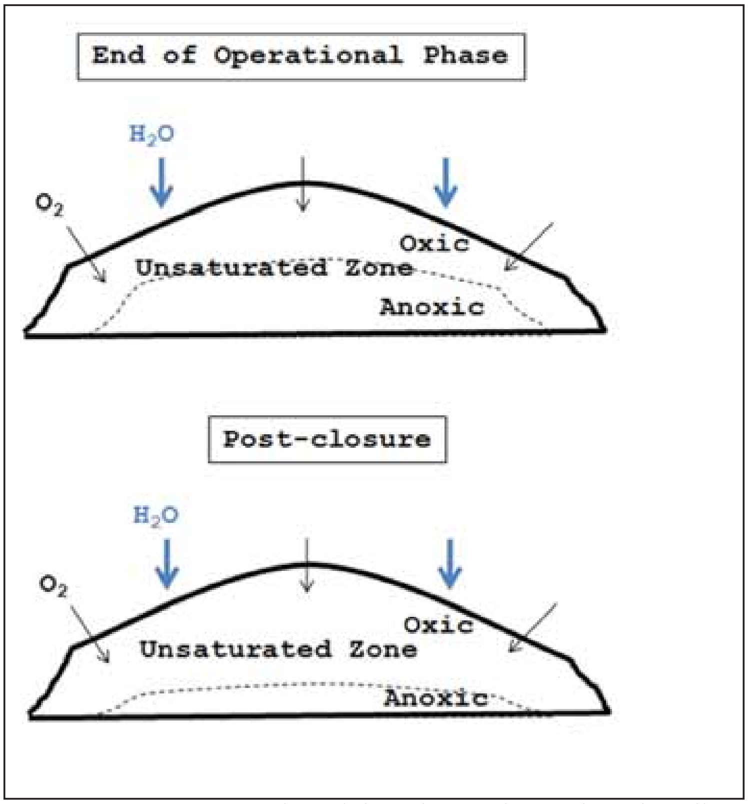


Figure 10.5: Conceptual model of the co-disposal facility illustrating the presence of the oxic and anoxic zones.

10.4.2 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+}, $sulphate^{2-}$ and acidity:

$$\text{pyrite} + 3.5H_2O + 3.75O_{2(aq)} \Rightarrow Fe(OH)_{3(ppd)} + 2\text{sulphate}^{2-} + 4H^+$$

- 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:

$$\text{calcite} + 2H^+ \Rightarrow Ca^{2+} + CO_{2(g)} + H_2O$$

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

$$\text{pyrite} + 2\text{calcite} + 5.5H_2O + 3.75O_{2(aq)} \Rightarrow Fe(OH)_{3(ppd)} + 2\text{gypsum} + 2CO_{2(g)}$$

- 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 does not have the same rock/water/gas ratio than the backfilled material in the mining pit. 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.

10.5 Geochemical Model

10.5.1 Introduction

The objective of the geochemical modelling was to estimate the mine water quality at the 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, numerical modelling was used to predict the Acid Mine Drainage (AMD).

The oxygen diffusion into the residue mine waste was modelled using a MATLAB version of PYROX. The code models 1) the diffusion of oxygen through the unsaturated zone, 2) the oxygen consumed by mineral oxidation, and 3) the subsequent sulphate, iron and acidity production.

The interaction between the mineral-, water- and the gas phases was modelled using the 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.

10.5.2 Modelling Scenarios

3 models were compiled as summarized in Table 10.15:

- Model A: Seepage water quality from opencast backfill;
- Model B: Seepage water quality from the co-disposal facility; and
- Model C: Seepage water quality from underground.

The %S and NP of the waste rock used for the models are given in detail in Table 10.16. The following comments relate to the model input and assumptions:

- Sample representativeness:
  - The samples were assumed to be representative of the backfilled waste rock; and
  - In the modelling it is assumed that the modelled rock is thoroughly mixed or that the pit water will be at least in contact with all rock materials;
- Pyrite and carbonate mineral content:
  - The average %S and NP used for the numerical modelling are summarized in Table 18;
  - The carbonate mineral content was calculated from the measured NP values; and

- The pyrite content was calculated from the weighted %S, assuming that all sulphur is present as pyrite. This is a worst case assumption as some sulphates or organic sulphur may be present in the sample.

Table 10.15: Description of geochemical model scenarios

Model scenario	Site	Description
Model A	Opencast	%S = 0.69 An 'average' composition of the backfill was assumed.
Model B	Discard	%S = 2.3 An 'average' composition of the discard was assumed.
Model C	Underground	%S = 1.21 An 'average' composition of the roof and floor coal was assumed to be representative of the UG mine rock left.

Table 10.16: Weighted average %S and NP in numerical model scenarios

Model Scenario	Site	Total (%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	Opencast	0.69	21.64	6.36	-15.27	0.29	Uncer-tain	I	II
Model B	Discard	2.30	71.72	32.49	-39.23	1.74	I	I	II
Model C	Underground	1.21	37.78	6.71	-31.07	0.25	I	I	I

10.5.3 Geochemical Outputs/Results

10.5.3.1 Model Output

The change in the modelled water quality in Model A – C is depicted as follows:

- Figure 10.6 and Figure 10.11: Changes in O_2(aq) over model time
- Figure 10.7 and Figure 10.12: Changes in pH concentration over model time;
- Figure 10.8 and Figure 10.13: Changes in sulphate concentration over model time;
- Figure 10.9 and Figure 10.14: Changes in Al, Fe and Mn concentrations over model time;
- Figure 10.10 and Figure 10.15: Changes in mineralogy over model time; and
- Figure 10.16: Changes in underground mine water over model time.

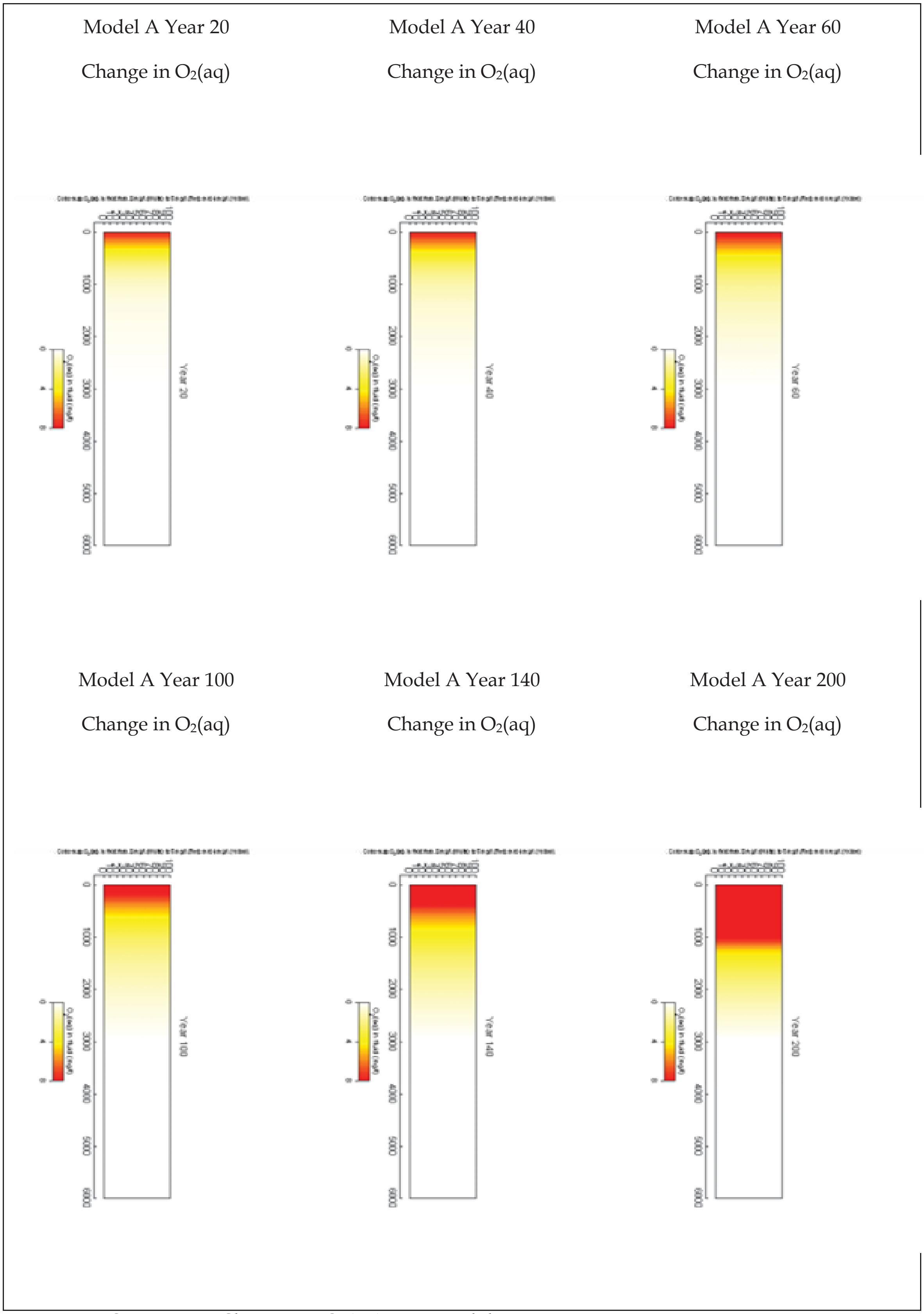


Figure 10.6: Scenario A: Changes in O_2(aq) over model time

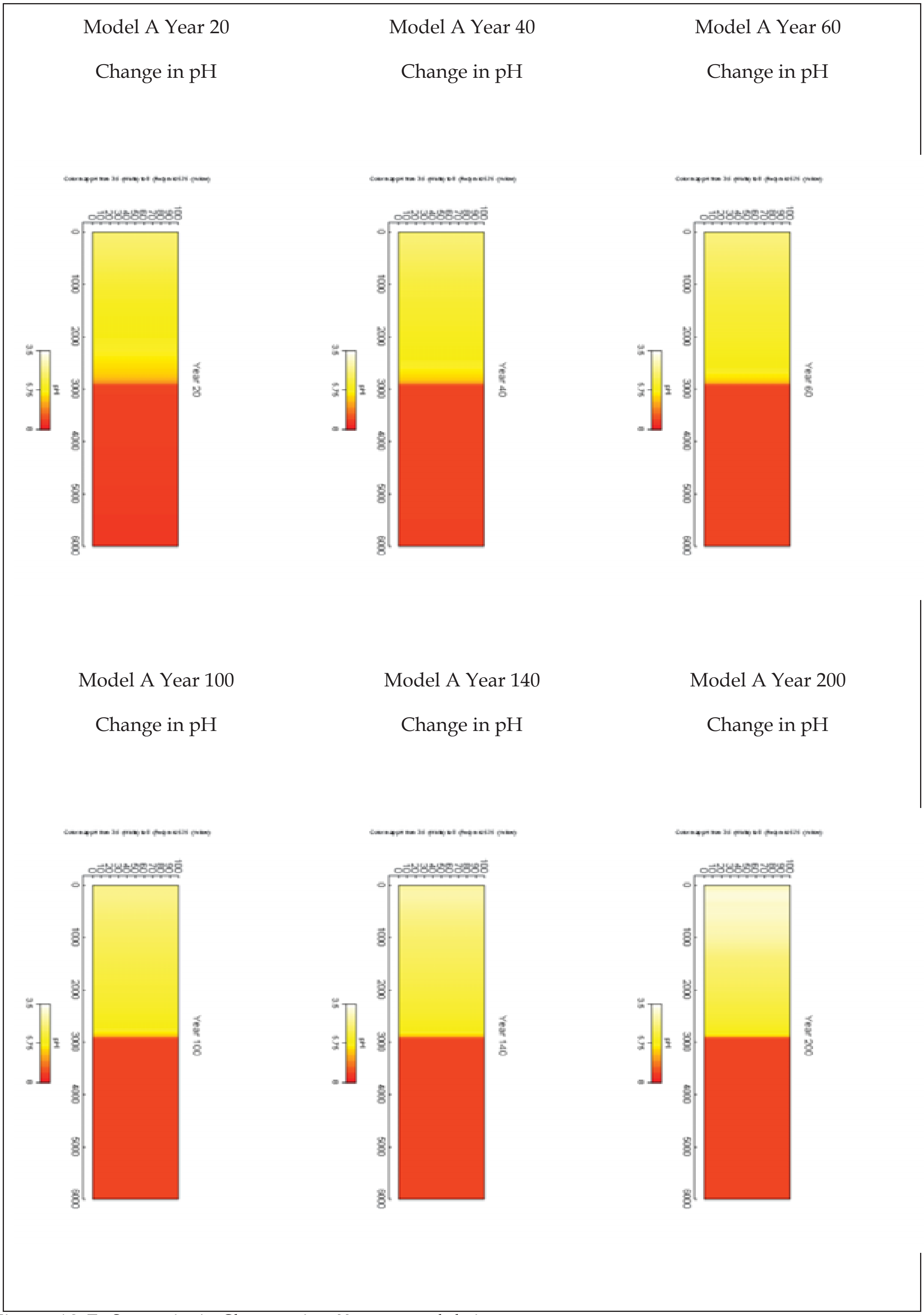


Figure 10.7: Scenario A: Changes in pH over model time

Model A Year 20

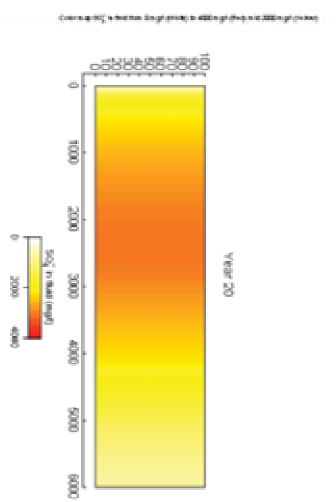
Change in sulphate

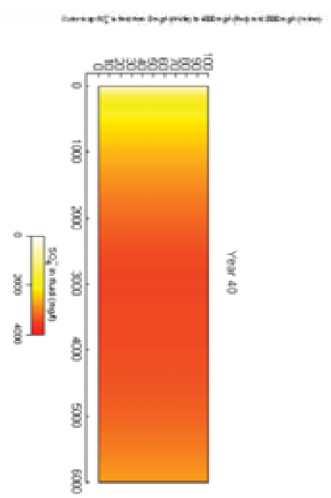
Model A Year 40

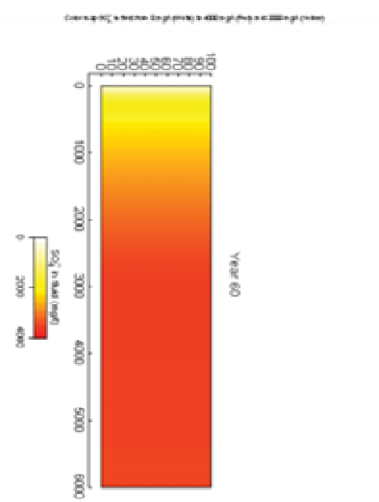
Change in sulphate

Model A Year 60

Change in sulphate







Model A Year 100

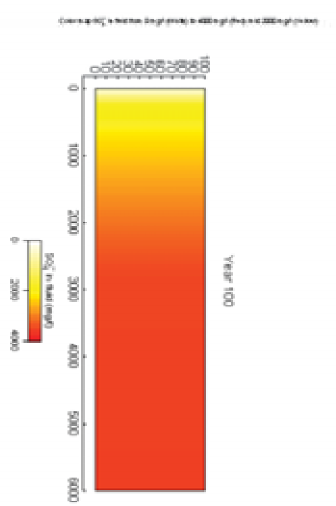
Change in sulphate

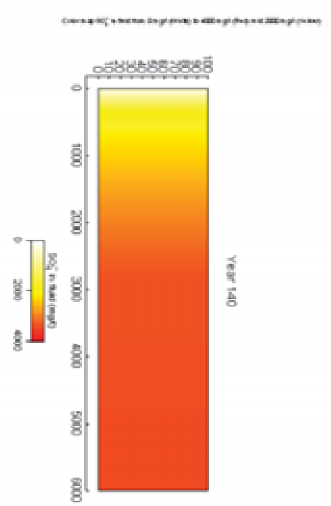
Model A Year 140

Change in sulphate

Model A Year 200

Change in sulphate





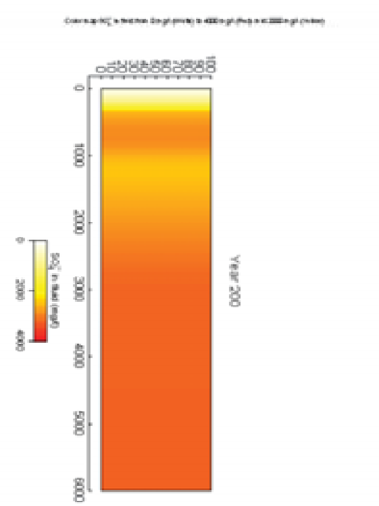


Figure 10.8: Scenario A: Changes in sulphate concentration over model time

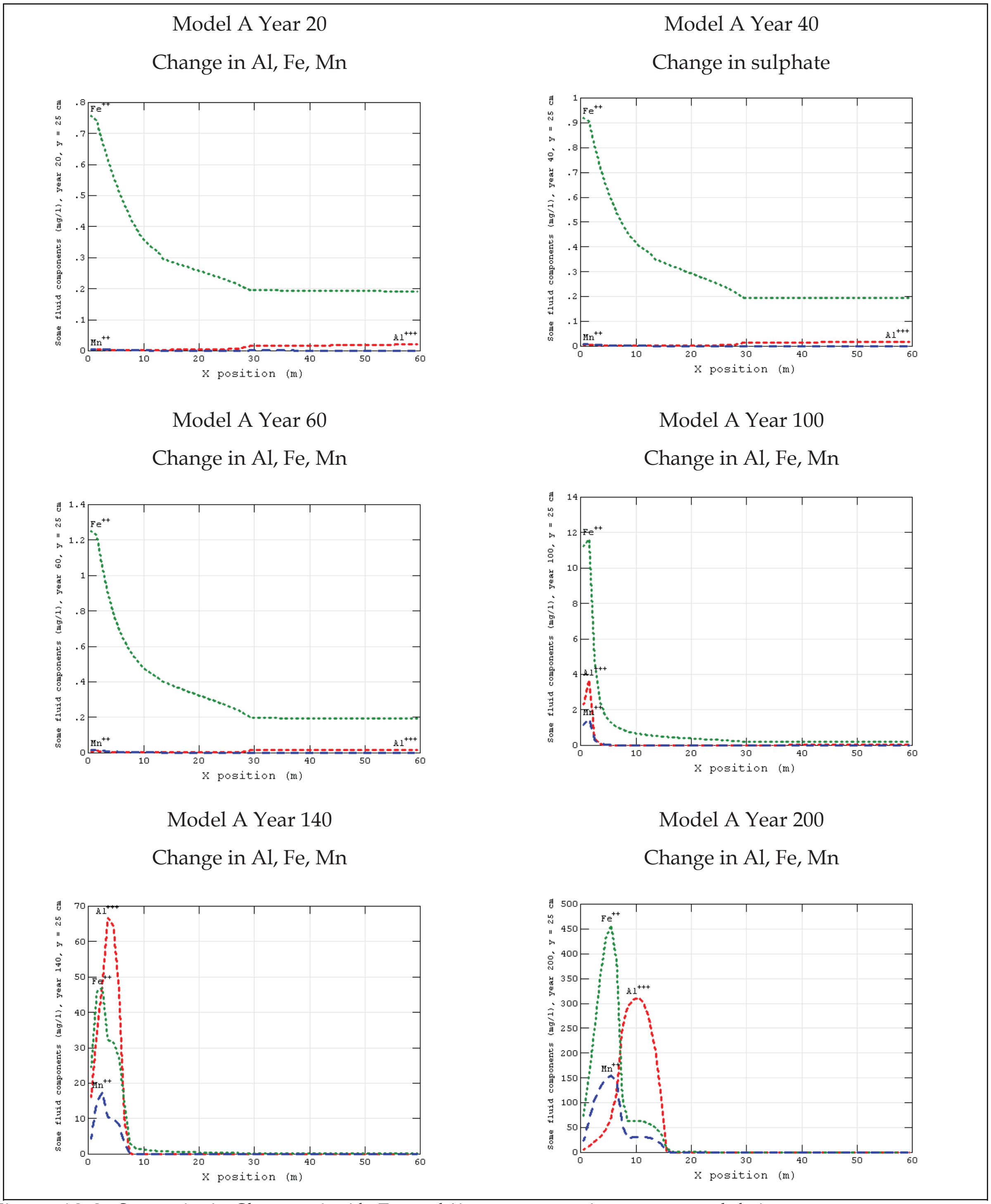


Figure 10.9: Scenario A: Changes in Al, Fe and Mn concentrations over model time

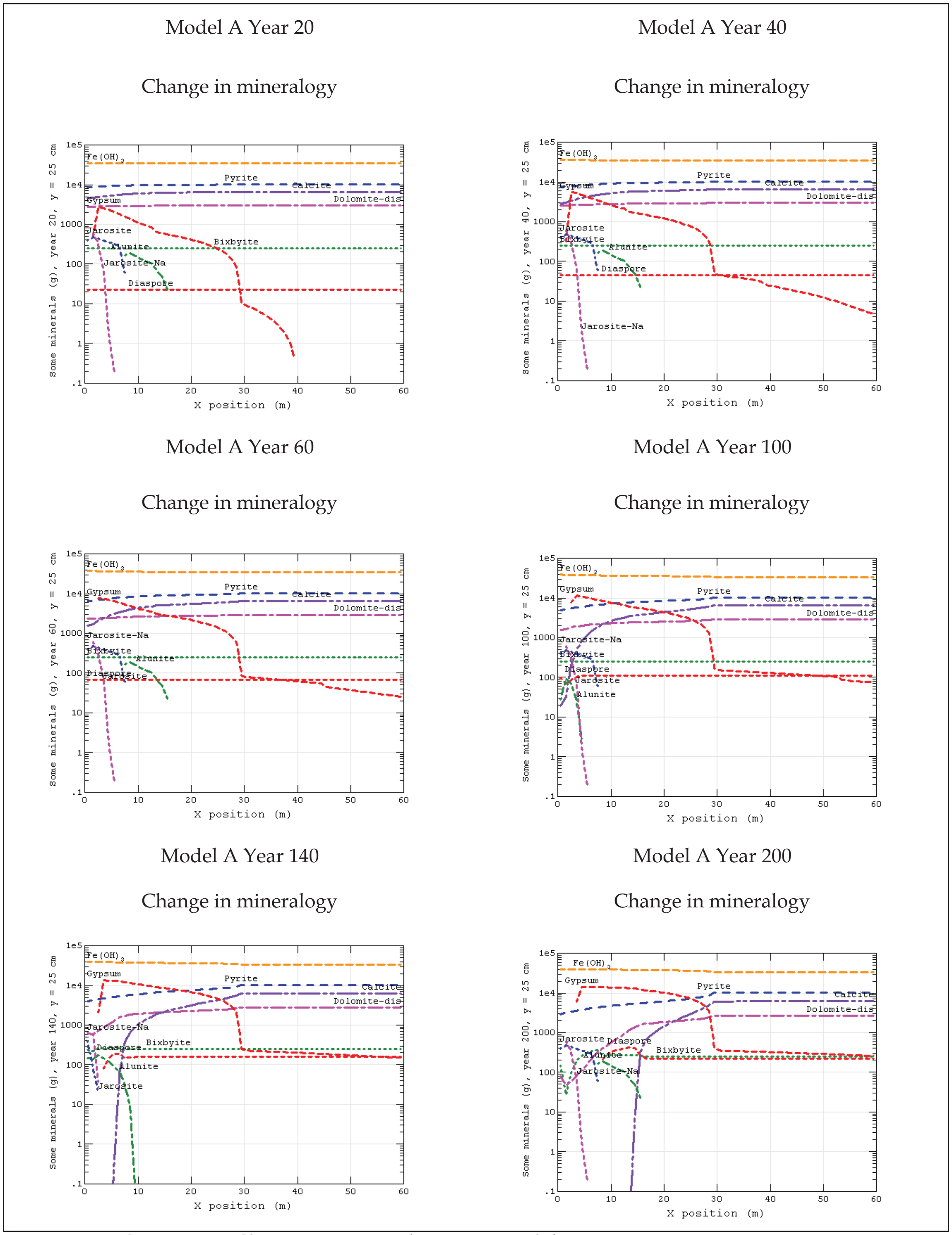
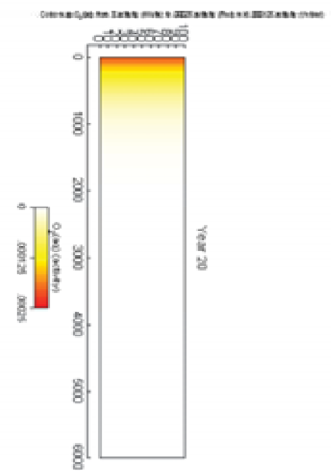


Figure 10.10: Scenario A: Changes in mineralogy over model time

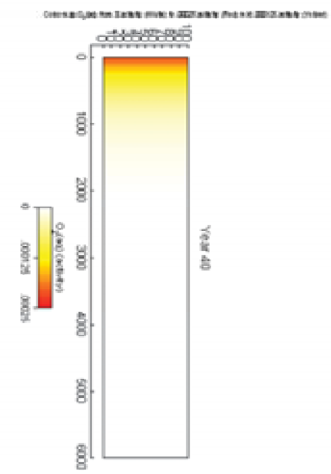
Model B Year 20

Change in O_2(aq)



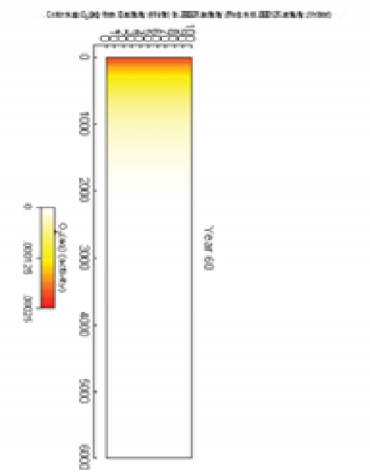
Model B Year 40

Change in O_2(aq)



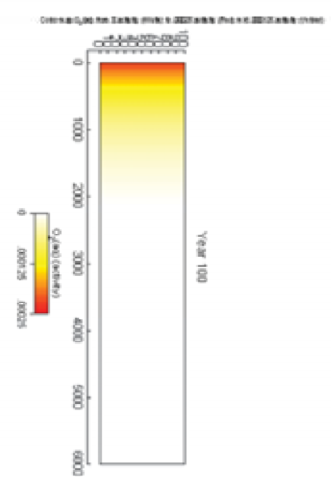
Model B Year 60

Change in O_2(aq)



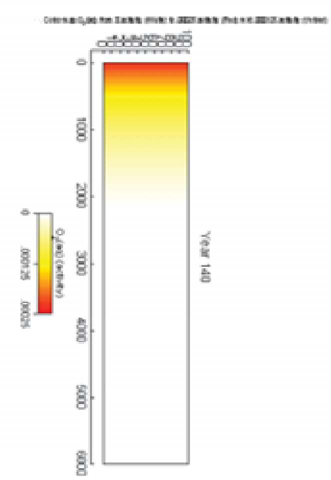
Model B Year 100

Change in O_2(aq)



Model B Year 140

Change in O_2(aq)



Model B Year 200

Change in O_2(aq)

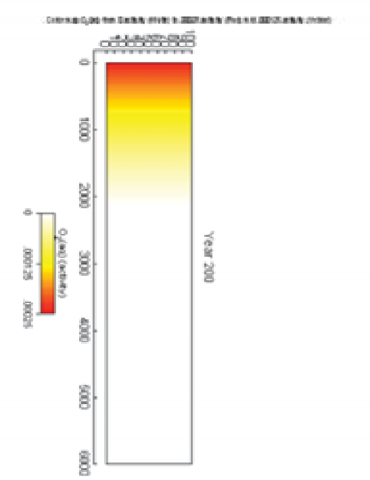


Figure 10.11: Scenario B: Changes in O_2(aq) over model time

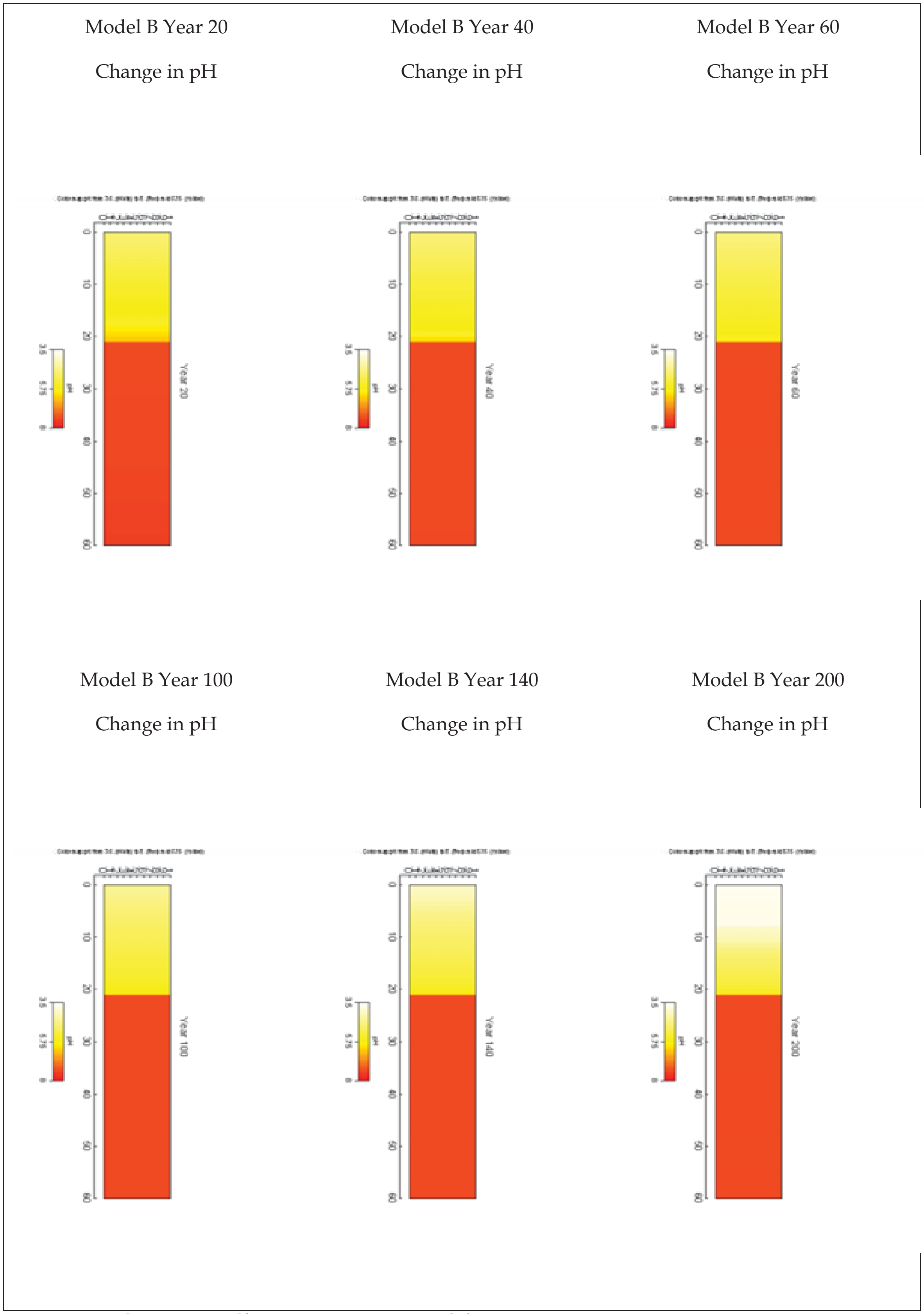


Figure 10.12: Scenario B: Changes in pH over model time

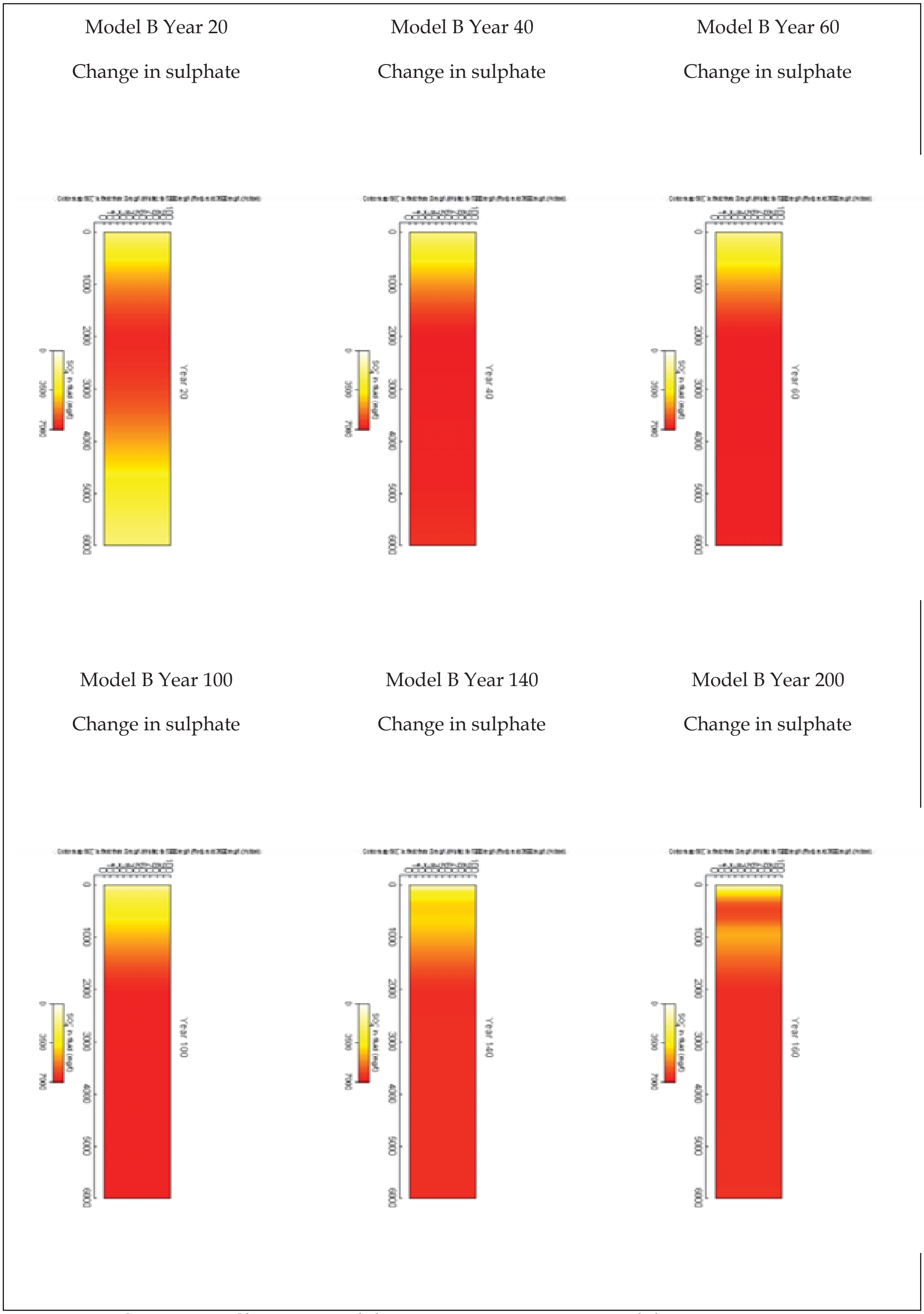


Figure 10.13: Scenario B: Changes in sulphate concentration over model time

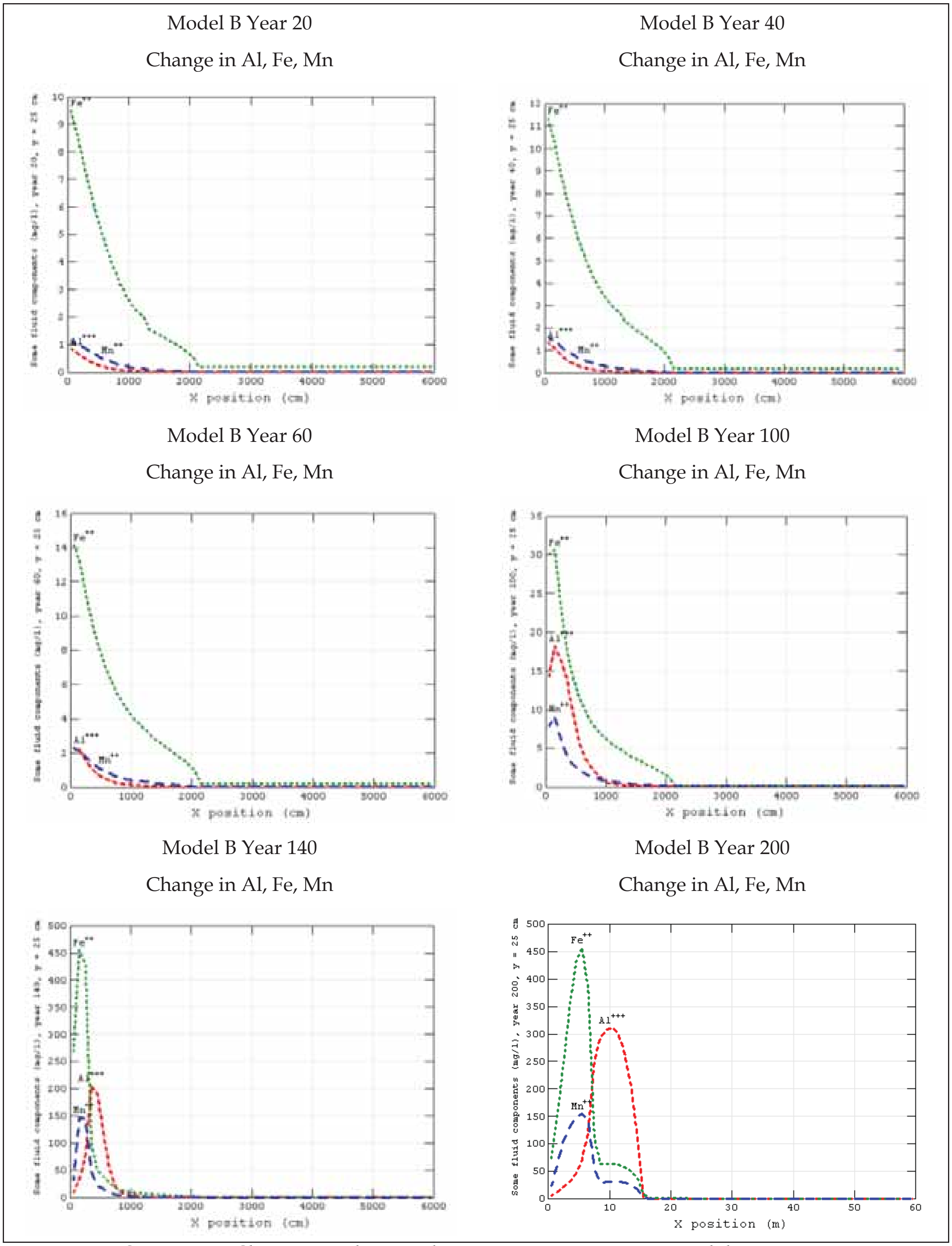


Figure 10.14: Scenario B: Changes in Al, Fe and Mn concentrations over model time

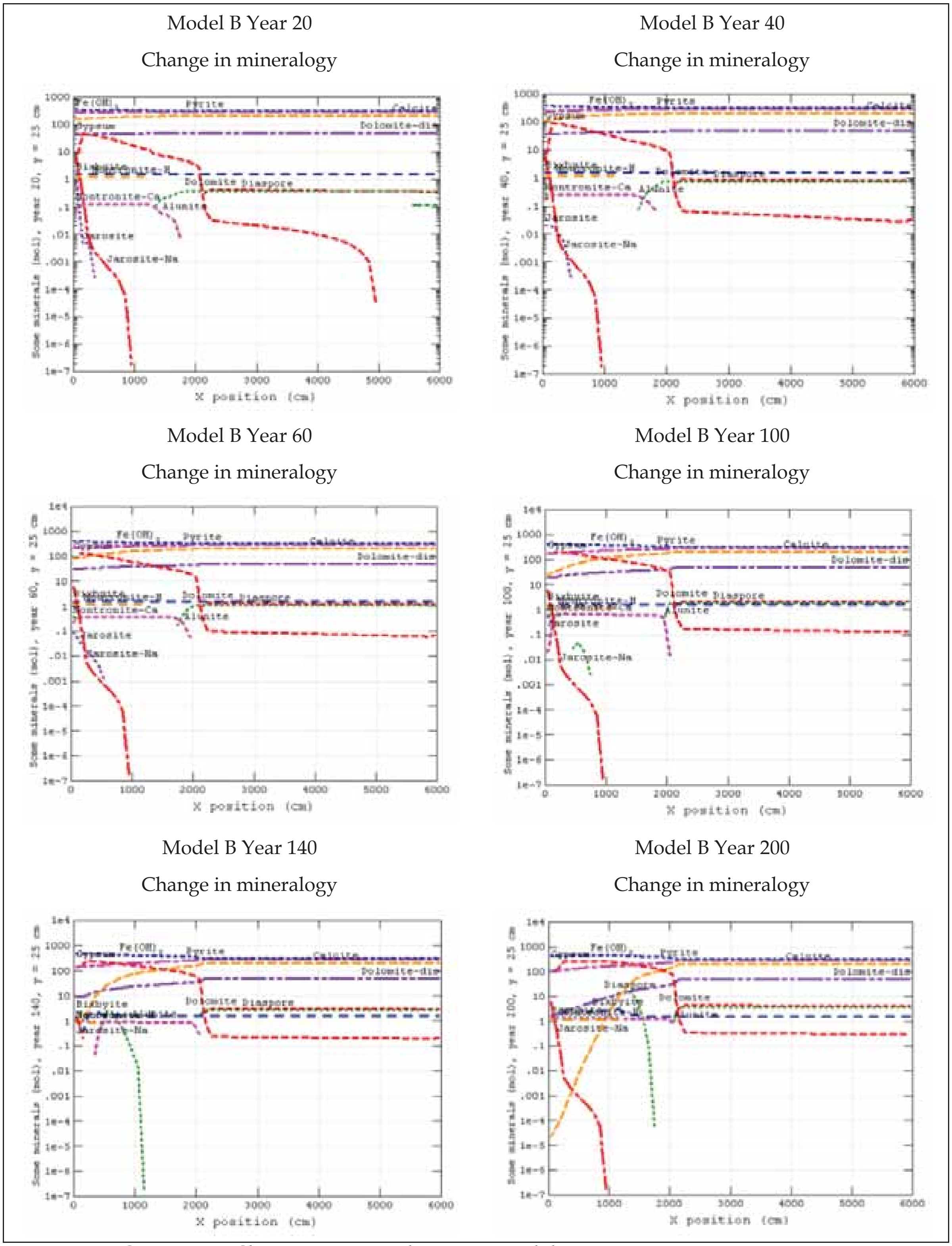


Figure 10.15: Scenario B: Changes in mineralogy over model time

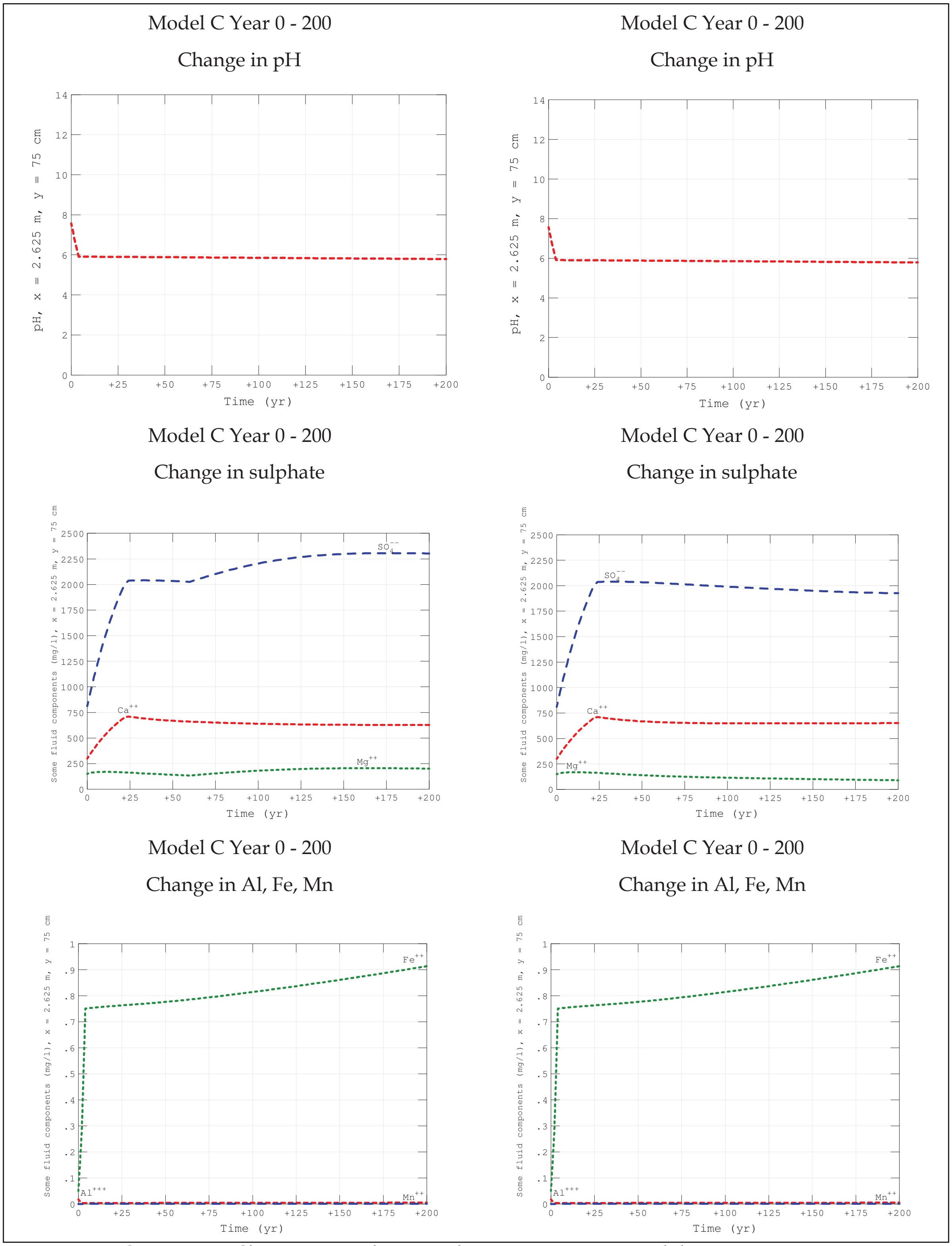


Figure 10.16: Scenario B: Changes in underground mine water over model time

10.5.3.2 Predicted Seepage Water Qualities

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

- The pH and sulphate for the different model scenarios is summarized in Table 10.17;
- The evolution in acid-mine drainage in terms of the mineralogy and the mine water quality is summarized in Table 10.18;

From the model results the following conclusions could be made:

Depth of oxidation

- The unsaturated depth over the pit will vary which will result in a difference in the oxygen infiltration over the lateral extent of the pit. AMD production depend on the presence of oxygen and therefore the AMD production will vary at different unsaturated depths;
- The oxygen concentration will decrease downwards in the unsaturated zone because of consumption by pyrite. The oxygen infiltration will eventually reach a pseudo-steady state; and
- The depth of oxygen infiltration is deeper in the opencast backfill than in the co-disposal facility due to less oxygen consumption in the backfill compared to the discard;
- Oxygen will be depleted in the underground by pyrite consumption and flooding of the mine if no infiltration of oxygen is present. Decrease in oxygen was modelled to coincide with the mine flooding;

Changes in major ions

- Alkalinity is the dominant anion in the recharge water in the unsaturated zone but is quickly replaced by sulphate;
- Ca and Mg are the dominant cations in the mine water due to the initial neutralization reactions of carbonate minerals. In some hot-spot material where carbonate minerals are depleted and conditions are acidic some metals also become more dominant upon acidification;
- Opencast: In the low %S backfill with neutral conditions, the sulphate concentration will be limited to around 1 500 - 2 500 mg/l by secondary Fe-sulphate and gypsum saturation in the unsaturated zone. The sulphate will however decrease in seepage to about 3 500 mg/l over the long-term as inadequate neutralisation potential is present in the material sampled;
- Co-disposal facility: Most discard will form hot-spot material and will acidify over the long-term if placed. Hot-spot interburden material will have a sulphate 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);

- Underground: Acid-mine drainage generation in the underground will depend on the oxygen ingress vs time for the mine to flood. While oxygen is still present the underground mine water will reach sulphate concentrations of about 2 000 - 2 300 mg/l for the higher (4% of MAP) and lower recharge rates (2% 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 so low that sulphate will remain at a fairly constant concentration of around 2 000 - 2 300 mg/l for several decades;

Changes in pH conditions

- Opencast: The backfilled rock has some net acid potential and the water in the oxic zone will acidify to a pH of 3.5 - 4.5 in the unsaturated zone within less than 20 years. The saturated zone will be near neutral and the pH at the contact between the unsaturated and saturated zone will be <pH 6 reaching pH 4.5 over time. The decant water of the mine will eventually be acidic. In terms of mitigation it is therefore the ideal is to place hotspot material (especially carbonaceous material) below the decant elevation;
- Co-disposal facility: 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. 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. The decant water of the mine will eventually be acidic. In terms of mitigation it is therefore the ideal is to place hotspot material (especially carbonaceous material) below the decant elevation;
- Underground mine: 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;

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 e.g. the underground mine;
- If acidification of the unsaturated water occurs, Al, Fe and Mn concentrations may reach maximum values of up to 50 mg/l and even up to 500 mg/l in highly carbonaceous rocks (e.g. coal discard). Over the long term Al will actually become more dominant as it is released from the silicate mineralogy. Metal concentrations under acidic conditions can

however expected to be very erratic and will change significantly between each monitoring run;

- The metal concentrations in the upper part of the saturated zone (where recharge with the acidic backfill seepage occur) 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).

It can therefore be concluded that, overall, the mine material will have a net neutralization potential. Because of the exposure to atmospheric conditions the seepage water in the opencast and the co-disposal facility will be acidic. The mine water in the underground will not acidify due to limited oxygen infiltration into the underground.

Table 10.17: Estimated pH and sulphate for opencast: seepage from unsaturated backfill*

Backfill material	Underground bord-and-pillar mine			Opencast backfill in unsaturated zone			Coal discard in unsaturated zone		
Term	Short term	Medium term	Long term	Short term	Medium term	Long term	Short term	Medium term	Long term
	0 - 20 years	20 - 100 years	100 - 200 years	0 - 20 years	20 - 120 years	120 - 200 years	0 - 10 years	10 - 100 years	100 - 200 years
AMD Stage	Stage 1	Stage 1	AMD stops	Stage 1	Stage 2	Stage 2&3	Stage 2&3	Stage 2&3	Stage 2&3
No selective mining.	6 - 8	6 - 8	6 - 8	8 - 6.5	6.5 down to 3.5	4.5 - 3.5	4.5 - 3.5	4.5 - 3.5	4.5 - 3.5
	500 - 2 300	2 000 - 2 300	2 300 down to 1 900	500 - 3 500	2 500 - 3 500	3500 - 3000	500 - 6 000	6 000	6 000

Table 10.18: 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. sulphate reaches maximum concentration in interstitial water.	Depleted in upper oxidation zone. sulphate decrease from maximum.
Calcite and dolomite	Dissolution	Depleted in upper oxidation zone.	Depleted in upper oxidation zone.
Gypsum	Precipitation, controls sulphate	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
sulphate	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.***

10.5.4 Model Limitation

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

Material heterogeneity and mine water variability

- In the backfill of a single opencast mine the mine water quality can vary significantly which is partly due to the heterogeneity of the 1) backfilled rock and 2) different depths of the unsaturated zone. It is impossible to adequate model this heterogeneity as it is not possible to know the exact spatial distribution and geochemical composition of the different materials;

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.

10.6 Conclusions Geochemical Modelling

Based on the results of the geochemical assessment, the following conclusions could be 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 acid-mine drainage (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 Fe;
- Opencast: In the low %S backfill with neutral conditions, the sulphate concentration will be limited to around 1 500 - 2 500 mg/l by secondary Fe-sulphate and gypsum saturation in the unsaturated zone. The sulphate will however decrease in seepage to about 3 500 mg/l over the long-term as inadequate neutralisation potential is present in the material sampled.
- The backfilled rock has some net acid potential and the water in the oxic zone will acidify to a pH of 3.5 - 4.5 in the unsaturated zone within less than 20 years. The saturated zone will be near neutral and the pH at the contact between the unsaturated and saturated zone will be <pH 6 reaching pH 4.5 over time. The decant water of the mine will eventually be acidic. In terms of mitigation it is therefore the ideal is to place hotspot material (especially carbonaceous material) below the decant elevation;

- Co-disposal facility: Most discard will form hot-spot material and will acidify over the long-term if placed. Hot-spot interburden material will have a sulphate 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. 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. The decant water of the mine will eventually be acidic. In terms of mitigation it is therefore the ideal is to place hotspot material (especially carbonaceous material) below the decant elevation;
- Underground: Acid-mine drainage generation in the underground will depend on the oxygen ingress vs time for the mine to flood. While oxygen is still present the underground mine water will reach sulphate concentrations of about 2 000 - 2 300 mg/l for the higher (4% of MAP) and lower recharge rates (2% 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 so low that sulphate will remain at a fairly constant concentration of around 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.

11 HYDROGEOLOGICAL CONCEPTUAL MODEL

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.

From the reviewed information the conceptual model consists of the following hydrogeological units:

- Weathered Karoo; and
- Fractured Karoo;

Kirchner et al. (1991) estimated 2-4% of annual effective rainfall recharge for the Karoo Basin. According to Hodgson & Krantz (1998), the true recharge figure is less than Kirchner's estimate and ranges between 1% and 3% of annual effective rainfall.

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 at an average water level of approximately 5.5 mbgl. Hydraulic conductivity values will 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 decreasing with depth. Hydraulic conductivity will therefore decrease with depth and will 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.

11.1.1 Source

The main potential on –site contamination sources are:

- Dorstfontein East site:
  - the opencast mines;
  - the underground voids; and
  - the slurry and co-disposal facility (co-disposal facility).
- Possible other contaminant sources could be:
  - the Pollution Control Dams (PCD's) and return water dam;
  - plant area with Erikson dams

11.1.2 Pathway

Possible pathways for on-site contaminations are:

1) The surface water streams; and
2) The weathered and upper fractured Karoo aquifers.

11.1.3 Receptor

Potential receptors are down gradient boreholes (mainly NBH6 and NBH20) in the study area used for drinking water, livestock watering and small scale irrigation (See Figure 7.1) and the Olifants River and two of its tributaries at the site.

12 HYDROGEOLOGICAL NUMERICAL MODELLING

12.1 Objective of the Model

The objective of the model is to simulate groundwater ingress into the mine operations. Scenario modelling is typically used to run future scenarios on varying changes in the natural environment or anthropogenic inputs. The potential scenarios to be simulated using the Dorstfontein regional model include the following:

- Determine or confirm decant points for the Dorstfontein East operations;
- Determine short-term and long term pollution (post-closure) potential of the co-disposal facility and conduct necessary tests for such determination; and
- Determine the quantity and quality of water that might decant from the underground working post-closure also the timing of such decant.

The deliverables from the modelling phase of the project include an updated regional groundwater flow model.

12.2 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:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)\pm W = S_s\frac{\partial h}{\partial t} \qquad (1)$$

where:

- Kxx, Kyy, and Kzz 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 the ground-water system, and W>0.0 for flow in (T-1);
- Ss is the specific storage of the porous material (L-1); and
- t is time (T).

Equation 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).

12.3 Model Software Package

The numerical model for the project was constructed using GMS 10.0.5, 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.

12.4 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 12.1. Table 12.1 provides a summary of the boundaries, boundary descriptions and boundary conditions specified in the hydrogeological model.

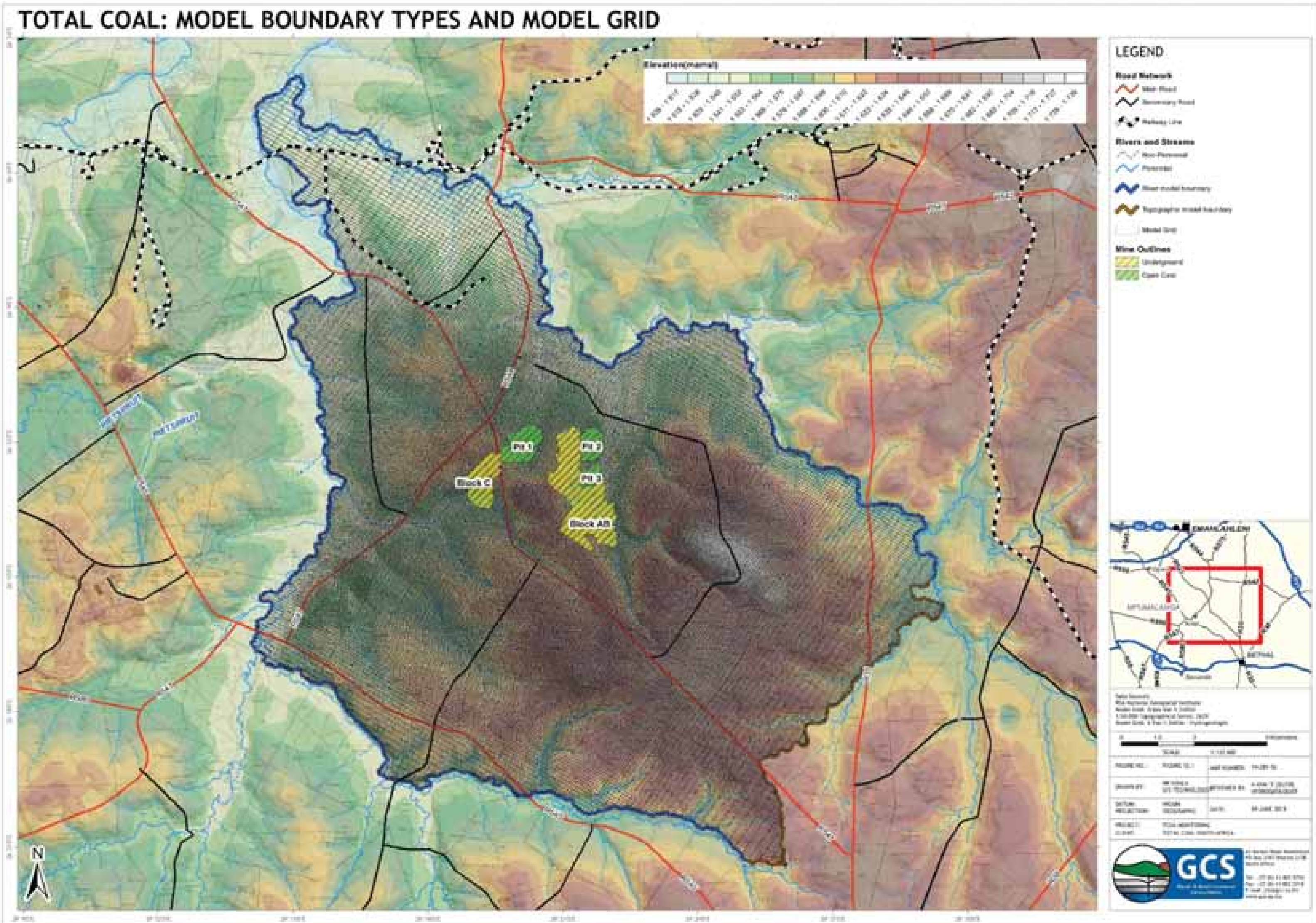


Figure 12.1: Model boundary types and model grid

Table 12.1 Identification of the real-world boundaries and the adopted model boundary conditions.

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

12.5 Construction of the Finite Difference Grid

Compilation of the finite difference grid using the GMS 10.0.5 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 12.5m x 12.5m cells around the Dorstfontein East and West mining areas with gradually coarser grid cell sizes away from the mining areas (Figure 12.1). . This is standard practise and does not influence the accuracy of the results obtained.

12.6 Vertical Discretization

Along the vertical direction, the steady state hydrogeological model is structured in 3 model layers (Figure 12.2). 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:

1. weathered Karoo layer (20 m thickness);
2. fractured Karoo:
    a. upper fractured Karoo layer with coal seams (60 m thickness); and
    b. lower fractured bedrock (40 m thickness).

12.7 Time Discretization

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).

The steady state groundwater flow model was used for sensitivity analysis.

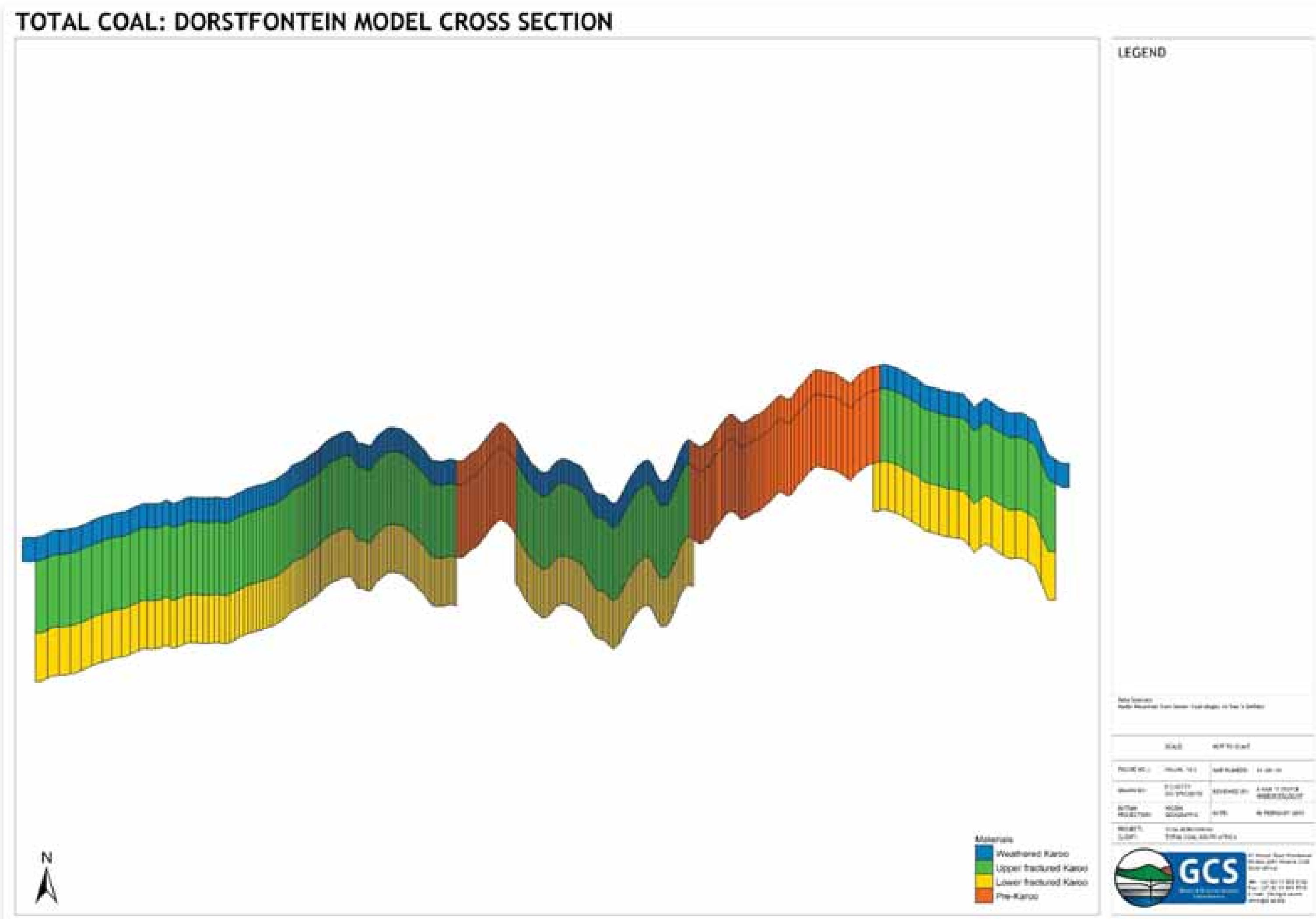


Figure 12.2: Model Cross Section

For the purpose of simulation of groundwater inflows into the mine, the transient simulation was discretized into stress periods of 6 months 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.

12.8 Mine Schedule

The mine schedules for the No. 2 and No 4 seams as presented in Section 5 were used is input for the model. The mining operations were simulated by means of drain cells.

12.9 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 falling head and pump testing results as carried out as part of the fieldwork for this project. 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 average annual rainfall was applied, which is approximately 6.5 mm per annum. Due 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 Dorstfontein East which was given a recharge value of 8% of annual rainfall. Recharge into the opencast pits after rehabilitation was estimated on information provided by Golder Associates in Pretoria, who carried out the Post-landform design for DCME specifically. An optimum recharge value of 6.5% was calculated based on the optimum between soil placement and water treatment costs. More imported soil means less recharge into the pits which leads to lower treatment costs due to the lower volumes of water to be treated.

12.10 Model 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% 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.

12.10.1 Calibration Targets

The groundwater levels of on-site monitoring boreholes for 2010 – 2014 (monitoring carried out by GCS) and 2014 (hydrocensus data) were available for model calibration. For the monitoring boreholes the groundwater levels in 2010 were used to minimise the impact of the mining activities.

12.10.2 Steady State Calibration

For steady state conditions the groundwater flow equation (1) reduces to the following equation:

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})\pm W=0 \qquad (2)$$

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 Dorstfontein 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 Dorstfontein 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 $ME = \frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i$;
- Mean Absolute Error $MAE = \frac{1}{n}\sum_{i=1}^{n}\left|h_m - h_s\right|_i$;
- Root Mean Square $RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2}$;
- Normalized RMS $RN = \frac{RMS}{H_{\max} - H_{\min}}$;

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 = 6.2 m and RMS = 7.9 m. The graph in Figure 12.3 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. The steady state mass balance for entire model domain presented in Table 8.2 achieved a water balance error of less than 0.0008% (Table 12.2).

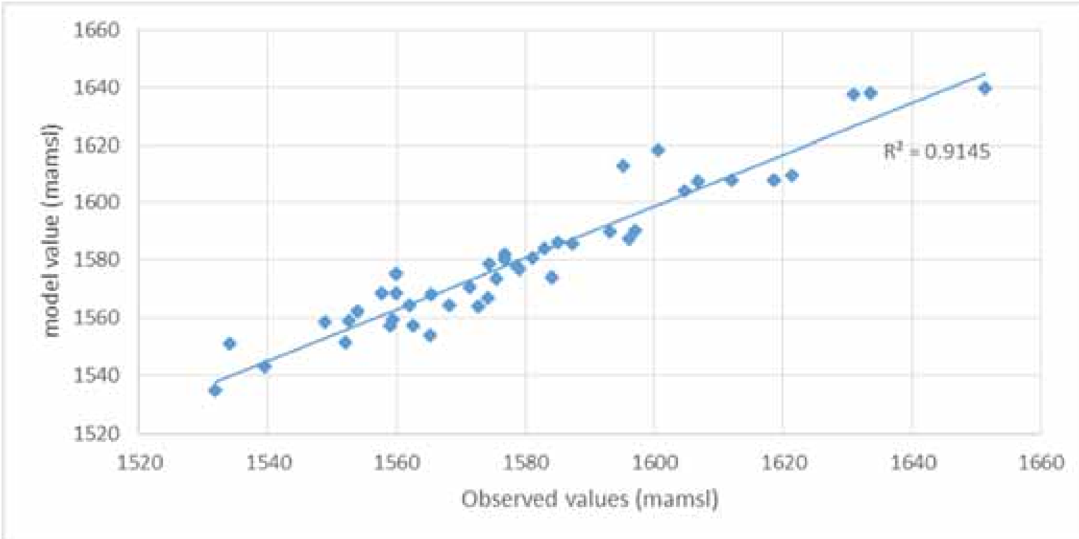


Figure 12.3: Steady State calibration results.

Table 12.2: Mass balance of steady state model (pre mining)

	Flow In (m^3/day)	Flow Out (m^3/day)
Sources/Sinks		
Mine inflow	0	0
River leakage	12494	- 4794
Recharge	8884	0
Drains	0	-16583
TOTAL FLOW	21378	- 21378
Summary	In - Out	% difference
Total	-0.19	-0.0008

12.10.3 Aquifer Hydraulic Conductivity

Initial estimates of the hydraulic conductivity for the different geological units were obtained from the aquifer test data collected as part of this investigation. 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 12.3 and Table 12.4. The transmissivity value of the model is in the same order of magnitude as the average transmissivity determined from the aquifer test results as discussed in Section 7.1.3.

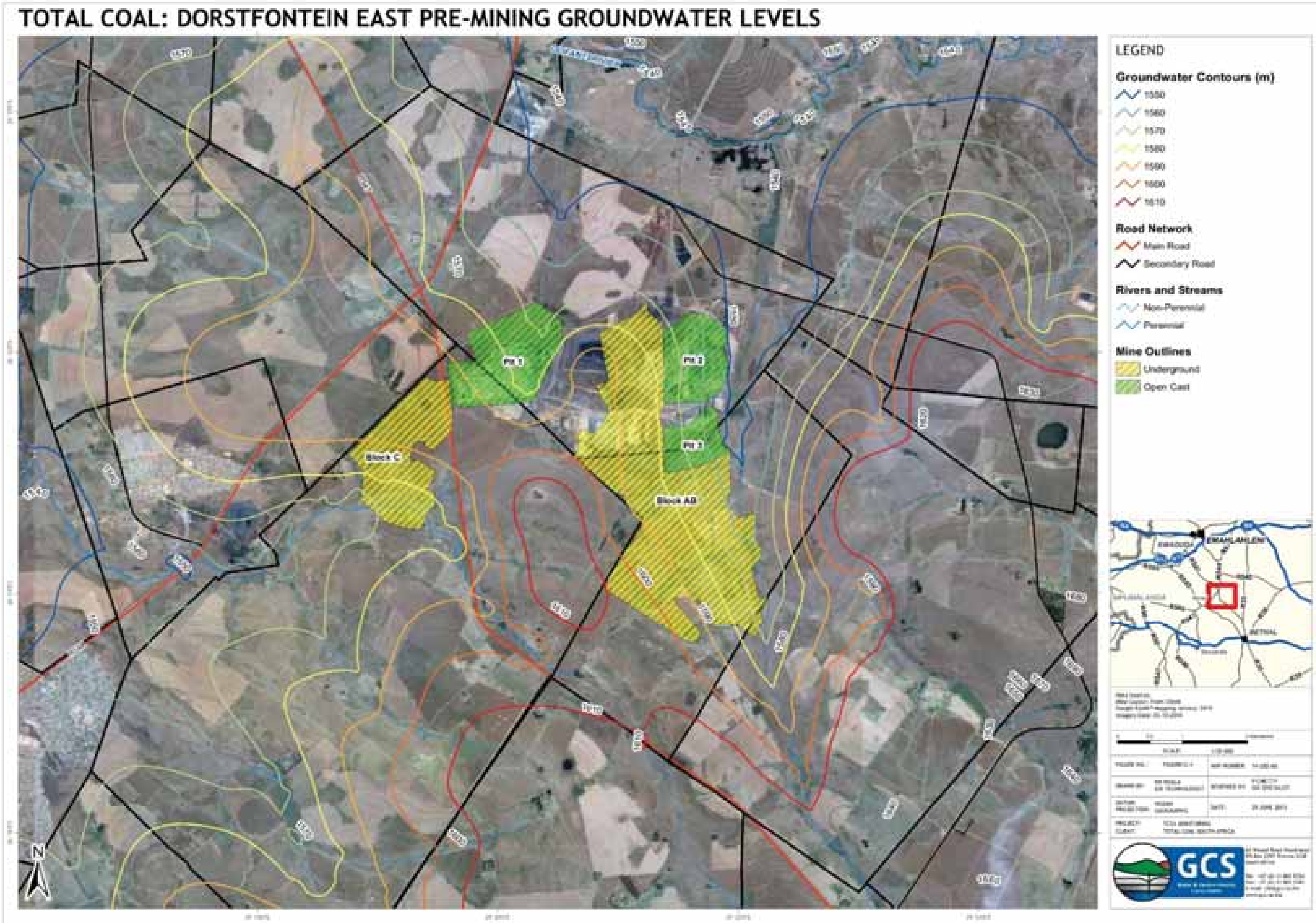


Figure 12.4: Pre-mining groundwater levels

Table 12.3: Calibrated values of horizontal and vertical hydraulic conductivities

Layer	Zone	Hydraulic conductivity (m/day)	
		Horizontal	Vertical
1	Weathered Karoo (Ecca)	$3.2x10^{-1}$	$3.2x10^{-2}$
2	Upper fractured Karoo (Ecca)	$1.1x10^{-2}$	$1.1x10^{-3}$
3	Lower fractured Karoo (Ecca and Dwyka)	$5x10^{-3}$	$5x10^{-4}$
1	Granite (Lebowa)	$5x10^{-3}$	$5x10^{-4}$
2	Granite (Lebowa)	$5x10^{-3}$	$5x10^{-4}$
3	Granite (Lebowa)	0	0

Table 12.4: Calibrated values of transmissivity for Karoo aquifers.

Layer	Thickness (m)	Lithology	Transmissivity values (m^2/day)
1	20	Weathered Karoo	1.0
2	60	Upper fractured Karoo	0.6
3	40	Lower fractured Karoo	0.2

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

12.10.4 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 Figure 12.5 below.

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 3 (moderately fractured bedrock). Based on these results it is recommended that the mine should consider groundwater monitoring programmes to provide improved data regarding these parameters. Time series of groundwater level data from these aquifer units will benefit future model updates the most.

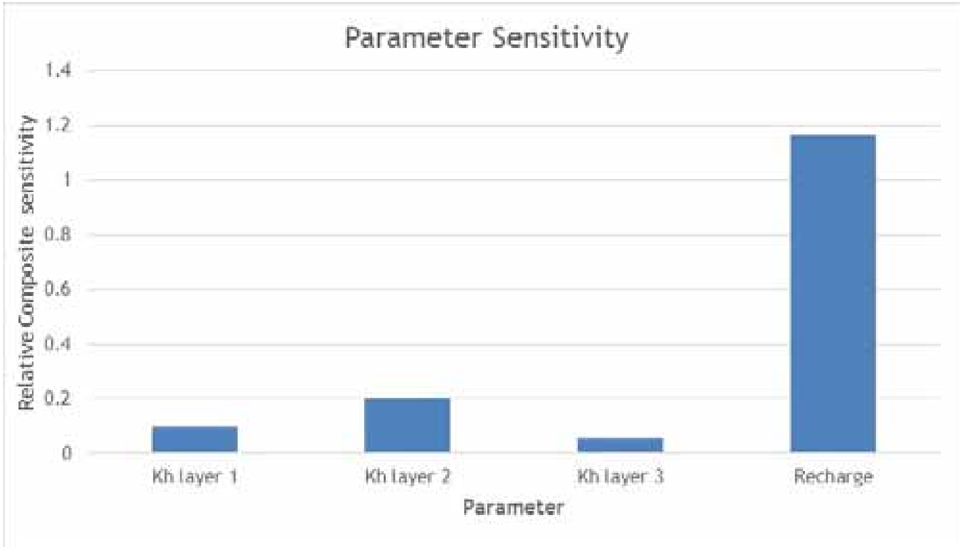


Figure 12.5: Parameter sensitivity (relative composite)

13 GROUNDWATER IMPACTS

13.1 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 measureable	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)	Medium/Low (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 indicted moderate (M) environmental significance; and
- less than 30 significance points indicated low (L) environmental significance.

13.2 Operational Phase

13.2.1 Groundwater Quantity (groundwater Level drawdown)

The floor elevation of the three opencast mines is below the general groundwater level thus causing groundwater inflows into the opencast mining areas from the surrounding aquifers during operations. The opencast mining areas will have to be actively dewatered to ensure a safe working environment. Pumping water that seeps into the mine areas to surface will cause dewatering of the surrounding aquifers and an associated decrease in groundwater level within the zone of influence of the dewatering cone.

The zone of influence of the dewatering cone depends on several factors including the depth of mining below the regional groundwater level, recharge from rainfall to the aquifers, 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 over time in the study area. The mining schedules as discussed in section 12.8 were taken in consideration when calculating the drawdown.

During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. At the time of the investigation boreholes *DFTNM8, DFTNM9, DFTNM12* and *DFBH* were slightly affected and *DFTNM3, DFTNM7, DFTNM10* and *DFTNH1* were affected to a higher degree by the drawdown cone of the existing mining activities. In order to interpret the changing cone of groundwater depression as mining progresses, scenario modelling has been carried out as illustrated in Figure 13.1.

The mine plans for the opencasts show mining up to 2020, with:

- opencast 1 (western pit): mining from 2012 to 2016;
- opencast 2 (north-eastern pit): mining from 2012 to 2019;
- opencast 3 (south-eastern pit): mining from 2016 to 2020.

The mine plans for the underground mining show mining up to 2032, with:

- Block A and B: mining from 2017 to 2032;
- Block C: mining from 2021 to 2027.

The forward predictions show the dewatering of the separate opencasts and underground mines will create a drawdown cone in the area surrounding all mining areas. As the pits and the underground voids increase in size, the cone of drawdown caused by the dewatering of the pits extends, with a maximum extent in 2027 as can be seen in Figure 13.1. As the mined out underground voids and opencasts start filling with water after 2032 the groundwater levels in the area will rebound. Groundwater levels are simulated to recover to pre-mining conditions within 35 years after the end of life (2032) of the Dorstfontein East mine.

The following deductions can be made:

- The water levels could be lowered over relative large area around and in between the mining areas;
- There are several monitoring boreholes in the potential affected area that currently experience a decline in water levels of 5m or more. Two privately owned boreholes are in close proximity of the opencasts, namely NBH6 and NBH20. NBH6 is an old windpump and is not in use. NBH20 is in use as a communal well but has been dry since the beginning of 2014 according to locals. However, monitoring boreholes DFTNM11 and DFTNM12 are located close to NBH20 but show no impact on groundwater levels. Therefore it is not likely that NBH20 is impacted upon by the dewatering at Dorstfontein East. It is not expected that the dewatering activities will impact negatively on existing privately owned boreholes.

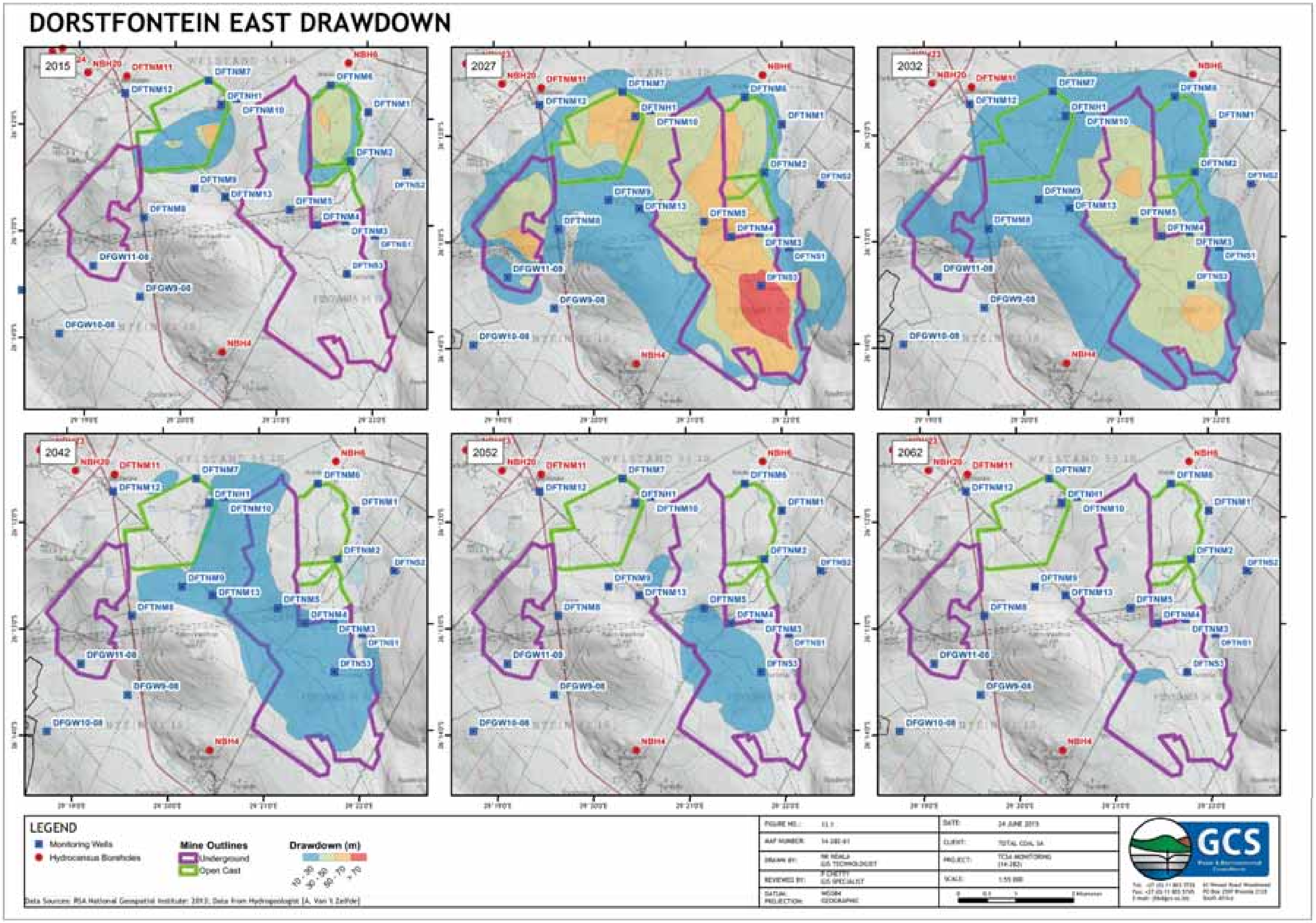


Figure 13.1: Drawdown Dorstfontein East Mine

13.2.2 Mine Inflow Volumes

It was possible to calculate the inflow into the underground workings from the numerical model. The computed inflow into the underground workings was calculated based on the mine schedules and shown below in

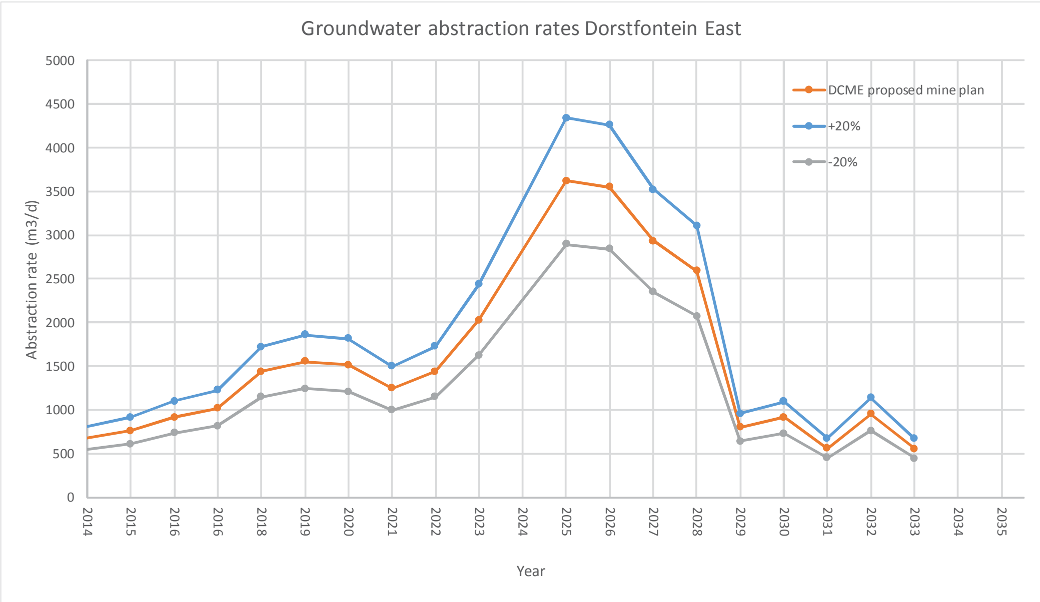


Figure 13.2. Due to several assumptions that had to be made for this model, these numbers must be considered as order of magnitude only, and actual values could deviate considerably from these.

The mine inflow volumes were calculated for the mine plan obtained from the client for the opencast and underground mining of No. 2 and No. 4 seam up to 2032 in three opencast pits and two underground blocks.

The inflow during the opencast mining increases between 2014 and 2017 from approximately 600 m^3/d to 1000 m^3/d mainly due to the increase in size of the mined areas. Between 2017 and 2021 underground 4 seam mining starts which increases the total groundwater inflow to approximately 1500 m^2/d. The groundwater inflow increases significantly between 2021 and 2025 to approximately 3500 m^3/d due to the increasing extent of underground mining of the deeper 2 seam. Between 2025 and 2029 the inflow decreases as in 2027 mining of the deeper 2 seam stops and the increase in mining area per year reduces. After 2029 the inflows are relatively stable around 800 m^2/d.

It is important to view these volumes for the water make of the mine in relation to natural evaporation. Evaporation will take place over the whole area of the opencasts, and will remove large amounts of water, especially in the dry season.

It must be cautioned that these calculations have been done using simplified assumptions of homogeneous aquifer conditions. The reality could deviate substantially from this and the model should thus be updated as more information becomes available.

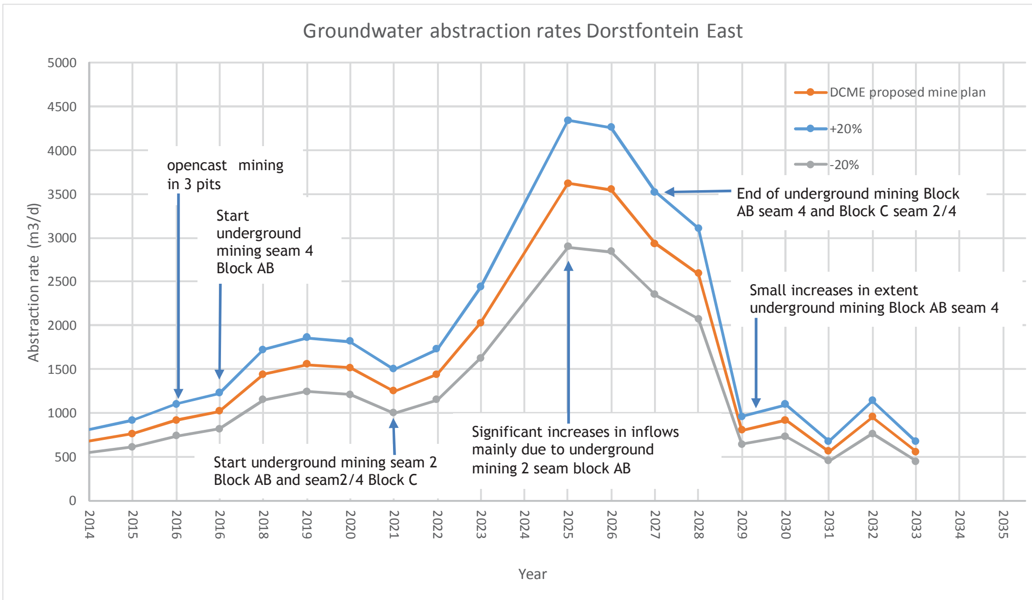


Figure 13.2: Simulated groundwater inflows into the Dorstfontein East opencast mines.

13.2.3 Groundwater Quality (Contamination of the surrounding aquifers)

The life of mine for the existing and proposed mining at Dorstfontein East is planned up to 2032. This allows sufficient time for chemical reactions to take place in the mined out areas, overburden dumps and other potential pollution sources to produce ARD conditions. Groundwater flow directions will be directed towards the mining areas due to the mine dewatering. Therefore contamination will be contained within the mining area, and little contamination will be able to migrate away from the mining area. The water return dam and pollution control dams are lined, thereby preventing contamination of the underlying aquifers. The mine residue consisting of overburden and plant residue is stored as overburden dumps. The fine and coarse waste materials from the pits are stored in a Co-disposal facility.

Contamination from the mining areas is generally contained within the mining areas. It is furthermore evident that boreholes DFTNH1 and DFTNM10 have been impacted by contaminants related to the mining activities. These impacted monitoring boreholes are likely affected by sulphate emanating from the co-disposal facility.

Table 13.1: Impacts on groundwater during Operational Phase

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Water quantity						
Opencast and 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.	Opencast/ underground Mining	24	L	Keeping the workings dry is necessary for mining and mitigation is not possible. No users are currently likely to be affected. Groundwater quality monitoring	24	L
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 opencasts and underground voids and contaminant migration away from the mining areas will be limited during active mining.	Opencast/ underground Mining	25	L	There is nothing that can be done to mitigate contamination from the underground areas. Groundwater quality monitoring	25	L
The co-disposal facility receives coal containing materials from the underground workings being exposed to water and oxygen, resulting in ARD. Contamination of the groundwater system will occur through seepage from the co-disposal facility.	Co-disposal facility	50	M	A co-disposal facility is needed to store the discard materials from the underground workings. Clean water needs to be diverted away from the co-disposal facility as much as possible to reduce seepage to groundwater. Groundwater quality monitoring	50	M

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Stockpiling of coal will expose coal to water and oxygen, resulting in ARD from stockpiles. Contamination of the groundwater system occurs from these sites, although at a lower significance than the opencast pits.	Coal stockpiling	25	L	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. Groundwater quality monitoring	20	L
Handling of waste and transport of materials cause various types of spills (domestic waste, sewage water, hydrocarbons) which can infiltrate and cause contamination of the groundwater system.	Waste Handling	20	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. Groundwater quality monitoring	16	L

13.2.4 Actions

- During the operational phase the mine water must 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 pit the higher it's TDS will be. It is not foreseen that mine water in contact with the pit material will acidify during the operational phase of future mining;
- As much as possible coal must be removed from the opencast/underground mine during the operational phase;
- Proper storm water management should be implemented and maintained. Berms should also be implemented to ensure separation of clean water and dirty water areas;
- Poor quality runoff from dirty areas should be contained and diverted to the pollution control dams for re-use;
- The footprint of dirty water areas like the pollution control dams, water return dam and coal stockpiles, workshops and oil and diesel storage areas should be minimised;
- If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply;
- Static groundwater levels should be monitored to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time;
- The monitoring results must be interpreted annually by a qualified hydrogeologist and network audited annually as well to ensure compliance with regulations;
- Sewage effluent emanating from latrines or ablution blocks should be treated to acceptable levels before discharge into the environment;
- 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;
- 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. 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 or are not operational should be grouted and sealed to prevent cross contamination of aquifers;
- All old exploration boreholes must be sealed off after closure;
- During backfill of the opencasts carbonaceous rocks (especially shale) and discard should be placed in the deepest part of the pit (as far as practical possible) and below the long-term pit water level in order to ensure that it is flooded and that pyrite oxidation is minimized;
- Soft overburden and weathered rock must be placed at the top of the backfill in order to minimize oxygen diffusion into the pit;
- The mined out sections of the pit must be backfilled, compacted and rehabilitated as soon as possible. Rehabilitation must include covering with a topsoil layer as well as vegetation thereof. Installation of a soil cover will significantly decrease water infiltration and contamination. If less water is infiltrating it will not have a negative effect on mine water quality (increasing in TDS) as the salt content is controlled by mineral saturation rather than straightforward dilution;
- The rehabilitated opencasts should be free draining away from the pit to reduce drainage into the pit.
- Boreholes should be drilled into the mine workings so that the rate of flooding and water level recovery and quality can be established. Stage curves should made which would aid in the management of closure phase;

13.3 Post-Closure Phase

13.3.1 Groundwater Quality

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 rainfall. Therefore groundwater contaminant plumes are likely to migrate from the mining areas once the water level in the rehabilitated pits have reached long term steady state conditions (i.e. each pit water level has reached the decant level). The contaminant plumes emanating from the rehabilitated opencasts will have a cumulative impact on the groundwater quality as seen in the post mining simulations (Figure 13.3 and Figure 13.4). The migration of contaminated water from the opencasts has been simulated for 50 and 100 years after colliery closure (i.e. it is assumed that all opencast have been rehabilitated and backfilled). Experience has shown that the plume stagnates after about 80-100 years, and no further movement after such time is expected.

The contaminant plume emanating from the western opencast and the co-disposal facility will move in a northerly direction towards the Olifants River (maximum distance from the mining area is approximately 500 m). The contaminant concentration is likely to increase over time as the plume develops. Shallow contaminated seepage may impact on the non-perennial tributaries to the Olifants River. This impact is however likely to be moderate.

One private borehole, NBH6, located in the fractured Karoo aquifer is likely to be impacted upon based on the impact simulations. However, this borehole does not seem to be in use.

13.3.2 Co-disposal facility

The co-disposal facility at Dorstfontein East 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. 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 rainfall 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 DCME co-disposal facility 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 co-disposal facility 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 co-disposal facility. 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 co-disposal facility with an impermeable cover or a combination of the systems mentioned above. It is recommended that a detail cover design is determined for the co-disposal facility 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.

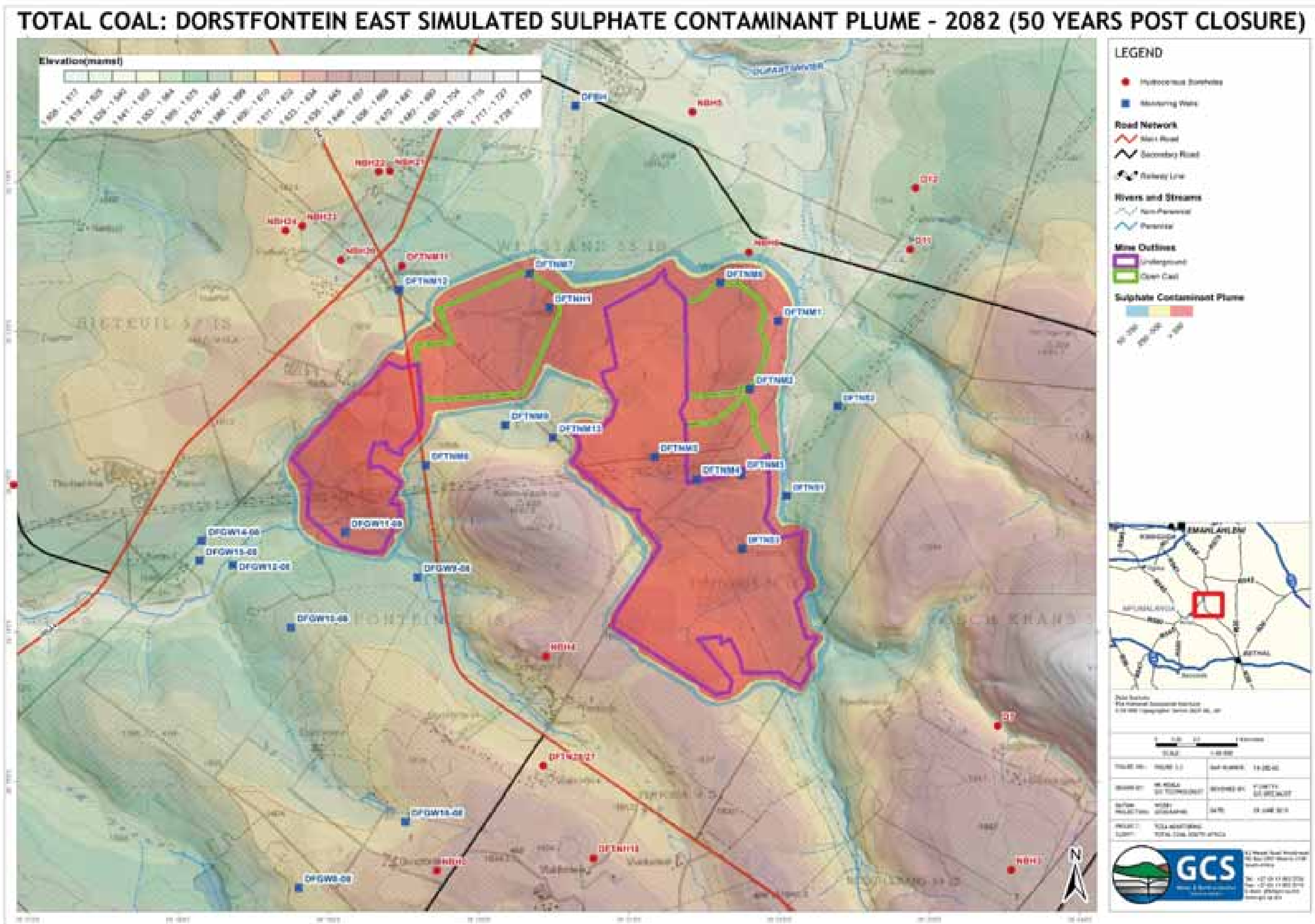


Figure 13.3: Simulated sulphate contaminant plume – 2070 (50 years post closure, confirmed mine plan)

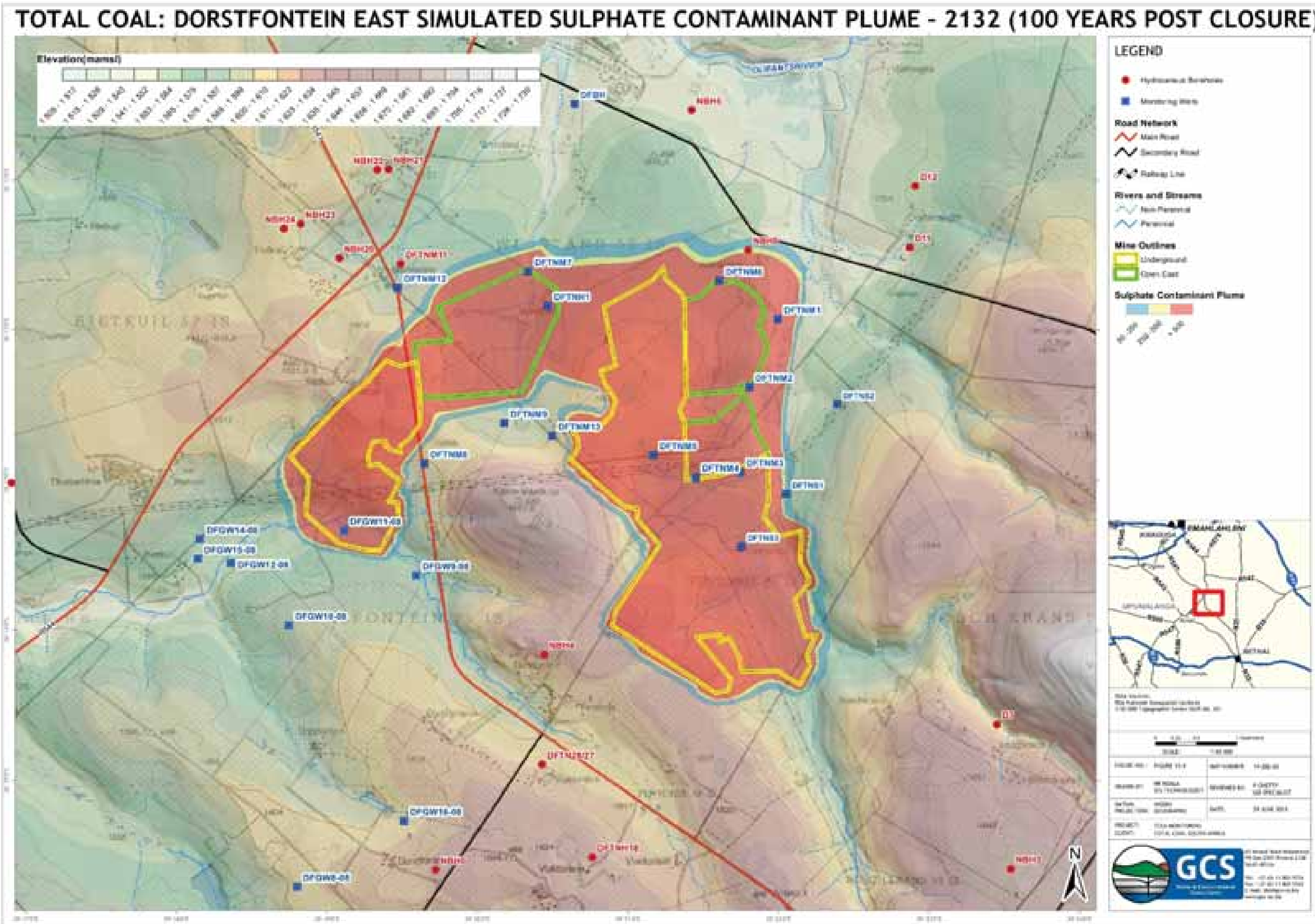


Figure 13.4: Simulated sulphate contaminant plume - 2120 (100 years post closure, confirmed mine plan)

13.3.3 Mine Water Decant

For open pit mining the decant point can be established as the lowest topographical point of the pit outline at the end of life of mine. When mining dewatering has ceased the groundwater level will tend to recover to pre-mining conditions. Decant will occur when the groundwater level recovers to above the lowest surface elevation of the pit. This can occur long after the end of life of mine and is referred to as the time-to-decant. For underground mines decanting occurs mainly at entrances to the underground workings such as shafts and box cuts.

At Dorstfontein East three opencast mines are planned. Based on the mine plans and topography potential decant points have been determined for each pit (Figure 13.5).

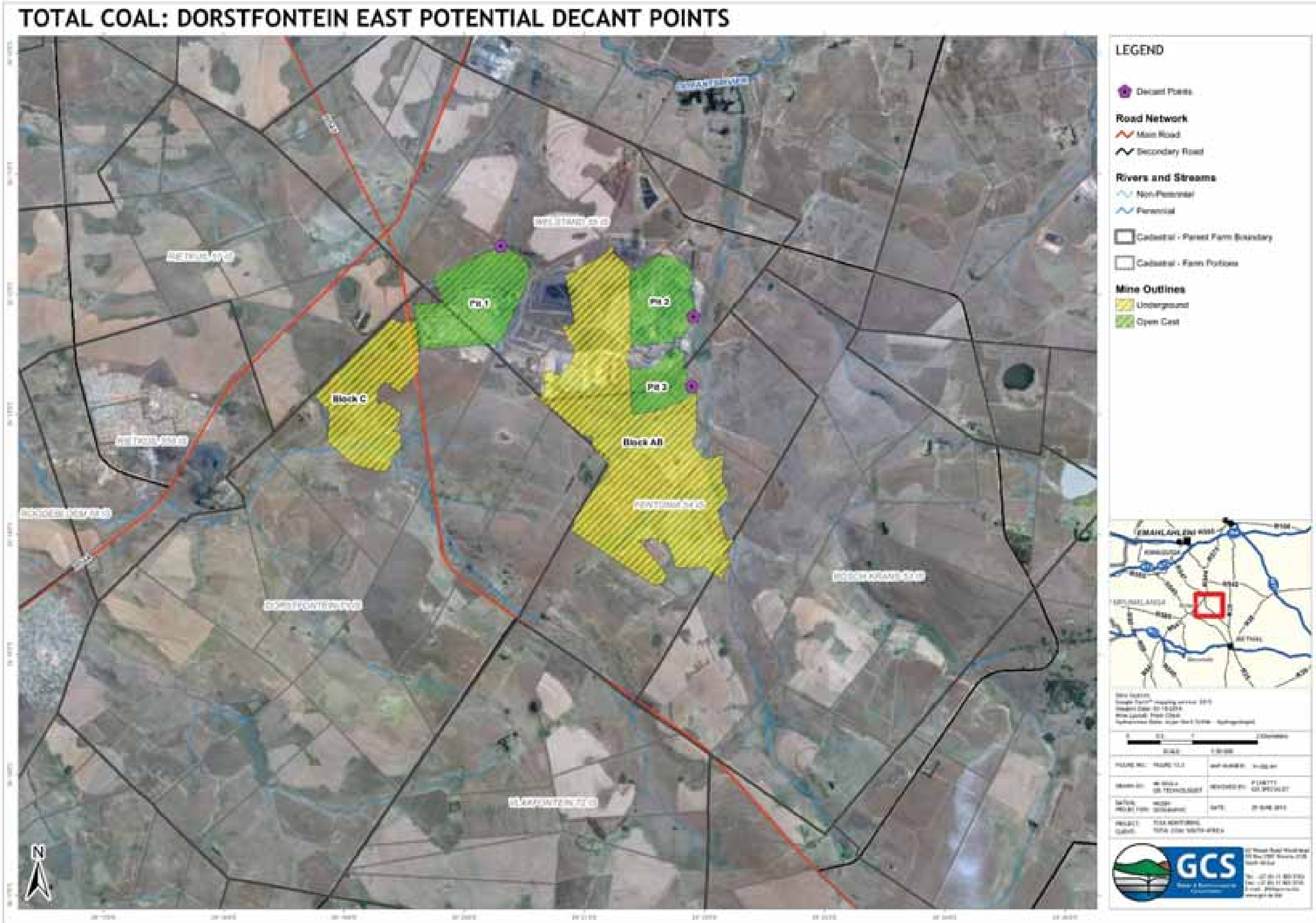


Figure 13.5: Potential Decant Points Dorstfontein East

The time-to-decant and decant volumes calculations were carried out using spreadsheet calculations. The volume of the opencast mines at Dorstfontein East was based on the depth and extent of the No. 2 and No. 4 coal seams. It is assumed the pits will be backfilled.

Values for porosity and recharge to opencast areas were taken from information on rehabilitation of the DCME opencast areas as obtained from Golder & Associates and du Plessis, J.L., 2010, "Decant Calculations and Groundwater – Surface Water Interaction in an Opencast Coal Mining Environment". The porosity of the backfill material was taken to be between 15% and 25% of the total mined volume. A recharge rate of between 6.5% and 16% was used for the time-to-decant and decant volume calculations. The lower recharge rate was taken based on the information of the current rehabilitation plan.

The calculations show that the time-to-decant ranges between approximately 25 and 150 years. Decant volume calculations show discharge rates of between approximately 91 and 585 m^3/d.

Table 13.2 Opencast mine volume calculations

	Total mined volume m^3 (below decant position)	Void volume (15% effective porosity)	Void volume (25% effective porosity)
Pit 1	53310693	7996604	13327673
Pit 2	22047489	3307123	5511872
Pit 3	17073083	2560962	4268271

Table 13.3 Time-to-decant calculations (years).

	Worst case scenario	Best case scenario
	Effective porosity 15%	Effective porosity 25%
	Recharge 16%	Recharge 6.5%
Pit 1	37	154
Pit 2	25	102
Pit 3	31	128

Table 13.4 Decant volumes (m^3/d).

	Pit surface area (m^2)	Recharge 6.5%	Recharge 16%
Pit 1	1878788	238	585
Pit 2	1165550	147	363
Pit 3	719924	91	224

However, decant discharge rates could be higher if the underground blocks stay interconnected with the opencasts. Groundwater from Block C would then flow into pit 1 and groundwater from Block A and B would flow into pit 2. This would increase the decant volumes as shown in Table 13.7. Time-to-decant will increase if the underground voids stay interconnected with the opencasts as shown in Table 13.6

Table 13.5 Decant volumes (m^3/d) including contribution from underground.

	Pit surface area (m^2)	Recharge 6.5%	Recharge 16%
Pit 1	1878788	359	706
Pit 2	1165550	184	400
Pit 3	719924	91	224

Table 13.6 Time-to-decant calculations (years) including underground.

	Worst case scenario	Best case scenario
	Effective porosity 15%	Effective porosity 25%
	Recharge 16%	Recharge 6.5%
Pit 1	34	93
Pit 2	60	146
Pit 3	31	128

Decant from pit 1 will flow towards the western tributary of the Olifants River; the decant from Pit 2 and 3 will flow towards the eastern tributary of the Olifants River. Potentially the quality of decant water could be in the range of 3000 mg/l. The calculated volumes and quality of the potential decant indicates a high impact on the water quality of the Olifants River and the tributaries on the site. To reduce the impact on surface water quality a water treatment plant may be needed to increase the water quality emanating from the opencast areas.

Table 13.7: Impacts on groundwater during Closure Phase

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Water Quality						
Contaminated groundwater seepage to streams (salt load)	Rehabilitated mining areas	53	M	Groundwater levels in the backfilled pits will recover. Pollution plumes may migrate to surface water bodies. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas. The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. 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 is an option to investigate.	40	M
Groundwater contaminant plume	Rehabilitated mining areas	55	M	Groundwater levels in the backfilled pits will recover. Pollution plumes may migrate to surface water bodies. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas. The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. Intercepting decant by a downstream trench is also an option to investigate. 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. The absence of groundwater users should be assessed bi-annually	45	M
Mine decant	Residual Impacts Post Closure (All Opencast)	60	H	It is very difficult to mitigate against AMD, as is evidenced by the water quality concerns within the Upper Olifants River catchment. 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 mine should also 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. Treating of decanting mine water to acceptable water quality levels can be achieved by the installation of a treatment plant. TCSA must continue with the investigations to the most effective way to possibly treat water on site if needed at the end of LoM. 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. Water treatment plants are however very energy intensive, raising questions about the long term viability of treatment plants as a solution to AMD, especially given the energy crisis in South Africa and South Africa's dependence on coal as a source of electricity. The installation of an RO plant should be seen as a last option. Hodgson et al. (WRC Report 1263/1/07; 2007) recommend the following measures for management of mine water: The feasibility and effectiveness of employing these measures at Dorstfontein should be investigated. 1)Select the mining method based on environmental considerations (deep bord-and-pillar mining generates the smallest water volumes, opencast mining the highest.); 2)Mine from deep to shallow; 3)Flood the mine workings; 4)Flush the mines after being flooded	35	M

POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Deterioration in water quality	Rehabilitated mining areas	60	H	It is very difficult to mitigate against Acid Mine Drainage. Current standard practice does not successfully deal with this problem, as evidenced by the water quality concerns within the Upper Olifants catchment. Typically mitigation measures follow one of two routes (or a combination of both): 1) Limiting the amount of water entering the voids left by the mined out areas can be achieved by replacing spoils in such a manner as to be free-draining and preventing the collection and pooling of water on rehabilitated mined land and thus reducing the volumes of water infiltrating into the old box cut. To further reduce infiltration of water, an impermeable or partially permeable layer should be recreated at variable depth within the rehabilitated landscape. This will prevent deeper infiltration of water into the mined out pits, but will also retain water in the landscape so as to increase productivity and re-create a semblance of the processes driving biodiversity support within the highveld. 2) Treating of decanting mine water to acceptable water quality levels can be achieved by the installation of a treatment plant. TCSA must continue with the investigations to the most effective way to possibly treat water on site if needed at the end of LoM. 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 DWEA. As a minimum, treated water should meet the standards for use for livestock watering and irrigation. Water treatment plants are however very energy intensive, raising questions about the long term viability of treatment plants as a solution to AMD, especially given the energy crisis in South Africa and South Africa's dependence on coal as a source of electricity. The timing, location and amount of decant that is expected to occur post mining should be determined to allow more detailed decisions to be made regarding possible mitigation and management measures to be implemented. The necessity and feasibility of treating the decanting water should also be investigated and treatment implemented if necessary	60	H
Deterioration in water quality	Co-disposal facility	60	H	The same mitigation measures as mentioned during the operational phase will apply, and should be maintained until such a time as seepage water out of the mine dump conforms to the relevant standards for aquatic ecosystems. Rehabilitation of the mine dump should also be undertaken in such a way as to limit infiltration of rain water into the mine dump. The use of a clay layer under the top soil should be investigated and implemented if feasible	60	H

13.3.4 Actions

- 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;
- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite;
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas;
- An evapotranspiration cover should be constructed on top of the opencasts. A capillary break should also be constructed between the overburden/clay and top soil. Root depth of grass is usually 0.4 to 0.6m, therefore the thickness of the top soil should be sufficient to promote root development.
- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts;
- The co-disposal facility needs to be closed and rehabilitated;
- Multiple-level monitoring boreholes must be constructed to monitor base-flow quality within sensitive zones and to monitor groundwater level behaviour in the backfilled pits. Use the results of the monitoring programme to confirm/validate the predicted impacts on groundwater availability and quality after closure;
- Audit the monitoring network annually;
- Update existing predictive tools to verify long-term impacts on groundwater, if required; and
- 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. Regular sampling of streams is essential.

13.4 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.

Groundwater monitoring should be conducted to assess the following:

- <u>The impact of mine dewatering on the surrounding aquifers.</u> 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 will be included in the monitoring programme;
- <u>Groundwater inflow into the mine workings.</u> This will be achieved through monitoring of groundwater levels in the monitoring boreholes as well as measuring water volumes pumped from mining areas;
- <u>Groundwater quality trends</u>. This will be achieved through sampling of the groundwater in the boreholes at the prescribed frequency; and
- <u>The rate of groundwater recovery and the potential for decant after mining ceases</u>. This can be achieved through drilling of additional boreholes into the opencast workings for monitoring purposes. These boreholes should be drilled in the deepest sections of the mine. Stage curves will 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 13.8 In addition to the existing, functioning boreholes the following recommendations are made:

- Boreholes *DFTNM13* should be re-drilled;
- Boreholes down-gradient of the Co-disposal facility, the pollution control dams and Erikson dams should be drilled to monitor the possible impact of these potential sources;
- Boreholes should be drilled into the opencast areas post-closure to measure the rate of groundwater recovery and flooding of the opencast areas.

The existing Dorstfontein East monitoring network and the proposed additional boreholes can be seen in Figure 13.6. It is envisaged that the frequency of monitoring remains on a quarterly basis.

Table 13.8: Groundwater Monitoring Programme

Monitoring position	Sampling interval	Analysis	Water Quality Standards
Construction, Operational, Decommissioning and Post Closure Phases			
All monitoring boreholes	Quarterly: measuring the depth of groundwater levels	• Quarterly groundwater levels since 2010 up to December 2014	N/a
All monitoring boreholes	Quarterly: sampling for water quality analysis	• Full analysis in April and October	South African Water Quality Guidelines: Domestic Use
Rainfall	Daily at the mine	• Rainfall data provided since 2012	N/a

13.4.1 Post-closure 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 seized.
- One monitoring point for each opencast and each underground mining block, for coal both seams are proposed for Dorstfontein East.
- As the aim is to measure recovering groundwater levels these points should be installed at the deepest points for each seam per opencast or underground block.

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 seam 2 and seam 4 overlap at the monitoring location, the monitoring point for seam 2 must be drilled through a pillar, and not a void, in seam 4.

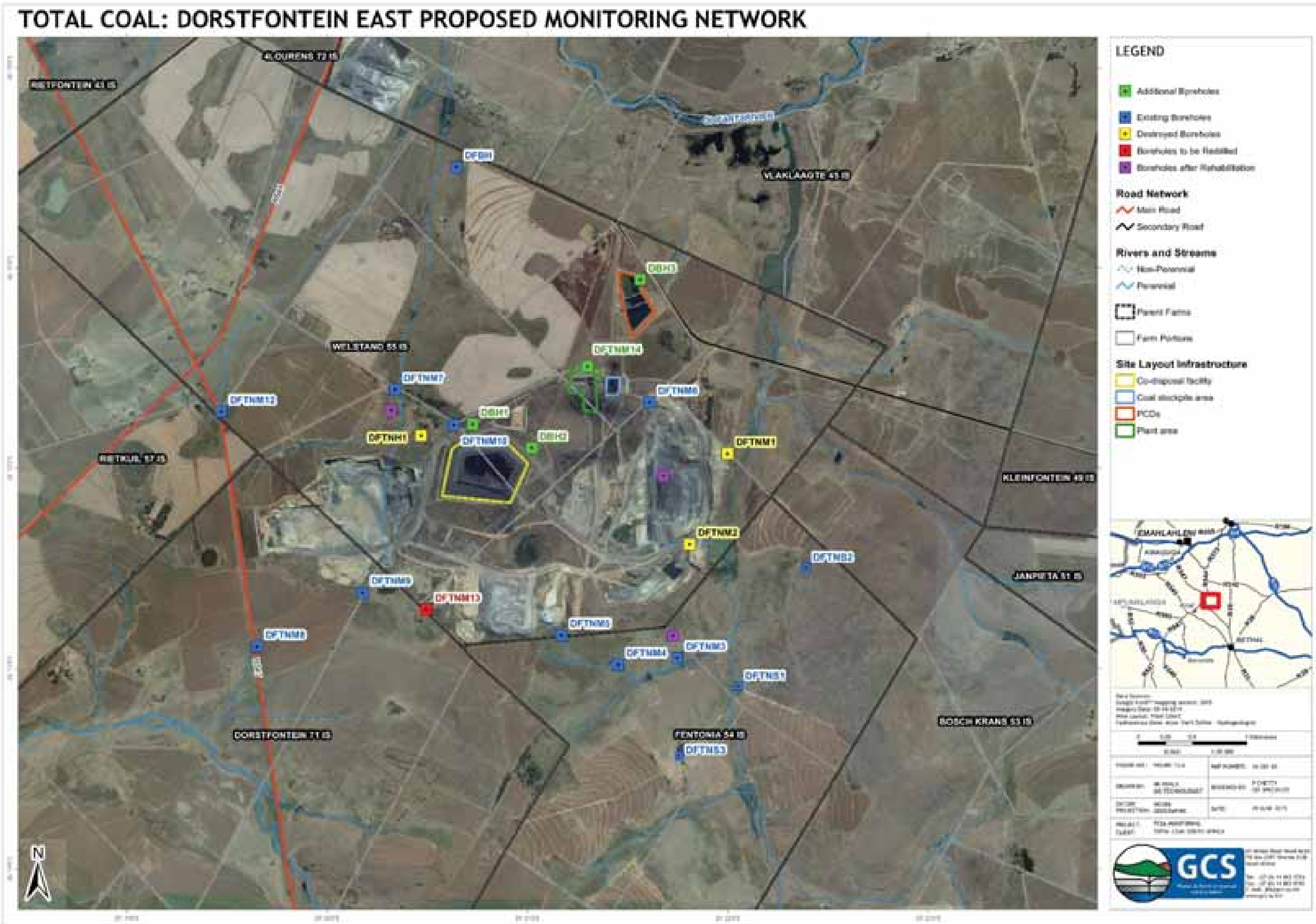


Figure 13.6: Proposed monitoring network

14 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), livestock watering. The groundwater quality in the area is generally good. Groundwater levels generally following topography at an average water level of 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^{-4} m/d for the lower layers. These values are typical of the Karoo type aquifers.

Seepage through the opencast backfill will become acidic over the long-term as the ABA results show that the material has the potential to generate acid-mine drainage. The sandstone and soft overburden have limited potential for acidic generation. Elevation of TDS and sulphate will occur as a result of pyrite oxidation. In the opencast the sulphate concentration will increase roughly to about 3500 mg/l over the long term;

DCME is an existing operation and as a result there are contaminant sources already present such as operational opencasts, operational underground workings, a co-disposal facility, coal stock piles, pollution control and return water dams and a plant area.

Monitoring boreholes DFTNH1 and DFTNM10 (down gradient of the co-disposal facility) indicate elevated sulphate concentrations. Based on these results there is a small sulfate plume localized near the co-disposal facility.

At the time of the investigation boreholes *DFTNM8, DFTNM9, DFTNM12* and *DFBH* were slightly affected and *DFTNM3, DFTNM7, DFTNM10* and *DFTNH1* were affected to a higher degree by the drawdown cone of the existing mining activities.

As a result of dewatering groundwater levels could be lowered over relative large area around the opencasts. Calculated groundwater inflow volumes are between 600 m^3/d and 3500 m^3/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 DCME. However, monitoring boreholes DFTNM10 and DFTNH1 were however affected by contaminants emanating from the Co-disposal facility. The impact significance is likely to be low during the operational phase.

There are several monitoring boreholes in the potential affected area that currently experience a decline in water levels of 5 m or more. It is not expected that the dewatering activities will impact negatively on existing privately owned boreholes.

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 rainfall. The contaminant plume emanating from the western opencast and the co-disposal facility will move in a northerly direction towards an unnamed non-perennial tributary of the Olifants River. The contaminant plume migrating from the two eastern opencasts will move in an easterly direction towards another unnamed non-perennial tributary of the Olifants River.

Shallow contaminated seepage may impact on the unnamed non-perennial tributaries to the Olifants River. This impact is however likely to be moderate. No privately owned boreholes located in the fractured Karoo aquifer are likely to be impacted upon based on the impact simulations.

Three potential decant points have been determined for the opencast pits. The decant calculations show that with varying porosity and recharge rates the time-to-decant ranges between 25 and 154 years and the discharge rate ranges between approximately 91 and 585 m^3/d. The impact of decant on surface water is likely to be high. It is proposed to treat the water emanating for the opencasts to increase the decant water quality.

The following recommendations are made:

- The groundwater monitoring network should be expanded for the existing and future mining activities at Dorstfontein East. Refer to paragraph 13.4 for the proposed monitoring network.
- The rate of water level recovery in the backfilled opencast areas and underground voids should be monitored. The monitoring boreholes should be located in the deepest parts of the opencast and underground parts of the mine. Stage curves should be developed which would aid in the management of closure phase.

- 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. Updates to the model should be carried out more frequently if significant changes are made to the mine schedule or plan.

15 REFERENCES

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