DIGBY WELLS ENVIRONMENTAL

Environmental Impact Assessment for Sasol Syferfontein Block 4 Expansion

Groundwater Report

Project Number:

SAS1744

Prepared for:

Sasol Mining (Pty) Ltd

January 2015

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Project Name:	**Environmental Impact Assessment for Sasol Syferfontein Block 4 Expansion**
Project Code:	**SAS1744**

Name	Responsibility	Signature	Date
Robel Gebrekristos	Author		14 January 2015
Lucas Smith	Review		15 September 2014

EXECUTIVE SUMMARY

Digby Wells Environmental (hereafter Digby Wells) has been appointed by Sasol Mining (Pty) Ltd (hereafter Sasol), as the independent Environmental Assessment Practitioner (EAP) to undertake an Environmental Impact Assessment (EIA) and associated studies for the proposed underground coal mine near the town of Secunda, Mpumalanga Province. This study assesses the groundwater usage and conditions (such as water quality and depth) before the mine operations are commenced as well as the prediction of mine impact on the groundwater environment during and after the mining operations.

The groundwater study can be grouped into the baseline and numerical modelling components. While the numerical model can be used for impact prediction and management planning, the baseline study can be used for future comparisons to evaluate if the proposed mine has impacted the groundwater.

The following conclusions are made based on the baseline hydrogeological assessment:

- A total of 66 boreholes were recorded during the hydrocensus. Of this:
  - 15 are used for drinking only;
  - 6 are used for drinking and livestock watering;
  - 5 are used for livestock watering only;
  - 1 is used for game watering;
  - 1 is used for drinking and game watering;
  - 1 is used for drinking, livestock and game purposes;
  - 10 are used for groundwater monitoring by the existing Syferfontein Mine;
  - 22 are boreholes of unknown use; and
  - The remaining 5 are unused.
- Fourteen representative boreholes were sampled for baseline water quality study:
  - None of the boreholes have elevated sulphate levels, which is indicative of little mine-related contamination to date;
  - Six of the boreholes are categorised as Class I water and are suitable for human consumption;
  - Four boreholes fall within the Class II range of the SANS 241:2005 standard. This is due to elevated nitrate, sodium, iron and manganese values; and
  - Four boreholes are not recommended for human consumption (exceeding the Class II range). This is due to high levels of fluoride and nitrate.

- The baseline water levels range between 0.3 m and 69.7 m below ground level (mbgl). The relatively large water level variation in a relatively short distance may indicate that some of the boreholes are near groundwater abstraction points or possibly from different aquifers.
- The groundwater flow direction is similar to the topography and is towards the streams on the east (Trichardspruit) and northwest (Dwars-in-die-wegspruit).
- Acid-base accounting analysis conducted illustrates that:
  - The average sulphide content of all of the samples (coal seam, overburden and underburden) is 0.44%, which is above the 0.30% benchmark required to sustainably generate acid. However, the sulphide content of these rocks is less than the typical values obtained from similar rocks of the Witbank Coalfield;
  - The overall conclusion based on the NNP value is that the geochemical compositions of the rocks at the project area are heterogeneous with some areas being likely to generate acid and in other areas slightly acid neutralising; and
  - Based on the ratio of NPR versus sulphide-sulphur of the six samples tested, one sample falls in the potentially acid generating zone, two in the non-acid generating zone, and three in the uncertain zone.
- The water strikes recorded in the aquifer characterisation boreholes are encountered at depths between 20 and 90 m below ground level, with the majority occurring between 60 and 90 mbgl. No water strike was encounter below 90 m, although the boreholes were drilled to a depth of up to 153 m.
- The aquifer permeability within the project area ranges between 10^{-4} m/d and 0.06 m/d.
- Sensitivity analysis shows that the model is more sensitive to the vertical permeability followed equally by all the other parameters. This means that changes in the vertical permeability will have slightly more impact on the model output than the other less sensitive parameters.
- Numerical model simulations show that at the end of operation the cone of dewatering could be up to 5 m in the top weathered aquifer. However, no private boreholes have been identified during the hydrocensus that fall within the radius of influence.
- The groundwater inflow rate is expected to increase, as the mine area increases, from 126 m^3/d (in 2015) to 710 m^3/d (in 2042).
- Considering the coal seam depth and site hydrogeology, no decant is expected to occur.

The following recommendations are made based on the baseline hydrogeological assessment:

- No mitigation at the project area is recommended during the construction phase since all the activities will take place from the existing Syferfontein Mine.
- If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. This will minimise or avoid oxidation reactions and potential acid generation.
- Abstraction from deep boreholes that are close to the mine workings should be avoided so that contaminants will not migrate away from the mine, towards the abstraction boreholes.
- Nitrate-based explosives should be avoided, if possible, to minimise groundwater contamination.
- It is recommended that the mine supply water to affected parties that rely on groundwater in the receiving environment, if proven that there is impact on specific users.
- Monitoring of groundwater quality and water levels is recommended (particularly down gradient of the mine site) with continuous refining and updating of the monitoring network based on the results obtained.
- Refine the conceptual and numerical models every year in the first four years and thereafter every five years based on groundwater monitoring results.
- Annual audits of monitoring and management systems should be conducted by independent environmental consultants.
- Groundwater monitoring has to continue during all phases of the mine operation to identify impacts on the groundwater environment over time. Effective measures can be undertaken at an early stage before serious damage to the environment takes place. There are several pieces of legislations that deal with the water management and water contamination prevention and the monitoring programme has to be conducted to ensure compliance with these legislations.
- The streams in the project area are gaining, with groundwater in the weathered aquifer contributing to baseflow of the streams. Therefore monitoring should also be conducted on the streams, in addition to the boreholes.
- In total 24 monitoring points are recommended for the purpose groundwater monitoring.
- Analyses of the following constituents are recommended:
  - Macro Analysis i.e. Ca, Mg, Na, K, SO_4, NO_3, F, Cl;
  - Full suite metals and then As, Al, Fe, Mn and other metals identified according to results of the initial analyses;
  - pH and Alkalinity; and

- TDS and EC.
- Since the model is more sensitive to the vertical permeability, any future groundwater study should focus on and refine this parameter.

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1 Introduction

Digby Wells Environmental (hereafter Digby Wells) has been appointed by Sasol Mining (Pty) Ltd (hereafter Sasol), as the independent environmental assessment practitioner to undertake an Environmental Impact Assessment (EIA) and associated studies for the proposed Syferfontein Block 4 and extension areas (Syferfontein) underground coal mine near Secunda, Mpumalanga Province.

Sasol Mining is planning to extend the existing Syferfontein Mine into the adjacent Block 4 reserves towards the north-west.

This specialist groundwater study was conducted as part of the overall EIA, to assess the potential impacts and mitigation plans on the groundwater environment during the construction, operation and closure phases of the mine.

1.1 Site Location

The project area is situated in the Mpumalanga Province approximately 120 km east of Johannesburg (Figure 1.1). This area is part of the Highveld Coalfield and falls within the Highveld Ridge and Bethal Magisterial Districts and the East Vaal Regional Services Council.

Details of the direction and distance to the nearest towns are shown in Table 1-1.

Table 1-1: Details of the direction and distance of the nearest towns

Town	Direction	Approximate distance (km)
Kinross	Southwest	2
Evander	South	7
Secunda	Southeast	13
Bethal	East	33
Kriel	Northeast	20
Leandra	West	21

1.2 Mine Description

The mineral deposit is a low-grade bituminous coal (Oryx, 2003) occurring in horizontal seams within the Vryheid Formation. The No. 2, 3, 4 and 5 coal seams are developed in this formation, although only the No. 4 coal seam will be mined at the underground mine using the bord and pillar method.

The Block 4 coal reserve will be accessed through the existing Syferfontein infrastructure. No surface infrastructure is planned to be constructed at the project site. The processing of the coal will occur on Sasol Mining's existing Tweedraai Mining area. The planned life of mine is approximately 24 years (from 2016 to 2040), as shown in the mine plan of Figure 1.3.

The mine plan was incorporated into the groundwater model for impact assessment and groundwater inflow estimations. The groundwater inflow (and associated impact) depends not only on aquifer properties but also on the mining plans and method.

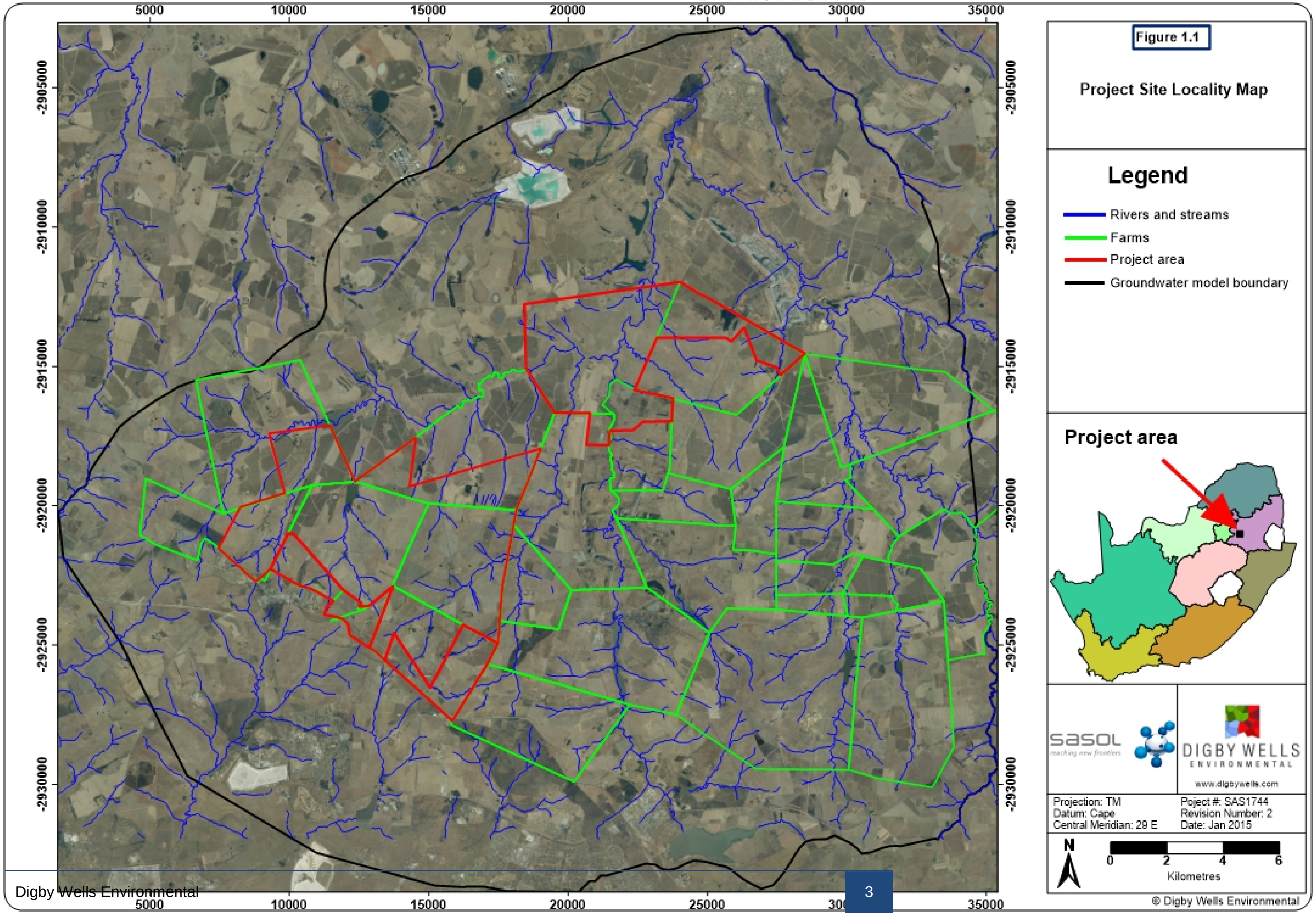
Figure 1.1
Project Site Locality Map
Legend
Rivers and streams
Farms
Project area
Groundwater model boundary
Project area
sasol
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Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
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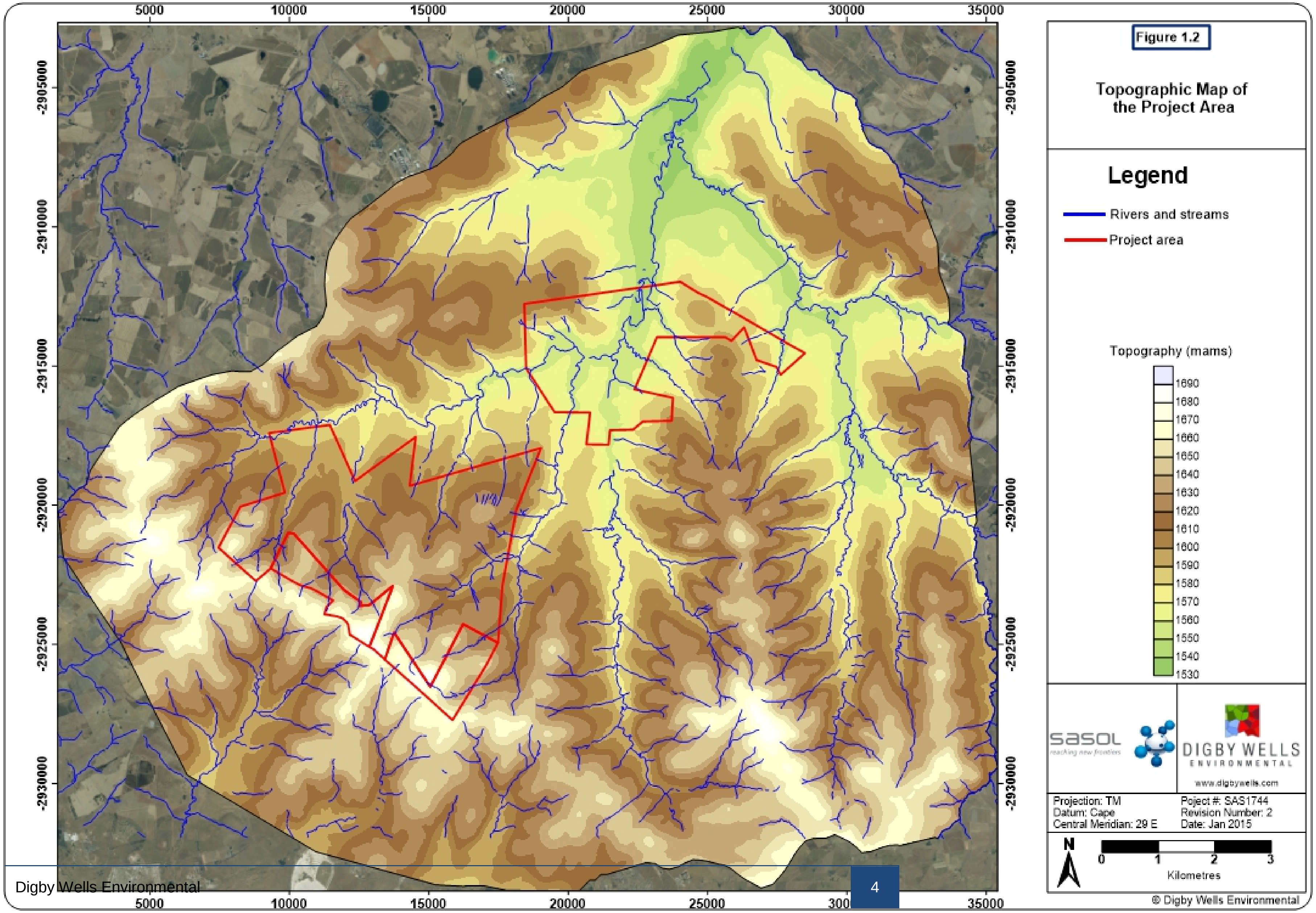
Figure 1.2
Topographic Map of the Project Area
Legend
Rivers and streams
Project area
Topography (mams)
1690
1680
1670
1660
1650
1640
1630
1620
1610
1600
1590
1580
1570
1560
1550
1540
1530
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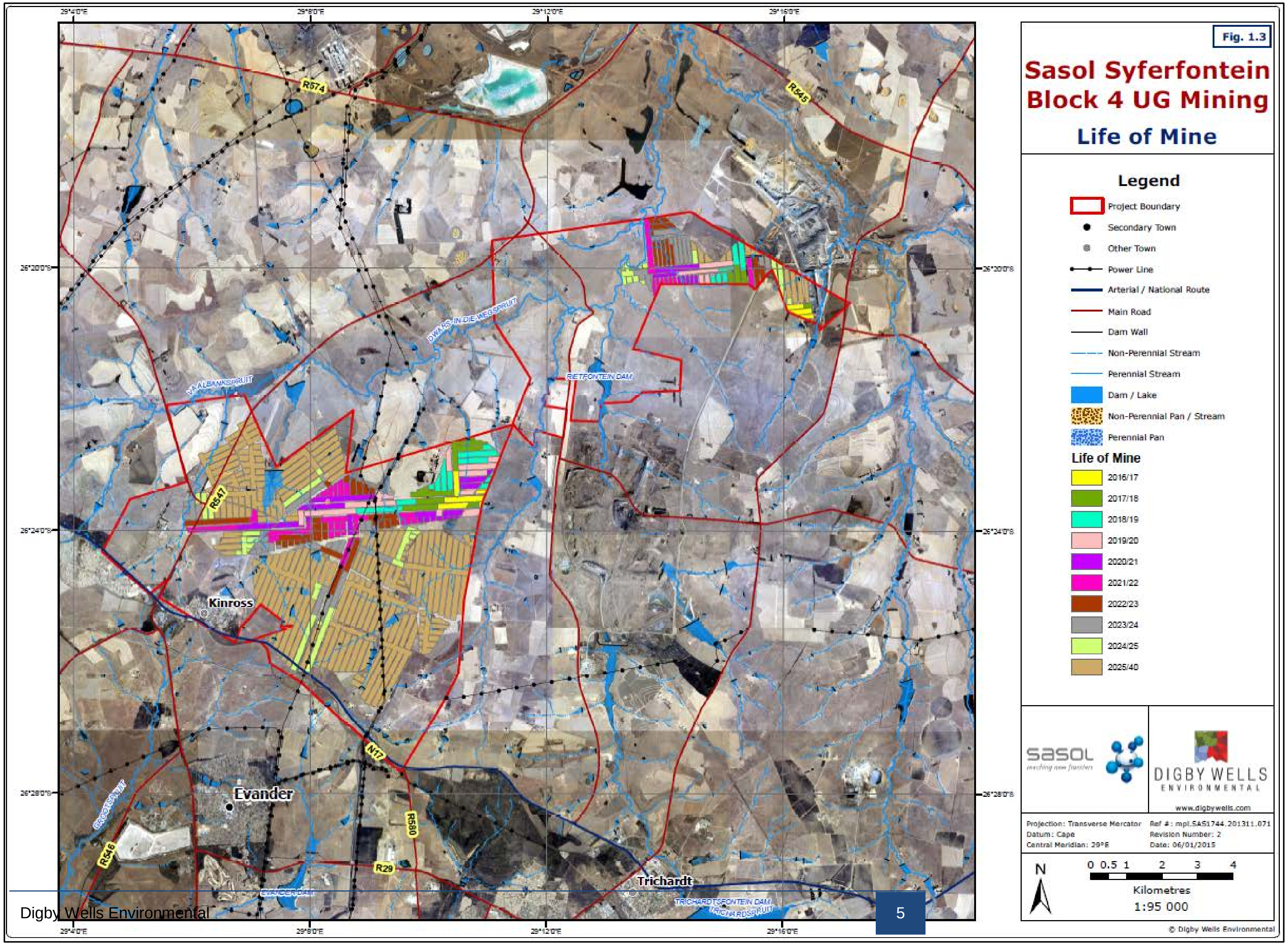
Fig. 1.3
Sasol Syferfontein Block 4 UG Mining
Life of Mine
Legend
Project Boundary
Secondary Town
Other Town
Power Line
Arterial / National Route
Main Road
Dam Wall
Non-Perennial Stream
Perennial Stream
Dam / Lake
Non-Perennial Pan / Stream
Perennial Pan
Life of Mine
2016/17
2017/18
2018/19
2019/20
2020/21
2021/22
2022/23
2023/24
2024/25
2025/40
Kinross
Evander
Trichardt
RETFONTEIN DAM
R574
R545
R547
N17
R580
R546
R29
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Projection: Transverse Mercator
Datum: Cape
Central Meridian: 29°E
Ref #: mpl.SAS1744.201311.071
Revision Number: 2
Date: 06/01/2015
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1.3 Topography and Drainage

The project area falls within the Olifants Water Management Area (WMA 07) and forms part of the Upper Olifants Catchment. The area is located within the quaternary catchment B11D. There are two main surface water drainages within the proximity of Syferfontein, namely the Trichardspruit to the east and Dwars-in-die-wegspruit to the north and west of the site.

The southern part of the area is a topographic high, striking from southeast to northwest. On a site specific scale the topography is sloping towards the local streams. The highest elevation within Syferfontein is approximately 1690 m above mean sea level (m amsl) in the southern portion, while the lowest is approximately 1544 m amsl in the northern portion of the site.

1.4 Climate

This climatic information is extracted from Digby Wells' (2014) Surface Water Specialist Report.

1.4.1 Temperature

Three-year average monthly maximum, mean and minimum temperatures for Syferfontein are given in Table 1-2. The average monthly maximum temperatures range from 21.3°C in January to 7.5°C in July, with monthly minima ranging from 19.9°C in December to 6.6°C in July. Annual mean temperature for Syferfontein is given as 14.5°C.

Table 1-2: Average monthly temperature values of Syferfontein

Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Maximum	21.3	20.2	19.3	15.5	12.2	8.8	7.5	11.0	15.5	17.4	19.5	21.1	15.8
Minimum	19.5	18.6	18.0	13.6	11.1	7.4	6.6	9.7	13.9	17.1	18.6	19.9	14.5
Average	20.5	19.5	11.5	14.7	11.5	8.0	6.9	10.2	14.8	17.2	19.1	20.3	14.5

1.4.2 Precipitation

The Syferfontein Project area lies in the rainfall zone B1A according to the Water Research Commission (WRC) Reports K5/1491 (WRC, 2005). The mean monthly precipitation for the climatic period from 1920 to 2004 is depicted in Figure 1-4.

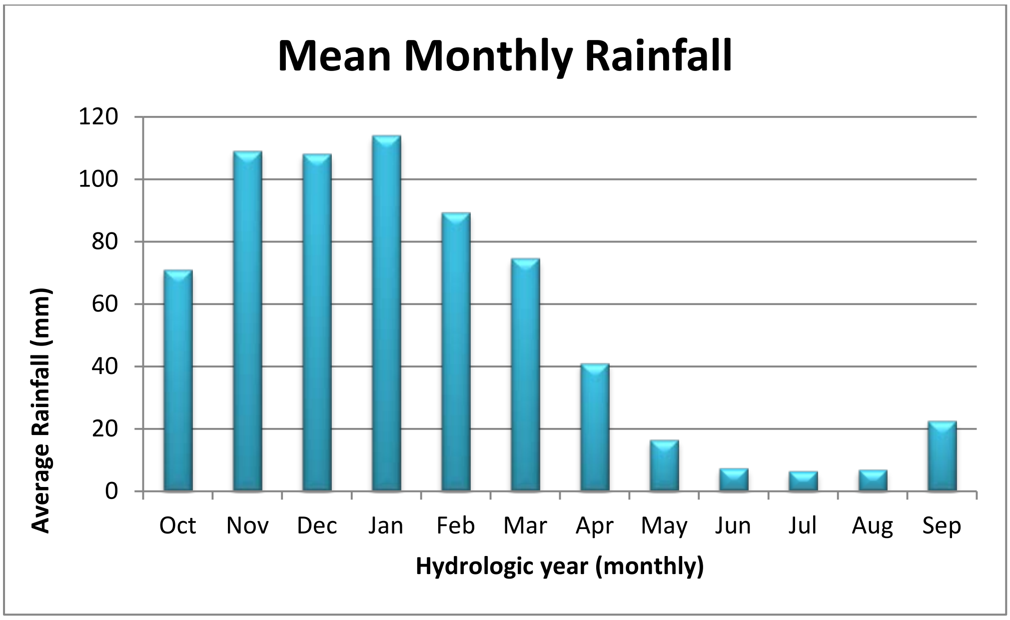

Figure 1-4: WRC, 2005 mean monthly rainfall for rainfall region B1A (1920 to 2004)

Recent records obtained from 2005 to 2011 (Table 1-3) shows that the three year annual maximum, minimum and mean monthly precipitation rates for the Syferfontein site are 82 mm, 43 mm and 57 mm, respectively. The highest monthly maximum precipitation (210 mm) occurs for January. The rate decreases to 8 mm in July. The monthly minimum precipitation ranges between 129 mm in December and no precipitation in June and July.

Table 1-3: Average monthly precipitation derived from the Syferfontein modelled data (2005-2011)

Precipitation (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAP
Maximum	210	92	110	67	16	9	8	28	31	93	116	208	988
Minimum	119	50	49	8	9	0	0	1	19	24	103	129	511
Average	158	77	13	42	13	3	3	10	23	64	110	167	683

1.4.3 Evaporation

As shown in Table 1-4, the annual maximum, minimum and mean monthly evaporation rates for the Standerton area for the period 1960 to 1987 are 186 mm, 89 mm and 140 mm, respectively. The highest monthly maximum evaporation (264 mm) occurs for December. The rate decreases significantly to 106 mm in June. The monthly minimum evaporation ranges between 153 mm in January and 7 mm in April. The South African Weather Statiion (SAWS) stopped monitoring evaporation in 1987.

Table 1-4: Average monthly evaporation values for the Standerton (South African Weather Service)

Evaporation (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAE
Maximum	228	188	196	140	123	106	122	178	231	259	200	264	2235
Minimum	153	110	100	7	60	61	68	89	118	147	140	17	1070
Average	180	149	147	107	95	80	89	131	164	184	168	186	1680

2 Legal Framework

Mining activities associated with the project area have the potential to impact on local groundwater resources over the short and long term through the exposure, disturbance and/or deposition of geological and waste materials.

The groundwater assessment was conducted under the following legislative requirements:

- The protection and use of water is legislated under the National Water Act (Act 36 of 1998) (NWA);
- Impact prediction as per the Department of Water Affairs and Sanitation's best practice guideline for Impact Prediction (2008);
- The assessment methodology is compiled in line with the National Environmental Management Act (Act 107 of 1998) (NEMA); and
- The use of water in mining is regulated under the NWA amendment of Regulation 704 (GN R 704) of 1999.

2.1 Study Objectives

The objectives of this baseline study were to:

- Establish the current groundwater flow characteristics in the saturated zone, considering the aquifer hydraulic parameters, recharge and discharge areas;
- Investigate the current groundwater conditions (water levels and quality). This represents the baseline groundwater conditions for the site considered for potential future liability claims and preparation to final closure application;
- Develop a conceptual and numerical model. This model forms the basis for the groundwater impact assessment, feeding into the overall EIA and IWULA applications;

- Perform Acid-Base Accounting (ABA) studies to evaluate the acid generation and acid neutralisation potential of the coal seam, the rock immediately above and below the coal seam that could be exposed to oxidation during and after mining;
- Estimate the inflow rates into the underground workings over the life of mine;
- Estimate the likely impact of the mine on the receiving environment;
- Simulate the contaminant plumes that could potentially be released from the mining activities;
- Evaluate the post-closure groundwater recovery rates and assess the long-term fate and transport of the contamination plume; and
- Recommend groundwater monitoring, management and pollution mitigation methods to minimise any potential impacts associated with the proposed mining activities.

2.2 Terms of Reference

The baseline groundwater assessment was undertaken within the scope of work outlined below:

- Desktop study: This task involved a review of available hydrogeological, geotechnical, geochemical, mine plans and geological data. Available data was selected and stored in a Water Interpretation System for Hydrogeologists (WISH) database.
- Hydrocensus: A site visit that included a hydrocensus of existing boreholes (community and/or private boreholes) was conducted following the desktop study. This was carried out to initiate the project and define the baseline groundwater usage in the area, as well as to gather information on activities and general groundwater related infrastructures. The hydrocensus findings are given in Appendix A, while the laboratory certificates of the water samples collected during the hydrocensus is available in Appendix B.
- Acid-Base Accounting (ABA) and leachability test: This was conducted to evaluate the acid-mine drainage (AMD) potential of the rock materials as well as the metal leachability under neutral and acidic rain. Samples were collected from the overburden, coal seam and underburden for an AMD assessment. Sulphur speciation was also investigated to determine at what oxidation state the sulphur is found. The laboratory results are given in Appendix C.
- Percussion Drilling: Based on the interpretation of the geophysical survey, site geology and mine plans, eight percussion boreholes were drilled. The drilling programme was aimed at refining the hydrogeological understanding of the site. The borehole logs are logs are given in Appendix D.
- Aquifer Testing: All of the boreholes drilled during this investigation were aquifer tested to determine responses and to calculate the parameters presenting the aquifer

hydro-dynamics underlying the investigation area. The pump test data is available in Appendix E.

3 Methodology

Coordinates in this report are expressed in Transverse Mercator, Lo29 projection and Cape datum, in accordance with Sasol's mapping system. If a different coordinate system is used, it has been described explicitly.

3.1 Desktop Study

In addition to reviewing Sasol Syferfontein's groundwater database, a number of hydrogeological reports were reviewed to define regional and local hydrogeological conditions. These reports are listed in the Reference section of the report.

3.2 Hydrocensus

The hydrocensus was conducted in two runs. The first was undertaken between 15 and 19 April 2013 and was done within a 2 km radius of the proposed Syferfontein Bock 4 area. The second was undertaken between 16 and 20 September 2013 and was conducted within a 2 km of the proposed extension area. The position of the hydrocensus boreholes is shown in Figure 3.1. During the hydrocensus, important data pertaining to the current groundwater conditions and use were collected. These include:

- Borehole locality;
- Owner and property details;
- Borehole depth;
- Rest water level;
- Borehole usage;
- Borehole status, drilling date and equipment;
- Groundwater abstraction rates; and
- Electrical conductivity, pH and groundwater sample details.

To locate and access all known boreholes and surface water sites in the area, the relevant land owners were visited by Digby Wells and they assisted in locating the water sources/ sites. The coordinates of each site were recorded on a handheld Garmin GPS. The equipment and borehole protection zone was then noted and recorded. Access for the dip meter was determined and the water level was measured if possible. The water use was recorded after interviewing the land owners.

A total of 52 boreholes were located within the area of interest as shown in Figure 3.1, with 14 being selected for quality analysis (8 from the Syferfontein Block 4 area and 6 from the extension area). The sites selected for sampling were chosen in an attempt to best represent the area within and bordering the mine site.

Samples were taken using single valve, decontaminated bailers, in the case of accessible boreholes and from pumps or taps in the case of boreholes which were in use; in which case a grab sample was taken. Standard 1 litre sample bottles were used and filled to the top. Samples were delivered to WaterLab in Pretoria for analysis.

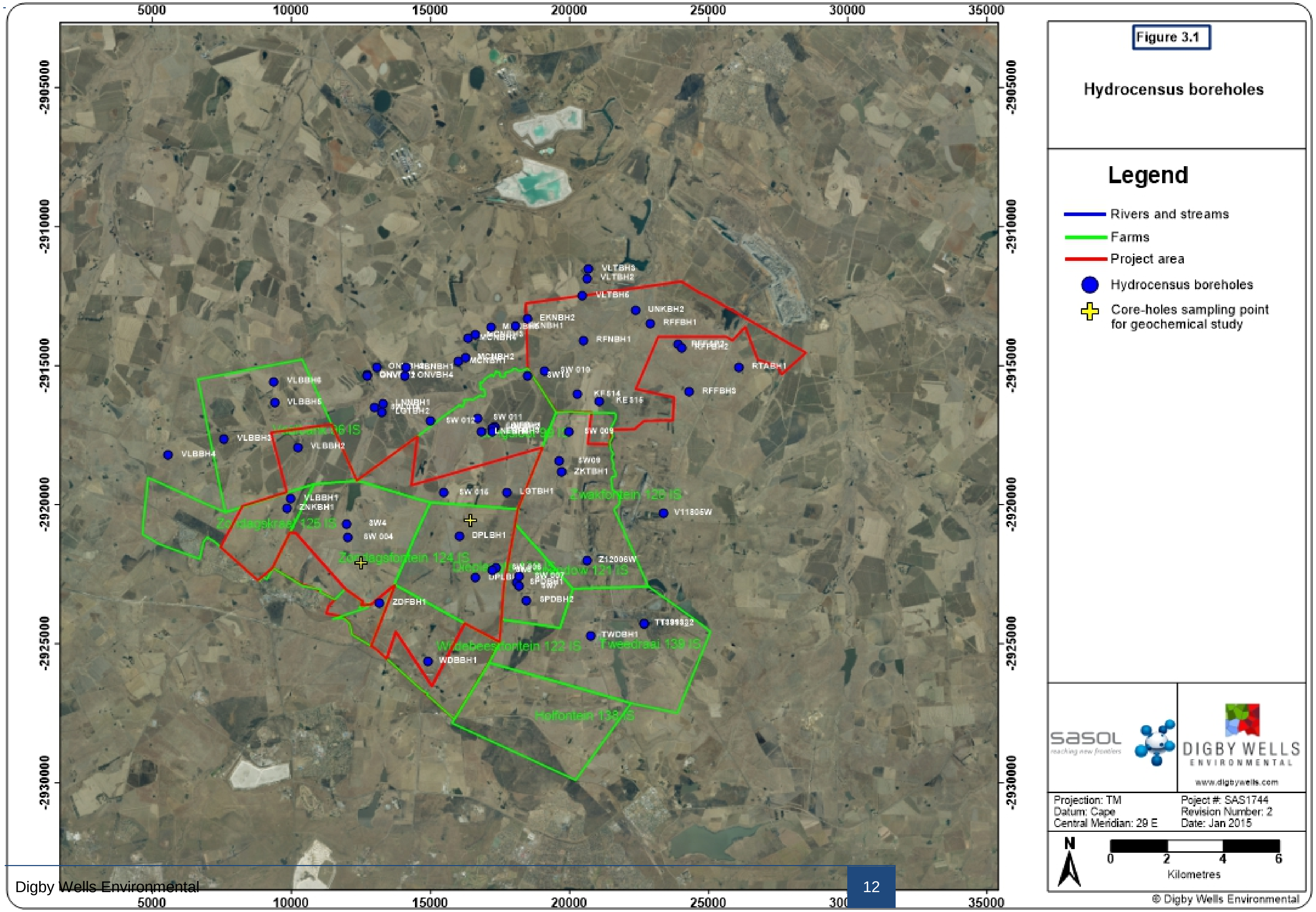
Figure 3.1
Hydrocensus boreholes
Legend
Rivers and streams
Farms
Project area
Hydrocensus boreholes
Core-holes sampling point for geochemical study
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
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Tweedraai 139 IS
Holfontein 138 IS
VLTBH3
VLTBH2
VLTBH6
UNKBH2
RFFBH1
EKNBH2
RFNBH1
RTABH1
RFFBH3
KE 514
KE 515
VLBBH6
VLBBH5
VLBBH3
VLBBH4
VLBBH2
VLBBH1
ZNKBH1
SW 016
LGTBH1
SW09
ZKTBH1
SW 009
V11806W
DPLBH1
Z12006W
SPDBH2
TWDBH1
ZDFBH1
WDBBH1
SW4
SW 004
SW 012
SW 011
MCNBH2
ONVBH4

3.3 Acid-base Accounting and Metal Leachability

Six core-hole samples that were considered to be representative of the project area were collected to estimate the acid generation potential, acid neutralisation potential and metal leachability of the coal and rocks found immediately above and below the coal seam. The samples were collected from two exploration boreholes (D123019 and Z124001) located within the project area as shown in Figure 3.1.

The samples represent:

- Two samples from the overburden (rocks above the No. 4 seams that could be exposed after mining);
- Two samples from the No. 4 coal seam; and
- Two samples from the underburden (rocks below the No. 4 seam that could be exposed after mining).

The sampling was undertaken by Sasol and was delivered to Digby Wells for sorting and submission to WaterLab Laboratory in Pretoria. The test consisted of:

- Phase pH: The paste pH is a type of ABA used to provide a preliminary estimation on the acid generation potential of a rock sample. The sample is placed in a plastic beaker and 10 ml of distilled water (pH 5.33) is added to make a paste. The paste is stirred with a wooden spoon to wet the powder. This way, a quick measure of the relative acid-generating (pH<4) or acid-neutralizing (pH>7) potential of the waste material can be evaluated (Sobek et al. 1978).
- Sulphur Speciation: The objective of sulphur analysis is to identify and measure the concentration of different sulphur species present in the sample. Sulphide minerals are the primary sources of acidity and leaching of trace metals and their measurement is a critical requirement for acid drainage chemistry prediction:
  - A set of rules, which has been derived based on several of the factors calculated in ABA, was reported by Soregaroli and Lawrence (1998). It has been shown that for sustainable long-term acid generation, at least 0.3% Sulphide–S is needed. Values below this can yield acidity, but this is likely to be only of short-term significance.
- Net Neutralisation Potential (NNP): The difference between the Neutralisation Potential (NP) and the Acid Potential (AP) is defined as the Net Neutralisation Potential of the sample (NNP):
  - NP – AP = NNP;
  - A positive NNP would indicate that there is more neutralising material than acid forming material in any given sample, i.e.:
  - NNP < 0 = potential to generate acid;
  - 0<NNP<20 = uncertain sample; and

  - NNP >20 = potential to neutralise acid.

- Neutralisation Potential Ratio: Similar to the NNP, the Neutralisation Potential Ratio (NPR) is used to identify and separate potentially acid generating from not potentially acid generating materials. The NPR is calculated by dividing the NP by the AP. The potential for acid generation was evaluated by using the screening criterion set by Price (1997) as shown in Table 3-1.
- Toxicity Characteristic Leaching Procedure (TCLP) test was conducted on the samples to allow for a static simulation of acid rain seepage through a coal stockpile or storage facility and represent a worst case scenario allowing the analysis of metals that could leach out into solution. In addition, the samples were also leached under distilled water to predict what elements will leach under neutral water.

Table 3-1: Criteria for interpreting ABA results (USEPA 1994; Price 1997)

Potential for AMD	Criterion	Comments
Likely	NPR<1	Potentially acid generating, unless sulphide minerals are non-reactive
Possible	1<NPR<2	Possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides
Low	2<NPR<4	Not potentially acid generating unless significant preferential exposure of sulphide
None	NPR>4	Non-acid generating

3.4 Borehole Drilling

Following the review of mine plans and geological data, percussion boreholes were drilled for aquifer characterisation. The boreholes were placed across the area to gain a representative understanding of the aquifer systems. The boreholes could be used for the long-term groundwater monitoring if require by the client.

Considering the project size, data availability and costing, eight percussion boreholes were drilled. The position of the boreholes in relation to the project area is shown in Figure 3.2 and listed in Table 3-2.

The drilling programme was carried out between 28 January and 28 February 2014 and was supervised by a hydrogeologist from Digby Wells. The drilling was performed using the rotary air percussion method, with an internal diameter of 165 mm. All boreholes were drilled to approximately 5 m below the coal seam and the borehole depths range between 85 and 153 m below surface. Due to the coal seam dip and topographic elevation, boreholes in the north are shallower than those in the south.

The information recorded during drilling includes:

- Lithological profile in 1 m intervals;
- Degree of rock weathering, as weathering may indicate groundwater content;
- Penetration rates;
- Positions of water strikes and corresponding blow yields;
- Details of the borehole construction:
  - The first metres (usually 6 to 12 m depending on the weathered zone depth) of each borehole was drilled using conventional percussion drilling of 203 mm diameter;
  - A starter casing of 203 mm outside diameter was installed across this zone at which point drilling at a diameter of 165 mm were commenced to the final borehole depth;
  - A 165 mm (internal diameter) steel casing was installed across the top section of the borehole; across the unconsolidated and unstable sections of the geology to avoid borehole collapse;
- Rest water level; and
- Final borehole blow yield.

Table 3-2: Info summary of the percussion boreholes drilling during the study

Borehole	X	Y	Elevation (m amsl)	Static Water level (m)	Depth (m)	Date Drilled
SFNBH1	8590	-2921480	1635	10.6	128	01-Feb-14
SFNBH2	10249	-2917897	1591	13.9	95	01-Feb-14
SFNBH3	11242	-2919222	1604	18.4	93	12-Feb-14
SFNBH4	13578	-2919490	1618	37.7	95	11-Feb-14
SFNBH5	13337	-2921322	1619	46.6	115	10-Feb-14
SFNBH6	13824	-2924023	1649	17.66	153	28-Jan-14
SFNBH7	15757	-2922668	1622	48.77	123	14-Feb-14
SFNBH8	17685	-2918907	1601	1.5	85	27-Jan-14

3.5 Aquifer Testing

All new boreholes were aquifer tested to calculate the hydraulic permeability and storativity values presenting the aquifer hydro-dynamics underlying the investigation areas. The test was conducted based on the record listed in Table 3-3.

3.5.1 Pump Testing

Only three of the new boreholes (SFNBH2, 3 and 8) yielded more than 0.2 L/s during the percussion drilling (as indicated in Table 3-3). These boreholes were therefore pump tested.

- The boreholes were first step tested by pumping at increasing rates. Each borehole was tested for 2 hours (each step being 30 minutes long). This was followed by a recovery test of either 2 hours long or to 90% recovery to the static water level, whichever was achieved first.
- Following the response of the boreholes to the step test, an 8-hour constant discharge test was performed in each of the three boreholes. This was again followed by either a 90% recovery of the static water level or 8 hours of recovery measurement.
- All three pump tested boreholes were sampled for hydro-chemical analysis. The laboratory certificate is included in Appendix B.

3.5.2 Slug Testing

Boreholes that yielded below 0.2 L/s were slug tested. The test was conducted by instantaneously adding 60 litres of water to the boreholes. The water level response was measured and recorded by using electronic water level logging devices. The recovery rate was measured for 2 hours after the addition of the slug or until a 90% recovery was achieved. All the slug tested boreholes were sampled for hydro-chemical analysis.

Table 3-3: Aquifer test decision record of the tested boreholes

Borehole ID	Borehole Depth (m)	Final Blow Yield (L/s)	Water Strike depth (m)	Slug test	Step drawdown test	Constant discharge test
SFNBH1	128	seepage	64	x		
SFNBH2	72	1.49	59		x	x
SFNBH3	93	1.11	57		x	x
SFNBH4	95	seepage	11	x		
SFNBH5	115	seepage	62	x		
SFNBH6	175	seepage	85	x		
SFNBH7	123	seepage	17	x		
SFNBH8	88	0.94	64		x	x

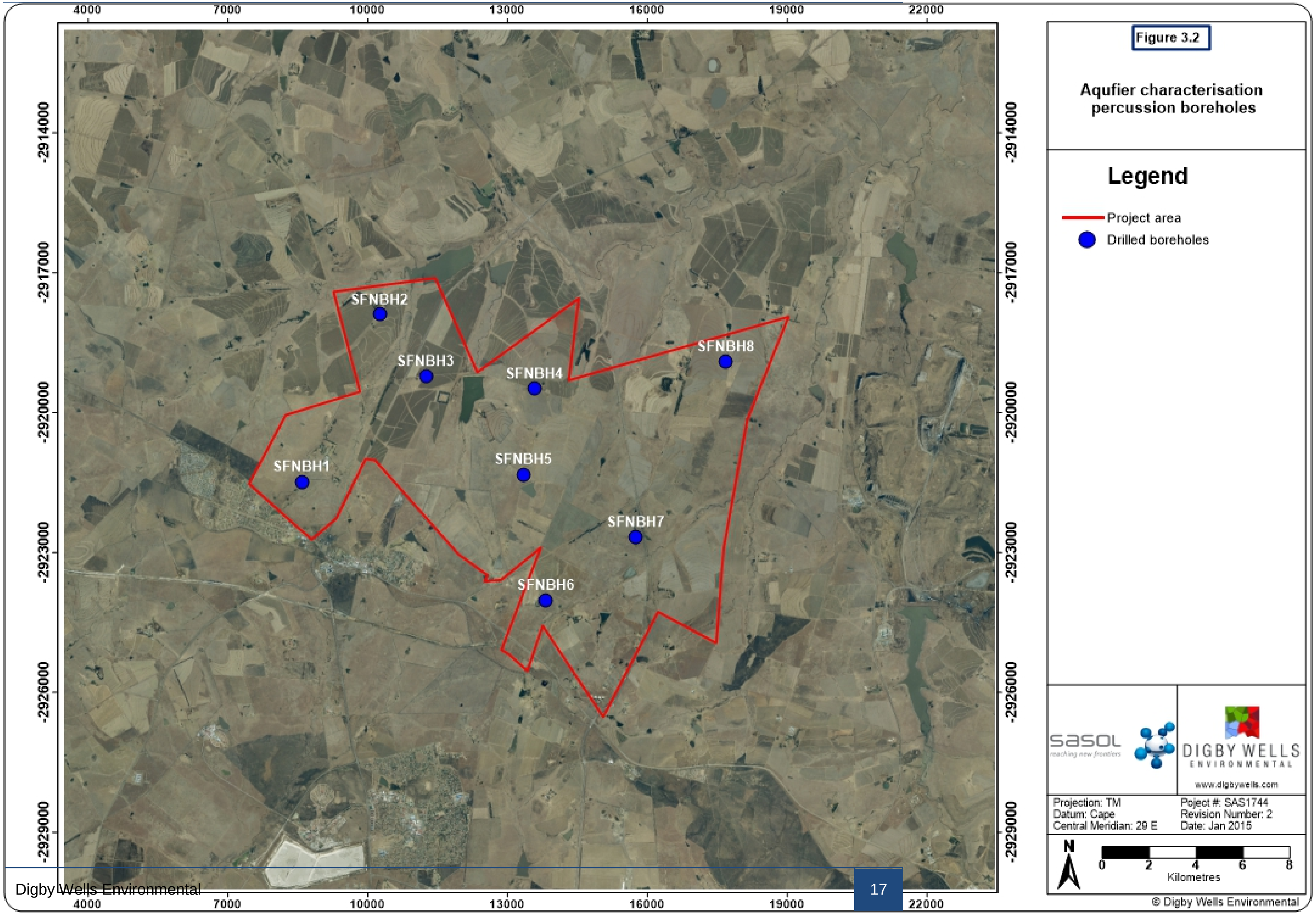
Figure 3.2
Aqufier characterisation percussion boreholes
Legend
Project area
Drilled boreholes
SFNBH1
SFNBH2
SFNBH3
SFNBH4
SFNBH5
SFNBH6
SFNBH7
SFNBH8
4000
7000
10000
13000
16000
19000
22000
-2914000
-2917000
-2920000
-2923000
-2926000
-2929000
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
N
0 2 4 6 8
Kilometres
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3.6 Numerical Modelling

A numerical model was developed to evaluate the potential impact of the proposed mine on the groundwater environment. Steady and transient state flow and transport model simulations were conducted to estimate the groundwater flow direction, groundwater inflow rates into the mine, and size of the contamination plumes at various stages of the life of the mine. Impacts on the streams, private boreholes and farms over time (construction, operational, decommissioning and post-closure phases) have also being addressed.

The software code chosen for the numerical modelling work was the modular 3D finite-difference groundwater flow model MODFLOW. MODFLOW is internationally recognised groundwater model published by the U.S. Geological Survey and is commonly used by groundwater specialists and environmental scientists. Processing MODFLOW Pro (v8.0) was used as a user interface.

The potential contaminant plumes originating from the underground mine were simulated using the transport module MT3DMS. The MT3DMS is utilised for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems.

3.7 Impact Assessment and Mitigation Plans

The model output was used to assess the potential impact of the proposed underground mine on the groundwater environment. In this task, the environmental impacts are rated based on their significance scoring before and after mitigation methods are implemented.

The long-term fate and transport of the contamination plume is assessed as it spreads from the mine footprint.

Finally, the recommended mitigation and management options to further minimise environmental impacts on the groundwater environment are presented.

4 Baseline Hydrogeological Conditions

4.1 Geology

4.1.1 Regional Geology

South Africa's coal deposits occur in the Karoo Supergroup, a thick sequence of sedimentary rocks deposited between 300 and 180 million years ago (McCarthy and Pretorius, 2009).

The project area is located within the Highveld Coalfield. The coalfield is underlain by pre-Karoo strata belonging to the Transvaal Supergroup and Bushveld Complex. Glacial events at the beginning of the Permian Period resulted in the deposition of tillite (Dwyka Formation) on the basement rocks over most of the area. Within the Karoo sedimentary sequence the Ecca Group rest on top of the Dwyka Formation.

The coal seams are found within the Ecca Group. Although rocks of the Ecca Group are widespread around the country, conditions suitable for the formation of coal did not occur everywhere and the coal deposits are restricted, occurring in the main Karoo basin in an arc from Welkom in Free State Province to Nongoma in KwaZulu-Natal, and in several smaller outlying remnants of the Karoo Supergroup (Figure 4.1).

In the Highveld Coalfield, six coal seams (numbered 1 through 6 from the base upwards) are contained in successions comprising dominantly of sandstone with subordinate siltstone, mudstone and shale (Vryheid Formation). Partings between the seams are relatively constant; however, seam splitting is common.

All the coal seams of the Highveld Coalfield are found towards the base of the Ecca Group in the Vryheid Formation. The distribution and attitude of the No. 1 and No. 2 Seams are largely determined by the pre-Karoo topography. Sub-crop positions of all seams are controlled by the present-day erosion surface.

It should be noted that the No. 6 Seam is rarely preserved in the present day strata of the Vryheid Formation. Generally the No. 1, 2, 4 and 5 Seams are considered economic based on seam thickness and quality.

Intrusive dykes and sills, predominately doleritic in composition, are common and devolatilisation of the coal adjacent to the intrusives can be significant.

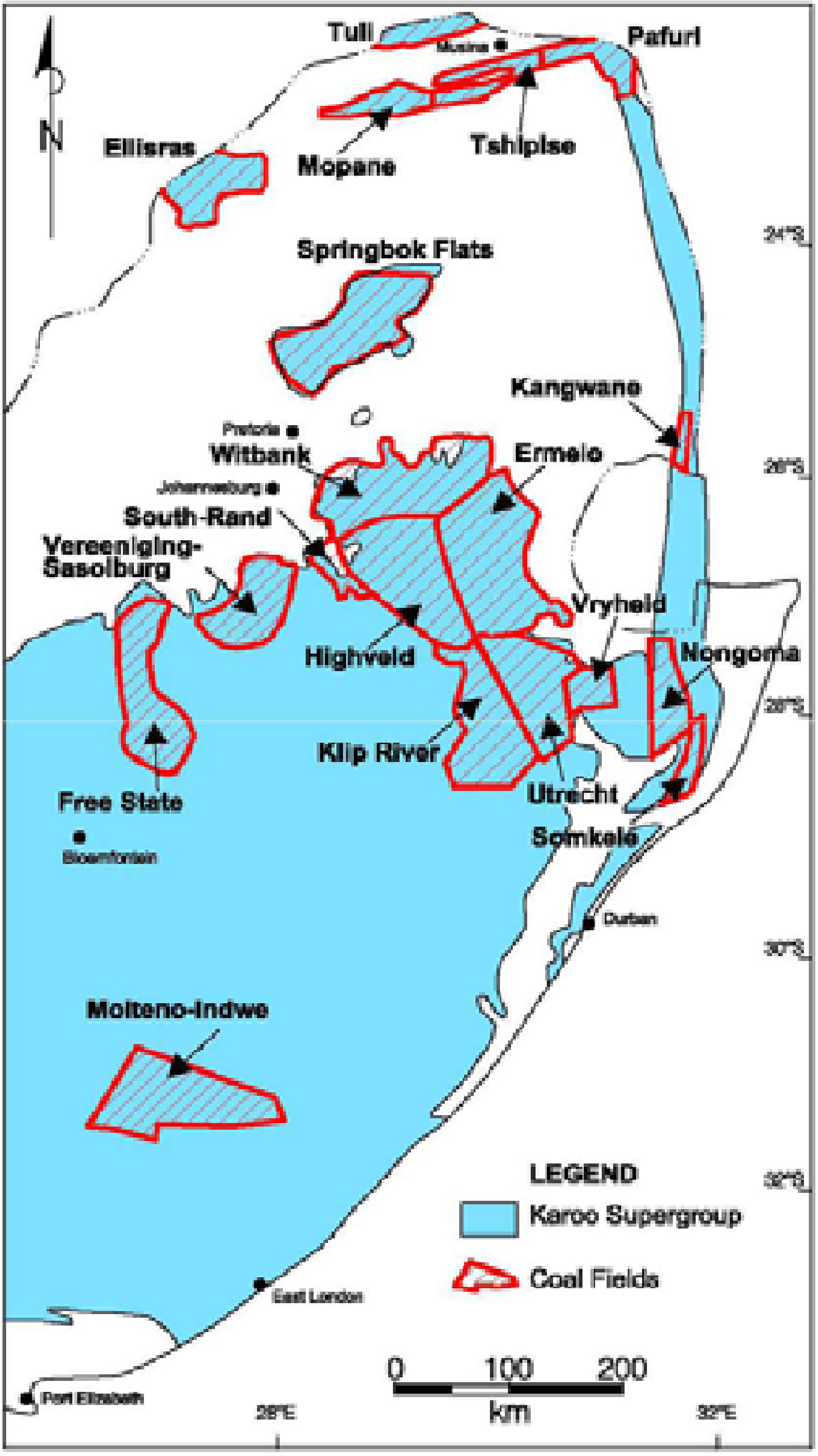

Figure 4.1: Karoo Supergroup and the coalfields regions (McCarthy *et al*, 2006)

4.1.2 Local Geology

Only the No. 4 seam will be mined at the project area, with an approximate thickness of 4.5 m. The other coal seams are either not fully developed, or are discontinued in the area. Available geological and geophysical data show that there are plenty of sills and dykes at the project area that have resulted in the devolatilisation of parts of the coal seam (Figure 4.2).

At the existing Syferfontein Mine, the No.4 coal seam floor forms a NNE-SSW coal floor contour high roughly in the middle of the reserve, ranging in elevation between 1520 and 1527 mamsl (Oryx, 2003). From this central high, the coal floor dips towards an elevation of 1500 mamsl at the highwall entrance of the mine workings. The coal floor also dips towards the eastern part of the reserve to a localised low of 1505 mamsl. Another coal floor elevation low can be seen in the most southern part of the study area, dipping to an elevation of 1495 mamsl.

These 3 low-lying areas form distinct compartments in terms of potential water storage during operational phase mining activities. Depending on the direction and sequence of mining, water can be stored in all of these units.

The Karoo sediments were intruded by two phases of post-Karoo dolerite intrusions (Oryx, 2003). The oldest intrusive (commonly known as the B4 sill), is a fine to medium crystalline dolerite sill, mostly restricted to the surface, with a maximum thickness of 48.5 m. This sill is mostly eroded away in the lower lying areas.

In the northern part of the current Syferfontein strip mine area, the B4 is surface bound, with the base being joint-stepped, sloping downwards in a north-westerly direction from surface, transgressing the No.4 coal seam.

The B8 dolerite is a fine grained (porphyritic) dolerite and intruded later than the B4, along semi-planar features. The result is almost vertical intrusives, ranging in thickness from very thin to a maximum of approximately 19 m.

The B8 dolerite sills usually feature near-vertical offshoots (dykes), where they transfer from one horizontal plane to another. These features occur predominantly along the planes of transference. This phenomenon results in extensive geological/ geohydrological compartmentalisation, mainly in the southern parts of the study area.

The prominent east-west striking dyke that cuts through the current Syferfontein Mine has a thickness of up to 15 m.

Displacement of the coal seams caused by dolerite intrusion is seen to range from no displacement, to more or less the thickness of the given coal seam.

The dolerite occurrences in the area have specific significance with regard to the hydrogeology of the study area. Not only can groundwater compartments exist as a result of these features, but the possible groundwater interaction between mines, will also be a function of the dolerite distribution.

Devolitalisation due to the DO8 and DO4 sills is evident (Figure 4.2). The effect of the DO8 sill extends towards the northeast, while the DO4 sill extends to the west.

The lithological log of one of the boreholes (SFNBH3) drilled at the project site is given in Figure 4.3. The logs of the remaining boreholes are given in the Appendix B.

4.2 Current Groundwater Use

The information obtained during the hydrocensus is available in Appendix A. The groundwater use within the hydrocensus area is displayed in Figure 4.4. A total of 66 boreholes were recorded during hydrocensus. Of this:

- 15 are used for drinking only;
- 6 are used for drinking and livestock watering;
- 5 are used for livestock watering only;
- 1 is used for game watering;
- 1 is used for drinking and game watering;
- 1 is used for drinking, livestock and game purposes;
- 10 are used for groundwater monitoring by the existing Syferfontein mine;
- 22 are boreholes of unknown use; and
- The remaining 5 are unused.

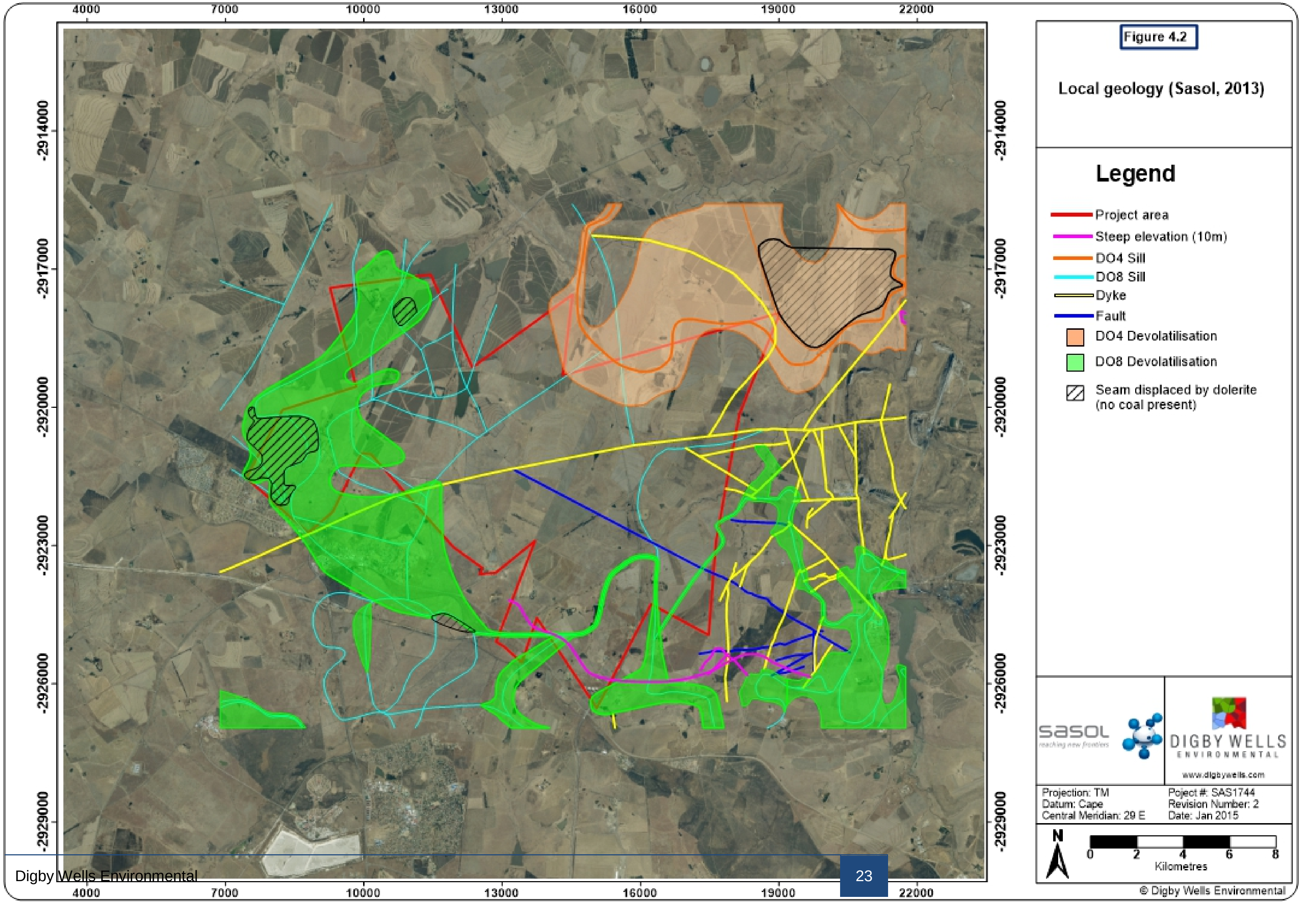
Figure 4.2
Local geology (Sasol, 2013)
Legend
Project area
Steep elevation (10m)
DO4 Sill
DO8 Sill
Dyke
Fault
DO4 Devolatilisation
DO8 Devolatilisation
Seam displaced by dolerite (no coal present)
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Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
N
0 2 4 6 8
Kilometres
© Digby Wells Environmental

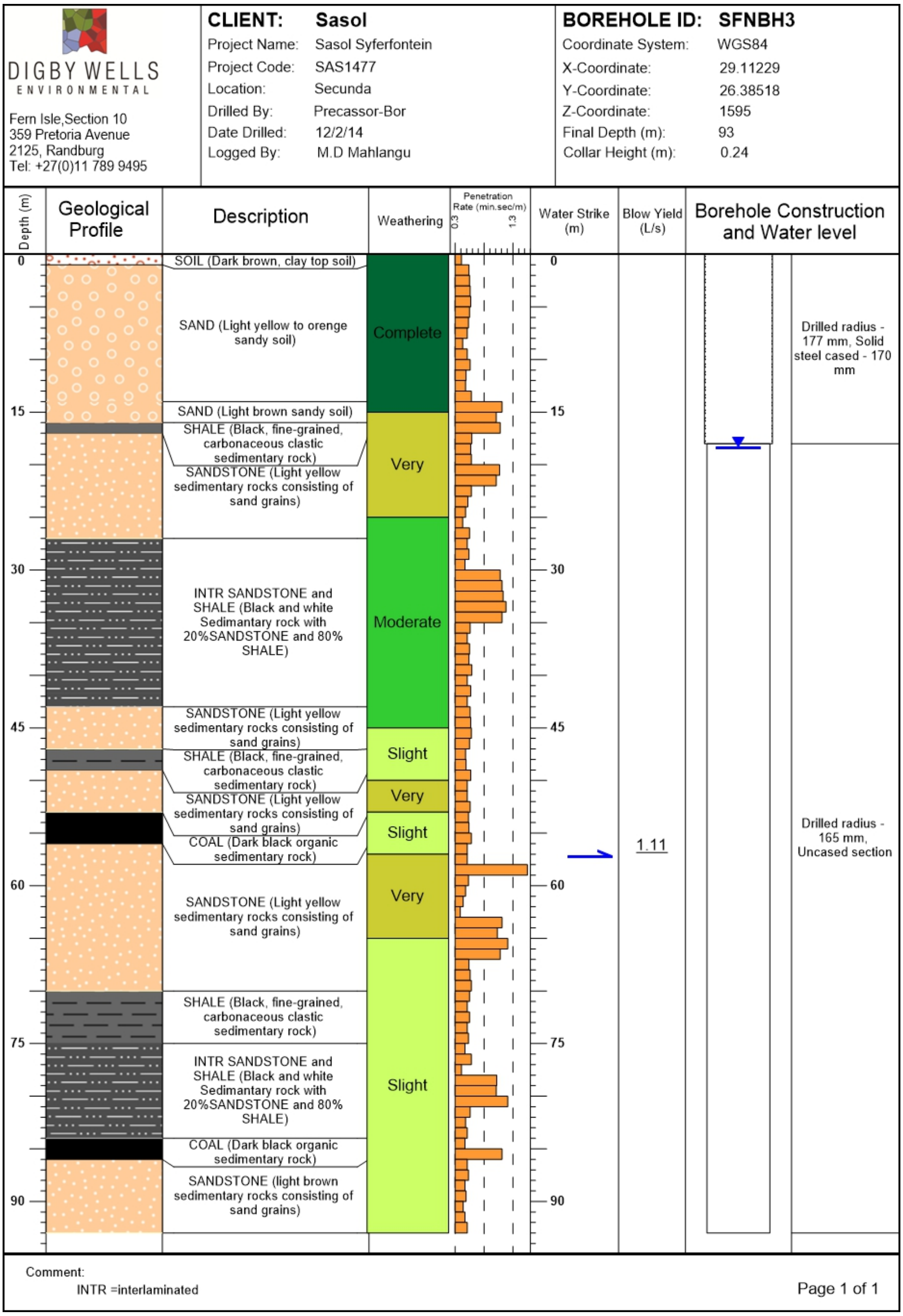

Figure 4.3: An example of a geological profile of the project area

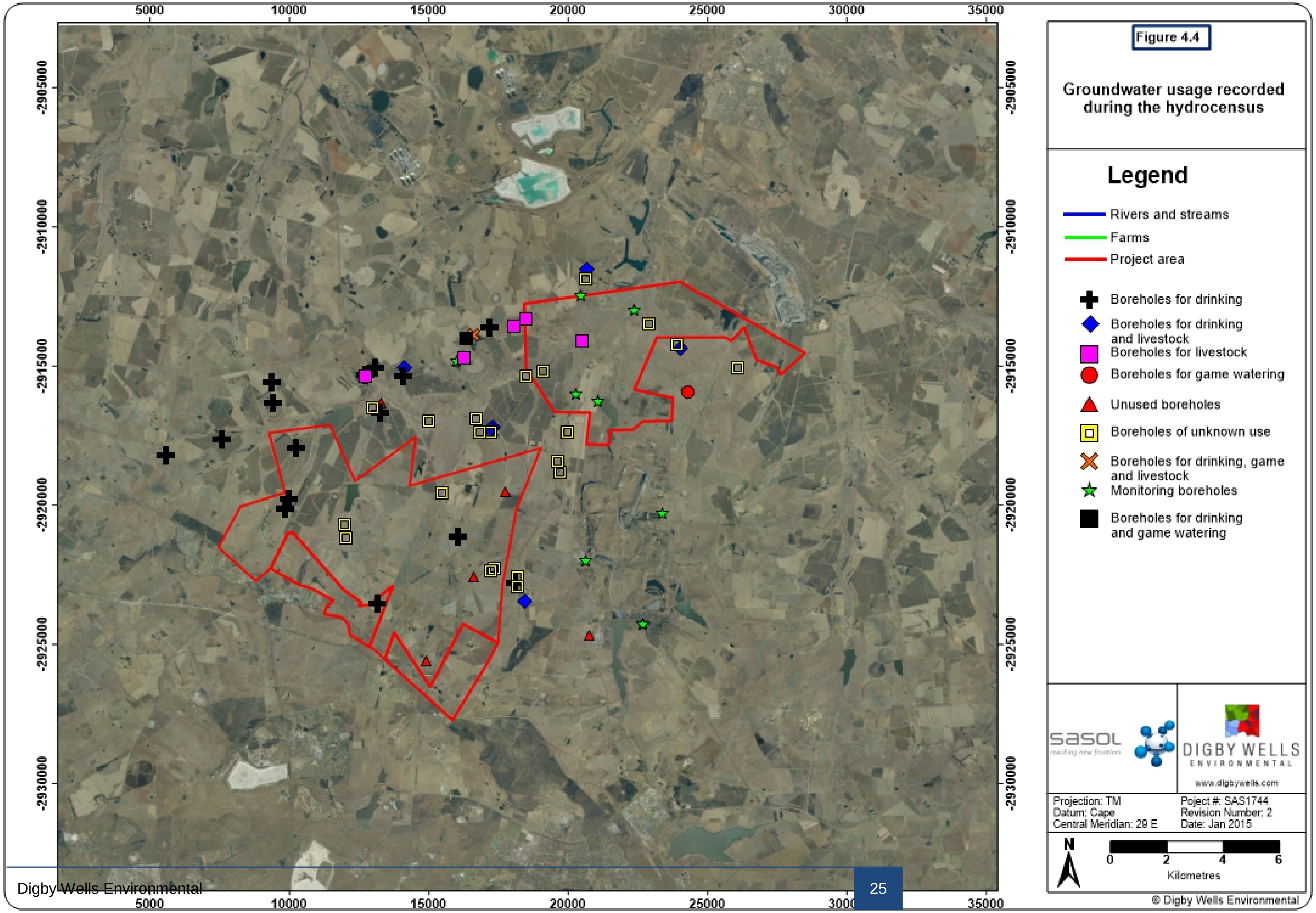
Figure 4.4
Groundwater usage recorded during the hydrocensus
Legend
Rivers and streams
Farms
Project area
Boreholes for drinking
Boreholes for drinking and livestock
Boreholes for livestock
Boreholes for game watering
Unused boreholes
Boreholes of unknown use
Boreholes for drinking, game and livestock
Monitoring boreholes
Boreholes for drinking and game watering
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
N
0 2 4 6
Kilometres
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4.3 Baseline Groundwater Quality

The groundwater quality results have been compared to the South African National Standards (SANS) 241: 2005 Standards for Drinking Water (Table 4-1) and have been grouped into Classes in accordance with the above stated standards. The laboratory result certificates are provided in Appendix B.

According to the SANS 241:2005 standards, water quality have two benchmarks: Class I and Class II:

- Concentrations below the Class I limits are considered of good quality and suitable for human consumption;
- Concentrations between Class I and II are considered as marginal. This is the maximum allowable concentration if consumed for not more than 7 years; and
- Concentrations more than the Class II limits (also referred as Class III) are unacceptable for human consumption.

4.3.1 Class I

Six of the 14 boreholes sampled are suitable for human consumption. None of the tested parameters exceeded the recommended Class I limits. These boreholes are DPLBH1, SPDBH2, VLBBH1, RFNBH7, KFS14 and RTABH2 and are displayed in Figure 3.1.

Noteworthy is the baseline sulphate levels in all of the boreholes. The recommended sulphate limit (maximum) for drinking is 400 mg/L, but the concentration in the sampled boreholes is currently less than 132 mg/L. Since sulphate is expected to be an element of concern in coal mines, the values obtained during this study can be used as a baseline for future contamination comparisons.

4.3.2 Class II

Four boreholes (ONVBH3, VLBBH6, ZDFBH1 and VLTBH2) fell within the Class II water quality range.

- Boreholes ONVBH3 and VLBBH6 are within the Class II category due to increased nitrate concentrations (14 and 13 mg/L respectively). The source for these is not fully understood, but is suspected to be due to dissolution from to fertiliser application or animal waste that ended up seeping to the groundwater;
- Borehole ZDFBH1 is in the Class II category due an increased sodium concentration (210 mg/L). The source for this is suspected to be due to fertiliser application or natural dissolution of the host rocks; and
- Borehole VLTBH2 is in the Class II category due to increased iron and manganese concentrations (0.89 and 0.18 mg/L). The source for these is suspected to be due to the natural dissolution of the host rocks.

4.3.3 Class III

Four boreholes (VLBBH2, VLBBH4, EKNBH2 and LNFBH4) are not recommended for human consumption:

- Boreholes VLBBH2, VLBBH4 and EKNBH2 have fluoride concentrations of 4.4, 3.1 and 5.1 mg/L respectively (the maximum recommended limit is 1.5 mg/L). This is probably due to the natural dissolution of the host rocks, particularly pre-Karoo intrusive rocks; and
- Borehole LNFBH4 has a nitrate concentration of 31 mg/L (the maximum recommended limit is 20 mg/L). The source of this is suspected to be the dissolution of fertilisers or animal waste.

4.3.4 Diagnostic Plots

Stiff diagrams (Figure 4.5) were used to characterise the groundwater by analysing the concentration of the major cations (Ca, Mg, Na+K) and anions (SO_4, Cl and HCO_3). In Stiff diagrams, cations are plotted in meq/L on the left side of the zero axis and anions are plotted on the right side. This diagram is useful in making a rapid visual comparison between water of different sources.

The diagram shows that all the samples are enriched in alkalinity and depleted in sulphates. This suggests that no mine-related contamination has taken place, as mine water is typically distinguished by enriched sulphate and depleted alkalinity.

The samples can be classified into two sources based on their cation content: those that are Ca+Mg dominated and those that are Na+K dominated. The Ca+$MgHCO_3$ type boreholes are typically encountered in recently recharged groundwater. This means that the groundwater does not have significant residence time and is relatively freshly recharged. The $NaHCO_3$ type water could be a result of mixing of recently recharged water from the weathered aquifer and water of the deep aquifer that are enriched with Na.

The water chemistry is also displayed using a Piper diagram as shown in Figure 4.6. A Piper diagram is used to classify the water type by plotting the ratios of the major cations (Ca, Mg, Na and K) and anions (Cl, SO_4 and HCO_3+CO_3) as two points in tri-linear fields. These two points are then extended into the main diamond-shaped field of the Piper diagram to plot as one point.

The Piper diagram also confirms the results observed in the Stiff diagrams. The dominant anion is HCO_3, while the dominant cations range from Ca+Mg to Na+K and are suspected to be results of ion exchanges between water of higher residence time and those that are recently recharged. No mine-related impacts are evident in the samples.

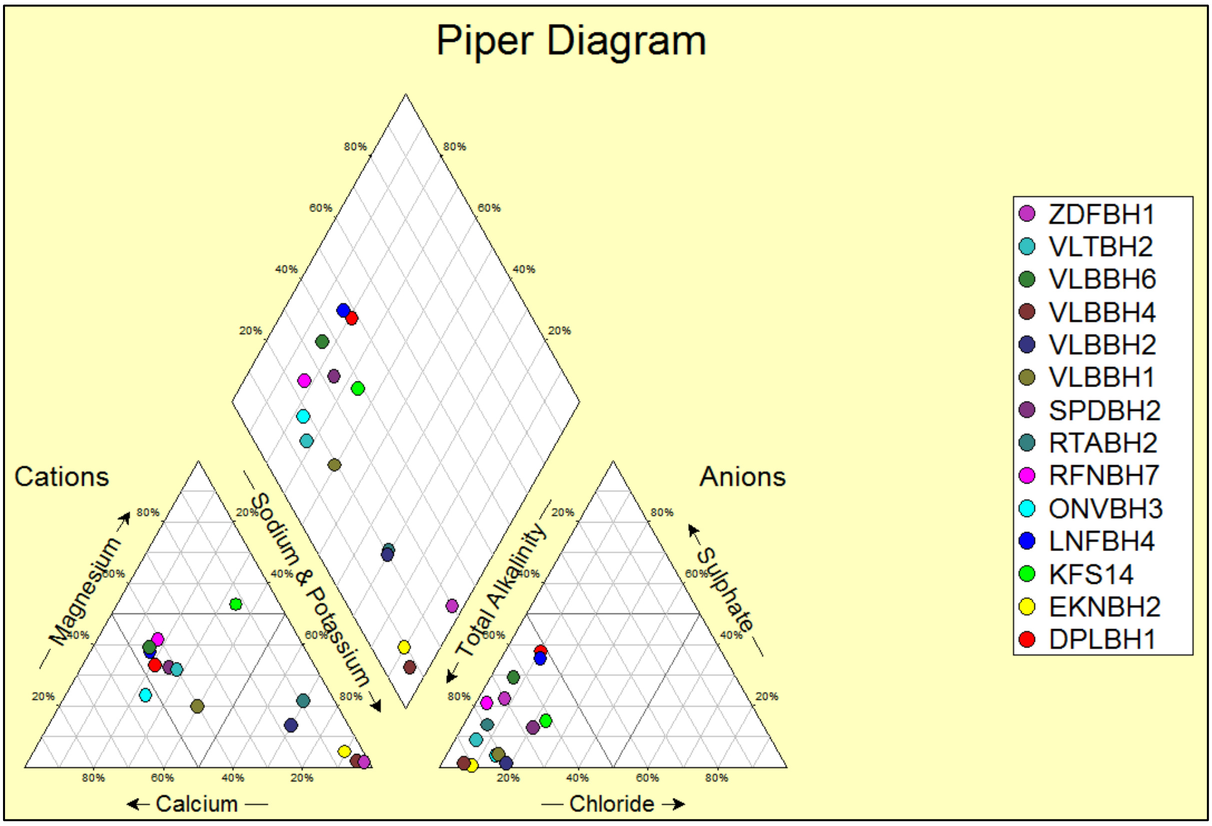

Figure 4.5: Piper diagram of the baseline water chemistry

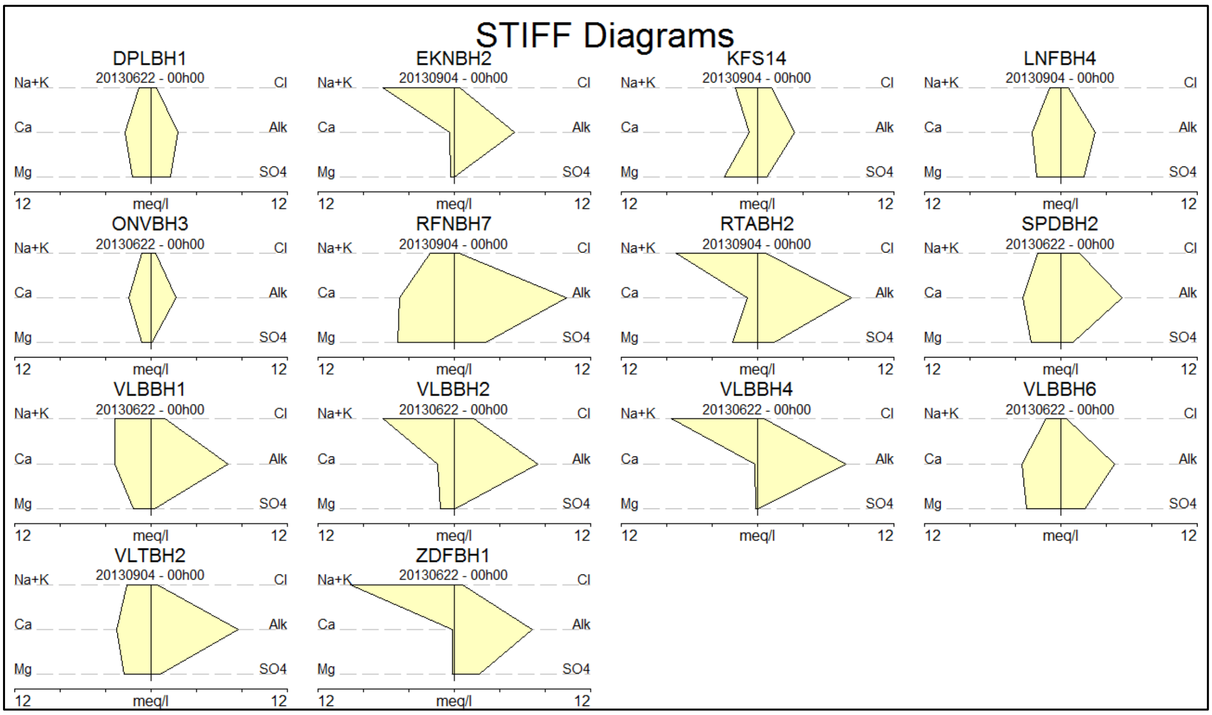

Figure 4.6: Stiff diagram of the baseline water chemistry

Table 4-1: Baseline water quality as classified based on the SANS 241: 2005

		Total Dissolved Solids	Nitrate NO_3 as N	Chlorides as Cl	Total Alkalinity as $CaCO_3$	Sulphate as SO_4	Calcium as Ca	Magnesium as Mg	Sodium as Na	Potassium as K	Iron as Fe	Manganese as Mn	Conductivity at 25° C in mS/m	pH-Value at 25° C	Aluminium as Al	Free and Saline Ammonia as N	Fluoride as F
Class I	(Recommended)	<1000	<10	<200	N/S	<400	<150	<70	<200	<50	<0.2	<0.1	<150	5-9.5	<0.3	<1	<1
Class II	(Max. Allowable)	1000-2400	10-20	200-600	N/S	400-600	150-300	70-100	200-400	50-100	0.2-2	0.1-1	150-370	4-5 or 9.5-10	0.3-0.5	1-2	1-1.5
	Duration	7 years	7 years	7 years	N/S	7 years	7 years	7 years	7 years	7 years	7 years	7 years	7 years	No Limit	1 year	None	1 year
Class III	(Not recommended)	>2400	>20	>600	N/S	>600	>300	>100	>400	>100	>2	>1	>370	<4 or >10	>0.5	>2	>1.5
DPLBH1	2013/06/22	318.00	6.00	17.00	120.00	84.00	45.60	20.10	19.80	7.62	-0.03	-0.03	49.00	8.00	-0.10	-0.20	0.30
ONVBH3	2013/06/22	242.00	14.00	14.00	112.00	5.00	38.40	10.20	17.00	3.77	-0.03	-0.03	36.60	8.10	-0.10	0.40	-0.20
SPDBH2	2013/06/22	404.00	0.40	59.00	268.00	50.00	66.90	31.20	44.80	3.13	0.03	0.03	70.80	8.20	-0.10	0.40	0.40
VLBBH1	2013/06/22	430.00	0.40	45.00	340.00	17.00	64.10	19.00	72.40	1.35	0.03	-0.03	72.50	8.20	-0.10	0.20	0.60
VLBBH2	2013/06/22	494.00	0.40	61.00	368.00	-5.00	29.50	14.80	143.00	1.82	-0.03	0.04	82.00	8.40	-0.10	0.40	4.40
VLBBH4	2013/06/22	446.00	-0.20	20.00	388.00	-5.00	5.50	1.92	174.00	1.49	0.05	-0.03	74.10	8.30	-0.10	0.70	3.10
VLBBH6	2013/06/22	496.00	13.00	18.00	236.00	103.00	68.70	36.70	26.30	5.23	-0.03	-0.03	73.10	8.30	-0.10	0.30	-0.20
ZDFBH1	2013/06/22	588.00	1.60	27.00	344.00	106.00	2.55	-2.00	210.00	-1.00	0.03	-0.03	88.00	8.40	-0.10	0.50	0.40
EKNBH2	2013/09/04	390.00	-0.10	19.00	277.00	1.40	7.40	4.30	143.00	2.50	0.02	0.00	64.80	8.50	0.00	0.60	5.10
RFNBH7	2013/09/04	608.00	4.40	15.10	406.00	132.00	97.00	60.00	48.00	0.80	0.01	0.00	96.10	8.00	0.02	-0.10	0.30
KFS14	2013/09/04	276.00	0.70	44.00	167.00	39.00	14.10	36.00	43.00	2.00	0.05	0.01	52.60	8.50	0.00	0.10	0.10
LNFBH4	2013/09/04	362.00	31.00	23.00	124.00	97.00	51.00	26.00	20.00	4.80	0.02	0.01	53.40	7.50	0.00	0.10	-0.10
RTABH2	2013/09/04	540.00	2.50	26.00	406.00	69.00	18.70	27.00	164.00	2.10	0.03	0.00	90.70	8.40	0.02	-0.10	0.30
VLTBH2	2013/09/04	500.00	-0.10	20.00	315.00	39.00	60.00	29.00	39.00	15.60	0.89	0.18	72.10	7.40	0.01	-0.10	0.30

Note: "-" values should be read as "<" (e.g. "-1" = "<1")

4.4 Acid-base Accounting

The ABA results of the rock samples are given in Table 4-2. The results are also displayed graphically in Figure 4.7 to show the NPR.

Another method for classifying non-potentially acid-generating materials from the potentially acid-generating materials is based on the ratio of NPR versus sulphide-sulphur or total sulphur content (Soregaroli and Lawrence, 1998). Should the NPR be less than 1 and the total sulphur content greater than 0.3%, the sample is considered as potentially acid generating. This method of classification is available in Figure 4.8.

4.4.1 The Coal Seam

- The coal seam has an average of 0.50% sulphide-S which is more than the 0.3% benchmark required to sustainably generate acid. This is, however, less than the typical sulphide values obtained in the No. 4 seam of the Witbank Coalfield, which is approximately 1.96% (Pinetown et al, 2004). Although the project area is in the Highveld Coalfield, no literature is available on the statistical distribution of the sulphide contents. Results were therefore compared with the Witbank Coalfield only;
- The coal seam has an average NNP of -4.74 kg $CaCO_3$/tonne, indicating that the amount of acid generating minerals are slightly higher than the neutralising minerals. Considering the sulphide content of 0.50%, the seam can be classified as a potentially acid generating;
- This is also further confirmed in Figure 4.7, with an NPR of 0.68;
- Unlike the other ABA results, the paste pH of the coal seam was neutral with an average of 7.4. However, paste pH alone is often not conclusive and should only be considered as a preliminary screening tool; and
- For the purpose of environmental impact prediction, the coal material should be considered as acid-generating and management procedures around the stockpiles and processing areas should be in place accordingly. The proposed management procedures are discussed at the end of this section.

Some of the mitigation options that can be considered to counter AMD formation from the coal stockpile include:

- The diversion and capturing of dirty water in pollution dams where water can be treated before being discharged into the environment or allowed to evaporate in evaporation ponds;
- Lining of stockpile areas to minimise potential pollution from coal stockpiles;
- If high volumes of AMD water is produced and captured in pollution dams the water can be treated through lime dosage to buffer the pH and allowing SO_4 and metals to precipitate and settle out before the water is discharged; and

- Monitoring boreholes can help as early warning systems, as well as seepage capturing abstraction boreholes should groundwater quality start to decrease.

4.4.2 Overburden Rocks

- The overburden contains an average of 0.53% sulphide-S, indicating the existence of pyrite minerals that could sustainably release acidity. This is nearly equal to the typical value obtained in the overburden rocks found at the Witbank Coalfield, which is approximately 0.56% (Pinetown et al, 2004);
- As shown in Figure 4.7, the overburden materials fall in the uncertain zone with an average NNP of 3.38 kg $CaCO_3$/tonne. Although there is sufficient Sulphide-S to potentially generate acid, the samples appear to contain neutralising minerals to buffer this;
- The NPR ratio of the overburden further shows that the samples fall in the uncertain zone with an NPR value of 0.92; and
- In summary, the overburden fall in the uncertain zone where by the acid generation/neutralisation will be determined by the mineral reactivity. There appears to be sufficient sulphur to generate acidity but this could be buffered if the neutralising minerals (such as dolomite and kaolinite) are reactive. Kinetic tests are often required to predict the long-term geochemical properties of such uncertain samples.

4.4.3 Underburden Rocks

- The underburden rocks contain an average of 0.28% sulphide-S and is slightly less than the 0.3% benchmark. This is also less than the typical value obtained at the corresponding underburden of the Witbank Coalfield, which is approximately 0.88% (Pinetown et al, 2004);
- Based on the NPR classification, the rocks fall into the not potentially acid generating zone, with an NPR of 2.5;
- The acid neutralisation potential of the underburden is also confirmed with the average NNP of being 21.0 kg $CaCO_3$/tonne; and
- In summary, the underburden rocks are classified as potentially non-acid generating due to their neutralising potential as well as limited sulphide content.

Table 4-2: ABA result summary

Sample ID	Depth (m)	Lithology	paste pH	AP (kg/t)	NP (kg/t)	NNP	NPR	Total S%	Sulphate S%	Sulphide S%	NAG pH
BH-D overburden	112.52 - 113.78	sandstone (overburden)	6.5	5.94	2.6	-3.34	0.438	0.18	0.01	0.17	5.6
BH-Z overburden	112.52 - 113.78	sandstone (overburden)	8	26	37	11	1.41	1.11	0.22	0.89	7.3
BH-D coal	112.52 - 113.78	4 seam	6.7	0.625	0.745	0.12	1.19	0.6	0.05	0.55	6.8
BH-Z coal	112.52 - 113.78	4 seam	8.1	11.6	2	-9.6	0.171	0.56	0.1	0.46	7.4
BH-D underburden	112.52 - 113.78	sandstone (underburden)	7.9	12	35	23	2.92	0.24	0.03	0.21	4.5
BH-Z underburden	112.52 - 113.78	sandstone (underburden)	6.5	22	41	19	1.89	0.39	0.04	0.35	4.5

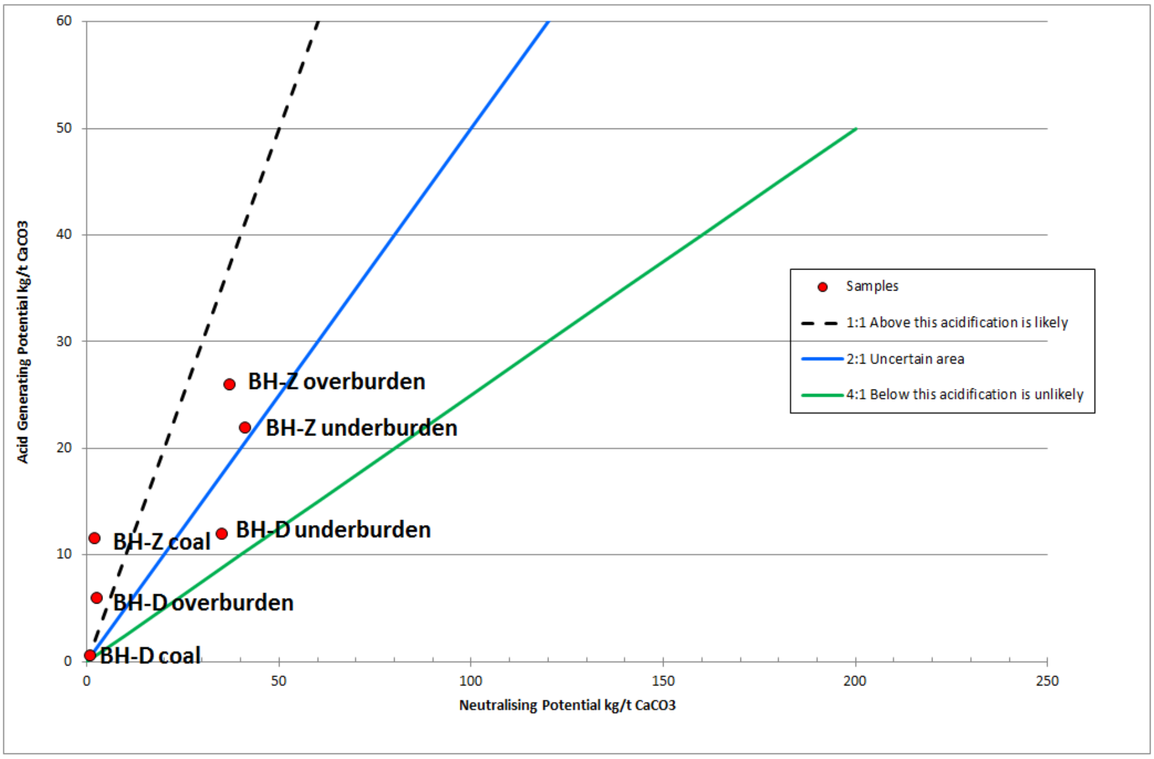

Figure 4.7: Comparison of the acid neutralisation and generation potential of the samples

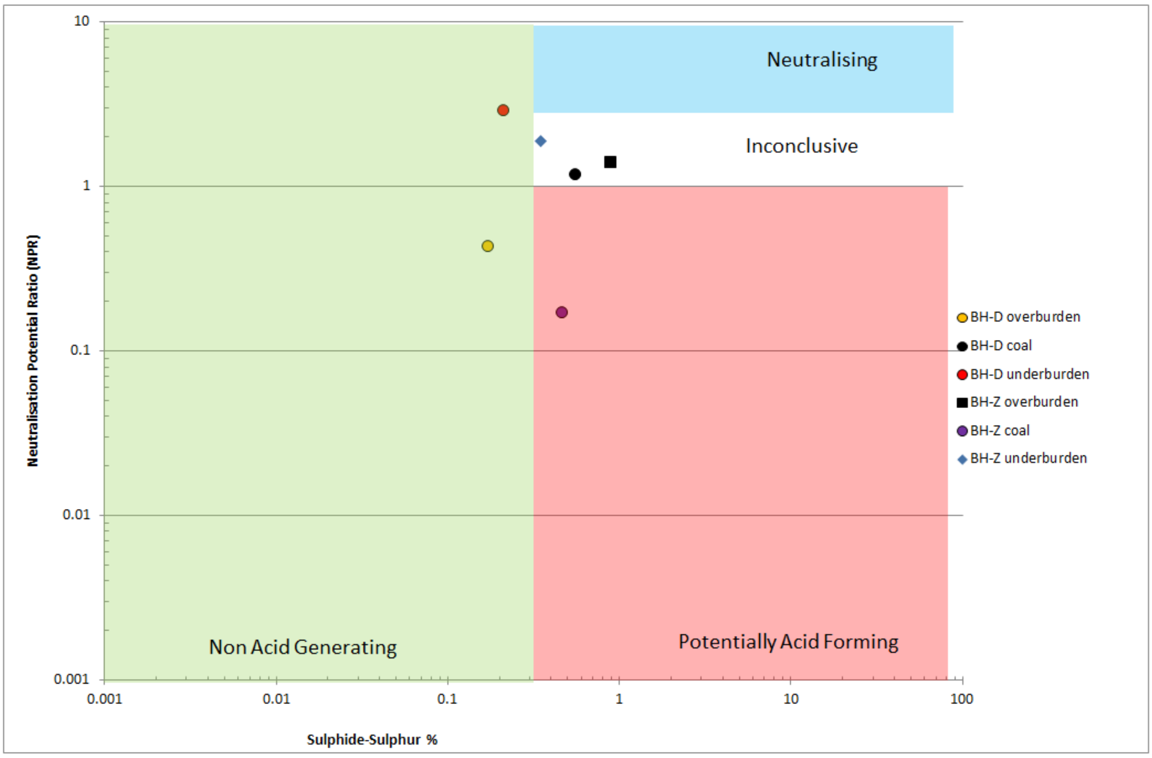

Figure 4.8: Total Sulphur vs NPR

4.5 Leachate Results

The distilled water and acid rain leachate results are shown in Table 4-3. It is interesting to note that no element leached at concentrations above the recommended SANS standards and are classified as not harmful to human health. The only exception is aluminium which could potentially leach from the coal discard if acidic conditions prevail, which has been shown to be the case from the ABA results.

Table 4-3: Distilled water and acid rain leachate result as compared with the SANS guidline

Parameter	Detection limit	SANS 241:2005 Drinking water guideline values	Distilled water						TCLP					
			Coal		Overburden		Underburden		Coal		Overburden		Underburden	
			D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001
Silver as Ag (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Aluminium as Al (mg/l)	<0.100	0.3	<0.100	0.129	0.078	<0.100	0.166	0.113	1.406	<0.100	0.206	0.146	0.108	0.11
Arsenic as As (mg/l)	<0.010	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron as B (mg/l)	<0.025	0.5	<0.025	<0.025	0.123	0.047	0.042	0.026	<0.025	0.027	0.105	0.144	0.079	0.053
Barium as Ba (mg/l)	<0.025	0.7	0.126	<0.025	0.333	0.318	<0.025	0.089	<0.025	0.142	0.07	0.598	0.371	0.502
Beryllium as Be (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Bismuth as Bi (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Cadmium as Cd (mg/l)	<0.005	0.003	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt as Co (mg/l)	<0.025	0.5	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.057	<0.025
Chromium as Cr (mg/l)	<0.025	0.05	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Copper as Cu (mg/l)	<0.025	0.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Iron as Fe (mg/l)	<0.025	0.2	0.16	<0.025	<0.025	<0.025	0.116	0.067	0.122	<0.025	0.067	<0.025	<0.025	<0.025
Manganese as Mn (mg/l)	<0.025	0.5	0.148	<0.025	0.065	0.077	<0.025	<0.025	<0.025	0.067	0.072	0.425	0.503	0.313
Molybdenum as Mo (mg/l)	<0.025	0.07	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Nickel as Ni (mg/l)	<0.025	0.07	0.029	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.132	<0.025
Phosphorus as P (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Lead as Pb (mg/l)	<0.020	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Antimony as Sb (mg/l)	<0.010	0.02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.01	<0.010	<0.010	<0.010
Selenium as Se (mg/l)	<0.020	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Silicon as Si (mg/l)	<0.2	N/A	0.597	<0.2	<0.2	<0.2	<0.2	<0.2	3.1	1.9	3	0.5	2.2	0.2
Tin as Sn (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.027	0.027	0.027	0.04	<0.025	<0.025
Strontium as Sr (mg/l)	<0.025	N/A	0.117	<0.025	0.98	1.204	<0.025	0.326	<0.025	0.233	0.244	1.635	1.591	1.827

Parameter	Detection limit	SANS 241:2005 Drinking water guideline values	Distilled water						TCLP					
			Coal		Overburden		Underburden		Coal		Overburden		Underburden	
			D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001	D123019	Z124001
Titanium as Ti (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.073	<0.025	<0.025	<0.025	<0.025	<0.025
Vanadium as V (mg/l)	<0.025	0.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Zinc as Zn (mg/l)	<0.025	5	<0.025	<0.025	<0.025	0.036	<0.025	<0.025	<0.025	<0.025	<0.025	0.096	<0.025	0.118
Zirconium as Zr (mg/l)	<0.025	N/A	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Calcium as Ca (mg/l)	<2	N/A	2	<2	32	30	<2	8	<2	3	3	78	59	57
Potassium as K (mg/l)	<1.0	N/A	1.127	<1.0	0.975	<1.0	1.366	2.662	<1.0	1.554	3	1.108	4.023	<1.0
Magnesium as Mg (mg/l)	<2	N/A	<2	<2	5	3	<2	2	<2	<2	2	13	22	9
Sodium as Na (mg/l)	<2	200	4	8	24	14	26	32	4	8	32	30	29	16
Chloride,Cl	5	300	<5	<5	<5	10	75	55	<5	<5	<5	<5	82	65
Nitrate,NO3	0.2	N/A	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Fluoride,F	0.1	1.5	<0.2	0.8	0.8	0.6	0.2	0.2	0.2	0.2	0.3	0.2	0.2	<0.2
SO4	5	500	<5	<5	14	38	<5	6	<5	<5	11	71	<5	<5
TDS		1200	28	10	98	144	274	226	100	42.0	114.0	380.0	442.0	298.0

4.6 Water Level and Flow Direction

The water levels measured during the hydrocensus are shown in Appendix A and ranges between 0.3 m and 69.7 m below ground level (mbgl). This corresponds to a piezometric head of between 1555.3 m and 1641.9 m above mean sea level (mamsl). The relatively large water level variation over a relatively short distance may indicate that some of the boreholes are groundwater abstraction points with no sufficient time to recover or possibly from different aquifers.

A comparison of the water level elevation with topography shows a good correlation of 97.3% (Figure 4.9). Only boreholes with a static water level were used to plot this figure. The boreholes that are currently in use were not included.

Figure 4.9 confirms that groundwater elevation mimics the topography and flows towards the streams to the east (Trichardspruit) and northwest (Dwars-in-die-wegspruit) of Syferfontein.

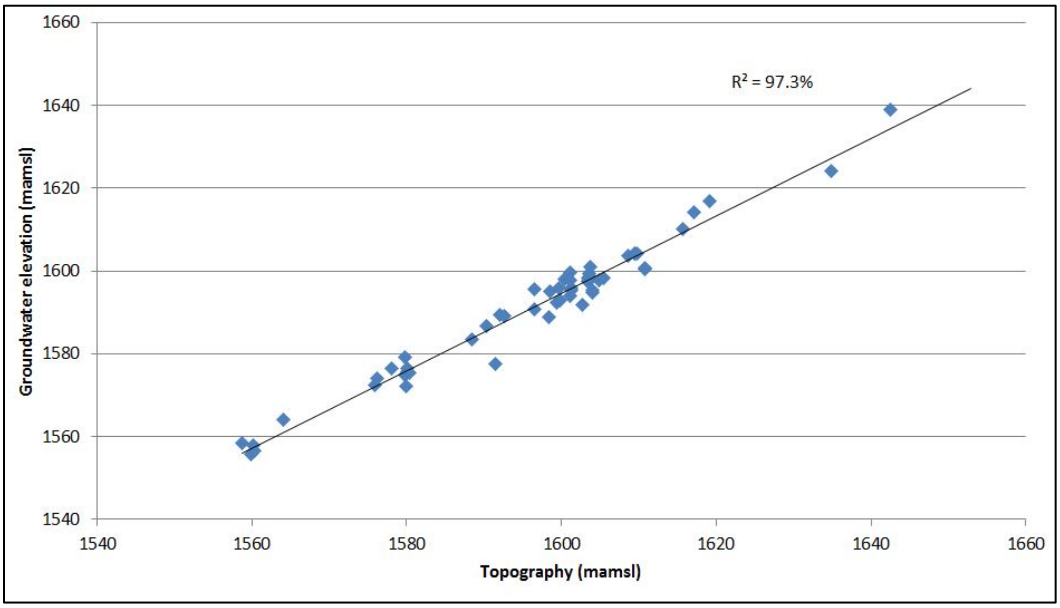

Figure 4.9: Correlation between topography and water level

4.7 Aquifer Hydraulic Permeability

The permeability value of each borehole is listed in Table 4-4 and displayed in Figure 4.10. Unfortunately borehole SFNBH6 is currently not accessible as the borehole cap was removed and subsequently blocked by an unknown object.

The aquifer underlying the project area is characterised by low hydraulic conductivity (permeability) ranging between 10^{-4} m/d (Borehole SFNBH1) and 0.06 m/d (Borehole SFNBH2). This indicates that the groundwater flow rate is limited and the contamination plume from the underground mine will not migrate far from the mine footprint even after mine closure. The plume will migrate very slowly, but high concentrations are expected to remain in the aquifer for a long time after loading has stopped. The aquifer permeability distribution is interpolated (Figure 4.10).

4.8 Aquifer storage

Determination of storativity is only required for the transient state simulation. The storativity values obtained from the aquifer test is listed in Table 4-4 and ranges between 0.012 to 0.145 with an average value of 0.078.

Table 4-4: Hydraulic parameters of the boreholes drilled at the project area

Borehole	Final Blow Yield (L/s)	Permeability (m/d)	Transmissivity (m^2/d)	Storativity
SFNBH1	Seepage	0.0001		
SFNBH2	1.49	0.0635	5.15	0.0125
SFNBH3	1.11	0.0178	1.33	0.0767
SFNBH4	Seepage	0.0012		
SFNBH5	Seepage	0.0013		
SFNBH7	Seepage	0.0005		
SFNBH8	0.94	0.00432	0.361	0.145

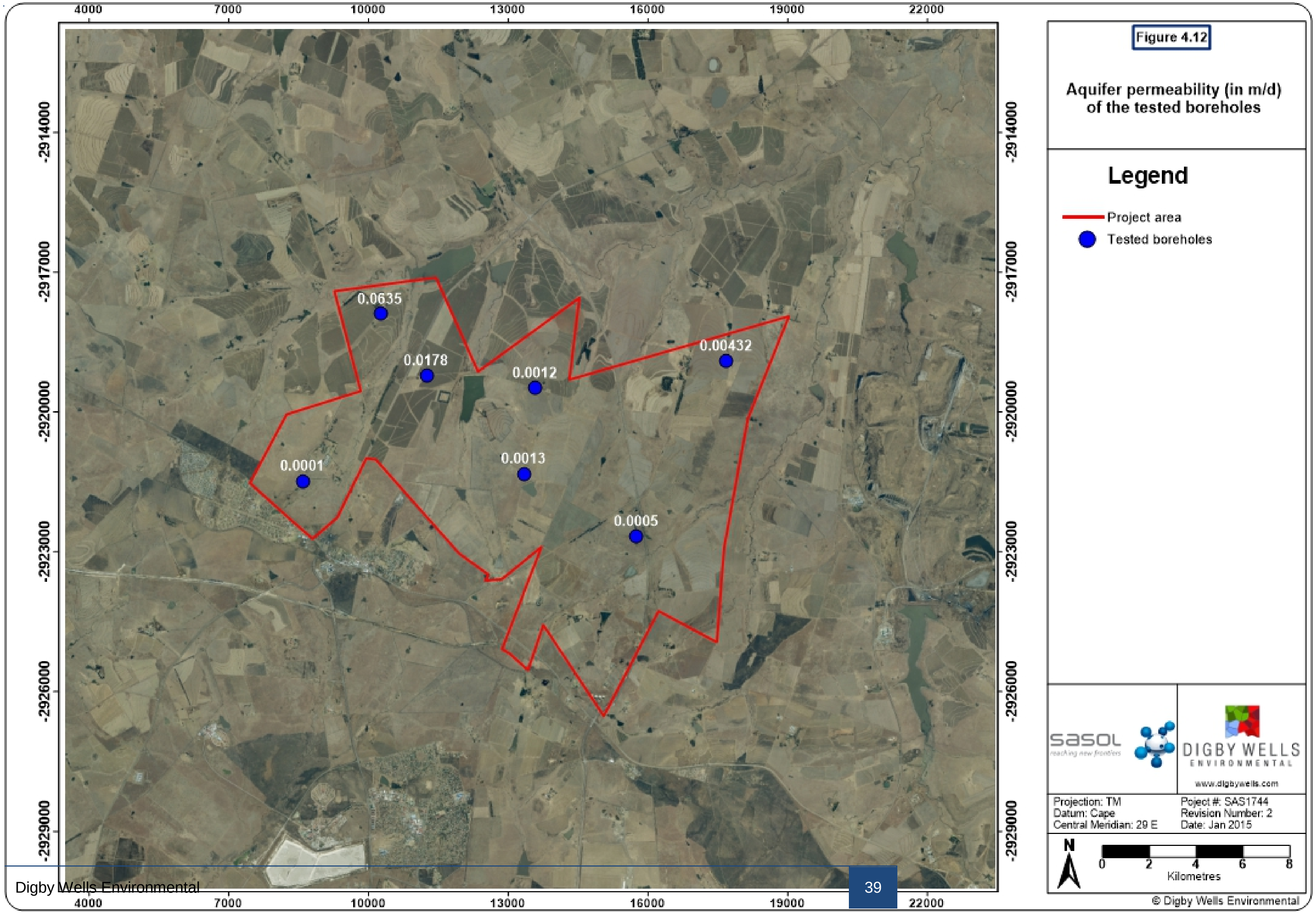
Figure 4.12
Aquifer permeability (in m/d) of the tested boreholes
Legend
Project area
Tested boreholes
0.0635
0.0178
0.0012
0.00432
0.0001
0.0013
0.0005
4000
7000
10000
13000
16000
19000
22000
-2914000
-2917000
-2920000
-2923000
-2926000
-2929000
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
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5 Numerical Modelling

Following the characterisation of the aquifer, contaminant source and groundwater receptors, the conceptual model was transformed into a numerical model so that the groundwater flow conditions and mass transport can be solved numerically. A conceptual model is a simplified, but representative description of the groundwater system that illustrates the interaction of the sources, pathways and receptors at the site.

- The sources represent any entity that contributes to the groundwater quantity and/or quality;
- The pathways are the aquifers through which the groundwater and contaminants migrate; and
- The receptors are humans, rivers or natural ecosystems that depend on the groundwater and will be impacted negatively if the water is depleted by dewatering or is contaminated.

As illustrated in Figure 5.1, an environmental risk exists only if the three components of a conceptual model (source, pathway and receptor) are linked.

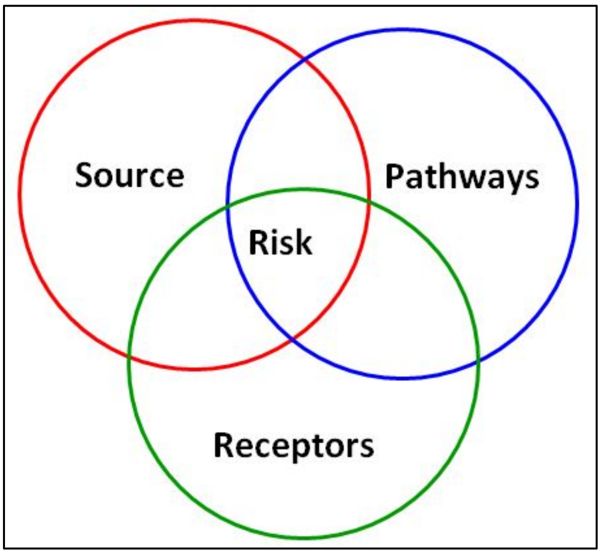

Figure 5.1: A conceptual model based environmental risk

5.1 Aquifer Layers

The groundwater systems in the Mpumalanga coalfields have been discussed extensively by Hodgson et al (1998) and Grobbelaar et al (2004). Three distinct superimposed groundwater systems are present. They are the upper weathered Ecca aquifer, the fractured aquifers within the unweathered Ecca sediments and the aquifer below the Ecca sediments.

The following aquifer description extracted from the previously stated references and field investigations conducted during this study is relevant to Syferfontein. Each aquifer layer has been incorporated in the groundwater model.

5.1.1 The weathered aquifer

The Ecca sediments are weathered to depths between 5 and 12 m below surface throughout the area. The upper aquifer is associated with this weathered zone and water is often found within a few metres below surface. This aquifer is recharged by rainfall. The percentage recharge to this aquifer is estimated to be in the order of 1 to 3% of the annual rainfall, based on work in other parts of the country by Kirchner et al. (1991) and Bredenkamp (1995).

It should, however, be emphasised that in a weathered system, such as the Ecca sediments, highly variable recharge values can be found from one area to the next. This is attributed to the composition of the weathered sediments, which range from coarse-grained sand to fine clay.

Based on the hydrogeological information obtained from the boreholes drilled at Syferfontein, the thickness of the weathered zone was approximated to 12 m. The numerical model was calibrated at a recharge of 1% of the mean annual precipitation (which his approximately 680 mm), and weathered aquifer permeability of 0.07 mg/d.

5.1.2 Fractured Ecca Aquifer

The pores within the Ecca sediments are well-cemented and do not allow any significant flow of water. All groundwater movement therefore occurs along secondary structures, such as fractures 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.

It should, however, be emphasised that not all secondary structures are water bearing. Many of these structures are constricted because of compressional forces that act within the earth's crust.

Based on aquifer test results at Syferfontein, the hydraulic permeability of this aquifer has been approximated at 0.01 m/d.

5.1.3 Coal Seam Aquifer

Hodgson et al (1998) states that of all the unweathered sediments in the Ecca, the coal seams often have the highest hydraulic conductivity. Since the aquifer permeability and storativity of the seam will also be enhanced by mine excavation, it has been simulated as a separate aquifer with an approximate permeability of 0.1 m/d. This permeability is in the same order of magnitude estimated for the coal seams by Hodgson et al. (1998). A recharge of 3% has been applied to the mined portion of the aquifer. Considering the mining method being a bord-and-pillar, an extraction factor of 40% has been assigned to the mined out section of the coal seam.

5.2 Model Setup

During model setup, the conceptual model is translated into a numerical model. This stage entails selecting the model domain, defining the model boundary conditions, discretizing the data spatially and over time, defining the initial conditions, selecting the aquifer type, and preparing the model input data. The above conditions, together with the input data are used to simulate the groundwater flow in the model domain for pre-mining steady state conditions.

5.3 Model Domain

The model domain (Figure 1.1) has dimensions of 33.9 km by 31.3 km. A rectangular mesh was generated over the model domain, consisting of 626 rows and 678 columns. The mesh was refined in the entire model domain to cell sizes of 50 by 50 m. Although a smaller grid size may result in prolonged running time, it was important to refine the model so that the groundwater gradient and pollution plumes can be calculated with accuracy.

Considering the frequency of the water strike distribution (discussed in Section 4.5) and the coal seam layer to be mined, three aquifer layers have been simulated. These are the top 90 m aquifer where all the water strikes were encountered followed by the less permeable fresh rocks underneath. The coal seam in the project site is found mainly below the depth of 90 m. Since this will be a separate aquifer once the mining starts and voids are formed, it has also been simulated as a separate layer in the model.

5.4 Boundary Conditions

The model domain is defined by surface water sheds and sub-catchments as illustrated in Figure 1.1. A no-flow boundary has been used along water divides and a drain-package along stream channels.

5.5 Steady State Simulation

Prior to the simulation of the mining and dewatering activities, a baseline (pre-mining) steady state groundwater flow model was set-up and calibrated. The objective of the steady state model was to simulate the undisturbed groundwater system in the region prior to mining. The impacts of mining activities on the groundwater environment can then be determined by comparing the transient state results with the steady state results.

Digby Wells compiled all the hydrocensus water levels and quality data into a centralised MS Excel database, in a WISH (Windows Interpretation System for Hydrogeologists) format. Historical water levels were obtained from the client and added to the WISH database to produce time-series water levels.

The model was calibrated by varying model input data until a realistic, but satisfactory match between simulated and observed water level data was achieved.

Since recharge and permeability are dependent on each other, via the measured heads, the model was not calibrated by changing the permeability and recharge simultaneously. The permeability was calibrated based on the aquifer test data while the recharge value was adjusted using the automatic parameter estimation programme - PEST.

The PCG2 package is used to solve the partial differential equations. Convergence criteria of a residual flux of 10^{-3} m^3/day and a head change of 10^{-3} m were selected.

A total of 44 observation boreholes were used for the steady state model calibration. Where more than one water level measurement was available, either the mean or one of the values was used. These boreholes are relatively uniformly distributed across the model domain.

After model calibration, an acceptable correlation of 93.7% was obtained between the simulated and observed groundwater elevation (Figure 5.2). An absolute mean error of 3.7 m for the model calibration was considered to be sufficiently small, given that the observed maximum head difference over the model domain area was 69.4 m and that the number of unknown input parameters was kept small.

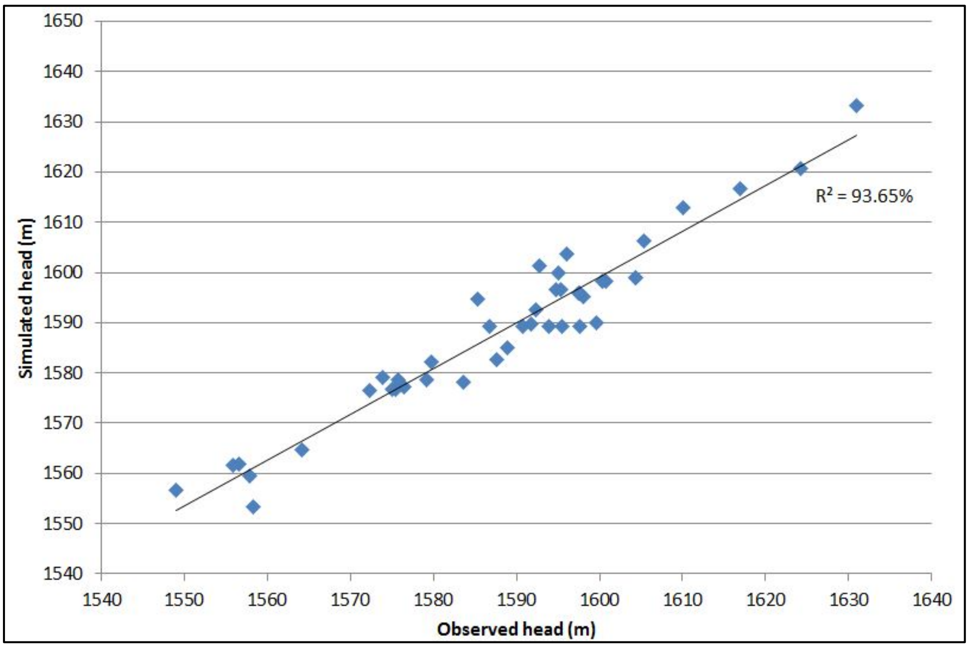

Figure 5.2: Correlation between observed and simulated head

5.6 Transient State Simulation

5.6.1 Flow Model

The impacts of mining activities are assessed in a transient model with different stress periods over time to simulate changes related to model parameters with time.

During the model setup, the steady state model is converted into a transient model. This stage entails selecting the appropriate time-dependent parameters such as artificial recharge (if any) and mine dewatering. The geometry of the model domain, boundaries, top and bottom of the layers, mesh size, layer type and natural recharge remain as defined in the steady state model. The solution of the calibrated steady-state model was used as initial hydraulic head distribution of the transient model.

After the completion of the transient state model setup, the mine plan (Figure 1.3) was incorporated into the model. This was done to estimate the groundwater inflow rates and also predict the potential cone of dewatering and environmental impacts associated with the mine plan.

5.6.2 Mass Transport Simulation

In most cases, contaminant transport is driven by advection, i.e. groundwater flow is the main mechanism controlling the movement of solutes in groundwater. Advection implies that contaminants migrate at a rate similar to the groundwater flow velocity and in the same direction as the hydraulic gradient. Therefore, knowledge of groundwater flow patterns and hydraulic parameters can be used to predict solute transport under advection. Other parameters to consider include dispersion, diffusion, effective porosity and the specific yield.

5.6.2.1 Dispersion and Diffusion

Dispersion of contaminants in groundwater is also important in terms of contaminant transport. Dispersive transport is caused by the tortuous nature of pores or fracture openings that result in variable flow velocity distributions within an aquifer and movement of contaminants due to the difference in concentration gradient.

Dispersion has two components; longitudinal and transversal dispersivities. The longitudinal dispersivity is scale dependent and is usually approximately 10% of the travel distance of the plume (Fetter, 1993). The transversal dispersivity is approximately 10% of the longitudinal dispersivity. The higher the dispersivity, the smaller the maximum concentration of the contaminant, as dispersion causes a spreading of the plume over a larger area.

Considering the coal seam depths and streams, a longitudinal dispersivity of 5 m is estimated. A diffusion coefficient of $1x10^{-5}$ m^2/day was selected, acceptable for Karoo sedimentary rocks (Gebrekristos *et al*, 2008).

5.6.2.2 Effective Porosity and Specific Yield

The percentage of void volume that contributes to groundwater flow is expressed by the term "porosity". Not all pores are interconnected and therefore cannot contribute equally to groundwater flow, leading to the derivation of the term "effective porosity", used to express the interconnected void volume that effectively contributes to groundwater flow and therefore contaminant transport. The higher the effective porosity, the slower the contamination migration rate, because more pore voids have to be filled. The specific yield of a unit volume aquifer is the quantity of water that can be released or drained as a result of gravity. This implies that the specific yield is either equal or less than the effective porosity.

The extraction factor of the coal seam was assumed to be 40%, while the porosity of the unmined portion of the aquifer was assumed to be 10%; acceptable for Karoo rocks (Van der Voort, 2001). A specific yield of 0.08 and storativity of 10^{-3} was applied across the entire model domain based on transient state model calibration.

5.6.2.3 Selection of the contaminant of concern

The potential contamination plumes from the project area have been simulated using a relative concentration of 100% at the sources. If for example the concentration of sulphate or total dissolved solids from the underground workings is 10 mg/L, a contour value of 50% indicates a concentration value of 5 mg/L, and a contour value of 10% indicates that a concentration value of 1 mg/L. A constant input concentration of 100% is therefore assumed from the beginning of operation. As per the DWA's best practice for impact prediction, the plume simulation has been conducted for up to 100 years after mine closure.

5.7 Sensitivity Analysis

The sensitivity of the model to the various hydraulic parameters was evaluated to quantify the uncertainty in the calibrated model caused by input parameters. Input parameters (horizontal permeability, vertical permeability, recharge, specific storage and specific yield) were varied within a factor of 0.5 and 2 of the calibrated value and the corresponding change of the groundwater inflow rate was measured.

Figure 5.3 presents the result of the sensitivity analyses for the various hydraulic parameters. The model is slightly more sensitive to the vertical permeability (hydraulic conductivity) followed equally by all the other parameters. This means that changes in the vertical permeability will have slightly more impact on the model output than the other less sensitive parameters.

Since the model is more sensitive to the vertical permeability, any future groundwater study is recommended to focus on and refine this parameter.

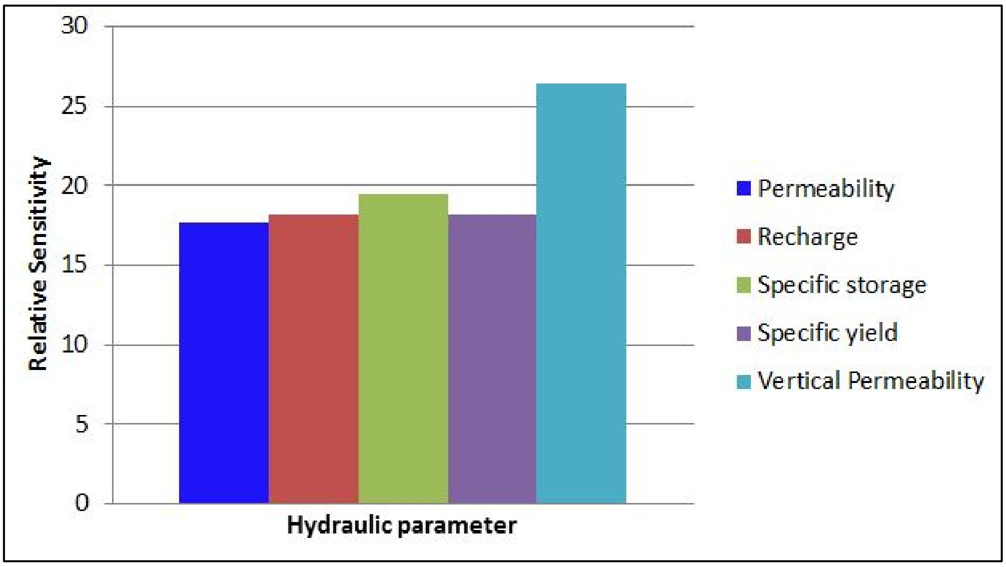

Figure 5.3: Model sensitivity to the hydraulic parameters

6 IMPACT ASSESSMENT AND MANAGMEENT PLANS

The groundwater impact was assessed considering the three phases of the life of mine: construction, operation and closure phases.

6.1 Introduction

The significance of the potential impacts is determined using the methodology described below. The method provides an indication in relative terms of the significance of potential impacts on the groundwater environment.

The system is based on ordinal data where a number is used to represent a category. Ordinal data allows for an increase or decrease in the scoring to provide a relative indication which cannot be interpreted on a linear scale.

The methodology determines the environmental significance using the following equation:

Significance of environmental impact = Consequence X Probability

The consequence of an impact can be derived from the following factors:

- Spatial scale;
- Duration of impact; and
- Severity / magnitude.

Duration is defined by how long the impact may be prevalent and spatial scale is the physical area which could be affected by an impact. The severity of an impact relates to how severe the impact will be. The overall probability of the impact can be determined and is related to the likelihood of such an impact occurring. The spatial extent, duration, severity and probability are ranked using the criteria indicated in Table 6-1 and then the overall consequence is determined by adding the individual scores.

Environmental impacts are obtained by multiplying the consequence of the impact with the probability of occurrence, as follows:

Significance = Consequence (severity + duration + spatial scale) x Probability

The maximum score that can be obtained is 147 significance points (Table 6-2).

Environmental impacts are rated as Major, Moderate, Minor and Negligible based on the significance scoring (Table 6-3).

- More than 108 points indicate Major environmental significance;
- Between 73 and 108 points indicate Moderate environmental significance;
- Between 33 and 73 points indicate Minor environmental significance; and
- Less than 33 points indicate negligible environmental significance.

Table 6-1: Descriptions and scales of the terms used to define the impact significance

Rating	Severity	Spatial scale	Duration	Probability
7	Very significant impact on the environment. Irreparable damage to highly valued species, habitat or eco system. Persistent severe damage.	International The effect will occur across international borders	Permanent: No Mitigation No mitigation measures of natural process will reduce the impact after implementation.	Certain/ Definite. The impact will occur regardless of the implementation of any preventative or corrective actions.
6	Significant impact on highly valued species, habitat or ecosystem.	National Will affect the entire country	Permanent: Mitigation Mitigation measures of natural process will reduce the impact.	Almost certain/Highly probable It is most likely that the impact will occur.
5	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate	Province/ Region Will affect the entire province or region	Project Life The impact will cease after the operational life span of the project.	Likely The impact may occur.
4	Serious medium term environmental effects. Environmental damage can be reversed in less than a year	Municipal Area Will affect the whole municipal area	Long term 6-15 years	Probable Has occurred here or elsewhere and could therefore occur.
3	Moderate, short-term effects but not affecting ecosystem function. Rehabilitation requires intervention of external specialists and can be done in less than a month.	Local Local extending only as far as the development site area	Medium term 1-5 years	Unlikely Has not happened yet but could happen once in the lifetime of the project, therefore there is a possibility that the impact will occur.
2	Minor effects on biological or physical environment. Environmental damage can be rehabilitated internally with/ without help of external consultants.	Limited Limited to the site and its immediate surroundings	Short term Less than 1 year	Rare/ improbable Conceivable, but only in extreme circumstances and/ or has not happened during lifetime of the project but has happened elsewhere. The possibility of the impact materialising is very low as a result of design, historic experience or implementation

Rating	Severity	Spatial scale	Duration	Probability
				of adequate mitigation measures
1	Limited damage to minimal area of low significance, (eg ad hoc spills within plant area). Will have no impact on the environment.	Very limited Limited to specific isolated parts of the site.	Immediate Less than 1 month	Highly unlikely/None Expected never to happen.

Table 6-2: Impact significance matrix as a product of Consequence and Probability

Significance

Consequence (severity + scale + duration)

Probability / Likelihood	1	3	5	7	9	11	15	18	21
1	1	3	5	7	9	11	15	18	21
2	2	6	10	14	18	22	30	36	42
3	3	9	15	21	27	33	45	54	63
4	4	12	20	28	36	44	60	72	84
5	5	15	25	35	45	55	75	90	105
6	6	18	30	42	54	66	90	108	126
7	7	21	35	49	63	77	105	126	147

Table 6-3: Impact significance classification based on the Significance scoring

Significance		
High (Major)	**108- 147**	
Medium-High (Moderate)	**73 - 107**	
Medium-Low (Minor)	**36 - 72**	
Low (Negligible)	**0 - 35**	

6.2 Construction phase

It is understood that the infrastructure (existing shafts and discard dumps) on the adjacent mining property of Syferfontein Mine will be used and no additional construction activities and associated impacts will take place at the project site during this phase.

6.3 Operation Phase

6.3.1 Impact of Activity 1: Mine dewatering

Inflow rate is not only a function of the aquifer properties, but also the mine plans. The mined area, depth and excavation rate do affect the inflow rates.

The estimated groundwater inflow rate at various stages of the life of mine is listed in Table 6-4. The inflow rate as a function of the mined coal seam area is given in Figure 6.1. The figure also contains a typical inflow rate expected at the coal mines (Grobbelaar et al, 2004). The inflow rate is expected to increase as the mine area increases from 83 m^3/d (in 2016 when the area is 0.84 km^2) to 1155 m^3/d (in 2040 when the area is 42.7 km^2).

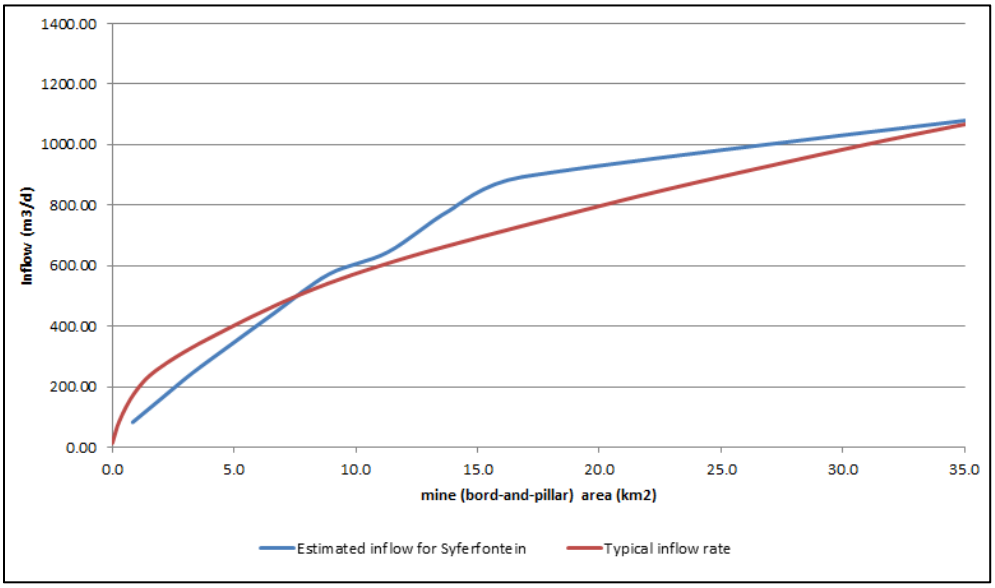

Figure 6.1: Estimated groundwater inflow rate as a function of coal seam area

Table 6-4: Estimated groundwater inflow rates

Starting Year	Ending Year	Coal seam area (km^2)	Cumulative coal seam area (km_2)	Inflow (m^3/d)	Inflow (L/s)
2016	2017	0.84	0.8	82.68	1.0

Starting Year	Ending Year	Coal seam area (km^2)	Cumulative coal seam area (km_2)	Inflow (m^3/d)	Inflow (L/s)
2017	2018	1.23	2.1	164.96	1.9
2018	2019	1.56	3.3	246.53	2.9
2019	2020	1.84	4.9	338.64	3.9
2020	2021	2.21	6.7	446.63	5.2
2021	2022	2.41	8.9	572.54	6.6
2022	2023	2.54	11.3	644.89	7.5
2023	2024	2.97	13.9	782.73	9.1
2024	2025	2.6294	16.8	893.27	10.3
2025	2040	25.86	42.7	1154.99	13.4

Mine dewatering is crucial to keep the underground workings dry for safe working conditions. The dewatering is recommended to start with the starting of the excavation. This however can potentially impact the groundwater environment negatively by lowering the water level and creating a cone of depression/dewatering.

Numerical model simulations show that no impact on the shallow weathered aquifer will occur due to the mine dewatering.

The cone of dewatering in the coal seam aquifer at the end of operation is shown in Figure 6.2.

The following conclusions are made on the impact of mine dewatering:

- The dewatering will mainly impact the groundwater in the deep coal seam aquifer;
- The environmental significance of the mine dewatering has been rated as shown in Table 6-5.

Table 6-5: Impact assessment during operation phase due to mine dewatering

Parameter	Impact Pre-Mitigation		Impact Post-Mitigation	
Duration	Project life	5	Project life	5
Scale	Local	3	Local	3
Severity	Serious	4	Moderate	3
Likelihood	Likely	5	Unlikely	3
Significance	Minor	60	Negligible	33

6.3.2 Mitigation of Activity 1: Mine dewatering

- Monitoring of water levels is recommended with continuous refining and updating of the monitoring network based on the results obtained. Since the operation phase will take place over a prolonged period, more monitoring boreholes will be required. The positions of the recommended monitoring boreholes are shown in Figure 7.1; and
- With the application of the above-stated mitigation plans, the impact of the dewatering can be lowered to Negligible (Table 6-5).

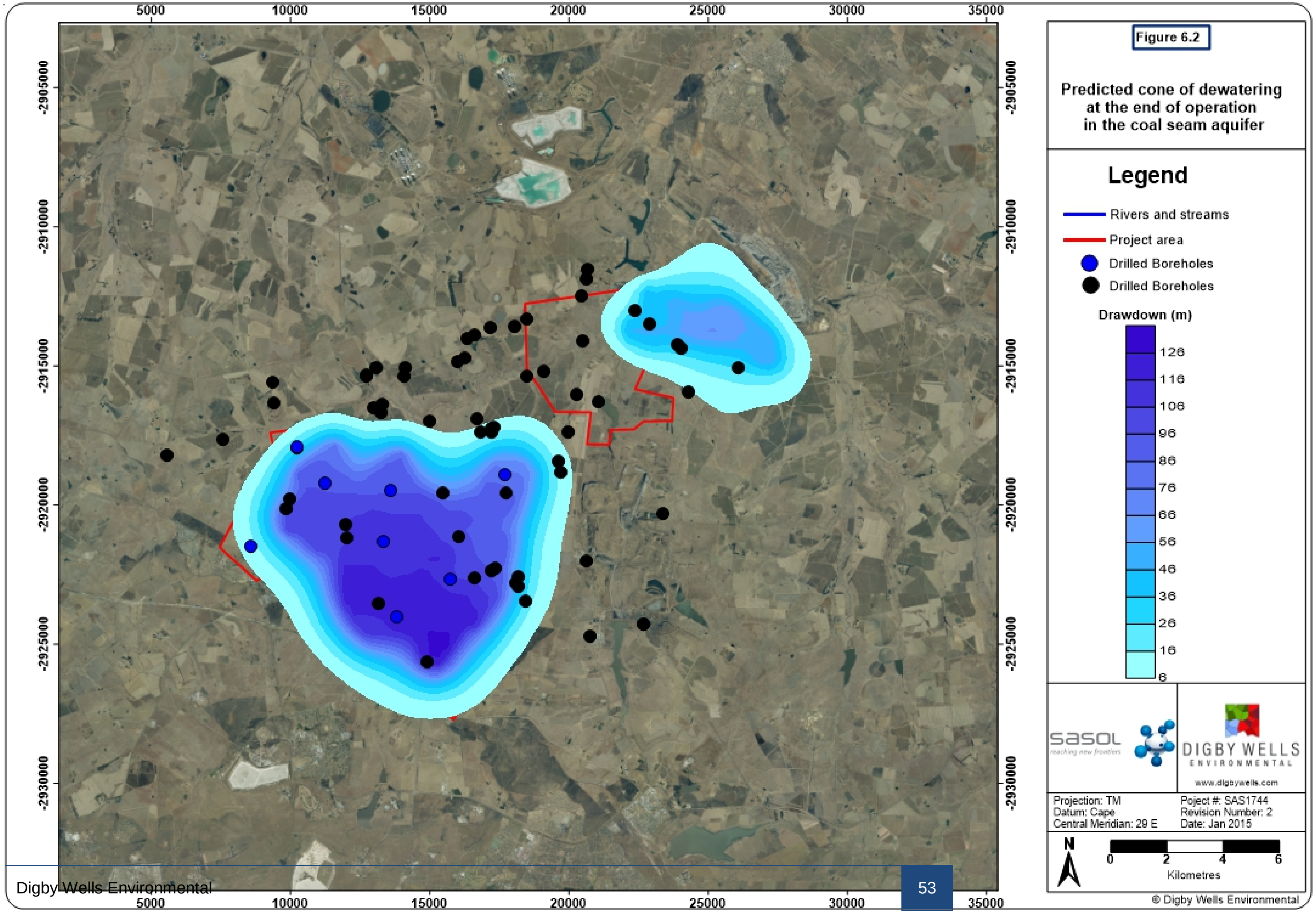
Figure 6.2
Predicted cone of dewatering at the end of operation in the coal seam aquifer
Legend
Rivers and streams
Project area
Drilled Boreholes
Drilled Boreholes
Drawdown (m)
126
116
106
96
86
76
66
56
46
36
26
16
6
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
N
0 2 4 6
Kilometres
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6.3.3 Impact of Activity 2: Mine water contamination

- No waste rock dumps and topsoil stockpiles are expected to exist on surface directly above the project area. The existing Sasol infrastructure on surface will be used and therefore no impacts associated with surface infrastructure will exist;
- Saline water with acidic or alkaline pH can be released from the underground workings once the coal pillar and nearby rocks are exposed to oxygen and moisture. Contaminants can also be generated as a result of drilling and blasting during the operation; and
- During operation any potential contaminants that could originate from the mine workings will be pumped out as part of the mine dewatering process and the hydraulic gradient will be towards the mine. No contaminants are expected to migrate away from the mine area into streams or private boreholes and therefore, the impact has been rated as Minor (Table 6-6).

Table 6-6: Impact assessment during operation phase due to contamination plume

Parameter	Impact Pre-Mitigation		Impact Post-Mitigation	
Duration	Permanent	6	Project life	5
Scale	Local	3	Site only	2
Severity	Very serious	5	Minor	2
Likelihood	Likely	5	Probable	3
Significance	Minor	70	Minor	27

6.3.4 Mitigation of Activity 2: Mine water contamination

- If subsidence occurs and sinkholes are formed during operation, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the atmosphere. This will minimise or avoid oxidation reactions and potential acid generation;
- Nitrate-based explosives should be avoided or minimised to lower groundwater contamination;
- Monitoring of groundwater quality and water levels is recommended (particularly down gradient of the mine site) with continuous refining and updating of the monitoring network based on the results obtained. Since the operational phase will take place over a prolonged period, more monitoring boreholes will be required. The positions of the recommended monitoring boreholes are shown in Figure 7.1;

- Refine the conceptual and numerical models every year in the first four years and thereafter every five years based on groundwater monitoring results; and
- Annual audits of monitoring and management systems should be conducted by independent environmental consultants.

6.3.5 Impact of Activity 3: Underground hydrocarbon spillage

- Organic solvents, diesel or other organic fluids may be spilled in the underground workings or leak from storage tanks during mine operation. This could have a potential negative impact on groundwater quality.
- This impact could occur over a longer period of time and could have the potential of impacting the environment; rated as Minor (Table 6-7).

Table 6-7: Impact assessment during operation phase due to hydrocarbon spillages

Parameter	Impact Pre-Mitigation		Impact Post-Mitigation	
Duration	Project life	5	Project life	5
Scale	Local	3	Site only	2
Severity	Moderate	3	Minor	2
Likelihood	Probable	4	Unlikely	3
Significance	Minor	44	Negligible	27

6.3.6 Mitigation of Activity 3: Hydrocarbon spillage

- All underground storage areas containing hazardous substances need to be bunded, with the necessary spill prevention and emergency response measures in place;
- It is recommended that diesel or other chemicals to be used are handled properly and not spilled;
- If a considerable amount of fluid is accidentally spilled, the contaminated rock should be scraped off and disposed of at an acceptable dumping facility;
- Both groundwater level and quality have to be monitored to detect any changes in water conditions. The positions of the proposed monitoring boreholes are listed in Table 7-2 and illustrated in Figure 7.1; and
- With the application of the above-stated mitigation plans, the impact of the hydrocarbon spills can be lowered to Negligible (Table 6-7).

6.4 Closure Phase

6.4.1 Impact of Activity 1: Mine water contamination

Once the mine is closed and dewatering ceases, groundwater will start to recover to its pre-mining level. Following full recovery; the contaminants will start to migrate away from the mine site. The simulated contamination plume in the coal seam aquifer 100 years after closure is displayed in Figure 6.3.

- No vertical migration of contaminants is expected to occur and therefore the contamination plume will not move towards the top weathered aquifer even after 100 years of model simulation; and
- Model simulation has shown that no contamination from the underground workings will reach nearby private boreholes in the long-run, except those that are within the mine boundary and drilled to the coal seam aquifer and rated as Moderate (Table 6-8).

Table 6-8: Impact assessment after closure due to contamination plume from the mine

Parameter	Impact Pre-Mitigation		Impact Post-Mitigation	
Duration	Permanent	6	Project life	5
Scale	Local	3	Local	3
Severity	Very serious	5	Moderate	3
Likelihood	Highly probable	6	Probable	4
Significance	Moderate	84	Minor	44

6.4.2 Mitigation of Activity 1: Mine water contamination

All the mitigation methods proposed during the operation phase are also applicable here. These include:

- Water monitoring should continue after mine closure. If sinkholes are formed, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface;
- Water abstraction from deep boreholes that are close to the mine workings should be avoided so that contaminants will not migrate towards the abstraction boreholes, and away from the mine voids; and

- Monitoring of groundwater quality and water levels is recommended (particularly down gradient of the mine site) with continuous refining and updating of the monitoring network based on the results obtained. The positions of the recommended monitoring boreholes are shown in Figure 7.1.

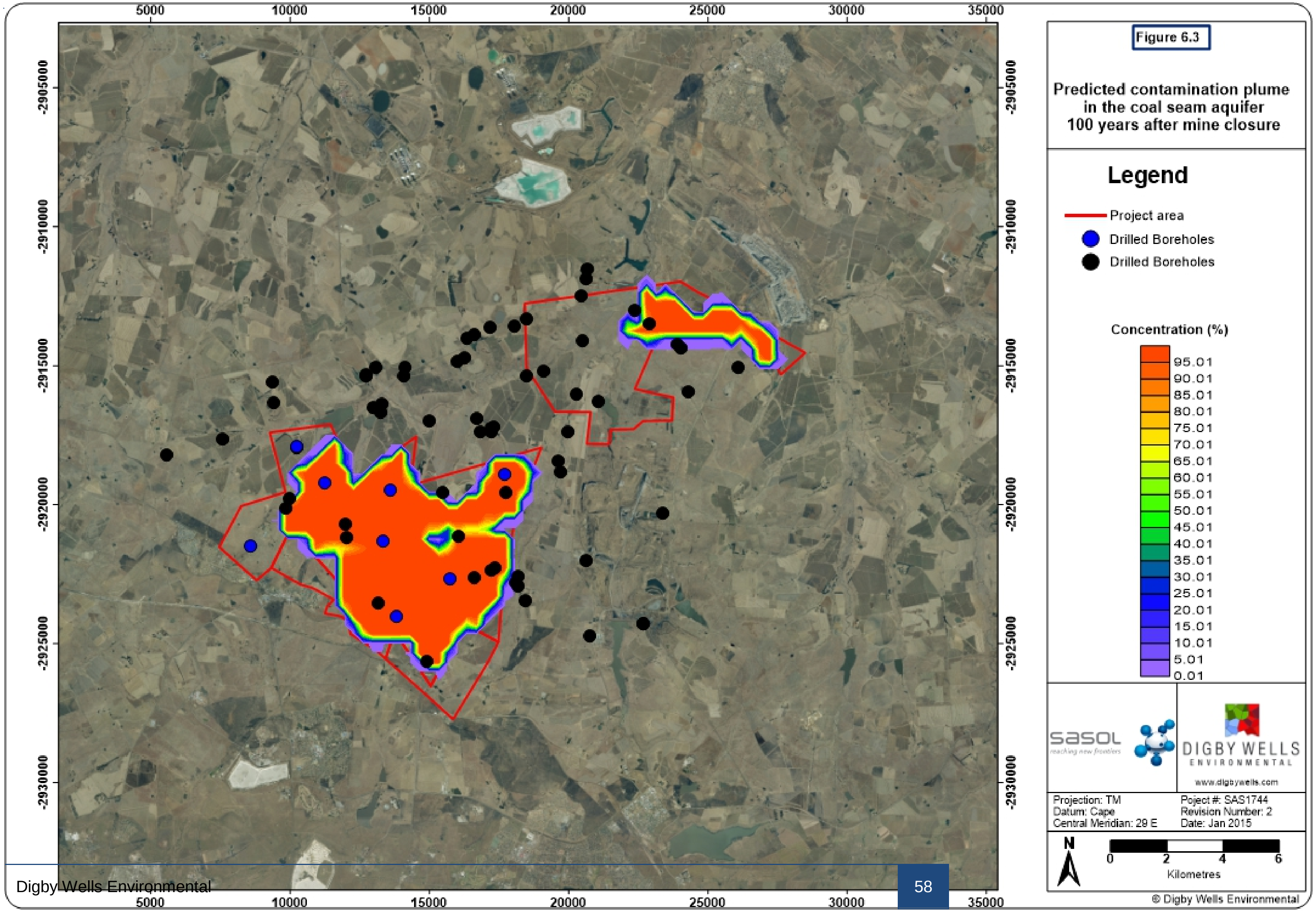
Figure 6.3
Predicted contamination plume in the coal seam aquifer 100 years after mine closure
Legend
Project area
Drilled Boreholes
Drilled Boreholes
Concentration (%)
95.01
90.01
85.01
80.01
75.01
70.01
65.01
60.01
55.01
50.01
45.01
40.01
35.01
30.01
25.01
20.01
15.01
10.01
5.01
0.01
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
Kilometres
0
2
4
6
N
5000
10000
15000
20000
25000
30000
35000
-2905000
-2910000
-2915000
-2920000
-2925000
-2930000
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6.4.3 Impact of Activity 2: Mine decant

Model simulations show that the mine is unlikely to decant after closure. As stated previously, no new shafts will be constructed within the project boundary. The only shaft in the area will be located at the existing Syferfontein Mine, east of the current project site.

If the effects of only the project area are considered, no decant at the shaft will take place. When the cumulative effect of the nearby mines and mine hydraulic connectivity are considered, however, decant at the shaft is possible.

Considering the coal seam depth and site hydrogeology, no decant is expected to occur. The potential impact due to decanting is therefore rated as Negligible (Table 6-9).

Table 6-9: Impact assessment after closure due to mine decanting

Parameter	Impact Pre-Mitigation		Impact Post-Mitigation	
Duration	Permanent	5	Project life	3
Scale	Local	3	Local	3
Severity	Very serious	5	Moderate	3
Likelihood	Unlikely	2	Unlikely	1
Significance	Negligible	26	Negligible	9

6.4.4 Mitigation of Activity 2: Mine decant

No decant mitigation is required, since no decanting is expected to occur at the shaft. However, if sinkholes are formed they should be sealed and rehabilitated as soon as possible to minimise or avoid decanting.

Should decanting occur, passive or active treatment plants should be considered for treatment before the decant joins the streams.

With the implementation of such precautionary mitigation methods in place, the environmental impacts of any potential decants (if they occur) can be reduced to Negligible (Table 6-9).

7 MONITORING PROGRAMME

Groundwater monitoring has to continue during all phases of the mine operation to identify impacts on the groundwater environment over time, and effective measures can be undertaken at the early stage before serious damage to the environment occurs. There are several pieces of legislations that deal with the water management and water contamination prevention and a monitoring programme has to be conducted to ensure compliance with these legislations. These include:

- The Environmental Regulatory Framework in South Africa (Sections 7, 8 and 24 of the Bill of Rights);
- Major Hazard Installation (MHI) Regulations (GNR 692 of 2001);
- National Environmental Management Act (Act 107 of 1998), as amended (NEMA), GNR 544 and GNR 545 (Section 24 (1));
- National Water Act 36 of 1998 (Sections 19-22) and GN 704;
- Water Services Act 108 of 1997;
- National Environmental Management: Waste Act (Act 59 of 2008) (NEMWA) and List of Waste Management Activities requiring a Waste Management Licence (WML) GN 718 of 2008;
- Hazardous Substances Act (Act 15 of 1973);
- Facilities Regulations (GNR 924 of 2004); and
- Hazardous Chemical Substances Regulations (GN 1179 of 1995).

Sasol should consider a legal register for the operations to ensure that all the requirements from the above are complied with.

7.1 Proposed Monitoring Boreholes

The main objectives in positioning the monitoring boreholes are to:

- Monitor the movement of polluted groundwater migrating away from the mine area; and
- Monitor the lowering of the water table and the radius of influence.

The positions of the recommended monitoring points are listed in Table 7-2 and displayed in Figure 7.1. The points are composed of existing boreholes, with additional recommended boreholes in areas of borehole scarcity.

Ideally the monitoring borehole should be made up of two monitoring sets: deep and shallow boreholes.

The purpose of the deep borehole is to monitor the groundwater conditions in the mine void and coal seam aquifer. All of the boreholes drilled during this study are deep and should be used for the monitoring of the coal seam aquifer.

The purpose of the shallow borehole is to monitor the weathered aquifer and should not be more than 15 m deep.

In total 24 monitoring points are recommended for the purpose groundwater monitoring as listed in Table 7-1.

Table 7-2: List of the proposed monitoring boreholes

Borehole	X	Y	Comment
SFNBH1	8590	-2921480	existing borehole
SFNBH2	10249	-2917897	existing borehole
SFNBH3	11242	-2919222	existing borehole
SFNBH4	13578	-2919490	existing borehole
SFNBH5	13337	-2921322	existing borehole
SFNBH6	13824	-2924023	existing borehole
SFNBH7	15757	-2922668	existing borehole
SFNBH8	17685	-2918907	existing borehole
MONBH1	10543.29	-2923618	proposed borehole
MONBH2	13731.07	-2926806	proposed borehole
MONBH3	18533.45	-2923494	proposed borehole
MONBH4	13275.68	-2917367	proposed borehole
MONBH5	19113.04	-2920513	proposed borehole
MONBH6	22093.83	-2913185	proposed borehole
MONBH7	23874.02	-2915048	proposed borehole
MONBH8	24577.81	-2913558	proposed borehole
MONBH9	27475.79	-2915504	proposed borehole
MONBH10	23470.51	-2911712	proposed borehole
MONBH11	26680.73	-2912696	proposed borehole

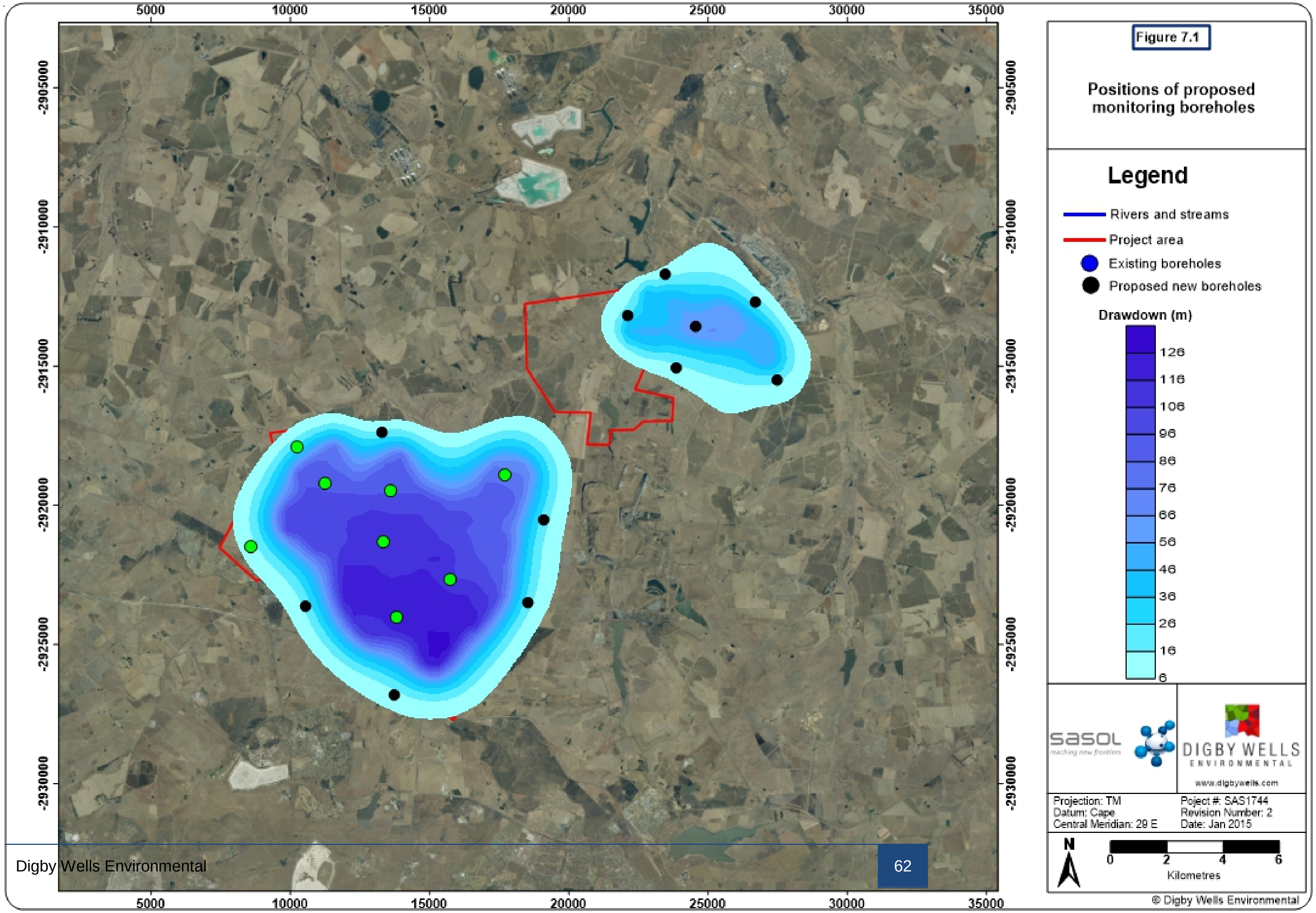
Figure 7.1
Positions of proposed monitoring boreholes
Legend
Rivers and streams
Project area
Existing boreholes
Proposed new boreholes
Drawdown (m)
126
116
106
96
86
76
66
56
46
36
26
16
6
Projection: TM
Datum: Cape
Central Meridian: 29 E
Poject #: SAS1744
Revision Number: 2
Date: Jan 2015
Kilometres
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7.2 Water Level

Groundwater levels must be recorded on a quarterly basis using an electrical contact tape or pressure transducer, to detect any changes or trends in groundwater elevation and flow direction.

7.3 Water Sampling and Preservation

When sampling the following procedures are proposed:

- One litre plastic bottles with a cap are required for the sampling exercises;
- Glass bottles are required if organic constituents are to be tested; and
- Sample bottles should be marked clearly with the borehole name, date of sampling, sampling depth and the sampler's name and submitted to a SANAS accredited laboratory.

7.4 Sampling Frequency

Groundwater is a slow-moving medium and drastic changes in the groundwater composition are not normally encountered within days. Considering the proximity of private boreholes and streams to the proposed mine, monitoring should be conducted bi-annually to reflect influences of wet and dry seasons.

Samples should be collected by an independent groundwater consultant, using best practice guidelines and should be analysed by an accredited laboratory.

It is suggested that bi-annual samples be collected, extending up to two years post closure and based on the results. Post closure monitoring should continue until a sustainable situation is reached and after it has been signed off by the Authorities.

7.5 Parameters to be monitored

At coal mining facilities, analyses of the following constituents are recommended:

- Macro Analysis i.e. Ca, Mg, Na, K, SO_4, NO_3, F, Cl;
- Initial full suite metals and then Al, Fe, Mn and other metals identified according to results of the initial analyses;
- pH and Alkalinity; and
- TDS and EC.

7.6 Data Storage

During any project, good hydrogeological decisions require good information developed from raw data. The production of good, relevant and timely information is the key to achieve qualified long-term and short-term plans. For the minimisation of groundwater contamination it is necessary to utilize all relevant groundwater data.

The generation and collection of this data is very expensive as it requires intensive hydrogeological investigations and therefore the data has to be managed in a centralised database if funds are to be used in the most efficient way. Digby Wells has compiled a WISH-based database during the course of this investigation and it is highly recommended that Sasol utilise this database and continuously update and manage it as new data becomes available.

8 Conclusions

The following conclusions are made based on the baseline hydrogeological assessment:

- A total of 66 boreholes were recorded during the hydrocensus. Of this:
  - 15 are used for drinking only;
  - 6 are used for drinking and livestock watering;
  - 5 are used for livestock watering only;
  - 1 is used for game watering;
  - 1 is used for drinking and game watering;
  - 1 is used for drinking, livestock and game purposes;
  - 10 are used for groundwater monitoring by the existing Syferfontein Mine;
  - 22 are boreholes of unknown use; and
  - The remaining 5 are unused.
- Fourteen representative boreholes were sampled for baseline water quality study:
  - None of the boreholes have elevated sulphate levels, which is indicative of little mine-related contamination to date;
  - Six of the boreholes are categorised as Class I water and are suitable for human consumption;
  - Four boreholes fall within the Class II range of the SANS 241:2005 standard. This is due to elevated nitrate, sodium, iron and manganese values; and
  - Four boreholes are not recommended for human consumption (exceeding the Class II range). This is due to high levels of fluoride and nitrate.
- The baseline water levels range between 0.3 m and 69.7 m below ground level (mbgl). The relatively large water level variation in a relatively short distance may indicate that some of the boreholes are near groundwater abstraction points or possibly from different aquifers.
- The groundwater flow direction is similar to the topography and is towards the streams on the east (Trichardspruit) and northwest (Dwars-in-die-wegspruit).
- Acid-base accounting analysis conducted illustrates that:

  - The average sulphide content of all of the samples (coal seam, overburden and underburden) is 0.44%, which is above the 0.30% benchmark required to sustainably generate acid. However, the sulphide content of these rocks is less than the typical values obtained from similar rocks of the Witbank Coalfield;
  - The overall conclusion based on the NNP value is that the geochemical compositions of the rocks at the project area are heterogeneous with some areas likely to generate acid and in other areas slightly acid neutralising; and
  - Based on the ratio of NPR versus sulphide-sulphur of the six samples tested, one sample falls in the potentially acid generating zone, two in the non-acid generating zone, and three in the uncertain zone.
- The water strikes recorded in the aquifer characterisation boreholes are encountered at depths between 20 and 90 m below ground level, with the majority occurring between 60 and 90 mbgl. No water strike was encounter below 90 m, although the boreholes were drilled to a depth of up to 153 m.
- The aquifer permeability within the project area ranges between 10^{-4} m/d and 0.06 m/d.
- Sensitivity analysis shows that the model is more sensitive to the vertical permeability followed equally by all the other parameters. This means that changes in the vertical permeability will have slightly more impact on the model output than the other less sensitive parameters.
- Numerical model simulations show that at the end of operation the cone of dewatering could be up to 5 m in the top weathered aquifer. However, no private boreholes have been identified during the hydrocensus that fall within the radius of influence.
- The groundwater inflow rate is expected to increase as the mine area increases from 126 m^3/d (in 2015) to 710 m^3/d (in 2042).
- Considering the coal seam depth and site hydrogeology, no decant is expected to occur.

9 Recommendation

- No mitigation at the project area is recommended during the construction phase since all the activities will take place from the existing Syferfontein Mine.
- If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. This will minimise or avoid oxidation reactions and potential acid generation.

- Abstraction from deep boreholes that are close to the mine workings should be avoided so that contaminants will not migrate away from the mine, towards the abstraction boreholes.
- Nitrate-based explosives should be avoided if possible, to minimise groundwater contamination.
- It is recommended that the mine should supply equal/better amount of water to affected parties that rely on groundwater in the receiving environment, if proven that there is impact on specific users.
- Monitoring of groundwater quality and water levels is recommended (particularly down gradient of the mine site) with continuous refining and updating of the monitoring network based on the results obtained.
- Refine the conceptual and numerical models every year in the first four years and thereafter every five years based on groundwater monitoring results.
- Annual audits of monitoring and management systems should be conducted by independent environmental consultants.
- Groundwater monitoring has to continue during all phases of the mine operation to identify impacts on the groundwater environment over time. Effective measures can be undertaken at an early stage before serious damage to the environment takes place. There are several pieces of legislations that deal with the water management and water contamination prevention and the monitoring programme has to be conducted to ensure compliance with these legislations.
- The streams in the project area are gaining, with groundwater in the weathered aquifer contributing to baseflow of the streams. Therefore monitoring should also be conducted on the streams, in addition to the boreholes.
- In total 24 monitoring points are recommended for the purpose groundwater monitoring.
- Analyses of the following constituents are recommended:
  - Macro Analysis i.e. Ca, Mg, Na, K, SO_4, NO_3, F, Cl;
  - Full suite metals and then As, Al, Fe, Mn and other metals identified according to results of the initial analyses;
  - pH and Alkalinity; and
  - TDS and EC.
- Since the model is more sensitive to the vertical permeability, any future groundwater study should focus on and refine this parameter.

10 Reference

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Appendix A: Hydrocensus Data

Appendix B: Water Quality Results

Appendix C: ABA and Leachate Results

Appendix D: Borehole Logs

Appendix E: Aquifer Test Data