GROUNDWATER IMPACT ASSESSMENT IN A COAL MINE AREA OF WITBANK, MPUMALANGA

Cobus Abraham Erasmus

Student no: 1533863

A Research Report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Hydrogeology

WITS UNIVERSITY

Supervisor: Professor Tamiru Abiye

August 2018

DECLARATION

I declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University. The original data contained within this report belongs to the mining company that provided the data and the interpretation of this data is the author's own.

(Signature of candidate)

15th day of August 2018 in Pretoria

ACKNOWLEDGEMENTS

I wish to thank and acknowledge the following individuals:

- My wife for your loving support
- Professor Tamiru Abiye for your valuable guidance, time and assistance during the course of my studies
- The management at the coal mine for their help and permission to use their data
- My employer for their accommodating attitude and assistance during my studies

ABSTRACT

A groundwater impact assessment was compiled of an operational coal mine situated in the Witbank region of Mpumalanga, South Africa. This was done by evaluating the existing groundwater level and groundwater chemistry datasets (2016 - 2012) from the groundwater monitoring programme of the mine. The study area is located within the Witbank coalfield with the local geology dominated by the Vryheid Formation of the Karoo Supergroup. A conceptual hydrogeological site model and a conceptual hydrogeological cross-section were produced using the results obtained from the data evaluation. The mine contains a shallow weathered zone aquifer, fractured aquifer and disturbed groundwater system (opencast coal mine). The 2013 groundwater level and groundwater chemistry dataset provided the most accurate representation of the actual conditions present within the study area (as it contains the most complete datasets). The regional groundwater flow trend appears to be radially inwards towards the central portions of the mine site (over the current mine workings). The regional groundwater trend differs from what would be expected from a natural groundwater system within the region. The variations in the regional groundwater trend were most probably caused by active mine dewatering and groundwater abstraction within the study area. Acid mine drainage reactions influenced most of the groundwater quality issues within the study area. Lowered pH coupled with high concentrations of sulphate and dissolved metals (iron, aluminium and manganese) were encountered within: the current (and rehabilitated) mine workings, the north of the mine site (over the old underground workings and near old mine dumps) and adjacent to, or downstream from, the mine discard stockpile (south-east portion of the mine site). High chloride concentrations in some monitoring boreholes were caused by runoff from agricultural areas and from the mine site within the region. Substantial mixing between contaminated water and fresh water was evident from all of the groundwater chemistry datasets evaluated.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

°C	Degrees Celsius
AMD	Acid Mine Drainage
DEAT	Department of Environment and Tourism
DTM	Digital Terrain Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
GIS	Geographical Information System
GPS	Global Positioning System
ha	Hectares
km	Kilometres
km^2	Square kilometres
l/s	Litres per second
LOW	Limit of Weathering
m	Meter
m^3/a	Cubic meters per annum
mamsl	Meters above mean sea level
MAP	Mean Annual Precipitation
mbs	Meters below surface
mg/L	Milligrams per Litre
mm	Millimetre
mm/a	Millimetres per annum
mS/m	MilliSiemens per meter
SANS	South African National Standard
SAWS	South African Weather Service
TDS	Total dissolved solids
WDMU	Witbank Dam Management Unit

1. INTRODUCTION

South Africa is the world's 6th biggest coal producer at present, producing over 333 Million tonnes of coal in 2014 (Hancox, 2016). Coal is widely used domestically for power generation by Eskom, with a large portion of produced coal (nearly 30%) exported to the international market (through the Richards Bay Coal Terminal).

Coal mining causes a marked impact on the environment, with these impacts differing in severity depending on various factors including: extraction techniques, site geology and operating status of the mine (Bell et al., 2001). Opencast and underground mining methods are both implemented to produce coal in South Africa, with approximately 63% of coal mined with opencast methods and around 37% of coal extracted using underground mining techniques (Barnes and Vermeulen, 2012). The two largest effects of coal mining on the groundwater regime of the coal mine are a reduction in groundwater quantity, and a decrease in groundwater quality (Barnes and Vermeulen, 2012; Thomas, 2013).

In a country with limited water resources like South Africa it is essential to understand the groundwater and surface water systems on a coal mine, and the impact that mining has on these systems. A thorough understanding of the natural water system and the impact coal mining has on it makes it possible to formulate effective environmental management plans to mitigate and prevent any possible negative environmental impacts on the mine. An important way to prevent/manage any negative environmental impacts caused by mining is to implement a comprehensive groundwater monitoring programme on the mine (Barnes and Vermeulen, 2012).

The groundwater monitoring programme on a mine should be assessed on a regular basis because the groundwater regime being monitored does not remain constant over time. Conditions on the mine site will vary with time due to new mining activities taking place, so it is important to check that the groundwater monitoring programme is accurately evaluating the ever changing site conditions (Barnes and Vermeulen, 2012).

1.1 Aims of the Research Report

The aim of the research report is to produce a Groundwater Impact Assessment on an operating opencast coal mine, based on an evaluation of existing groundwater levels and groundwater chemistry data extracted from the groundwater monitoring programme of the mine.

The specific outcomes of the research report include the following:

- Assessment of existing groundwater level data of the mine site
- Evaluation of existing groundwater chemistry data of the mine site
- Compilation of a Conceptual Hydrogeological Site Model (based on the existing data)
- Production of detailed data maps of the study area
- Analysis of the groundwater monitoring programme that can act as a quality control of the current understanding of the mine site

1.2 Research Report Outline

The research report is divided into 8 sections that were compiled to be read in sequence.

Section 1 is an introduction to the aims of the research report and provides background information regarding the study.

Section 2 covers the sources of the data collected and used in the research report.

Section 3 describes what methods were used to evaluate and analyse the data so that the specific aims of the study could be reached.

Section 4 provides a detailed site description which includes descriptions of the general site topography, climate, surface drainage and surface features.

Section 5 provides a thorough discussion on the general geological setting of the study area and a detailed description of the local geology and geological features of the region.

Section 6 covers the hydrogeology of the mine site in two subsections namely: regional hydrogeological setting and local hydrogeology. Within the local hydrogeology subsection the results of the data analysis of the groundwater monitoring programme are presented, discussed and interpreted.

Section 7 is a concluding section that summarises the important findings of the research report and is followed by *Section 8* which contains the recommendations of the research report.

2. DATA COLLECTION

After discussions with the relevant management on the coal mine situated within the study area, it was agreed that the study could be conducted by using existing data from the mine. The research results can be compared with the mine's current understanding of the hydrogeology of the area to act as a quality control. A non-disclosure agreement was finalised and signed by both parties, in order to get access to the required data. Data is presented within the research report in such a way that the non-disclosure agreement is adhered to throughout. In some instances localities, names of monitoring points and the origin of certain data is purposely presented vaguely to adhere to the stipulations of the non-disclosure agreement. Existing data was used to compile this research report with no new additional data collected from the mine site.

A literature review was performed as a first step to source data required to supplement the provided mine data. Data sourced from the literature study is referenced accordingly within the research report.

Data provided by the mine from their various databases can be broadly classed into the following data types:

- Geological Data
- Survey Data
- Water chemistry Data and other Hydrogeology Data

The following sections describe all of the data received from the mine databases according to the different data types indicated above.

2.1 Geological Data

Borehole collars and seam pick files were received for a total of 1547 core drilled coal boreholes from the mine database. The borehole collar data included the coordinates (in LO29 WGS84 datum), surveyed borehole elevations and end of borehole depths. The seam pick data contained the "from" and "to" depth intervals (in meters) of the coal seams intersected within the boreholes. The seam pick data also contained the depth intervals of the recorded LOW (limit of weathering), Dwyka Group lithologies and basement rock intercepts.

Grids of the thickness, seam floor elevations and seam roof elevations of the S2S, S2T, S4S, S4T and S5 coal seams were provided out of the geological model of the mine, compiled by the senior mine geologist (in CSV format).

2.2 Survey Data

The robust survey dataset contained the following relevant data: surveyed DTM (digital terrain model) of the site, detailed mine surface plans (roads, rivers, dams, wetlands, mine infrastructure, mine dumps, powerlines, mining blocks and mineral rights boundaries), mined out areas and planned mining areas and geological features (identified dolerite intrusions and coal seam sub-outcrop positions). The surveyed data was obtained in DXF format from the mine database.

2.3 Groundwater Data

The groundwater dataset was finalised and received at the end of May 2017 and included the available time-series groundwater monitoring data from the mine for the years 2012, 2013, 2014, 2015 and 2016.

The groundwater data included groundwater chemistry data and groundwater level data from the environmental monitoring programme of the mine (for the period 2012 – 2016, in Excel spreadsheets). Internal hydrogeological reports of the mine, annual monitoring reports, partial weather station data and some field forms of the monitoring programme were also contained within the groundwater dataset. The groundwater datasets are discussed in more detail within the relevant sub-sections of the hydrogeology chapter of this report.

3. METHODOLOGY

The study involved the analysis of existing datasets and information provided by the mine (from its robust database) as described in section 2. The study was broken down into three components: Desktop Literature Review, Data Analysis and Data Modelling (for the survey, geology and hydrogeology datasets) and Interpretation of the data modelling results to gain a conceptual hydrogeological understanding of the mine site.

Detailed descriptions of the methods followed during certain research activities are provided in-text within the various sections of the report, where necessary. This section summarises the general methodology followed during the study.

3.1 Desktop Literature Review

A literature study of all available relevant data was performed to provide additional data where required. Data sourced from the literature study was incorporated into the entire research report and referenced accordingly. Data was sourced from: science literature (journals, textbooks, reports, maps etc.), GIS (Geographical Information System) data available to the author, SAWS (South African Weather Service) weather station records, and available relevant scientific work performed on the study area. A detailed list of all the sources of the literature incorporated into the research report is provided in the reference list in section 9.

3.2 Data Analysis and Data Modelling

The following software programs were used during the computer assisted data analysis and data modelling phase of the study:

- Microsoft Excel – data table software program
- Geovia Minex™ 6.5.2 – geological modelling software
- PlanetGIS™ – geographical information system
- Surfer12™ – data contouring, gridding and surface mapping system
- Garmin BaseCamp – GPS coordinate software
- GW Chart™ – water chemistry plotting software

The provided survey data was imported into Geovia Minex™ 6.5.2 modelling software and PlanetGIS™ software to convert the DXF survey files into useable formats (CSV format and

Grids). The survey data was then exported and used during the data modelling of the geology and hydrogeology datasets.

Geology data provided was evaluated using Geovia Minex™ 6.5.2 modelling software and Surfer12™ gridding and contouring software. The thickness, seam floor elevations and seam roof elevations grids of the S2S, S2T, S4S, S4T and S5 coal seams from the geological model was imported into Geovia Minex together with the provided geological borehole data. The surveyed DTM of the mine site and geological features (dolerite intrusions) were imported. A geological structure model (containing the surface DTM, coal seam roof, floor and thickness grids and non-coal surfaces (LOW and basement grids)) was compiled in Geovia Minex.

The groundwater level and groundwater chemistry datasets for 2016, 2015, 2014, 2013 and 2012 were edited in Excel so that the data could be evaluated in Surfer and Minex. The correct coordinates and borehole elevations were added to the groundwater monitoring borehole database and all the original borehole names were changed.

All of the groundwater datasets (groundwater levels and groundwater chemistry) were divided into wet season (January, February, March, October, November and December) and dry season (April, May, June, July, August and September) datasets. This was done in order to evaluate the data per season and also to make the large datasets more manageable and easier to interpret. Various data maps, data tables, graphs and piper plots of the groundwater data was compiled in Surfer, Excel and GW Chart for use during interpretation of the data.

3.3 Conceptual Hydrogeological Site Model

Relevant geological, hydrogeological and hydrogeochemical data (identified during the data analysis and modelling phase) were utilised in order to design a conceptual hydrogeological site model of the study area. The conceptual model is based on the geological model and groundwater monitoring data evaluation compiled of the site.

4. SITE DESCRIPTION

4.1 Study Site Locality and Description

The study site covers an operating opencast coal mine and its surrounding areas and is situated within the western part of the Mpumalanga Province of South Africa (Figure 1).

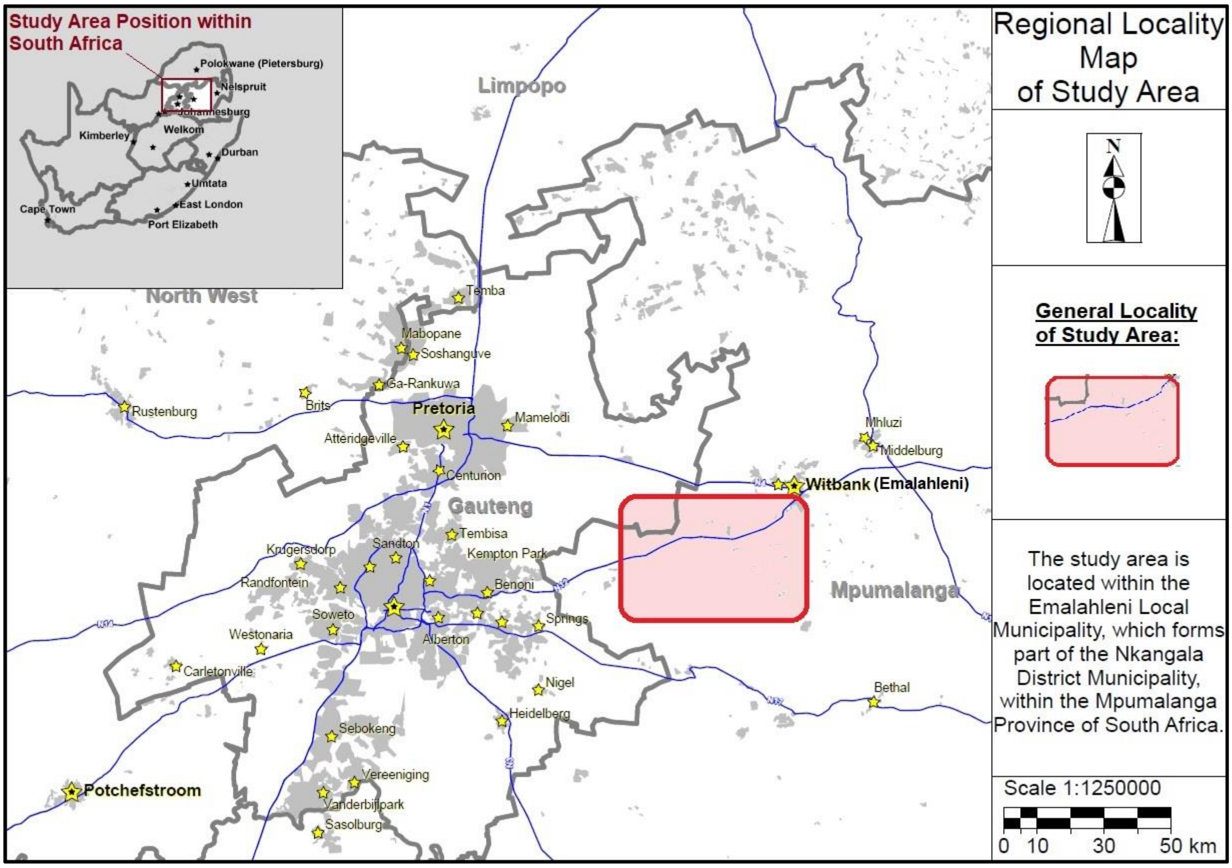


Figure 1. Regional Locality Map of Study Area

The study area is located within the Emalahleni Local Municipality, which forms part of the greater Nkangala District Municipality. The general land usage within the study area, and its immediate surroundings, is dominated by numerous coal mining activities (including neighbouring opencast and underground coal mines) and agricultural activities (grazing and planted fields).

Historical underground mined-out coal workings are present within certain parts of the site together with the rehabilitated mined-out areas of the operating coal mines in the region. Typical mine infrastructure encountered within the mine site includes the following (according to the mine data obtained): run of mine coal dumps, waste rock dumps, mine roads (tar and dirt roads), conveyer belts, evaporation dams and railway sidings. Regional tar roads intersect the study area and built up areas and settlements are located in close proximity to the site.

4.2 Regional Topography

The study area is located within the Highveld region of the Mpumalanga Province, which is characterised by a gentle sloping hills and valleys type terrain. The regional topography of the site has surface elevations ranging from roughly 1650 mamsl (meters above mean sea level) to about 1530 mamsl. The regional topography of the study area and adjacent parts is depicted in Figure 2. Surface elevation data was extracted from the 20 m interval contours of the 1:50 000 Topographical Map Sheet of the region (Topographical Map Series of South Africa, 1995) and edited in Surfer 12™ software to produce the displayed topographical maps. The 3-dimensional topography map (the top image in Figure 2) is vertically exaggerated for illustrational purposes.

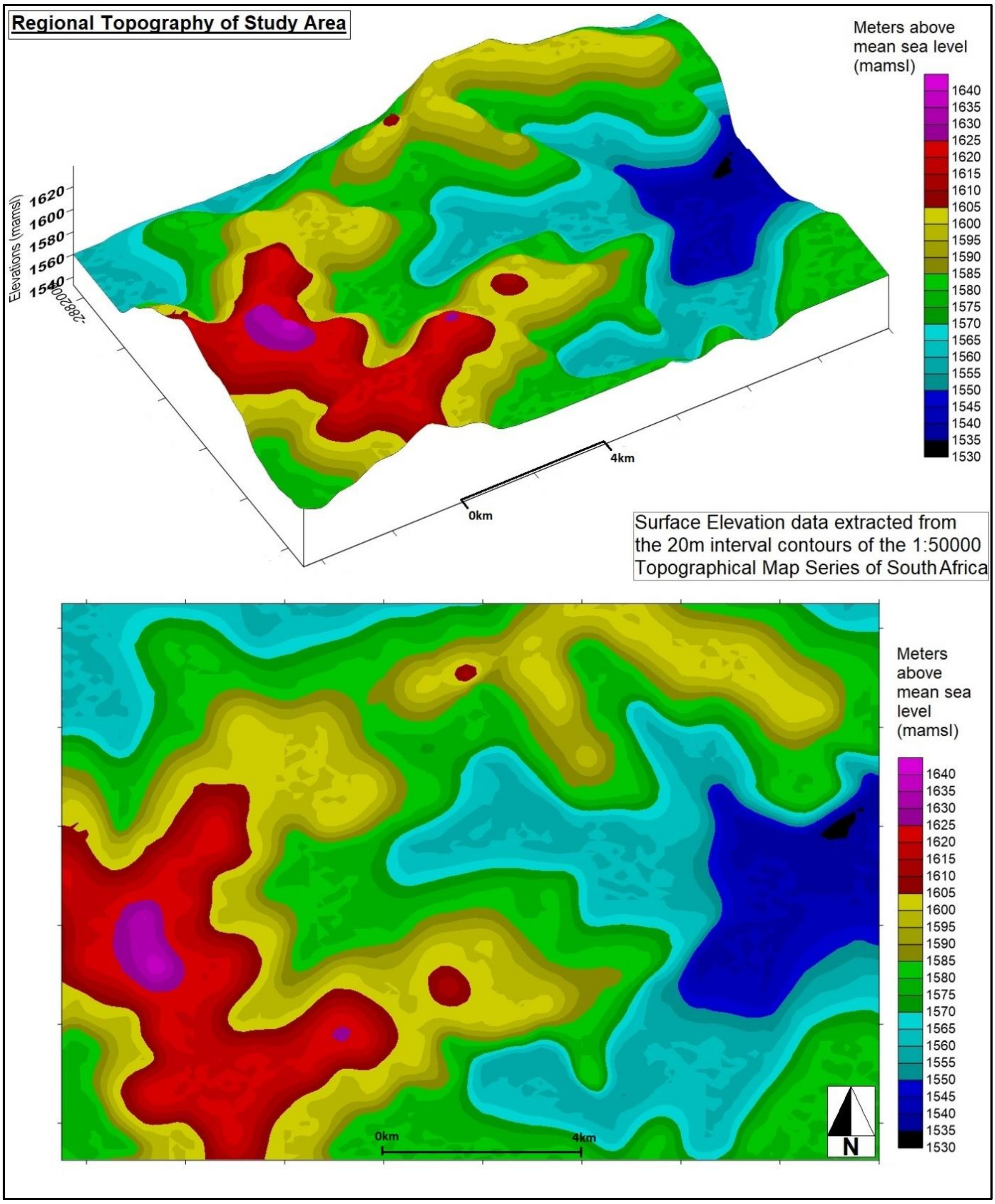


Figure 2. Regional Topography of Study Area - 3D & 2D topography maps (modified from the 1:50 000 Topographical Map Series of South Africa, 1995)

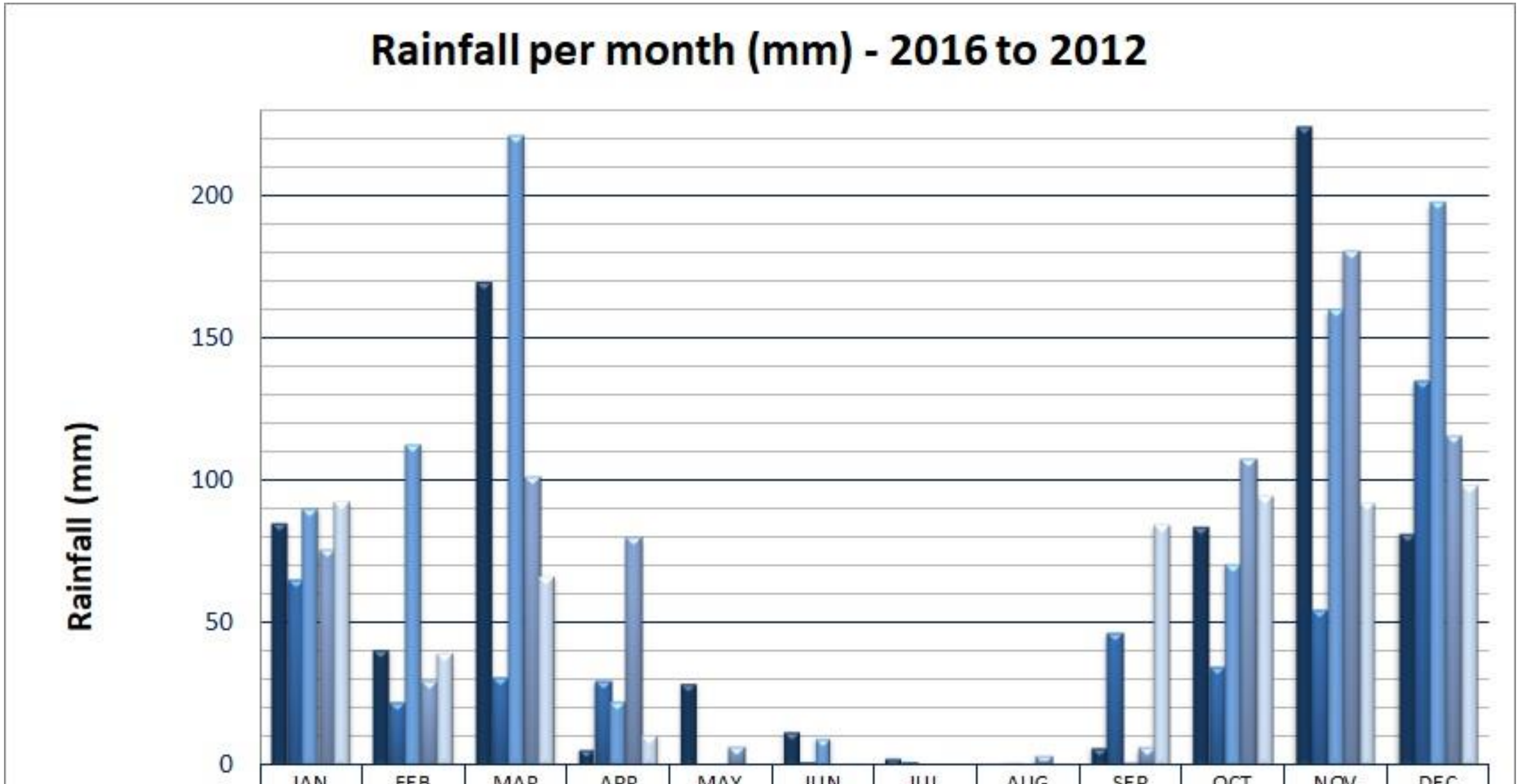
The highest elevations within the area are located towards the south-west of the study site and range from 1600 mamsl to 1640 mamsl. The lowest elevations are encountered in the eastern part of the site, with elevations ranging between 1550 mamsl and 1530 mamsl. Surface elevations within the mine property generally fall between 1550 mamsl and 1625 mamsl. The topography slopes gently from the high lying regions towards the low lying parts of the site, where small streams and pans are found. A digital terrain model (DTM) of the site was created from detailed surveyed data obtained from the mine, which provides the most accurate surface elevations of the study area. This detailed DTM is included in section 5 (Figure 16) of this report.

4.3 Climate and Local Weather

The study area is situated within a part of South Africa where the majority of rain occurs in the summer months. The climate is characteristic of the Highveld region with cold winters (with little to no rain) and wet summers that are warm and humid. Climatic data records were obtained for the Witbank Automatic Weather Station (South African Weather Service) during 2018, to evaluate the climate and weather of the study area (the Witbank Weather Station is in close proximity to the study site). Temperature, rainfall humidity and pressure data for the years 1993 to 2016, was contained within the provided dataset.

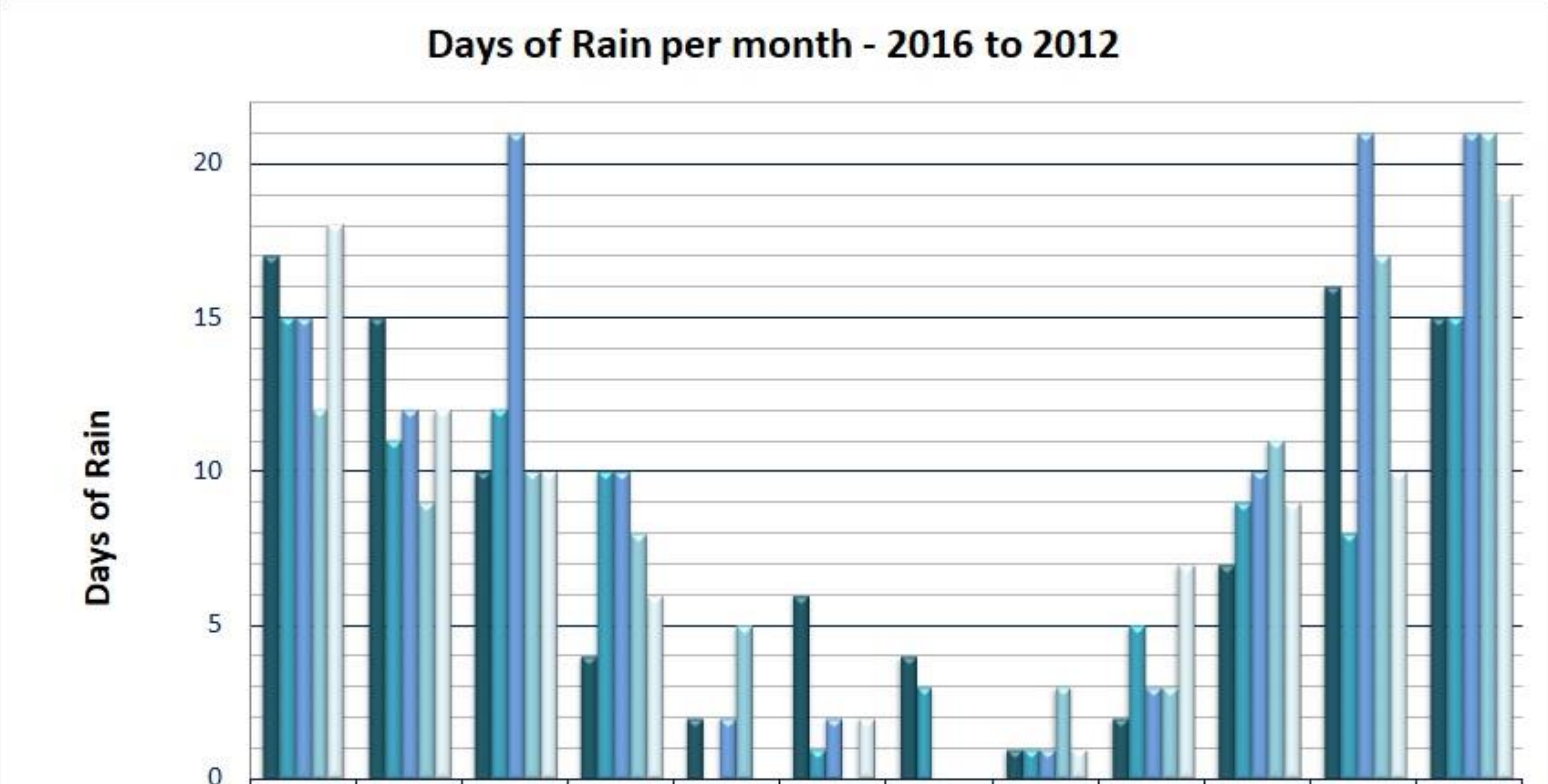
Mean annual precipitation (MAP) within this part of Mpumalanga historically range from 622 mm/a to 752 mm/a (DEAT, 2000). The MAP recorded for 2016 within the region was 743.6 mm/a with nearly 81% of all rain occurring in the months of January, February, March, October, November and December of 2016 (SAWS, 2018). This summer rain predominantly occurs during short high intensity thunderstorms. The amounts of rainfall per month (in mm) for the years 2016 to 2012 (as recorded at the Witbank Weather Station) is shown in Figure 3. The number of days where at least 0.1 mm of rain fell, per month (for the Witbank Weather Station) is indicated in Figure 4.

Summer (December to February) temperatures during 2016 ranged between a maximum of 29.5 °C and a minimum of 15.3 °C, with winter (June to August) temperatures fluctuating between a maximum of 23.3 °C and a minimum of 3.4 °C (SAWS, 2018). The average maximum temperature for 2016 was 24.7 °C and the average minimum temperature for 2016 was 10.6 °C (Figure 5). These average temperatures for 2016 correlate closely with the historical minimum and maximum temperatures recorded at the Witbank Weather Station (SAWS, 2018).



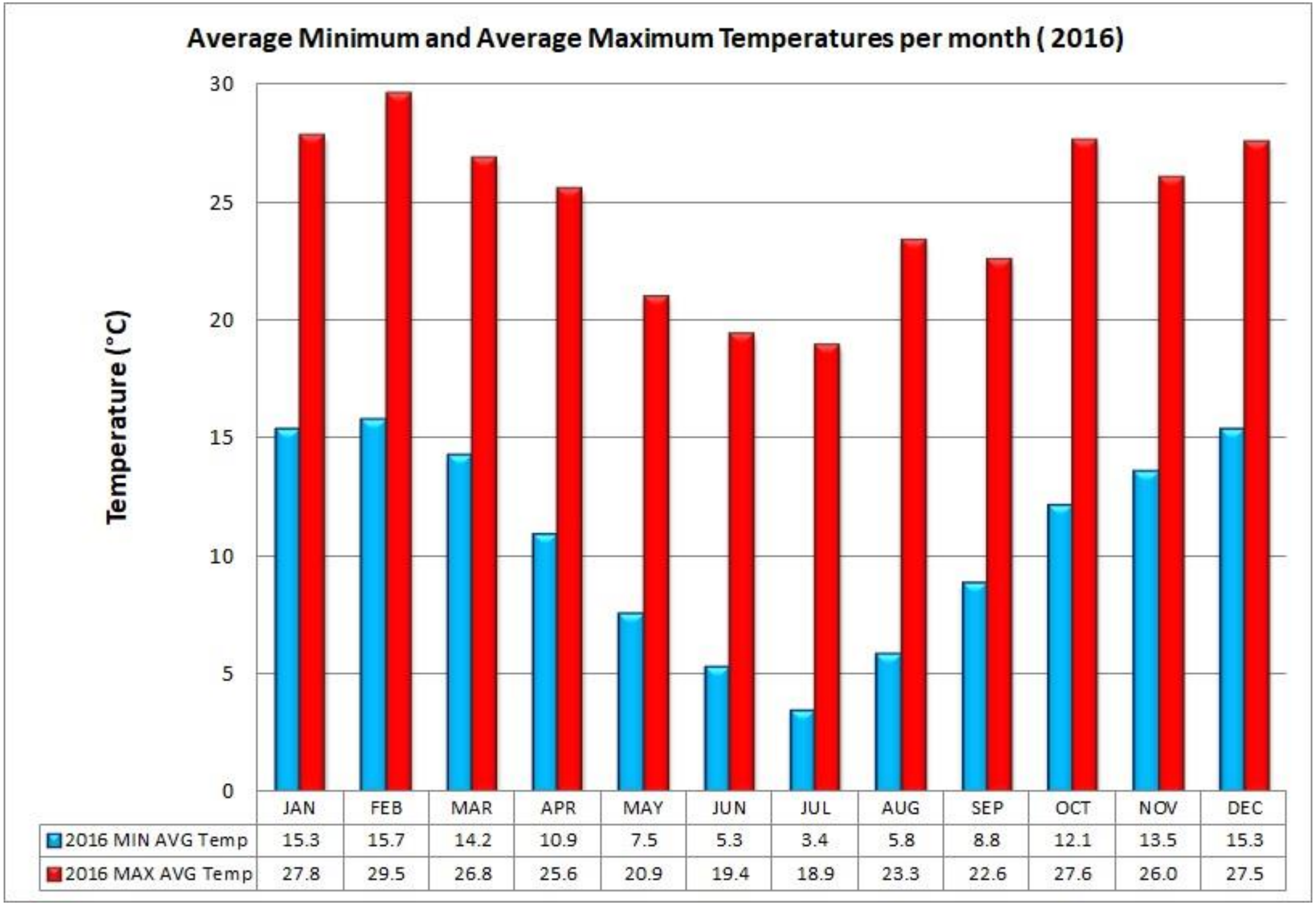
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2016 Rainfall (mm)	85.4	40.8	170.2	5.8	29	12	3	0.6	6.4	84	224.6	81.8
2015 Rainfall (mm)	65	21.8	30.6	29.4	0	0.8	1	0.4	46.2	34.2	54.2	135.2
2014 Rainfall (mm)	90.6	113	221.4	22.8	0.4	9.4	0	0.4	1.2	71	160.2	197.8
2013 Rainfall (mm)	75.4	29.4	101	79.8	6.4	0	0	3.2	6	107.6	180.8	115.6
2012 Rainfall (mm)	92.6	39.8	66.6	10.8	0	0.8	0	0.6	84.8	94.8	92.4	98.6

Figure 3. Rainfall per month (mm) – 2016 to 2012 for the Witbank Weather Station (SAWS, 2018)



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2016 Days of Rain	17	15	10	4	2	6	4	1	2	7	16	15
2015 Days of Rain	15	11	12	10	0	1	3	1	5	9	8	15
2014 Days of Rain	15	12	21	10	2	2	0	1	3	10	21	21
2013 Days of Rain	12	9	10	8	5	0	0	3	3	11	17	21
2012 Days of Rain	18	12	10	6	0	2	0	1	7	9	10	19

Figure 4. Days of rain per month (at least 0.1 mm of rain in a day) – 2016 to 2012 for the Witbank Weather Station (SAWS, 2018)



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2016 MIN AVG Temp	15.3	15.7	14.2	10.9	7.5	5.3	3.4	5.8	8.8	12.1	13.5	15.3
2016 MAX AVG Temp	27.8	29.5	26.8	25.6	20.9	19.4	18.9	23.3	22.6	27.6	26.0	27.5

Figure 5. Average Minimum and Maximum Temperatures per month (2016) - for the Witbank Weather Station (SAWS, 2018)

4.4 Surface Drainage and Surface Features

The mine site is situated within the Greater Upper-Olifants River primary catchment, and forms part of the Olifants River Water Management Area, Management Area B as designated by the Department of Water Affairs (AGIS database, 2018). The site lies within secondary catchment area B1, within the upper parts of tertiary catchment area B11F (Internal mine report, 2013; AGIS database, 2018).

Rivers from this tertiary catchment area flow towards the Olifants River, which in turn drains northwards into the Witbank Dam and then on to the Loskop Dam. From there the Olifants River flows through the Kruger National Park, into Mozambique and eventually discharges into the Indian Ocean. The tertiary catchment area B11F covers an area of approximately 430 km^2 with an estimated Mean Annual Run-off that ranges between 14 $\times 10^6$ and 28×10^6 m^3/a (DEAT, 2000).

Surface water within the mine site flows in the general direction of the surface elevation gradients, from areas of higher elevation to areas of lower elevation. Figure 6 indicates the rivers, dams, and wetlands present within the study area, together with the surface elevation contours of the site. Surface elevations were modelled from the surveyed DTM of the mine giving an accurate and detailed surface topography of the area. The thick blue line in Figure 6 shows the location of an artificial river diversion constructed by the mine, in the central part of the site (from the obtained survey data from the mine). The river diversion forces water to flow through only the constructed channel within the central part of the mine site, avoiding the mining activities within the site.

All of the rivers indicated within the mine site appear to be non-perennial. Surface water typically drains the area in an eastern and north-eastern direction, eventually flowing into tributaries of the Olifants River (situated several kilometres to the north-east of the site). The surface topography has a gentle slope which allows water to pond up on the surface and form wetlands adjacent to the streams and pans in the region (Potgieter, 2015). Several wetland areas are indicated in Figure 6 along the streams and pans present in the mine site (with green polygons). The watershed boundary of tertiary catchment B11F is located just to the north-west of the mine site (AGIS database, 2018).

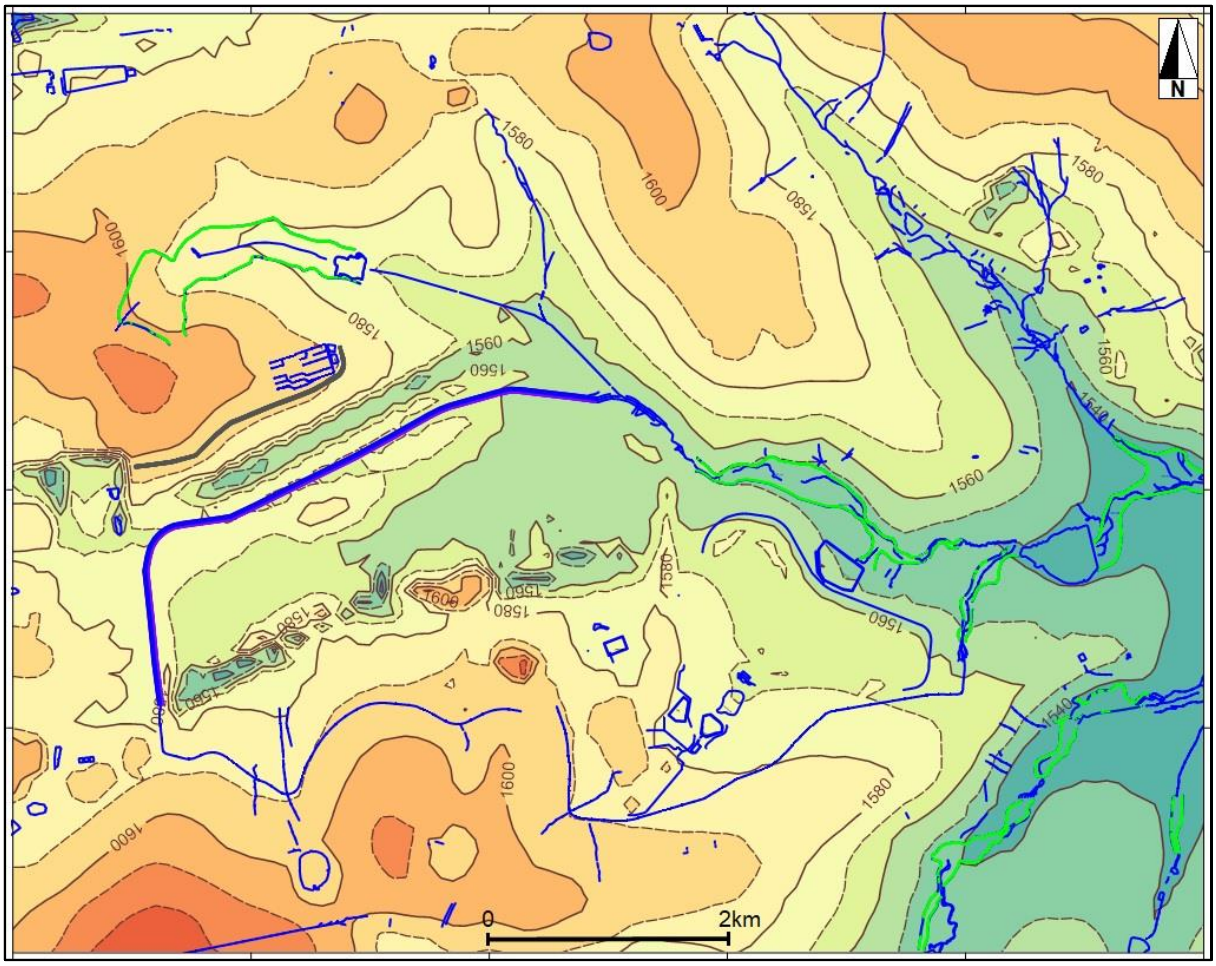


Figure 6. Surface drainage of the mine site with rivers (blue lines), wetland areas (green polygons) and surface contours (from the surveyed mine DTM) indicated

5. GEOLOGY

5.1 Regional Geological Setting

Within the regional geological framework of South Africa, the study area is situated within the north eastern portion of the Main Karoo Basin of the Karoo Supergroup (indicated in shades of grey in Figure 7). Rocks of the Karoo Supergroup were deposited from the Late Carboniferous to Middle Jurassic eras, with coal seams deposited during the Permian period (Cairncross, 2001). Although there is still some debate the Main Karoo Basin is widely considered to be a retro-arc foreland system (Catuneanu et al., 1998; Johnson et al., 2006; Hancox and Götz, 2014). The Karoo aged sediments in South Africa were deposited mainly into two distinct tectonic environments. The first being sediments deposited into the Main Karoo Basin (where compressional tectonic stresses were dominant) and the second being sediments deposited into fault-bound basins to the north of the Main Karoo Basin (where rifting and extensional tectonic stresses were dominant)(Hancox and Götz, 2014).

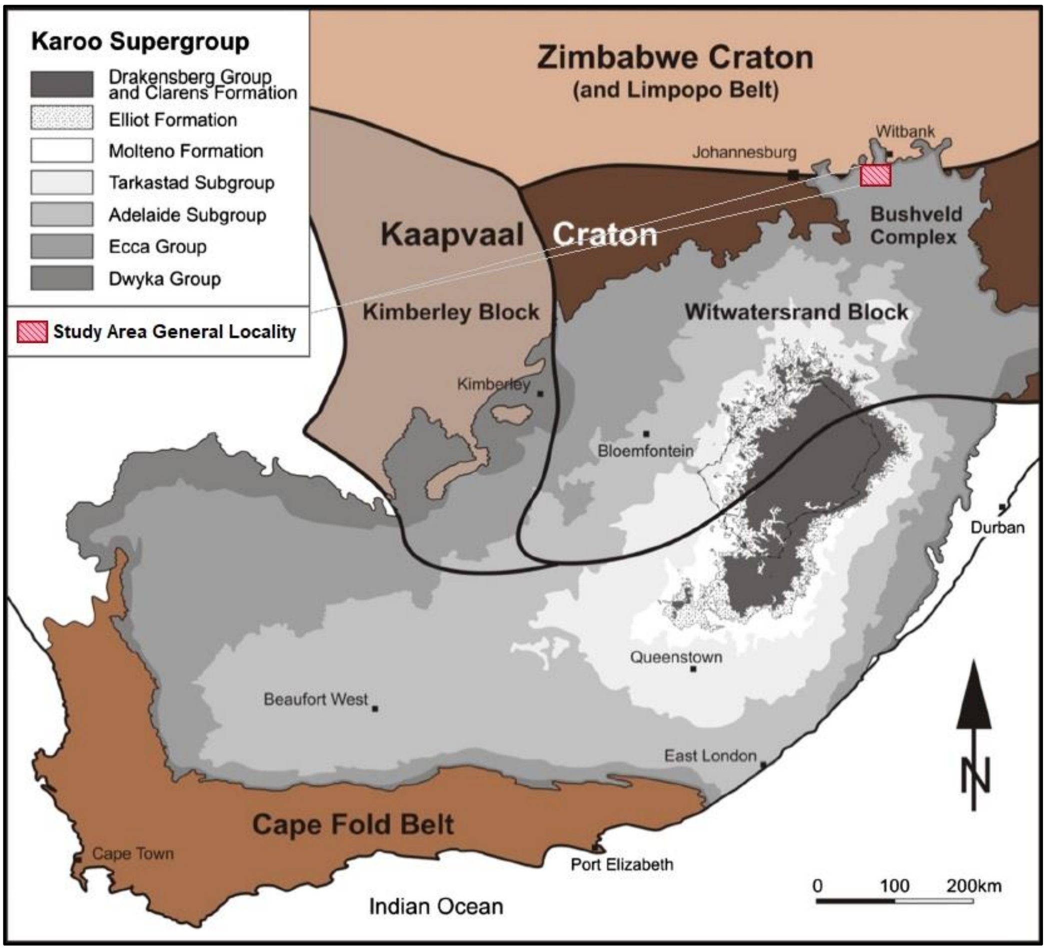


Figure 7. Geology of the Main Karoo Basin (Source: Catuneanu et al., 1998; Hancox and Götz, 2014) indicating the suggested boundaries of the Kaapvaal Craton (Source: Bordy et al., 2004)

The sedimentary rocks of the Karoo Supergroup are split into four major stratigraphic units based on their lithology. These four identified units are, from the lowermost unit to the top (Figure 7):

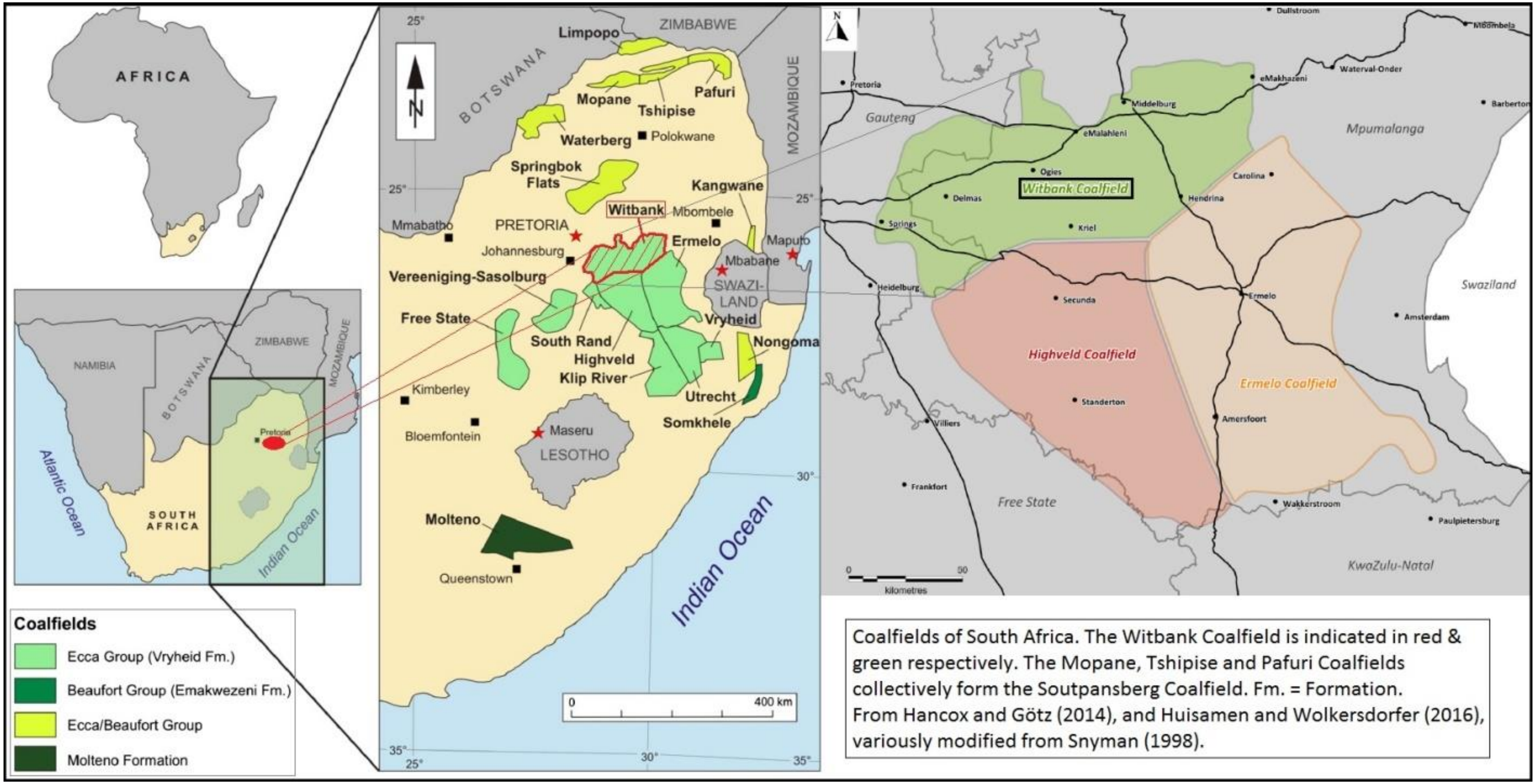
- Dwyka Group
- Ecca Group (Pietermaritzburg, Vryheid and Volksrust Formations)
- Beaufort Group (Adelaide Subgroup and Tarkastad Subgroup)
- Stormberg Group (Molteno, Elliot and Clarens Formations)

These four recognised groups are overlain by the Drakensberg Group (composed of basaltic lavas) over the north central Main Karoo Basin (Johnson et al., 2006). Dolerite intrusions (dykes and sills) are linked with the basaltic lavas of the Drakensberg Group and transect the strata of the Karoo Supergroup.

The nature of palaeo sedimentary basins encountered within the Karoo Supergroup varies greatly. They range from the glacial deposits of the Dwyka Group (at the base of the succession), to shallow marine and coastal plain deposits of the Ecca Group, and then to deposits of non-marine fluvial and aeolian origin of the Beaufort and Stormberg groups (Hancox and Götz, 2014).

The study area is situated within the central part of the Witbank Coalfield (Figure 8). The Witbank Coalfield covers an area of approximately 568 000 ha predominantly within the Mpumalanga Province of South Africa (Hancox and Götz, 2014).

The Witbank Coalfield is located in the northern portion of the Main Karoo Basin and stretches roughly 180 km in an east to west direction and about 50 km in a north to south direction. The northern limits of the Witbank Coalfield are defined by the extent of the coal-bearing Vryheid Formation (where the Vryheid Formation terminates against pre-Karoo lithologies), whilst the southern boundary in the central portion of the basin is widely considered to be the sub-outcrop against a basement palaeo-high known as the Smithfield Ridge (Figure 9), which is composed primarily of pre-Karoo felsite (Falcon, 1986; Hancox and Götz, 2014). The Witbank Coalfield is bordered by the Highveld Coalfield (which is similar stratigraphically to the Witbank Coalfield) to the south, and by the Ermelo Coalfield (which generally has thinner coal seams and more variable structure than the Witbank Coalfield) to the south-east and east.



Coalfields of South Africa. The Witbank Coalfield is indicated in red & green respectively. The Mopane, Tshipise and Pafuri Coalfields collectively form the Soutpansberg Coalfield. Fm. = Formation. From Hancox and Götz (2014), and Huisamen and Wolkersdorfer (2016), variously modified from Snyman (1998).

Figure 8. Locality of the Coalfields of South Africa with the Witbank Coalfield indicated in red (on the left) and in green (on the right) (Source: Hancox and Götz, 2014; Huisamen and Wolkersdorfer, 2016; variously modified from Snyman, 1998).

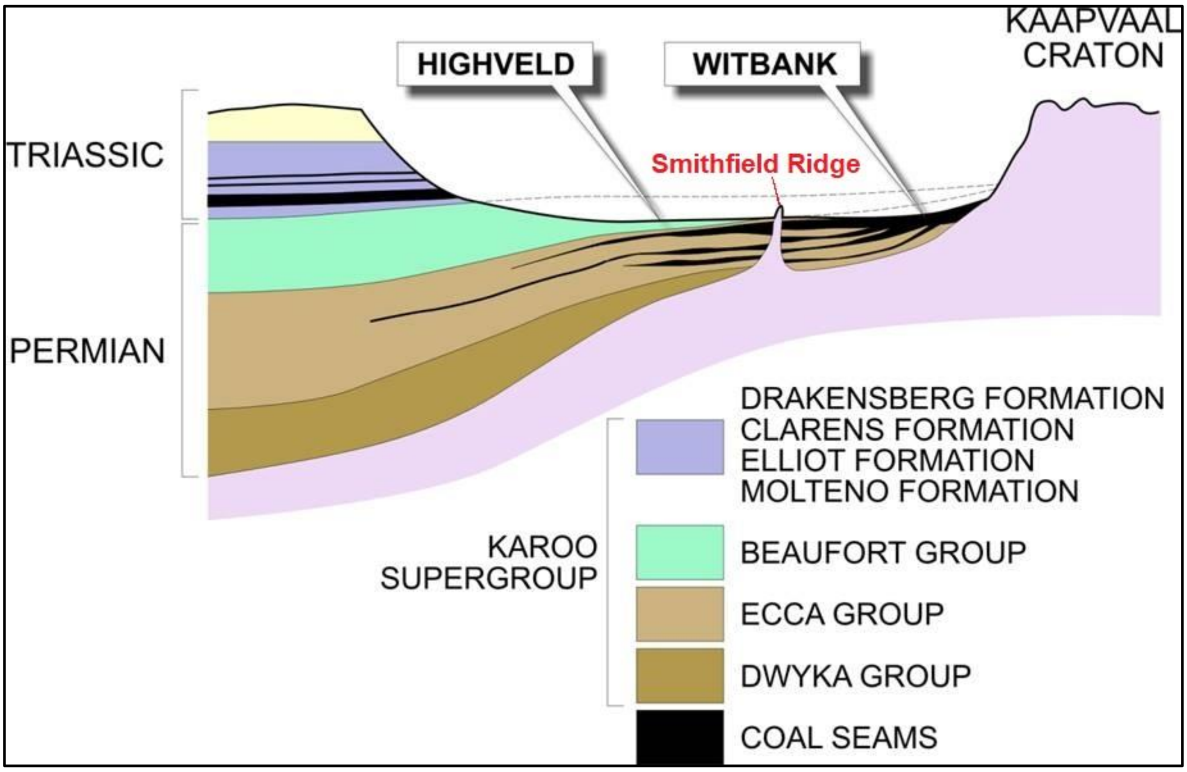


Figure 9. North-South Cross-section of the Witbank and Highveld Coalfields with the position of the Smithfield Ridge border between the coalfields indicated (Source: Falcon, 1986)

The sediments of the coal-bearing Ecca Group within this coalfield were deposited on to an undulating pre-Karoo palaeo-topographic terrain, which had a significant influence on the nature; distribution and thickness of the geological units and coal seams present (Snyman, 1998). Due to the large extent of the Witbank Coalfield the geology of the pre-Karoo basement (underlying the Karoo Supergroup lithologies) differs greatly over the coalfield. The geology and general effect of palaeo-topography on the coal seams is illustrated in Figure 10. The basement is composed of dolomite and metamorphic rocks (meta-sedimentary and meta-volcanic rocks) of the Transvaal Supergroup, within the western Witbank Coalfield. Felsite and granite (linked to the Bushveld Complex due to similar ages of emplacement) and granite and metamorphic rocks (meta-sedimentary and meta-volcanic rocks) related to the Waterberg Group; generally form the basement within the central and eastern Witbank Coalfield (Hancox and Götz, 2014).

Erosion that took place after the deposition of the Karoo aged rocks has removed the Volksrust Formation (Upper Ecca) from the stratigraphic sequence within the Witbank Coalfield. The coal-bearing Vryheid Formation predominates within this coalfield and directly overlies the glacial deposits of the Dwyka Group (Hancox and Götz, 2014). The Pietermaritzburg Formation (Lower Ecca), which usually forms the base of the Ecca Group is absent in the Witbank Coalfield. A maximum of 180 m of the Vryheid Formation is intact within the Witbank Coalfield according to Snyman, 1998.

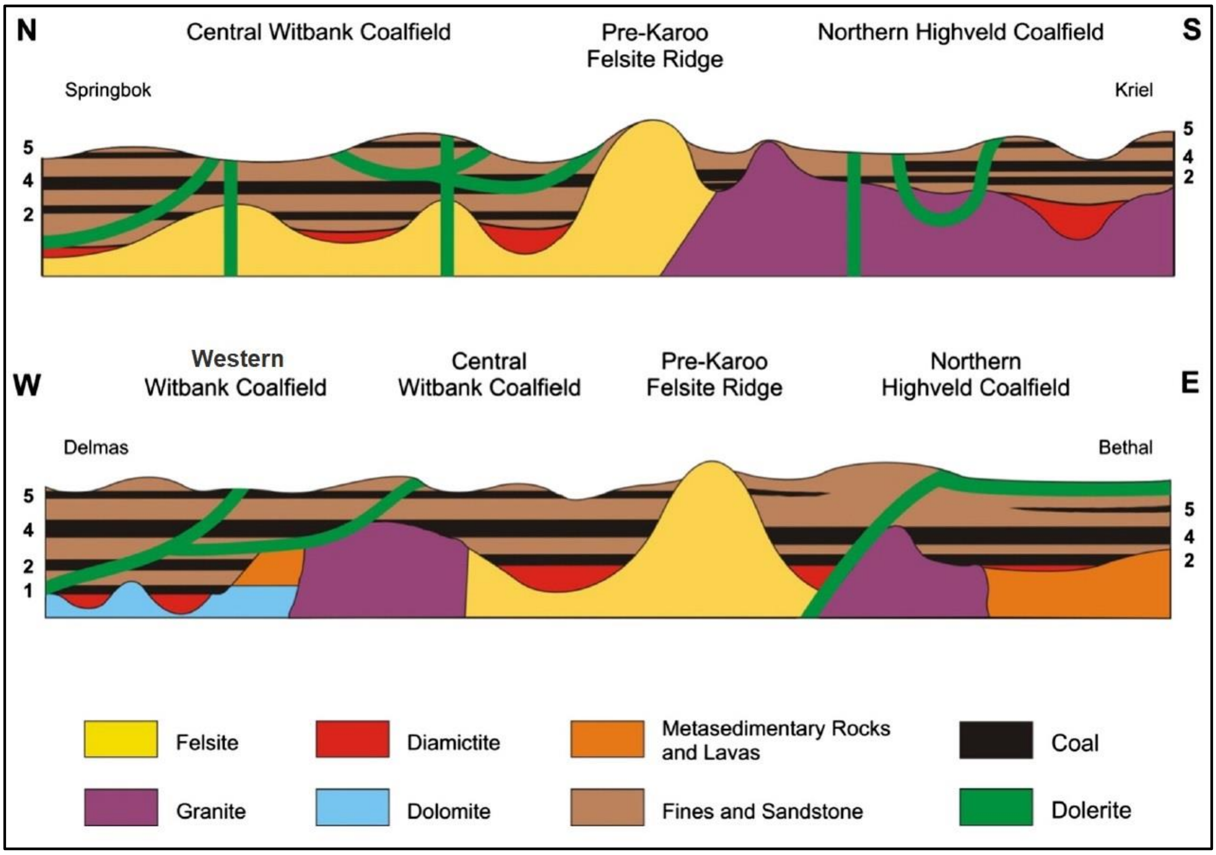


Figure 10. N–S and E–W cross sections of the Witbank and Highveld coalfields, illustrating the basement and Vryheid Formation relationships (Source: Smith, 1970; Hancox and Götz, 2014).

The Vryheid Formation overlies the Dwyka Group (of the Karoo Supergroup), which is composed predominantly of tillite, with some siltstone and minor shale present. The upper part of the Dwyka Group is reworked in certain portions of the coalfield.

Glacial scouring that took place during the deposition of the Dwyka Group lithologies caused the formation of numerous palaeo-ridges and palaeo-valleys along the northern margin of the Witbank Coalfield. The most prominent palaeo-valleys that were formed are the: Grootvlei-, Vischkuil-, Coronation-, Bank- and Arnot Valleys (Figure 11). Accommodation space produced by these aforementioned palaeo-valleys was filled by sedimentary rocks of the Dwyka Group and Vryheid Formation.

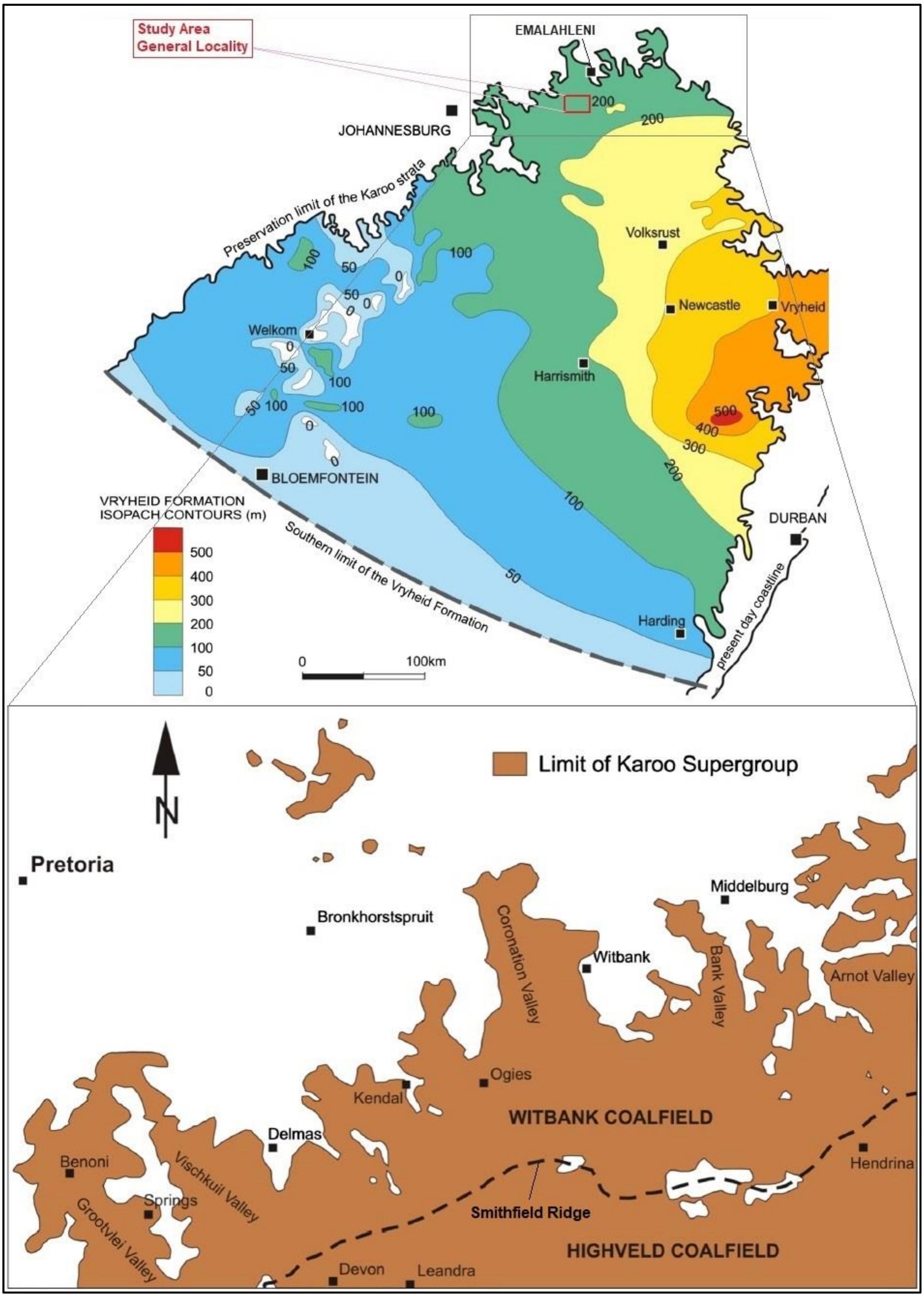


Figure 11. Isopach map of the Vryheid Formation (Source: Cadle, 1982) together with the limit of Karoo Supergroup Rocks in the Witbank Coalfield (Source: Smith and Whittaker, 1986).

The Vryheid formation is composed of sedimentary rocks that include sandstone, mudstone, shale and siltstone (Johnson et al., 2006; Hancox and Götz, 2014), together with the five main recognised coal seams in the Witbank Coalfield. A typical stratigraphic sequence of the Witbank Coalfield is summarised in Figure 12.

The major identified coal seams present within the Witbank Coalfield are numbered, from the top of the stratigraphic sequence to the base, as follows (Jonson et al., 2006):

- Number 5 Seam;
- Number 4 Seam;
- Number 3 Seam;
- Number 2 Seam;
- Number 1 Seam.

The coal seams are present within a 70 m thick sequence with parting thicknesses between the various coal seams generally not varying greatly (Smith and Whittaker, 1986), however these inter-seam partings tend to be more variable along the northern border of the coalfield (where most of the stratigraphic units usually become thinner). Intra-seam splits (splits within the coal seams themselves) do occur regularly within certain parts of the coalfield, with partings within the coal seams ranging significantly. The parting between splits can attain thicknesses of up to 8 m in some areas according to Snyman, 1998.

The Number 4 Coal Seam can be split up into the Number 4 Upper and Number 4 Lower coal seams (Number 4 Coal Zone) respectively (in some places), and likewise The Number 2 Coal Seam can be split up into the Number 2 Upper and Number 2 Lower coal seams (Number 2 Coal Zone) (Cairncross and Cadle, 1988).

Locally intra-seam splits can also cause the formation of various lesser coal seams (in conjunction with the principal identified seams) within the Witbank Coalfield (Figure 13). The Number 1 Seam and Number 2 Seam are situated in close proximity to one another causing these coal seams to combine in certain areas to form a continuous coal thickness. A minor coal seam is sporadically intersected below the Number 1 Seam and is usually named the Number 1 Lower Seam or Number 1A Seam.

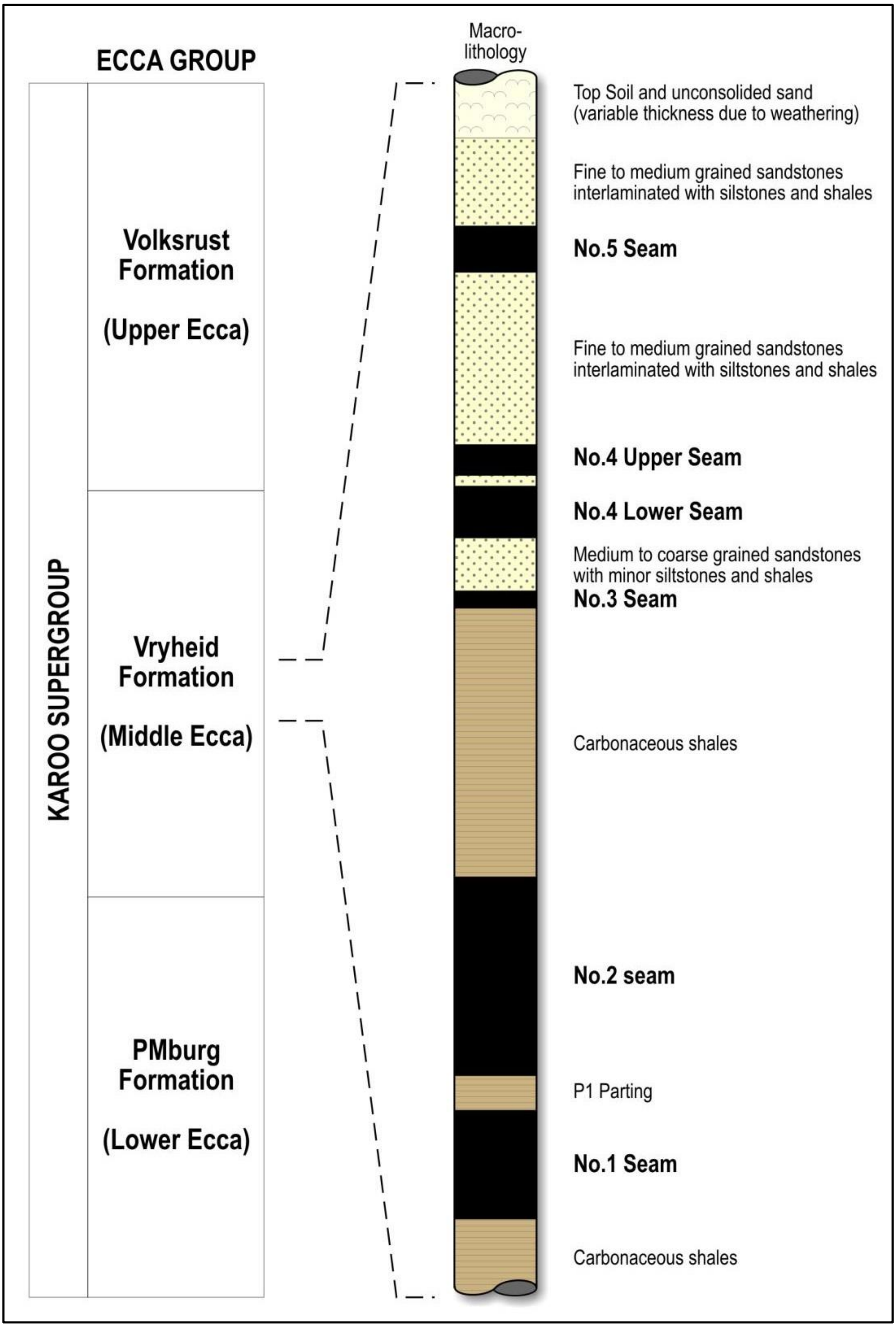


Figure 12. The stratigraphic sequence of the main coal seams in the Witbank Coalfield (Source: Snyman, 1998)

The development of the Number 2 Seam and Number 1 Seam is predominantly controlled by the palaeo-topography of the basement rocks due to these coal seams position at the bottom of the stratigraphy. The Number 4 Seam and Number 5 Seam are located higher up in the stratigraphy causing the distribution of these coal seams to be primarily dependant on the present day erosional surface (Snyman, 1998). Large portions of the Number 5 Seam and Number 4 Seam have been eroded away within some parts of the Witbank Coalfield.

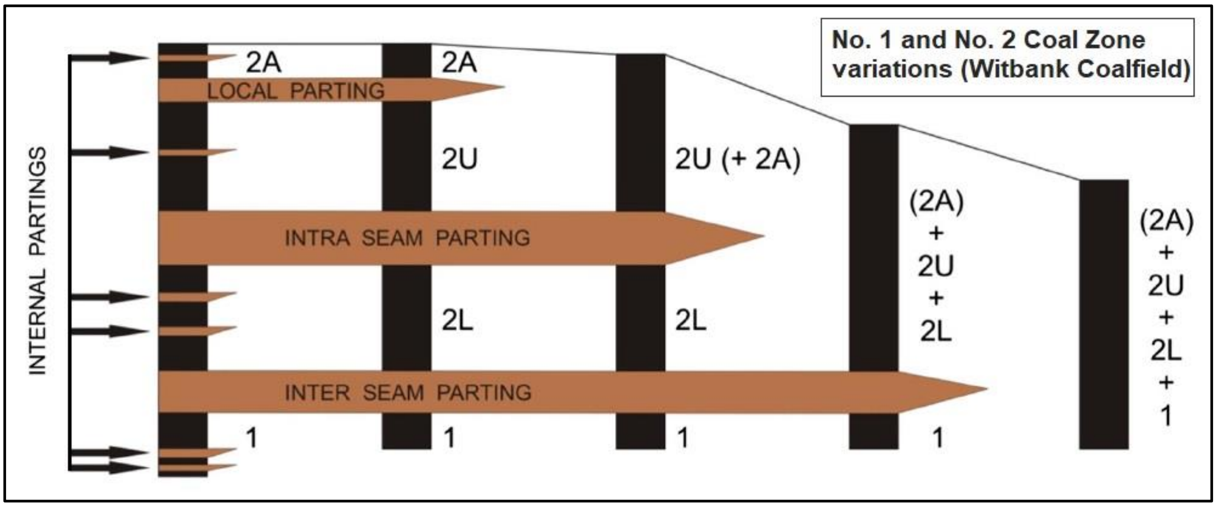


Figure 13. Various partings and coal layers within the Number 1 and Number 2 Coal Zones (Witbank Coalfield) (Source: Cairncross and Cadle, 1988)

The **Number 2 Seam** is regarded as the most important coal seam from an economic standpoint and makes up most of the coal resources within the Witbank Coalfield (Snyman, 1998). The coal seam attains an average thickness of around 6.5 m within the central region of the coalfield and thins to approximately 3 m towards the east (Hancox and Götz, 2014). Coal qualities are highly variable within the Number 2 Seam with distinct zones of diverse coal qualities normally present.

The **Number 4 Seam** is recognised as the second most economically important coal seam present. The coal seam ranges in thickness from roughly 2.5 m to 6.5 m and is composed typically of dull to dull lustrous coal (Snyman, 1998; Hancox and Götz, 2014). Overall the Number 4 Seam tends to usually exhibit poorer coal qualities than the Number 2 Seam. The seam is split up into the Number 4 Upper and Number 4 Lower seams by intra-seam partings in various parts of the coalfield.

The **Number 5 Seam** displays a highly erratic distribution throughout the Witbank Coalfield due to this coal seams removal by erosion over large areas of the coalfield. The Number 5 Seam is most prominent within the central portion of the coalfield and attains an average thickness of roughly 1.8 m. The thicknesses of the coal seam can range between 0.5 m to 2 m and it is commonly composed of good quality, mixed to bright coal.

The **Number 1 Seam** is intermittently developed throughout the Witbank Coalfield and attains thicknesses ranging from 0.25 m up to 2 m thick in some places. It contains relatively poor coal qualities and is normally deemed sub-economic unless it forms a part of the Number 2 Seam base (Figure 13).

The **Number 3 Seam** is generally less than 0.5 m thick and although it consists of high quality coal it is mostly not considered an economic coal seam due to its thin nature.

5.2 Local Geology

The project area sub-surface geology is dominated by the coal-bearing Vryheid Formation (**Pv**), of the Ecca Group within the Karoo Supergroup, as indicated on the 2826 East Rand Map (Geological Survey, 1986) (Figure 14). Karoo aged dolerite intrusions (**Jd**) are indicated outcropping towards the northern and south-western parts of the study area while the Dwyka Group rocks (**Pd**) sub-outcrop to the north of the mine site. The pre-Karoo Selons River Formation of the Rooiberg Group (which forms part of the Transvaal Supergroup) is present within the central and southern parts of the study area. Quaternary aged alluvium deposits (Q) are found in riverbeds and the banks of pans and dams within the study area.

Locally the Selons River Formation consists of felsite and rhyolite that make up the basement lithologies within the area. The basement rocks are overlain by glacial deposits of the Dwyka Group composed of tillites. The Vryheid Formation overlies these rocks and is made up of sandstone, siltstone, shale and coal seams (Geological Survey, 1986). A simplified local stratigraphic column of the study area is included in Figure 15, which shows the idealised sub-surface stratigraphic units present within the mine area from the bottom to the top of the succession (provided mine data was used to compile the local stratigraphic column).

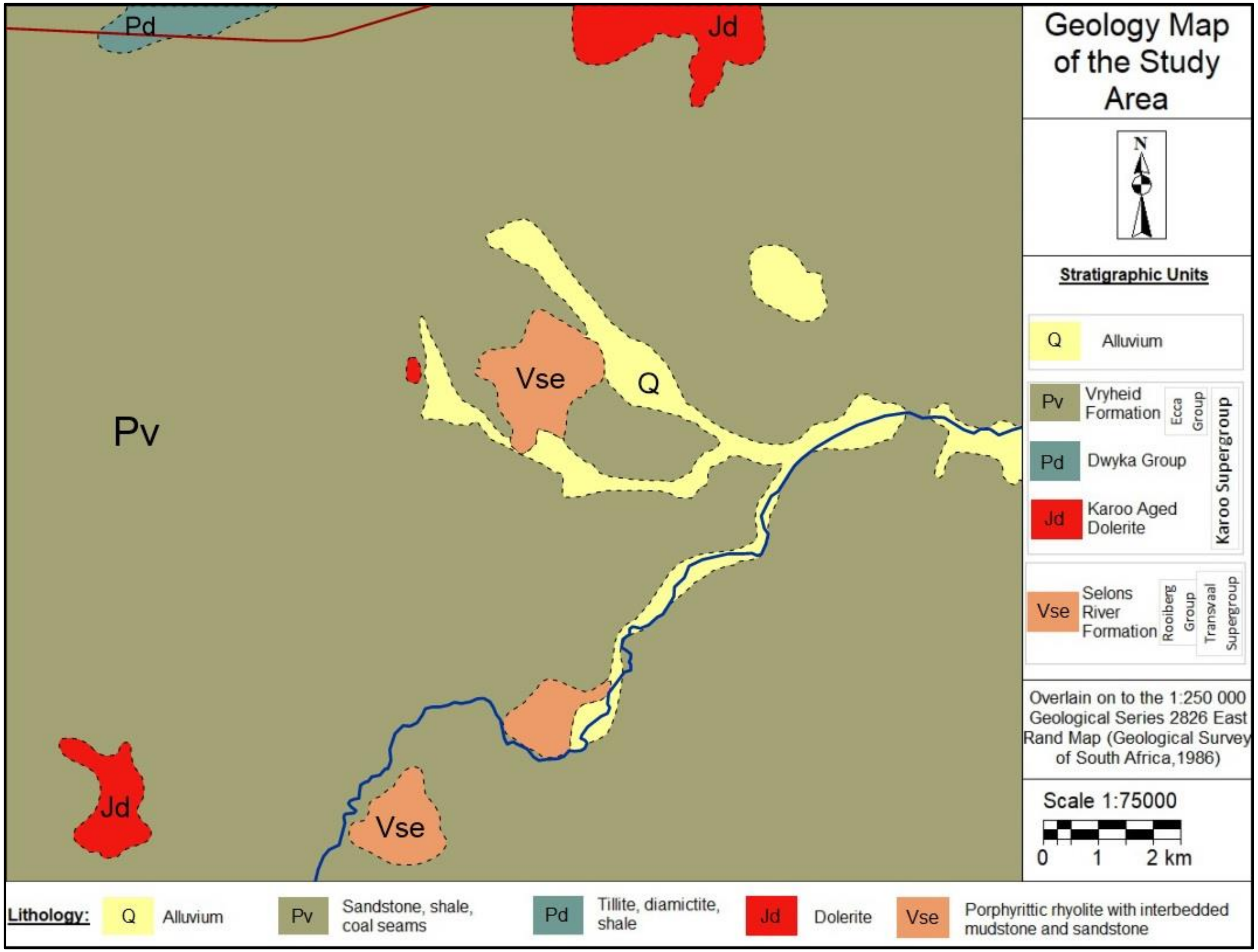


Figure 14. Geological map of the Study Area (modified from the Geological Survey of South Africa, 1986)

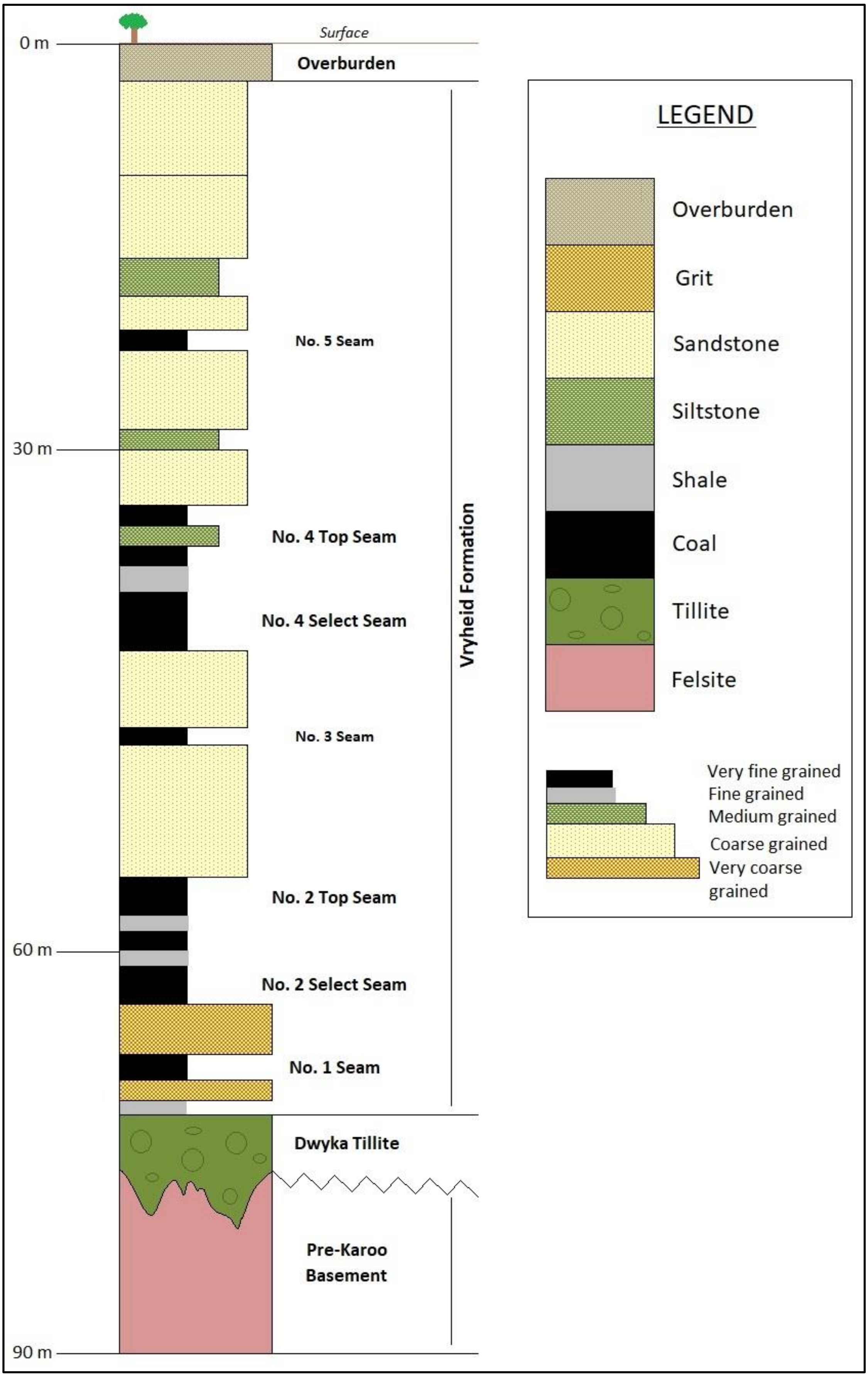


Figure 15. Local Stratigraphic Column (prepared for this work from internal reports)

The Vryheid Formation within the study area contains all five of the main coal seams identified within the Witbank Coalfield (Figure 15). Within the mine area the Number 4 Seam and Number 2 Seam are split up by partings and named the following: Number 4 Top Seam, Number 4 Select Seam, Number 2 Top Seam and the Number 2 Select Seam. The Number 1 Seam is encountered at the base of the succession with the Number 5 Seam found at the top. Coal is mined up to the base of the Number 2 Seam (Number 5 Seam, Number 4 Seam and Number 2 Seam is mined) within the mine site, using opencast coal mining methods.

A geological model of the project area was compiled using Geovia Minex^{TM} 6.5.2 modelling software, from all the relevant geology and survey data provided by the mine. The following data was imported and used in the geological model (from the robust mine database):

- Surveyed Digital Terrain Model (DTM)
- Surveyed geological, mining and surface features
- Borehole collar information (coal exploration boreholes)
- Coal seam floor elevation, roof elevation and thickness grids
- Dwyka Group lithology and basement lithology intervals
- Limit of Weathering (LOW) intervals

Using the compiled geological model a good understanding of the local geology within the mine site was gained. This is important because the geology and structure of the area is the single most important aspect influencing the groundwater regime within the site.

Surface elevations within the mine site vary between approximately 1518.16 mamsl to about 1626.08 mamsl, with an average elevation of around 1574.98 mamsl (according to the surveyed DTM) (Figure16).The average depth of weathering in the project area was estimated at 11.72 m with a maximum recorded value of about 48 m (from the geological borehole database). The base of the LOW has elevations ranging from 1517.57 mamsl to 1620.41 mamsl with an average of 1536.77 mamsl.

The roof elevations of the Dwyka Group (which form the base of the coal bearing succession within the project area) fluctuate from 1575.67 mamsl to 1492.38 mamsl, with an average of 1527.05 mamsl. The Dwyka Group exhibits the highest roof elevations in the south and south-east of the site. The Pre-Karoo basement topography (situated below the Dwyka Group) follows a similar pattern with roof elevations between 1466.10 mamsl and 1591.37

mamsl. The basement forms prominent palaeo-highs (which influenced coal deposition) within the east and south-east of the project area.

Coal occurrence within the mine site is mainly controlled by the pre-Karoo basement rocks, as well as the current surface topography and resultant weathering profile. The Number 2 Seam is well developed within the site and sub-outcrops towards the east and south-east of the mine site where prominent basement palaeo-highs are encountered (Figure 17). The Number 2 Seam floor elevations range from 1488.46 mamsl to 1564.98 mamsl. The average seam floor elevation for the Number 2 Seam is about 1542.30 mamsl. The Number 4 Seam is encountered within the majority of the mine site and sub-outcrops within similar areas as the Number 2 Seam, in the east and south-east of the project area (Figure 18). The Number 4 Seam floor topography has a maximum of 1507.5 mamsl and a minimum of 1576.11 mamsl. The average Number 4 Seam floor topography is estimated as 1544.46 mamsl. The Number 5 Seam (at the top of the succession) is developed in two separate areas within the mine site, within the north and south of the project area. The Number 5 Seam sub-outcrops within the central, eastern and south-eastern parts of the site (Figure 19). The floor elevations of the Number 5 Seam vary between 1534.95 mamsl and 1588.15 mamsl, with an average of 1556.38 mamsl.

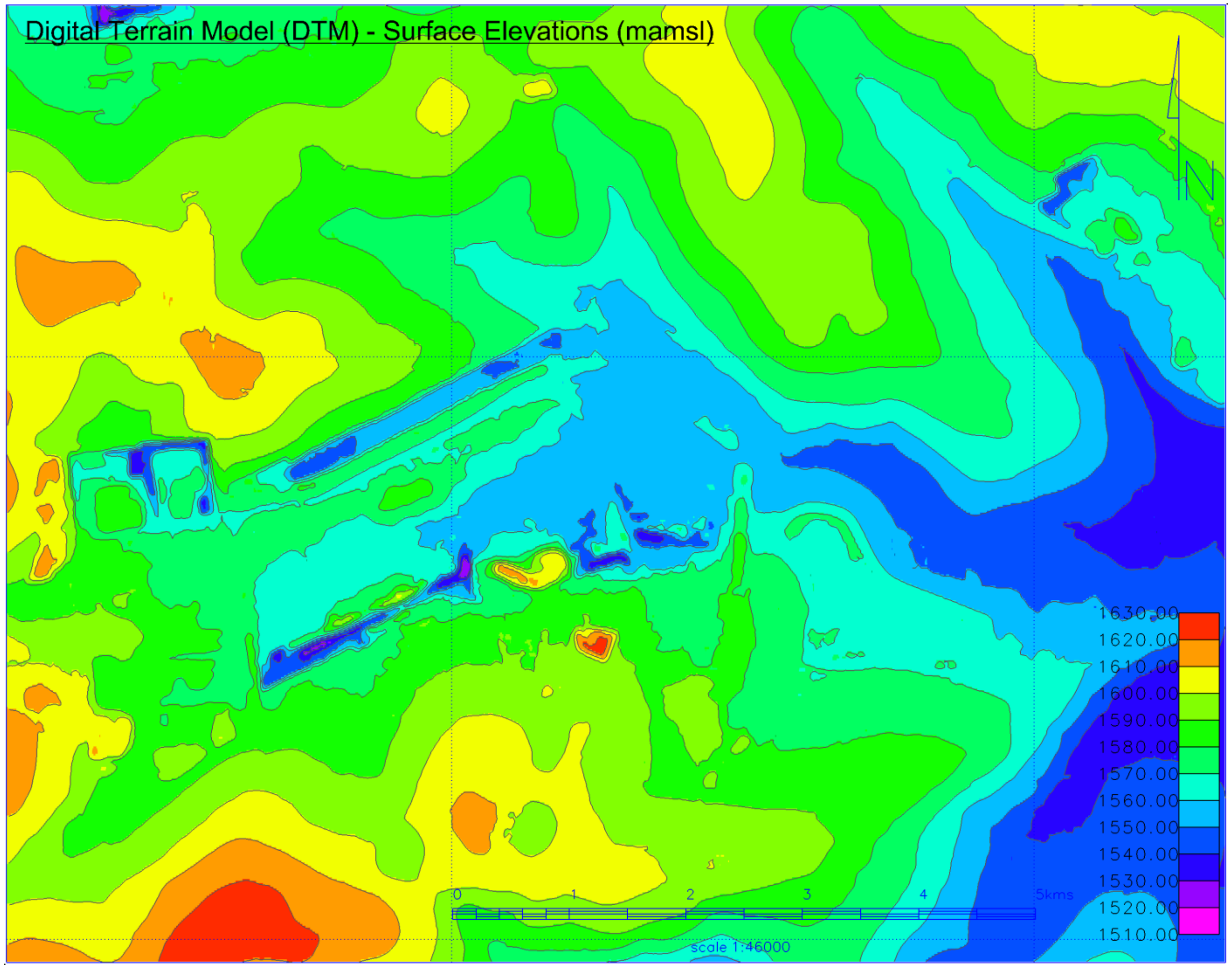


Figure 16. Digital Terrain Model (DTM) of mine site (prepared for this work in Geovia Minex)

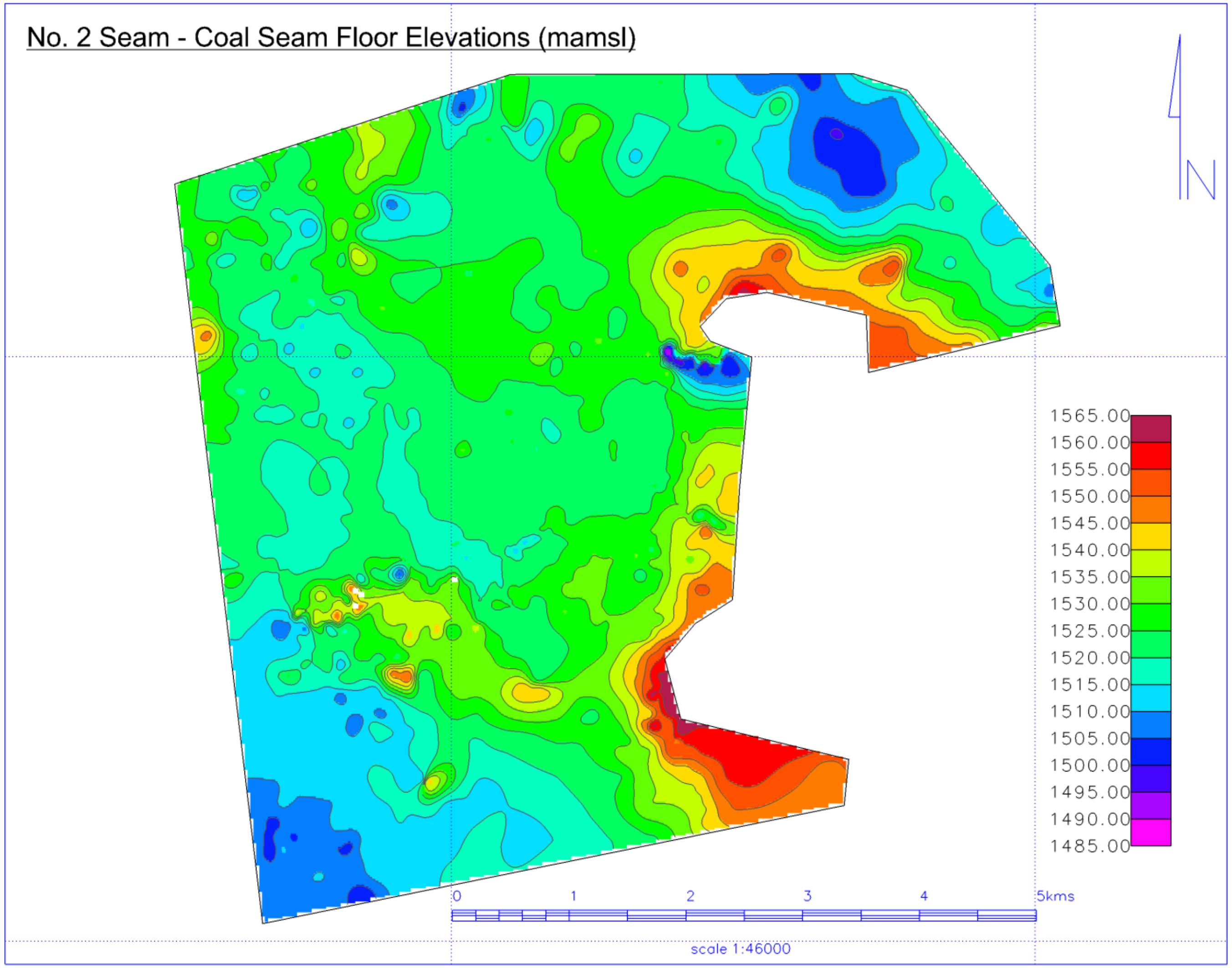


Figure 17. Number 2 Seam – Coal Seam Floor Elevations (prepared for this work in Geovia Minex)

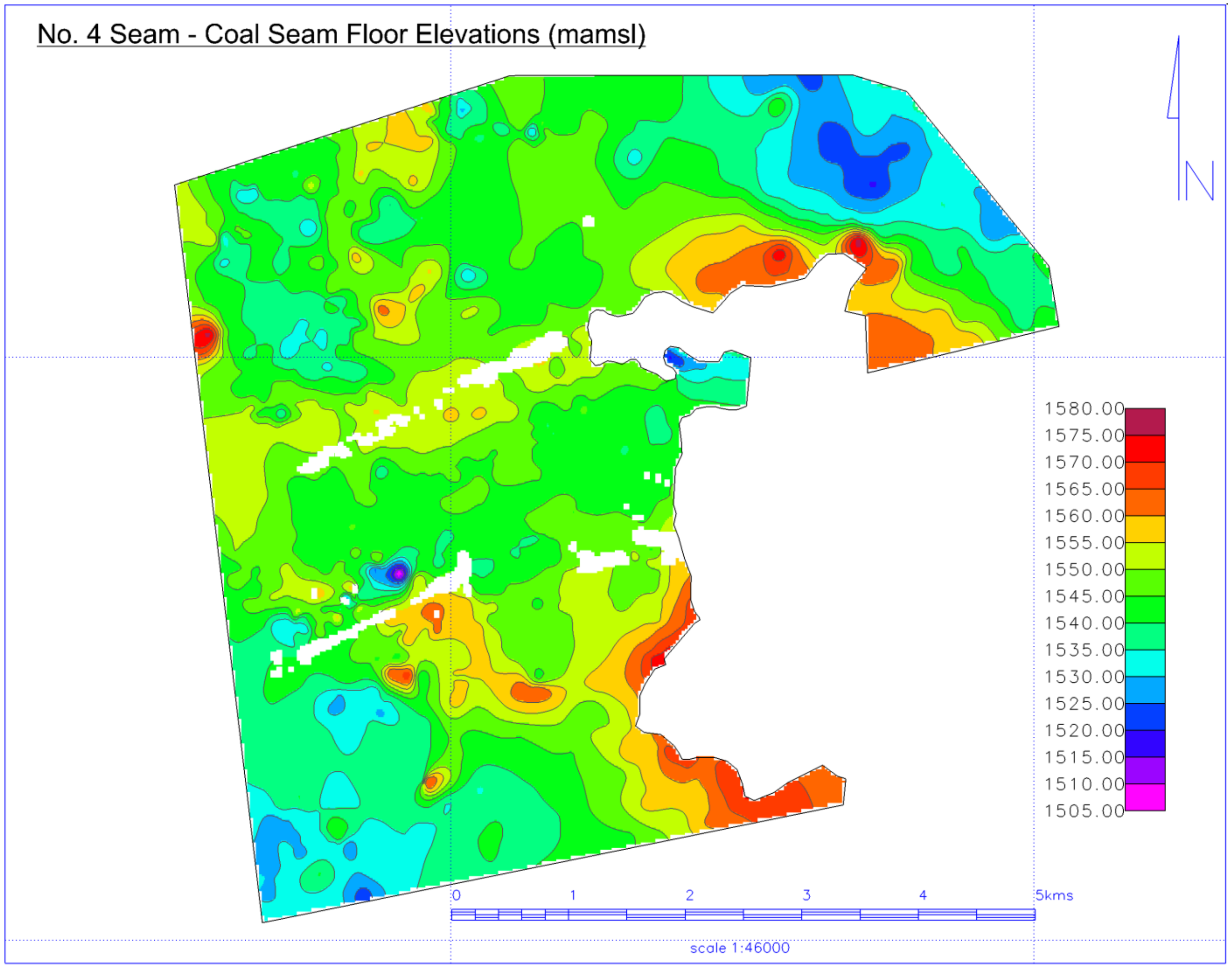


Figure 18. Number 4 Seam – Coal Seam Floor Elevations (prepared for this work in Geovia Minex)

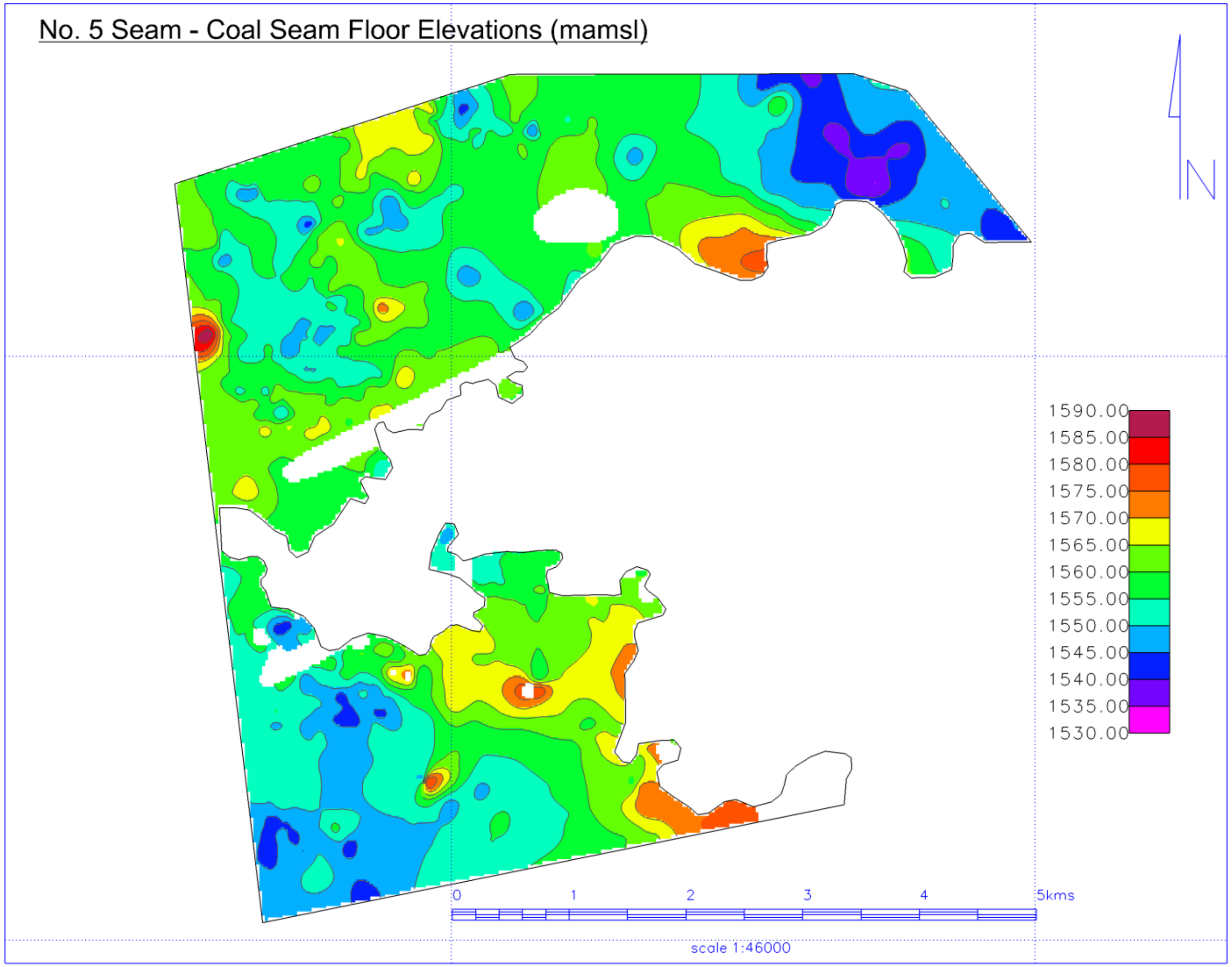


Figure 19. Number 5 Seam – Coal Seam Floor Elevations (prepared for this work in Geovia Minex)

5.3 Dolerite Intrusions

Numerous dolerite dykes and sills of Jurassic age are found throughout the Witbank Coalfield and intruded the Karoo aged lithologies. The dykes intersect existing sedimentary lithologies with sills being sheet-like intrusions emplaced between layers of sedimentary rocks. Dolerite intrusions (dykes and sills) cause significant displacement of coal seams, which seriously affects coal mining activities in many areas. According to Jeffrey (2005), the dykes present in the region tend to typically strike east, north-east and north; with thicknesses ranging from thinner than 1 m up to nearly 15 m. Faults are rare within the Witbank Coalfield, except in areas where displacement has been caused by dolerite intrusions, and fractures are common within competent lithologies such as sandstone and coal (Hodgson et al., 2004).

Within the Witbank Coalfield the Ogies Dyke is the largest dolerite intrusion present (over 14 m thick in places), and stretches from west to east for over a 100 km across the central part of the coalfield (Snyman, 1998; Hancox and Götz, 2014).The Ogies Dyke strikes in an approximate east-west direction in close proximity to the north of the general mine area (Figure 20). The Ogies dyke is situated along the northern boundary of a historical underground mined out area found within the northern and north central parts of the mine site. Several smaller dolerite dykes, which have been intersected during mining operations, have also been encountered within the site. These local dykes strike predominantly northeast-southwest, east-west and north. The positions of the local dykes present in the site, together with the current mined out opencast areas, historical underground mined out areas and surface geology are shown in Figure 20.

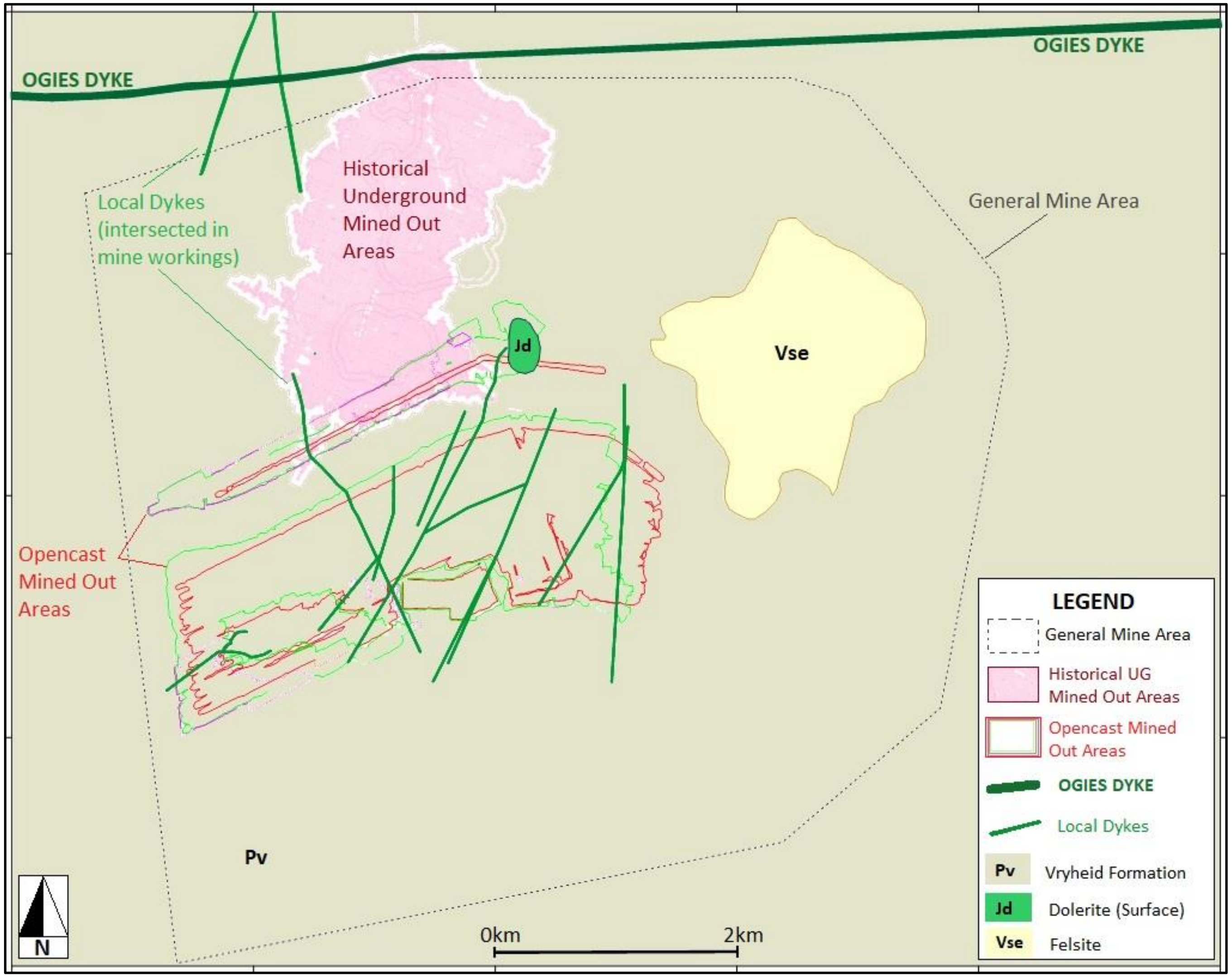


Figure 20. Ogies Dyke and Local Dolerite intrusions map of mine site with surface geology (generated from provided mine data [in Surfer], and modified from the Geological Survey of South Africa, 1986)

6. HYDROGEOLOGY

6.1 Regional Hydrogeological Setting

The general study area was overlain on to the 1:500 000 scale Johannesburg hydrogeological map (JHM) (DWAF, 1999), to evaluate the regional hydrogeological character of the study area (Figure 21).

The hydrogeological properties of the mine site (within the unmined areas), are primarily governed by the geology of the region, with lithology forming the basis on which the hydrogeological map was compiled according to the JHM brochure (DWAF, 1999). The surface lithology indicated within the study area is mainly composed of arenaceous rocks of the Vryheid Formation (consisting mostly of sandstones). Some lesser tillites of the Dwyka Group outcrop to the north-west of the site. Felsites of the Selons River Formation and surface dolerite outcrops are also present within the region according to the geological map of the site (Figure 14).

The regional aquifer is identified as an intergranular and fractured (double porosity) aquifer type, typical of the Vryheid Formation of the Karoo Supergroup, according to DWAF, 1999. Groundwater flow on a local scale (within the Vryheid Formation) is controlled by fracture flow, and on a regional scale groundwater flow is influenced by the presence of dolerite dykes (Figure 20), that intruded the Karoo strata (Botha et al., 1998). The intergranular and fractured aquifer type contains groundwater within the intergranular voids and in the fractures intersecting the sedimentary rock layers. The intergranular and fractured aquifer is grouped into 2 borehole yield classes (with low to moderate yields) within the study area, namely (see Figure 21):

- d2 class (with borehole yields of 0.1 – 0.5 l/s) and;
- d3 class (with borehole yields of 0.5 – 2.0 l/s)

The regional groundwater quality map of the region was compiled using available borehole electrical conductivities (mS/m), with points where fluoride concentrations exceed 1.5 mg/l indicated (DWAF, 1999). Within the central region of the study site low electrical conductivities of between 0 – 70 mS/m are indicated, with elevated electrical conductivities (70 – 300 mS/m) present within the western and eastern parts of the region (Figure 22). Fluoride concentrations of above 1.5 mg/L were recorded at a point within the eastern part of the mine site on the regional groundwater quality map.

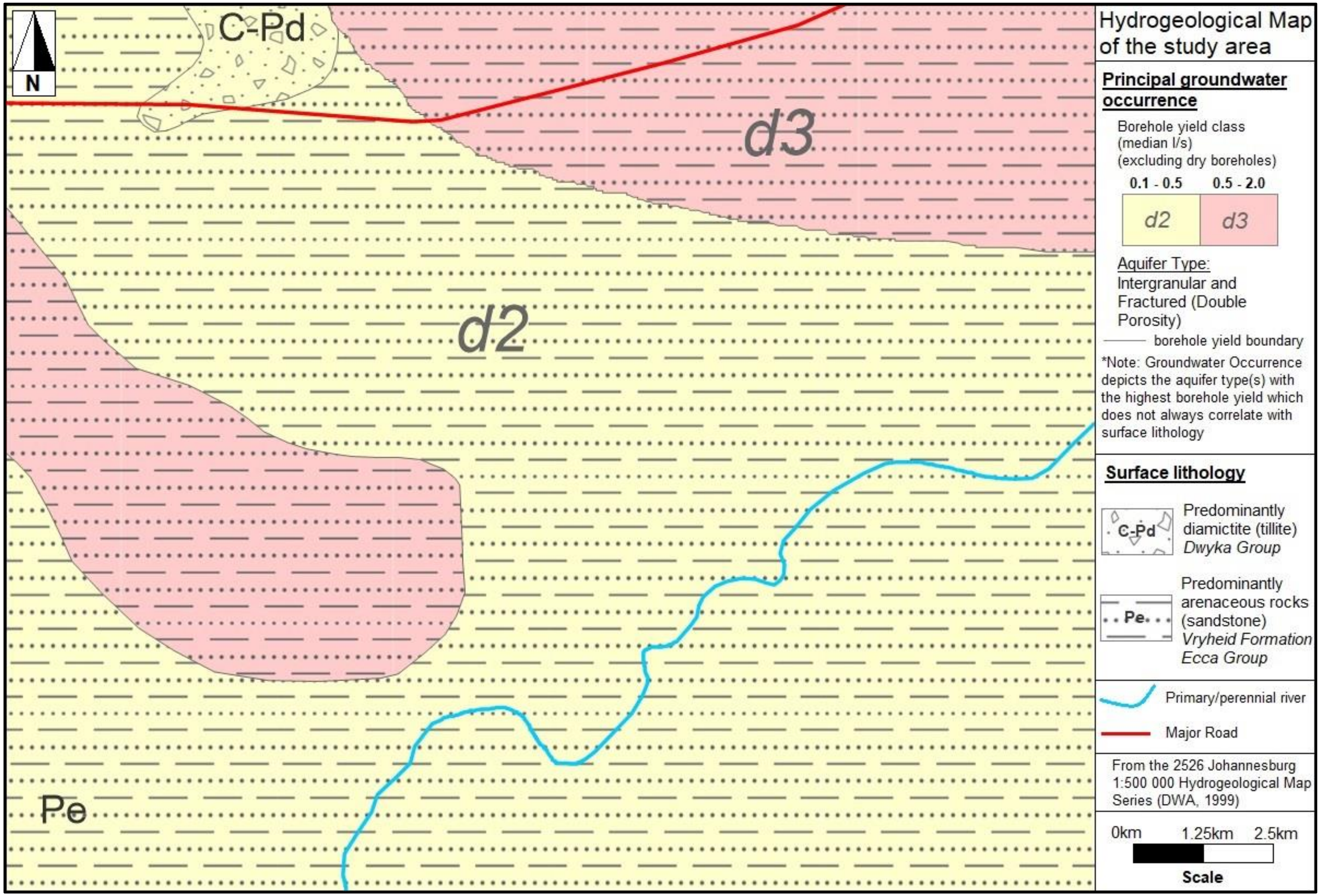


Figure 21. Hydrogeological Map of the study area (modified from DWA, 1999)

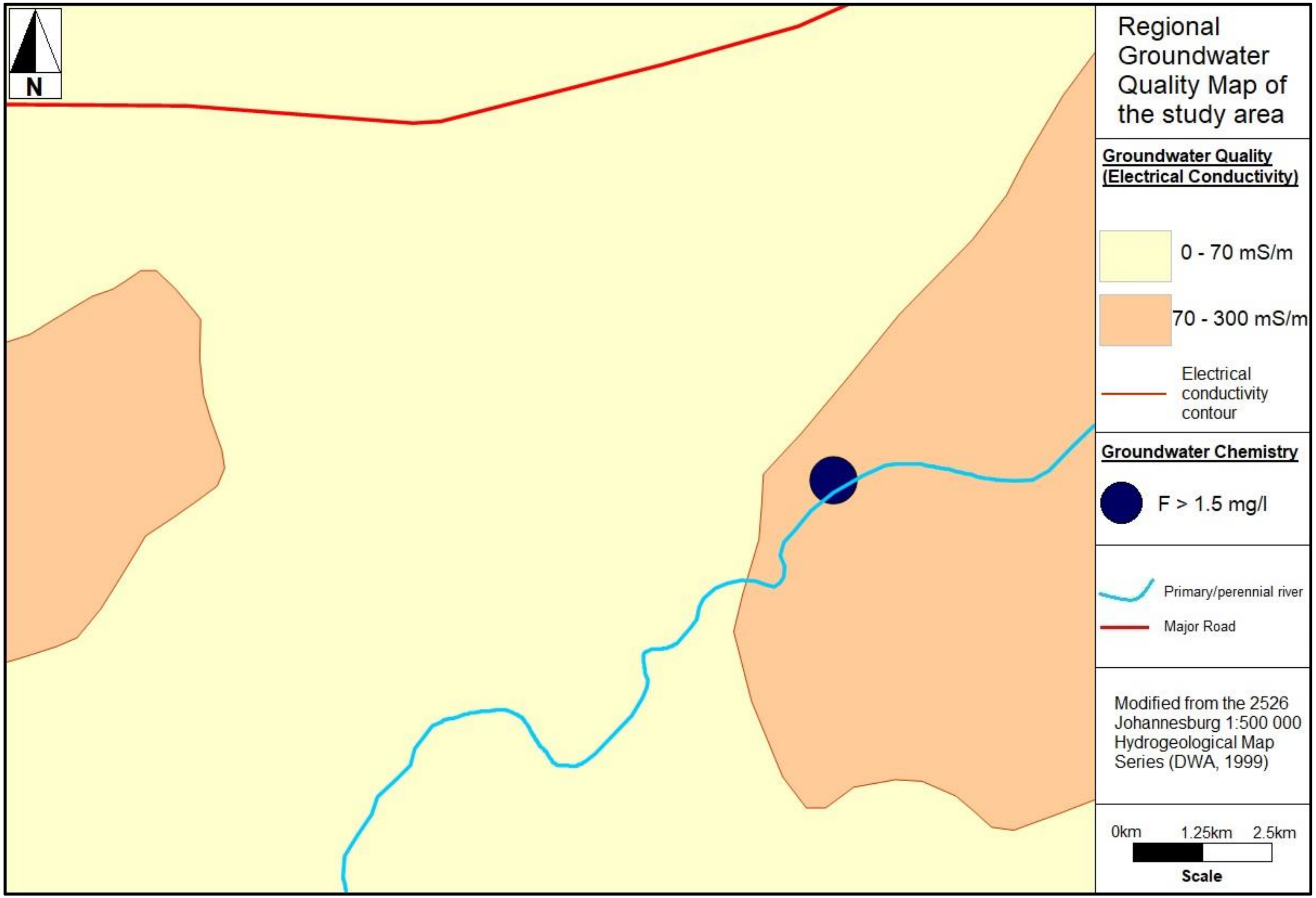


Figure 22. Regional Groundwater Quality Map of the study area (modified from DWA, 1999)

According to Hodgson et al. (2004), there are generally 3 discrete groundwater systems identified within the region. These are the shallow (weathered zone) aquifer perched on top of the fresh Karoo lithologies, the fractured Karoo rock aquifers and the pre-Karoo aquifers at the base of the succession.

1. **Shallow perched aquifer (weathered zone aquifer)**

- Aquifer associated with the weathered zone (weathering depths regionally vary between 5 m – 12 m)
- Water is usually intersected only a few meters below surface
- Groundwater flow often mimics the surface topography forming natural springs where the surface is intersected
- Recharge is high, between 1 – 3 % of mean annual precipitation, according to Hodgson et al. (2004)
- Low yielding aquifer due to relatively thin thickness of the aquifer

2. **Fractured Karoo rock aquifers**

- Pore spaces within the host sedimentary rocks are consolidated and cemented thoroughly, inhibiting significant groundwater flow
- Groundwater flow occurs mainly within secondary structures like fracture zones and joints
- Distinct aquifers are formed within the more permeable coal seams and sandstone layers (Geo Pollution Technologies, 2012)
- The coal seams frequently exhibit higher hydraulic conductivities in comparison to the other unweathered sedimentary rocks present (Figure 23)
- The coal acts as an aquitard which causes flow of groundwater along the contacts of the coal seam with the host sedimentary rocks (Geo Pollution Technologies, 2012)
- Dolerite intrusions also effect groundwater movement acting as either aquifuges (thick unweathered dolerite) or aquifers (indurated and fractured contact zones near dolerite intrusions)

Statistics	2 Seam Permeability	Dwyka Permeability
Mean (m/d)	0,1017	0,0034
Median (m/d)	0,0743	0,0024
Standard Deviation (m/d)	0,1295	0,0034
Minimum (m/d)	0,0007	0,0002
Maximum (m/d)	0,5007	0,0148
Number of tests	21	21

Figure 23. Packer test statistics of hydraulic conductivities of the Number 2 Seam and Dwyka tillite (Source: Hodgson et al., 2004)

3. Pre-Karoo basement rock aquifers

- Boreholes are rarely drilled into Pre-Karoo aquifers due to their great depth from surface and relatively low yielding characteristics (these aquifers are poorly understood)
- The relatively impermeable Dwyka Group (Figure 23) overlying the basement aquifers (over large areas) causes these aquifers to have low recharge values (Hodgson et al., 2004)

6.2 Local Hydrogeology

6.2.1 Local Aquifer Types

Locally within the study area two main types of aquifers have been identified during various investigations conducted on the mine site. These two aquifers fall within the regional classification of Karoo aquifers (described in the previous section), and are identified as follows:

- **Shallow Weathered Zone Aquifer**
- **Fractured Aquifer**

The **shallow weathered zone aquifer** is located within the weathering zone of the Vryheid Formation lithologies with an aquifer thickness that is associated with the local limit of weathering depths. Groundwater level data from the monitoring boreholes (between 2016 and 2012) indicated that average water level depths below surface within the shallow weathered aquifer ranged between 0.66 m – 22.75 m, with an average of approximately 6.68 m (Table 3).

Groundwater flow within the **fractured aquifer** is linked to the fracture zones and joints present within the aquifer, and with the interconnectivity of the pore spaces within this aquifer (double porosity aquifer type). Local dolerite intrusions can cause the formation of aquifer compartments, where these intrusions act as groundwater flow barriers, within the fractured aquifer. Contacts between the coal seams and country rock can form preferential groundwater flow paths along these contacts. Groundwater level data from the monitoring boreholes (between 2016 and 2012) indicated that average water level depths below surface within boreholes of the fractured aquifer ranged between 0.47 m – 3.40 m, with an average of approximately 1.94 m.

Regions where coal mining has occurred (rehabilitated mine areas) or is taking place (current mine areas) are termed as a separate groundwater zone (**disturbed groundwater system**) within the mine site. This is because in mined-out and current mining areas the hydrogeology differs considerably in comparison to undisturbed regions (Hodgson et al., 2004). The regions disturbed by mining activities would have large porosities in relation to the surrounding undisturbed areas, with the possibility of subsidence occurring within the mine affected areas (Holland, 2015). Groundwater level data (between 2016 and 2012) from the monitoring boreholes drilled within the mine workings indicated that average water level depths below surface within boreholes drilled in the mine workings ranged between 3.14 –

24.10 m, with an average of approximately 12.97 m. Mine dewatering during active coal mining could cause the lowered groundwater levels within the boreholes drilled in the mine workings.

Evaluation of the lithological logs of the boreholes within the mining region indicated that none of the groundwater monitoring boreholes solely intersected Pre-Karoo or Dwyka group lithologies. This excludes the presence of any extensive Pre-Karoo basement rock aquifers within the study area. The evaluated geology and hydrogeology data of the mine site did not indicate the presence of any noteworthy perched aquifers within the mine site hydrogeological regime. The aquifer zones present within the study area can thus be classified in terms of an unsaturated zone and a saturated zone.

The average thickness of the unsaturated zone was estimated by evaluating the depth to groundwater levels recorded in all of the monitoring boreholes present within the study area (Table 1, included in the Appendix in section 10). The depth to groundwater level (unsaturated zone thickness) in the monitoring boreholes drilled within the shallow weathered aquifer and fractured aquifer (from 2016 to 2012); vary between a minimum depth of 0.36 m and a maximum depth of about 24.19 m. The depth to groundwater level (unsaturated zone thickness) in the monitoring boreholes drilled within the mine workings (from 2016 to 2012); vary between a minimum depth of around 2.68 m and a maximum depth of about 48.15m.

A common method to estimate the aquifer thickness (thickness of the saturated zone) within a coal mining area is to subtract the estimated static groundwater elevations with the floor elevations of the lower most coal seams to be mined. This method would not provide an accurate unsaturated zone thickness within the area due to the following (compiled from internal mine report):

- Insufficient data of groundwater strikes measured in the existing monitoring boreholes
- Prominent water strikes within boreholes which yielded large quantities of water were related to geological structures (faults or bedding planes) or to the boundaries between different rock types, and not to the coal seams specifically
- Where the lowermost coal seam (S2S within the site) occurs deep below surface, the aquifer thickness will be greatly exaggerated. The aquifer thickness will also be inaccurately estimated in areas where no coal is found (places where coal is eroded away or where pre-Karoo rocks are present)

As an example the static groundwater elevations estimated for 2016 (Wet Season) were deducted from the S2S coal seam floor elevations of the mine site (Figure 24). This resulted in a minimum aquifer thickness of 6.45 m and a maximum aquifer thickness of 98.23 m, with an average aquifer thickness of 53.22 m. The area where the aquifer was estimated at its thickest was where the S2S coal seam was developed deepest below the surface (in the south-west and north-east of the project area). The estimated aquifer thickness was the thinnest where the S2S coal seam sub-outcropped along the east and south eastern parts of the study area.

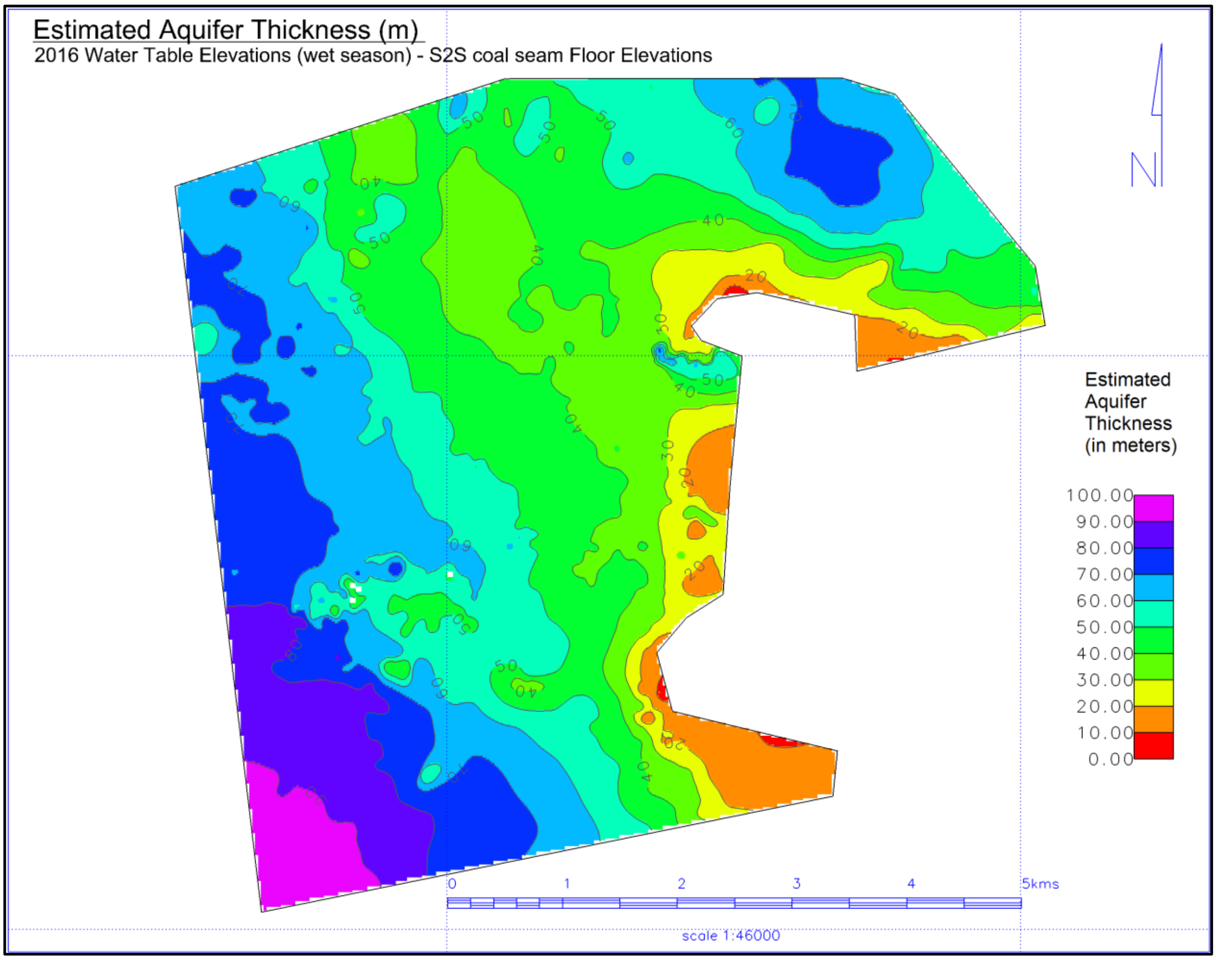


Figure 24. Estimated Aquifer Thickness in meters (compiled by subtracting the 2016 wet season water table elevations with the S2S coal seam floor elevations)

A more accurate method to estimate the thickness of the saturated zone (aquifer) is to use the depths where the lowermost water yielding fractures were encountered within drilled boreholes as the base of the aquifer. The aquifer thickness will then still only be an assumption because the fractures and structures influencing the aquifer are heterogeneous with varying unknown orientations and sizes of fracture openings, occurring in different lithologies. According to data compiled by the mine based on borehole results obtained from many previous investigations, the **aquifer thickness (saturated zone)** is estimated to range between roughly **8 m and 40 m** (which is a more accurate assumption of the aquifer thickness).

6.2.2 Groundwater Monitoring Boreholes

A total of 38 groundwater monitoring boreholes with useable water level and water chemistry data (for the period 2012 to 2016) were present in the dataset provided by the mine (from the groundwater monitoring programme of the mine). The positions of these 38 groundwater monitoring boreholes within the general mining area (indicated with the dotted line polygon) are shown in Figure 25. All of the original borehole names have been changed in line with the non-disclosure agreement.

The new borehole names given to the groundwater monitoring points have prefixes that indicate within what aquifer type each borehole has been drilled. The borehole prefixes, and their descriptions, are as follows:

- BW – Shallow Weathered Zone Aquifer Borehole (total of 28 boreholes)
- BF – Deeper Fractured Aquifer Borehole (total of 3 boreholes)
- BM – Mine Workings Borehole (total of 6 boreholes)
- BP – Perched Aquifer Borehole (total of 1 borehole)

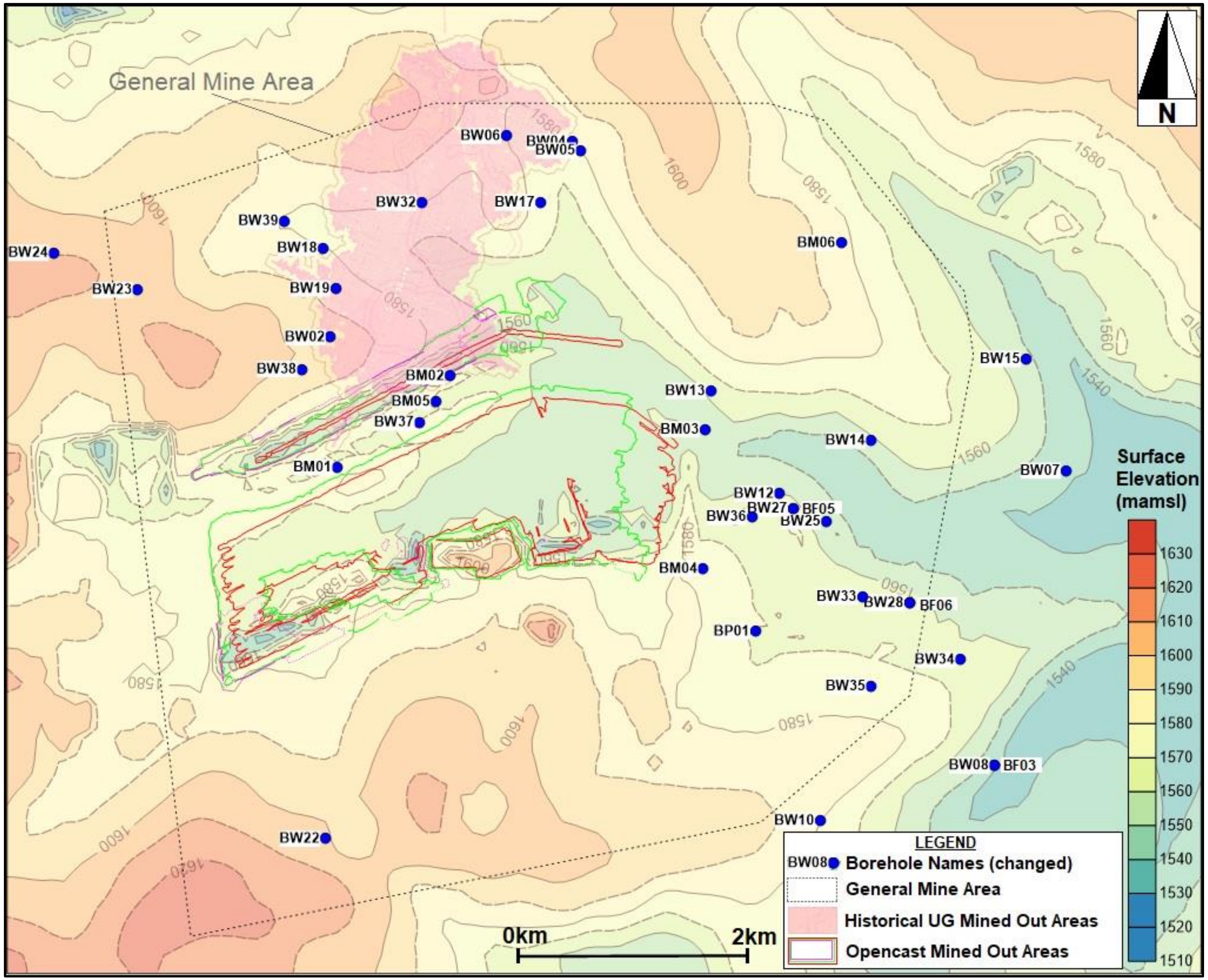


Figure 25. Groundwater Monitoring Borehole positions within the mine site (all borehole names changed, compiled from provided mine data)

During the period from 2012 to 2016 only some of the listed boreholes have data for the different years. This could be due to numerous reasons such as: lack of physical access to boreholes, borehole blockages, dried up boreholes, lack of sampling of boreholes for various reasons and destruction of boreholes due to mining activities. A detailed summary of all the groundwater monitoring boreholes data from 2012 to 2016 (including the 38 useable holes identified previously) are provided in Table 1 (included in the Appendix). The presence of any water level data or water chemistry data in the provided database for each year (2012 – 2016) is indicated with an "X" in the table.

Relevant comments pertaining to the groundwater monitoring points summarised in Table 1, are the following:

- Boreholes with prefixes "BW", "BF" and "BP" were monitored on a quarterly basis during March, June, September and December of each year (2012 – 2016)
- The "BM" boreholes were monitored on a monthly basis (from 2012 – 2016)
- Borehole BP01 is classified as being drilled within a localised perched aquifer, but is used together with the "BW" boreholes during analysis as the data of this hole is very similar to the shallow weathered zone aquifer borehole data
- Numerous boreholes present within the monitoring programme have been discontinued or demolished over the years. Borehole names shown in dark red in Table 1 have been discontinued or demolished for various reasons
- The following borehole pairs have the same positions (twin boreholes): BF03 and BW08, BF05 and BW27, BF06 and BW28
- Borehole BW11 was incorrectly added to the groundwater monitoring points database, but was removed because it was found that it is a surface water monitoring point
- Two water chemistry samples (deep and shallow), and one water level measurement is taken at all of the following boreholes: BM01, BM02, BM03, BM04, BM05 and BM06

The groundwater monitoring boreholes provided by the mine only had GPS coordinates in the format Latitude/Longitude (WGS84 Datum) with no borehole elevation data. The GPS borehole positions were converted into X and Y coordinates (South African Grid – Lo29 WGS84) and the GPS elevations extracted from Google Earth, using Garmin BaseCamp™

software, in order to use the boreholes for data modelling purposes. The groundwater monitoring borehole elevations (Z values) were determined by importing the converted borehole collars into Geovia Minex^{TM} 6.5.2 modelling software and extracting the surveyed DTM elevations for each borehole position. The groundwater monitoring borehole collar elevations (Z values) are thus the elevation of the surveyed DTM at each borehole position.

It is critical to have accurate elevations for the monitoring boreholes because during data modelling these elevations were used to calculate the groundwater elevations (by subtracting the groundwater level depths from the borehole elevations) for each monitoring borehole. The surveyed DTM elevation values for the groundwater monitoring boreholes are considerably more accurate than the GPS elevations of the boreholes. A comparison of the DTM Z values and GPS Z values, for each specific borehole, is provided in Table 2. The difference in elevations between the DTM borehole elevations (used during data modelling) and the GPS borehole elevations, range from 0.02 m to 25.40 m, with an average elevation difference of around 10.20 m. Within the “Difference” column in Table 2 negative values indicate that the GPS elevations are more than the DTM elevations for a specific borehole, and positive values show that the GPS elevations are less than the DTM elevations for that borehole. The DTM elevations are the most accurate and were used during the data modelling stage of the study.

Table 1. Groundwater Monitoring Boreholes comparison between the GPS elevations and DTM elevations (elevations shown in mamsl; generated from provided mine data).

BH_ID (names changed)	GPS borehole Elevations (mamsl)	DTM borehole Elevations (mamsl)	Difference (DTM Z values - GPS Z values)
BF03	1560.900	1540.610	-20.290
BF05	1560.900	1566.380	5.480
BF06	1550.300	1568.080	17.780
BP01	1578.700	1568.190	-10.510
BW02	1597.000	1595.890	-1.110
BW04	1599.900	1580.770	-19.130
BW05	1599.500	1580.130	-19.370
BW06	1593.900	1580.090	-13.810
BW07	1557.700	1542.190	-15.510
BW08	1565.800	1540.400	-25.400
BW10	1594.800	1579.860	-14.940
BW12	1560.900	1561.570	0.670
BW13	1586.900	1562.830	-24.070
BW14	1583.200	1558.370	-24.830
BW15	1553.800	1551.880	-1.920
BW17	1580.100	1575.720	-4.380
BW18	1588.200	1580.470	-7.730
BW19	1584.900	1584.920	0.020
BW22	1606.700	1603.370	-3.330
BW23	1608.800	1609.390	0.590
BW24	1606.100	1609.560	3.460
BW25	1556.800	1552.510	-4.290
BW27	1562.900	1566.380	3.480
BW28	1555.000	1568.080	13.080
BW32	1593.600	1580.010	-13.590
BW33	1563.600	1568.560	4.960
BW34	1563.800	1564.640	0.840
BW35	1573.100	1574.320	1.220
BW36	1564.000	1569.240	5.240
BW37	1584.800	1570.950	-13.850
BW38	1602.500	1597.470	-5.030
BW39	1596.000	1579.880	-16.120
BM01	1587.000	1572.340	-14.660
BM02	1582.300	1570.490	-11.810
BM03	1569.400	1550.490	-18.910
BM04	1578.800	1575.370	-3.430
BM05	1584.400	1566.910	-17.490
BM06	1588.200	1583.080	-5.120

6.2.3 Groundwater levels and flow characteristics

Groundwater levels were provided as time-series measurements within the groundwater monitoring programme database. The groundwater level measurements taken during the period 2012 to 2016, for boreholes "BW', "BP", "BF" and "BM", were made available from the mine database. The groundwater level data was separated into wet season and dry season datasets for each year (2012 to 2016). The average values for the wet season and dry season groundwater levels was calculated respectively with a total of 10 datasets compiled (an average wet season values and average dry season values dataset for every year from 2012 – 2016). The wet season was taken as January, February, March; October, November and December of a year; with the dry season being taken as April, May, June, July, August and September of each year. These months correspond with the wettest and driest months as indicated by the local rainfall data of the mine site (see section 4.3).

Groundwater levels in boreholes with prefixes "BW', "BP" and "BF" were measured during March, June, September and December of each year (2012 – 2016). The groundwater levels in the boreholes with prefixes "BM" were measured on a monthly basis during the year (2012 – 2016). This data was used to compile average wet season and dry season groundwater level measurements for the years: 2012, 2013, 2014, 2015 and 2016 (10 datasets compiled in total). The averaged seasonal datasets for each year (2012 – 2016) differed in regards to available and useable data for the groundwater monitoring boreholes.

The following number of boreholes contained useable groundwater level data for each year's wet season and dry season (out of a total of 38 possible groundwater monitoring borehole measurements):

- **2016**: 24 boreholes (3 "BF", 3 "BM" and 18 "BW" holes) with groundwater level data (for both the wet season and dry season) – approximately 63% of the available boreholes contained groundwater level data for 2016 (wet and dry seasons)

- **2015**: 30 boreholes (3 "BF", 3 "BM", 1 "BP" and 23 "BW" holes) with groundwater level data (for both the wet season and dry season) – approximately 79% of the available boreholes contained groundwater level data for 2015 (wet and dry seasons)

- **2014**: 33 boreholes (3 "BF", 3 "BM", 1 "BP" and 26 "BW" holes) with groundwater level data (for both the wet season and dry season) – approximately 87% of the available boreholes contained groundwater level data for 2014 (wet and dry seasons)

- **2013**: 35 boreholes (3 “BF”, 5 “BM”, 1 “BP” and 26 “BW” holes) with groundwater level data (for both the wet season and dry season) – approximately 92% of the available boreholes contained groundwater level data for 2013 (wet and dry seasons)

- **2012**: 6 boreholes (6 “BM” holes), with groundwater level data (for both the wet season and dry season) – approximately 16% of the available boreholes contained groundwater level data for 2012 (wet and dry seasons)

A summary of the average seasonal groundwater level values (averages, minimums and maximums) for the years 2012 to 2016 was compiled from the provided dataset for each aquifer type (borehole types: “BW”, “BF” and “BM”), and is presented in Table 3. The borehole identified with a “BP” prefix was analysed together with the “BW” boreholes as these boreholes’ data were very similar to the data from borehole BP01.

The average seasonal variation in water levels (estimated from the average wet and dry season values) from 2016 to 2012 is the following (from Table 3):

- Shallow Weathered Zone Aquifer (BW boreholes)
    - 2016 – 0.30 m, 2015 – 0.06 m, 2014 – 0.12 m, 2013 – 0.24 m, 2012 – no data
    - The average seasonal variation over 5 years was: 0.18 m, and over 3 years it was: 0.16 m
- Deeper Fractured Aquifer (BF boreholes)
    - 2016 – 0.29 m, 2015 – 0.06 m, 2014 – 0.19 m, 2013 – 0.64 m, 2012 – no data
    - The average seasonal variation over 5 years was: 0.30 m, and over 3 years it was: 0.18 m
- Mine Workings (BM boreholes)
    - 2016 – 0.71 m, 2015 – 0.63 m, 2014 – 0.17 m, 2013 – 1.60 m, 2012 – 0.82 m
    - The average seasonal variation over 5 years was: 0.79 m, and over 3 years it was: 0.50 m

The seasonal variations in groundwater depths below surface within the shallow weathered zone aquifer boreholes and the deeper fractured zone aquifer boreholes appear to be more similar in ranges, and are not as pronounced as what the seasonal variations are of the mine workings boreholes groundwater depths below surface. This could indicate that the weathered zone aquifer and fractured zone aquifer are more influenced by natural recharge processes than the disturbed groundwater system of the mine workings (which is influenced by artificial processes like active mine dewatering).

Table 2. Groundwater Monitoring Borehole Water Levels Summary (compiled from provided mine data). Data divided into Wet Season and Dry Season average measurements

GW Monitoring Borehole Type	YEAR AND SEASON (WET/DRY)* from 2016 to 2012											
Groundwater Level Data from **SHALLOW WEATHERED AQUIFER** Monitoring Boreholes **(BW)**	**2016 WET SEASON**	**2016 DRY SEASON**	**2015 WET SEASON**	**2015 DRY SEASON**	**2014 WET SEASON**	**2014 DRY SEASON**	**2013 WET SEASON**	**2013 DRY SEASON**	**2012 WET SEASON**	**2012 DRY SEASON**	**5 year Averages (2016-2012)**	**3 year Averages (2016-2014)**
Average Water Level (mbgl)	6.20	6.50	6.40	6.46	6.47	6.59	7.28	7.52	-	-	6.68	6.44
Minimum Water Level (mbgl)	0.68	0.43	0.48	0.78	0.56	0.67	0.79	0.92	-	-	0.66	0.60
Maximum Water Level (mbgl)	24.15	24.18	17.65	19.53	24.00	24.12	24.17	24.19	-	-	22.75	22.27
Average Seasonal Change in Water Level (m)	*2016 WL Change (m)*		*2015 WL Change (m)*		*2014 WL Change (m)*		*2013 WL Change (m)*		*2012 WL Change (m)*		*2016-2012 WL Change AVG*	*2016-2014 WL Change AVG*
	0.30		0.06		0.12		0.24		-		0.18	0.16

GW Monitoring Borehole Type												
Groundwater Level Data from **FRACTURED AQUIFER** Monitoring Boreholes **(BF)**	**2016 WET SEASON**	**2016 DRY SEASON**	**2015 WET SEASON**	**2015 DRY SEASON**	**2014 WET SEASON**	**2014 DRY SEASON**	**2013 WET SEASON**	**2013 DRY SEASON**	**2012 WET SEASON**	**2012 DRY SEASON**	**5 year Averages (2016-2012)**	**3 year Averages (2016-2014)**
Average Water Level (mbgl)	1.99	2.28	2.01	2.07	1.14	1.33	2.04	2.68	-	-	1.94	1.80
Minimum Water Level (mbgl)	0.47	0.49	0.53	0.58	0.36	0.36	0.45	0.49	-	-	0.47	0.47
Maximum Water Level (mbgl)	3.13	3.38	3.73	4.27	2.42	2.71	3.75	3.8	-	-	3.40	3.27
Average Seasonal Change in Water Level (m)	*2016 WL Change (m)*		*2015 WL Change (m)*		*2014 WL Change (m)*		*2013 WL Change (m)*		*2012 WL Change (m)*		*2016-2012 WL Change AVG*	*2016-2014 WL Change AVG*
	0.29		0.06		0.19		0.64		-		0.30	0.18

GW Monitoring Borehole Type												
Groundwater Level Data from **MINE WORKINGS** Monitoring Boreholes **(BM)**	**2016 WET SEASON**	**2016 DRY SEASON**	**2015 WET SEASON**	**2015 DRY SEASON**	**2014 WET SEASON**	**2014 DRY SEASON**	**2013 WET SEASON**	**2013 DRY SEASON**	**2012 WET SEASON**	**2012 DRY SEASON**	**5 year Averages (2016-2012)**	**3 year Averages (2016-2014)**
Average Water Level (mbgl)	5.75	6.46	6.03	6.66	4.58	4.75	21.17	22.77	25.33	26.15	12.97	5.71
Minimum Water Level (mbgl)	3.41	4.25	3.10	3.16	2.68	2.68	2.95	3.23	2.78	3.12	3.14	3.21
Maximum Water Level (mbgl)	8.46	8.66	9.46	11.09	6.76	6.63	47.56	48.15	47.06	47.21	24.10	8.51
Average Seasonal Change in Water Level (m)	*2016 WL Change (m)*		*2015 WL Change (m)*		*2014 WL Change (m)*		*2013 WL Change (m)*		*2012 WL Change (m)*		*2016-2012 WL Change AVG*	*2016-2014 WL Change AVG*
	0.71		0.63		0.17		1.60		0.82		0.79	0.50

WET SEASON MONTHS: January, February, March; October, November, December. DRY SEASON MONTHS: April, May, June, July, August, September.

The average, minimum and maximum groundwater level seasonal averages for the three borehole types ("BW', "BP" and "BF") are illustrated in Figure 26. The combined static water levels of all the monitoring boreholes in the general mining area vary from between 1.00 m and 32.36 m, with and average difference of 0.37 m between the wet and dry season.

The deepest groundwater levels were recorded in the mine workings boreholes with values above 40 m in depth. This could be caused by pumping of the groundwater within the active mine areas to dewater the mine. The groundwater level depths closest to the surface (less than 0.5 m from the surface) were found within the fractured aquifer boreholes. This could be explained by the fact that the "BF" boreholes were drilled in relatively low lying regions of the site, where the water table is generally closer to the surface. Deep water levels encountered within the "BW" boreholes are possibly not due to mining activities, but to the pumping of some of these holes for agricultural or other purposes.

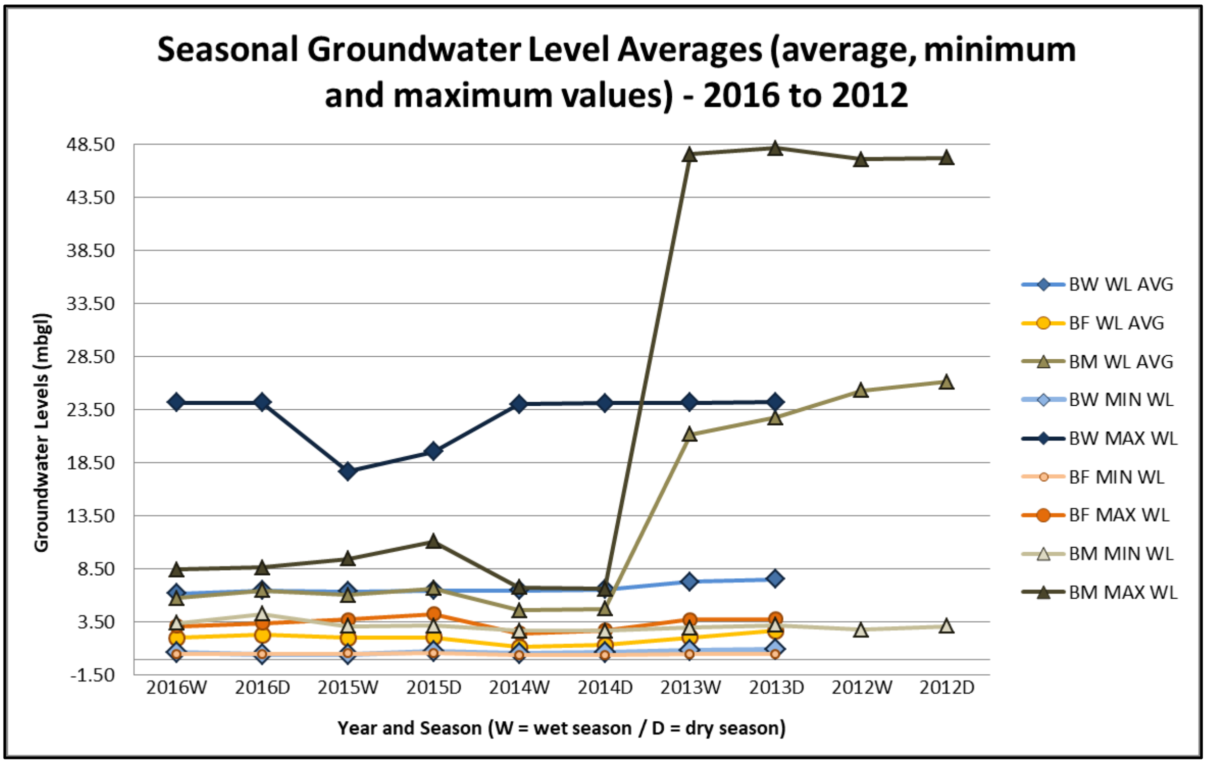


Figure 26. Seasonal Groundwater Level Averages (average, minimum and maximum values) – 2016 to 2012

In order to evaluate and interpret the groundwater depths and groundwater flow characteristics a series of data maps and graphs were produced of the wet season and dry season groundwater level averages datasets for the years 2016 to 2012. A description of the compilation of each map is provided below (the method, data the map was based on, and the year for which the map was made; is described in the list):

- **Thematic groundwater depths below surface maps** were compiled in Surfer 12^{TM} software. This was done with the wet season and dry season averages datasets of the years: 2016, 2015, 2014, 2013 and 2012. The symbols on the maps are scaled proportionally to the depth below surface of the groundwater levels. The boreholes with greater groundwater depths will have larger symbols, and conversely the symbols of the boreholes with shallow groundwater depths are displayed smaller. The surface elevations, general mine area (dotted line polygon), historical mined-out underground areas, recent opencast mined out areas, dolerite intrusions (local and regional) and local rivers are indicated on the maps.

- **Static groundwater elevation contour maps** were produced in Surfer 12^{TM} software by constructing grids of the wet season averages dataset for the years 2016, 2015, 2014 and 2013. Not enough data was available in the 2012 dataset to produce a meaningful data map of this sort for 2012. The groundwater elevations were calculated by subtracting the DTM borehole collar elevations from the measured water level depths in each borehole that contained relevant data. The differences between the wet season and dry season averages datasets were negligible, with only small changes in the groundwater elevations. The general shape and trend between the wet season and dry season groundwater elevation contours was near identical. Although the estimated groundwater elevations are bound to contain local over- and/or under estimations, the wet season groundwater elevation contours are deemed to be representative of the general regional static groundwater level trends. Vector maps (arrows on the maps) of the groundwater elevation grids were overlaid over these maps, to illustrate the flow directions and flow gradients present. The monitoring borehole positions (dark blue points), historical mined-out underground areas, recent opencast mined out areas, regional dolerite intrusions and local rivers are indicated on the maps to assist with the interpretation of these maps.

- **3 Dimensional groundwater elevation contour maps** were produced in Surfer 12^{TM} software using the same groundwater elevation grids that were used to compile the static groundwater elevation contours maps. 3D groundwater elevation contour maps were made for the years 2016, 2015, 2014 and 2013. The 2012 dataset lacked enough groundwater level data to compile a meaningful 3D groundwater elevation contour map for this year. These specific maps were also overlain by vector maps of the groundwater elevation contours grids, in order to visualise the groundwater flow directions and flow gradients in three dimensions. The monitoring borehole positions are indicated as dark blue points on the maps.

- **The graphs for the groundwater Elevations versus Surface Topography** were constructed in Microsoft Excel to analyse the correlation between the groundwater elevations and the surface topography (DTM) of the mine site. Graphs were compiled for 2016, 2015, 2014, 2013 and 2012 using all of the measured data of each borehole for each specific year.

The compiled data maps will be presented, discussed and evaluated in the following sequence (for each year separately starting with 2016 and ending with 2012):

1. Groundwater Elevations versus Surface Topography graph
2. Thematic groundwater depths below surface map
3. Static groundwater elevation contour map
4. 3 Dimensional groundwater elevation contours map

Please refer to Figure 25, to get a clear idea of the monitoring borehole positions and given names (changed from original borehole names); as it was not possible to clearly indicate the borehole names on most of the data maps compiled without making the maps too cluttered.

The available monitoring borehole datasets (on which the data maps were based) differ to varying degrees between each year (2016 – 24 boreholes, 2015 – 30 boreholes, 2014 – 33 boreholes, 2013 – 35 boreholes and 2012 – 6 boreholes) as described in section 6.2.3. This should be kept in mind when assessing the compiled data maps that follow on the next page.

The groundwater elevations versus surface topography graph for **2016** is shown in Figure 27. There is a strong correlation between the 2016 recorded groundwater levels and the surface elevations within the mine site. The groundwater elevations show a correlation coefficient of R^2 = 0.9281, which means that roughly 93% of the measured water levels closely follow the surface elevation trends. The majority of the groundwater elevations thus mimic the surface elevations within the study area according to the 2016 dataset. The groundwater levels from borehole BW32 (indicated with the red circle) showed a poorer correlation to the surface topography than the rest of the water level data for 2016.

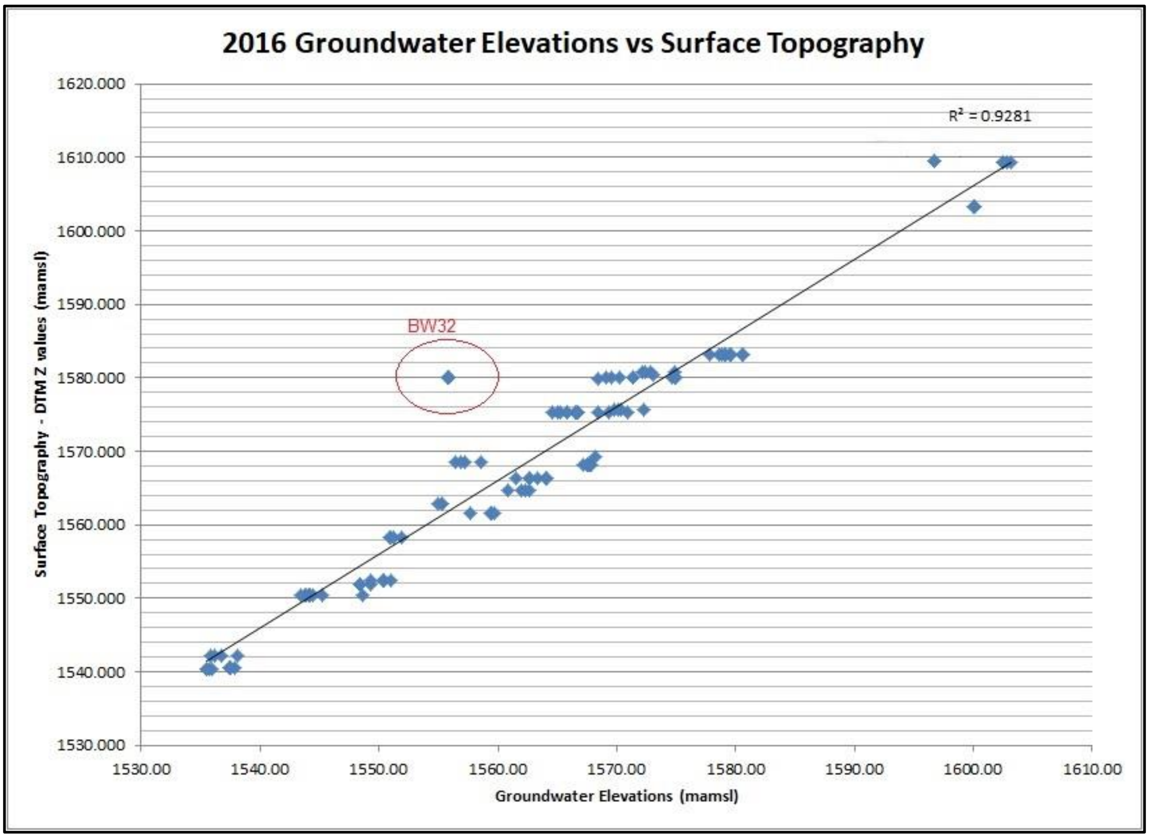


Figure 27. Groundwater Elevations vs Surface Topography for 2016 (compiled from all available recorded water level data for 2016)

The averaged groundwater level data for the 2016 wet season and dry season is illustrated in Figure 28 as a thematic map (in meters below the surface). The 2016 groundwater levels generally ranged between 10.81 m and 0.47 m for the wet season and between 11.76 m and 0.49 m for the dry season. Borehole BW32 was the only exception exhibiting the deepest averaged groundwater level measurements of 24.10 m for the wet season and 24.20 m for the dry season, for 2016. Borehole BW32 is situated on top of the historical underground mined out area (shown in light red on Figures 28 and 29), and is clearly influenced be the dewatering of groundwater into these old mine workings.

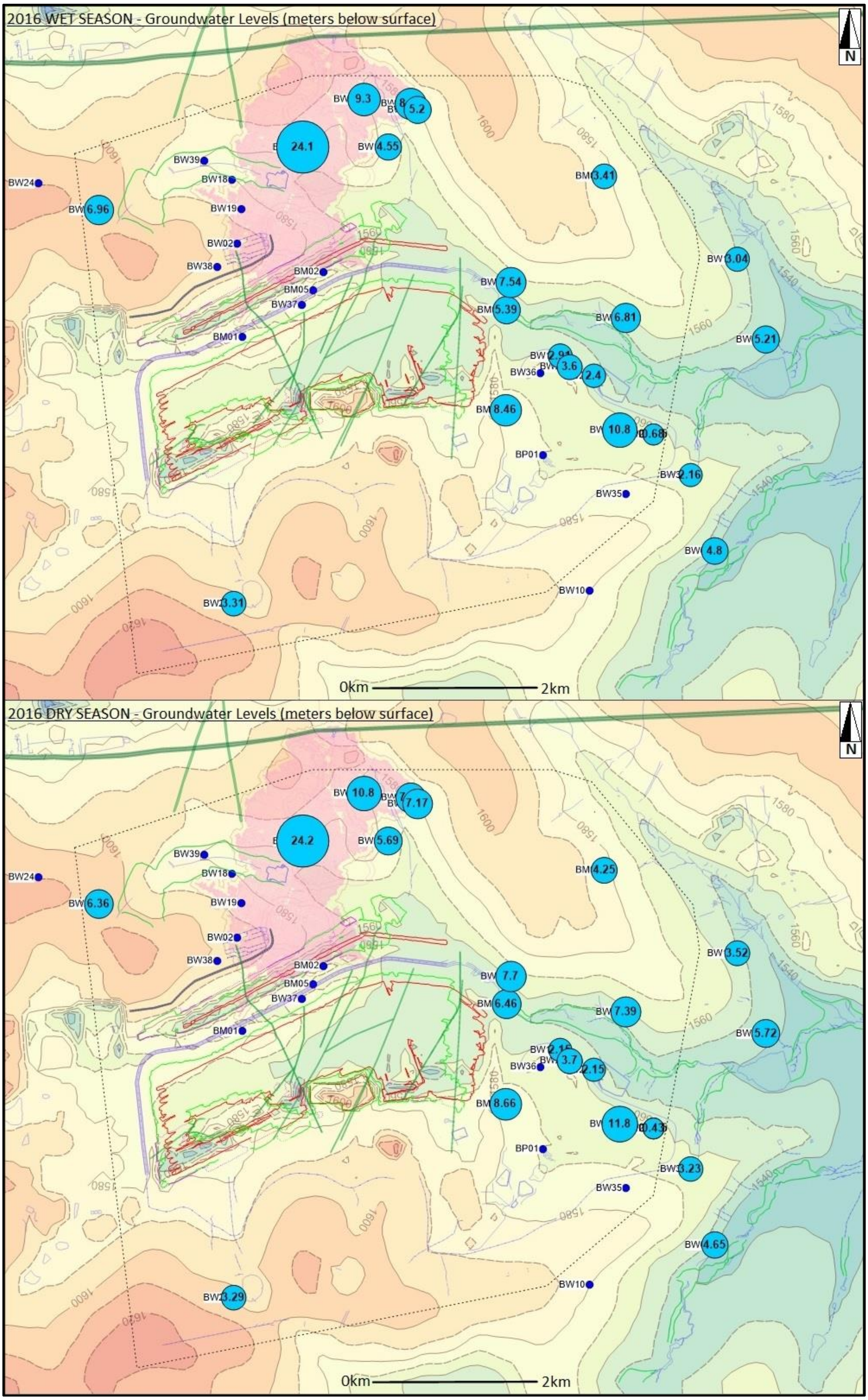


Figure 28. Wet and Dry Seasons Groundwater Depth Levels Thematic Map - 2016

The **2016** static groundwater elevation contours of the mine site are presented in Figure 29 (in mamsl). The highest groundwater elevations (above 1600 mamsl) are found in the western and south-western regions of the study area. The higher groundwater elevations correspond with the presence of higher surface elevations in these parts of the site. The lowest groundwater elevations (below 1540 mamsl) are situated towards the south-eastern parts of the study area, following the drainage direction of the rivers present in the region. The mean of the groundwater elevations for 2016 over the entire project area was 1571.83 mamsl.

The direction of groundwater flow generally occurs from the northwest of the site (which is topographically higher), towards the south-eastern (lower lying) portions of the site (Figure 30). Groundwater flow direction is shown with arrows on Figure 29 and Figure 30, with longer arrows indicating steeper flow gradients and shorter arrows indicating gentler flow gradients. Groundwater flow converged towards the central region of the study site mainly due to pumping of groundwater within the actively mined area.

Irregular groundwater elevations were encountered over the following parts of the site:

- The historical mined out area (borehole BW32), had a groundwater elevation of 1555.86 mamsl, which is considerably lower than the surrounding data points. This is possibly due to the dewatering effect of the historical mined out block in this region, or groundwater abstraction from this site. The groundwater flow direction in this area is radially inward towards borehole BW32.

- To the east of the current opencast mined out area a pronounced lowering of the groundwater elevations (below 1550 mamsl) takes place over borehole BM03. This could be caused by the abstraction of groundwater from this borehole in order to dewater the current mining areas. Borehole BM03 has a collar elevation of 1550.490 mamsl and was drilled in a topographic low area, where the groundwater may be present closer to the surface than normal.

- Slightly higher groundwater elevations (above 1560 mamsl) are found within the south-east corner of the general mine area over boreholes: BW28, BW33, BF06, BP01, BW36, BW27, BF05 and BW12 (see Figure 30). The higher groundwater elevations in this part of the site can be ascribed to the presence of a large discard stockpile over this area. Artificial recharge from the discard stockpile could be causing the higher groundwater elevations in this portion of the mine site.

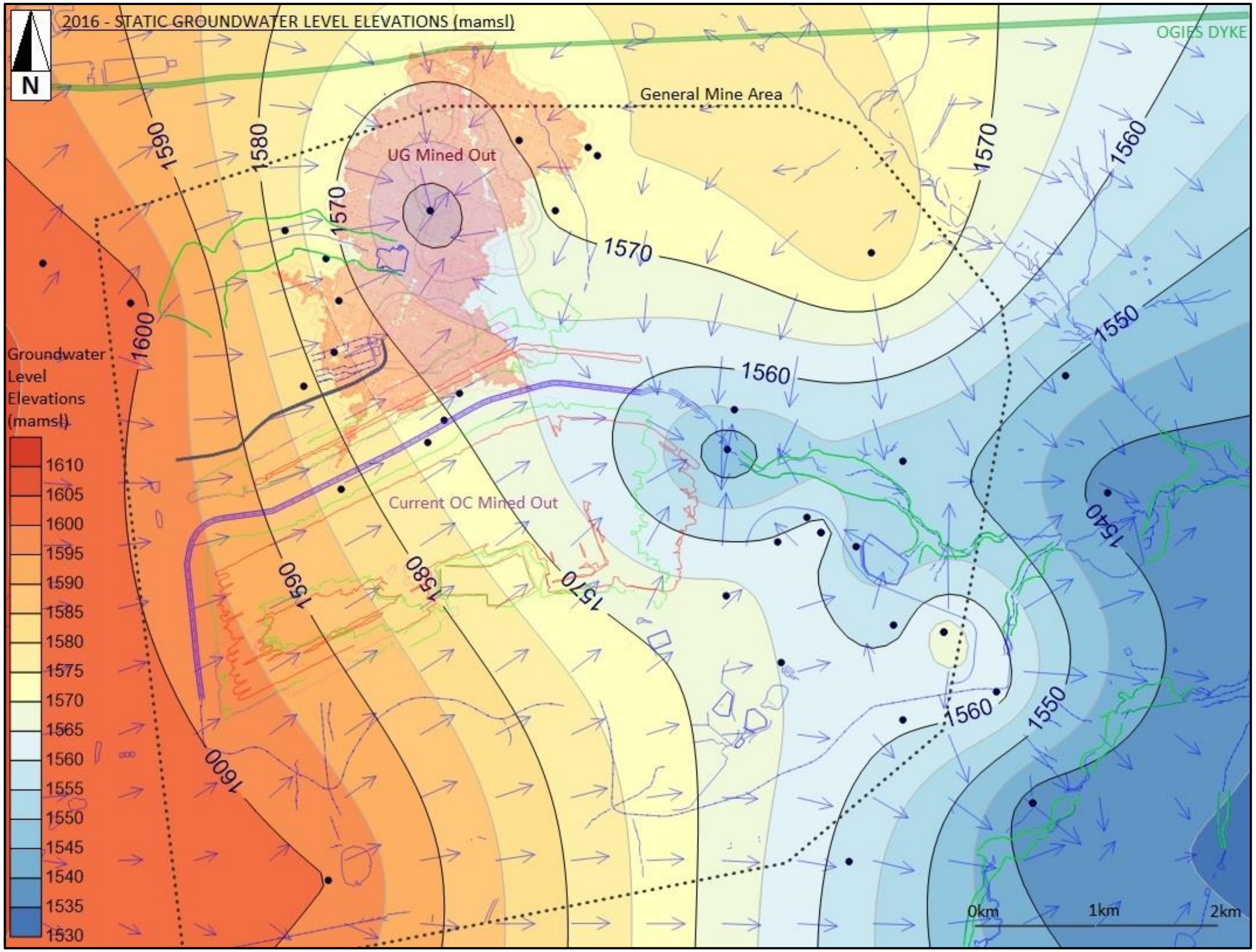


Figure 29. Static Groundwater Level Elevation Contours (mamsl) - 2016

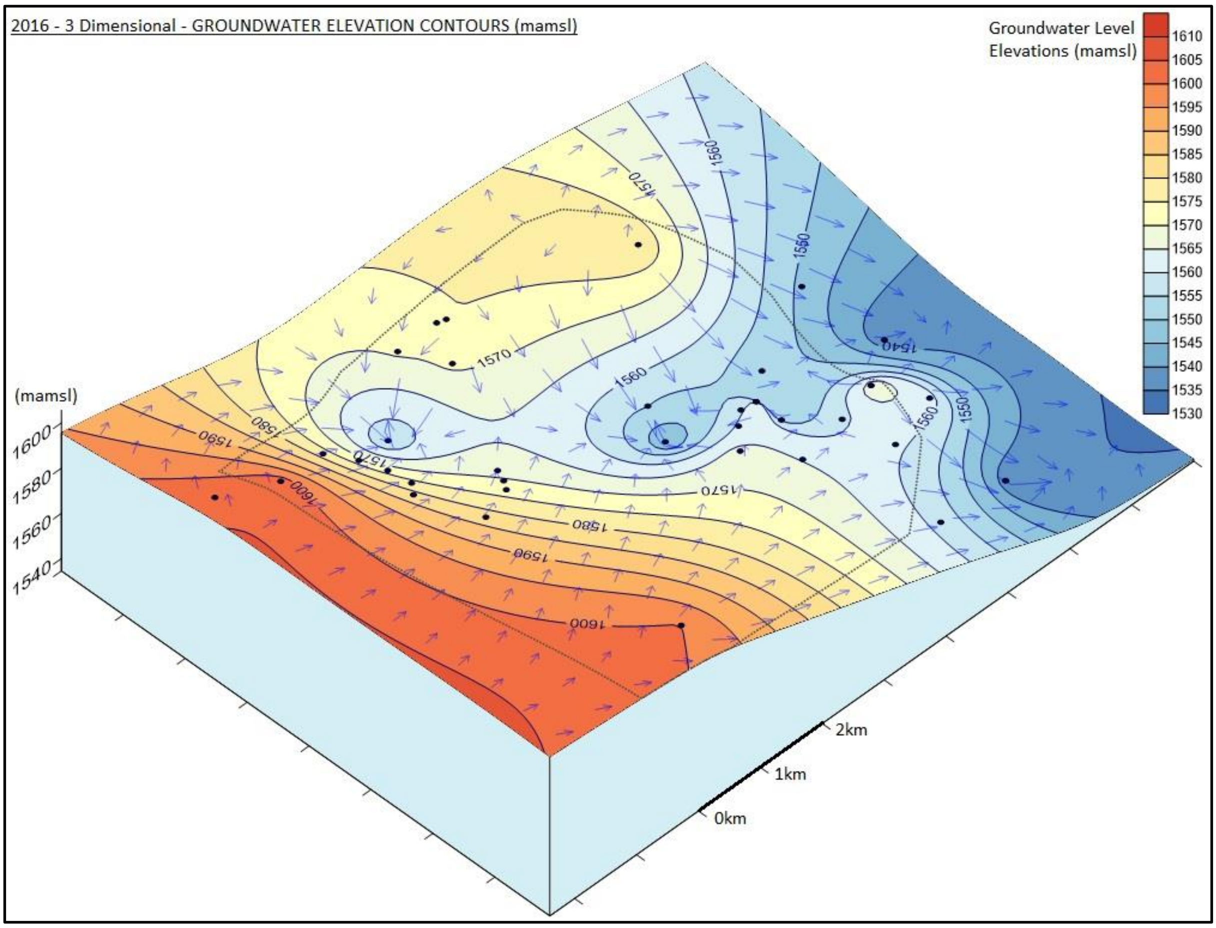


Figure 30. 3D Groundwater Elevation Contours Map (mamsl) – 2016

The **2015** groundwater elevation versus surface topography graph is included in Figure 31. In general, the groundwater elevations correlate well with the surface topography with a correlation coefficient of R^2 = 0.9403. This shows that about 94% of the measured groundwater level variations are related to surface elevation variations. The 2015 groundwater elevations dataset for the most part copy the trend of the surface elevations within the study area. Groundwater levels from boreholes BW35, BW38 and BW24 (red circles in graph) are exceptions and do not exhibit good correlations with the surface topography.

The averaged groundwater level data for the 2015 wet season and dry season is summarised in Figure 32 as a thematic map (in meters below the surface). The 2015 groundwater levels predominantly ranged between 11.94 m and 0.48 m for the wet season and between 12.02 m and 0.58 m for the dry season. Borehole BW35 has an anomalous 2015 wet season groundwater depth of 17.65 m which falls outside of the general range. Similarly borehole BW38 has a dry season groundwater depth of 19.53 m for 2015 (and no recorded values for the wet season). Borehole BW24 also had relatively large groundwater depths below surface of 11.94 m for the wet season, and 12.02 m for the dry season.

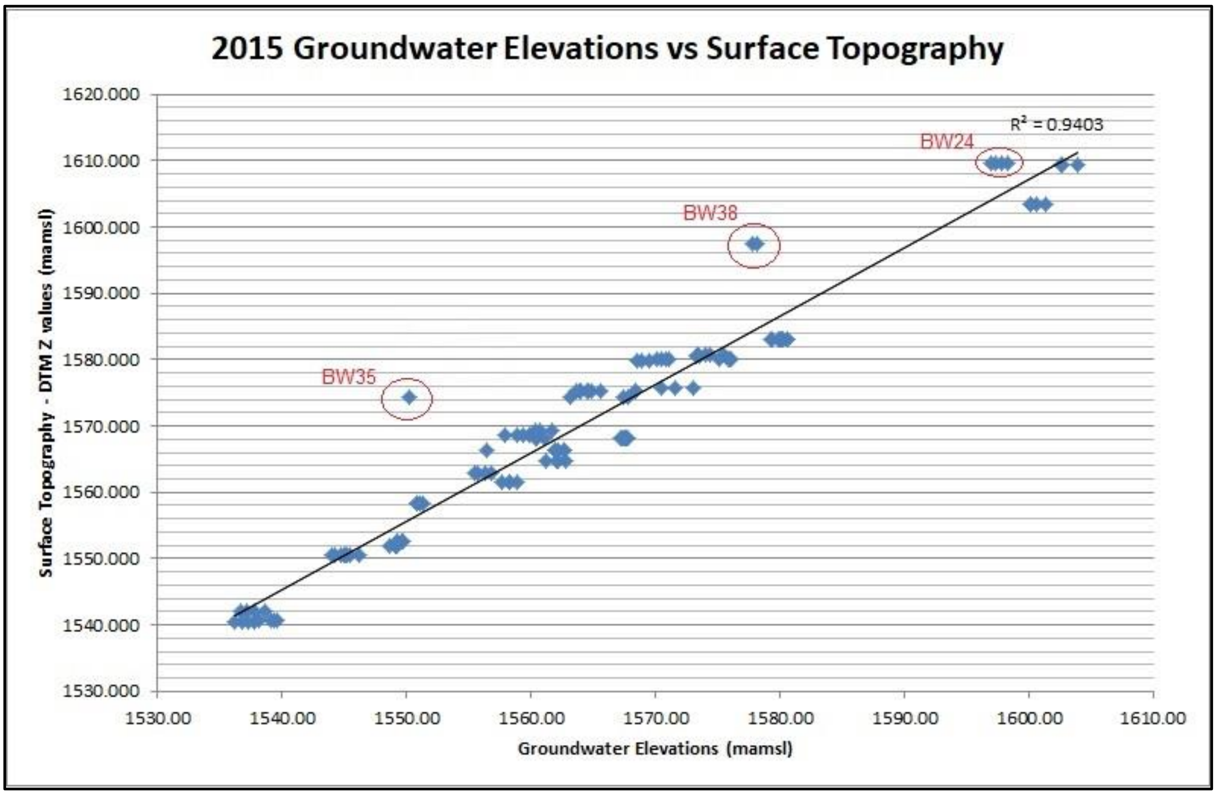


Figure 31. Groundwater Elevations vs Surface Topography for 2015 (compiled from all available recorded water level data for 2015)

Borehole BW38 is situated adjacent to the south-west border of the historical underground mined out area and just to the north-west of the recent opencast mined out areas (Figure 32). Mine dewatering into these mine workings could cause the lowering of groundwater levels in the region that this borehole is located in.

Borehole BW24 is located just outside of the north-western corner of the general mine area, and was drilled on a relatively high elevation of 1609.56 mamsl. The slightly deeper groundwater levels recorded at this borehole could be due to the higher elevation of this borehole, and not related to any specific mining activities.

Borehole BW35 lies within the south-eastern part of the general mine area over 2 km away from the current mine workings. The lowered groundwater levels during the wet season in this borehole are probably due to the pumping of groundwater from this borehole for domestic or agricultural use, and not related to any coal mining activities.

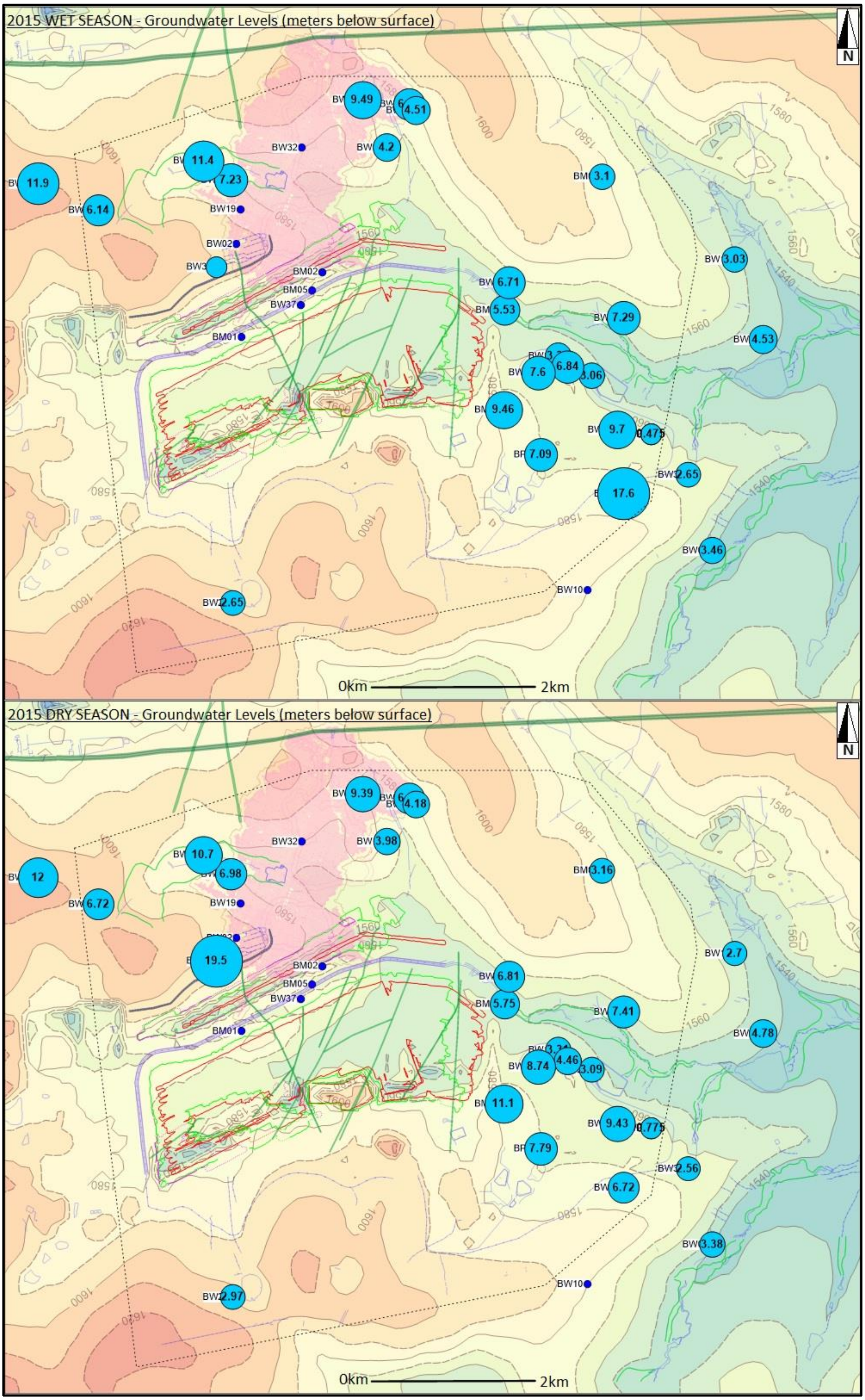


Figure 32. Wet and Dry Seasons Groundwater Depth Levels Thematic Map - 2015

The **2015** static groundwater elevations of the mine site are presented in Figure 33 (in mamsl). The 2015 static groundwater elevations are very similar to those of 2016. The highest groundwater elevations (above 1600 mamsl) are found in the western and south-western regions of the study area. The higher groundwater elevations correspond with the presence of higher surface elevations in these parts of the site. The lowest groundwater elevations (below 1540 mamsl) are situated towards the south-eastern parts of the study area, following the drainage direction of the rivers present in the region. The mean of the groundwater elevations for 2015 over the entire project area was 1571.78 mamsl. The direction of groundwater flow is generally from the west and north of the site (which is topographically higher), towards the south-eastern (lower lying) portions of the site, during 2015, following the same trend as the 2016 dataset (Figure 33).

Anomalous groundwater elevations that do not fit in with the regional groundwater elevations were identified at these portions of the mine site:

- Over the historical mined out areas (underlying borehole BW32 and near boreholes BW38 and BW39), lowered groundwater levels (below 1575 mamsl) are found that are slightly lower relative to the groundwater levels of the surrounding boreholes (above 1575 mamsl). Groundwater flows inwards towards the historical mined out areas indicating that interaction between this mined out portion and the groundwater system is taking place.

- The lower groundwater elevations (under 1570 mamsl) at borehole BW39 (just to the west of the historical mined out block) could be caused by mine dewatering into the old mine workings or due to the abstraction of groundwater from this borehole.

- To the east of the current opencast mined out area a pronounced lowering of the groundwater elevations (under 1550 mamsl) takes place again over borehole BM03 (like in the 2016 data maps). This is most probably caused by the pumping of groundwater from this borehole in order to dewater the current mining areas. Borehole BM03 was drilled in a topographic low area (1550.490 mamsl), where the groundwater may be present closer to the surface than normal.

- Elevated groundwater elevations occur within the south-east corner of the general mine area (once more as in 2016) over boreholes: BW28, BW33, BF06, BP01, BW36, BW27, BF05 and BW12 (see Figures 33 and 34). Artificial recharge from the discard stockpile above this part of the mine site can cause the higher groundwater elevations in this region (of over 1565 mamsl).

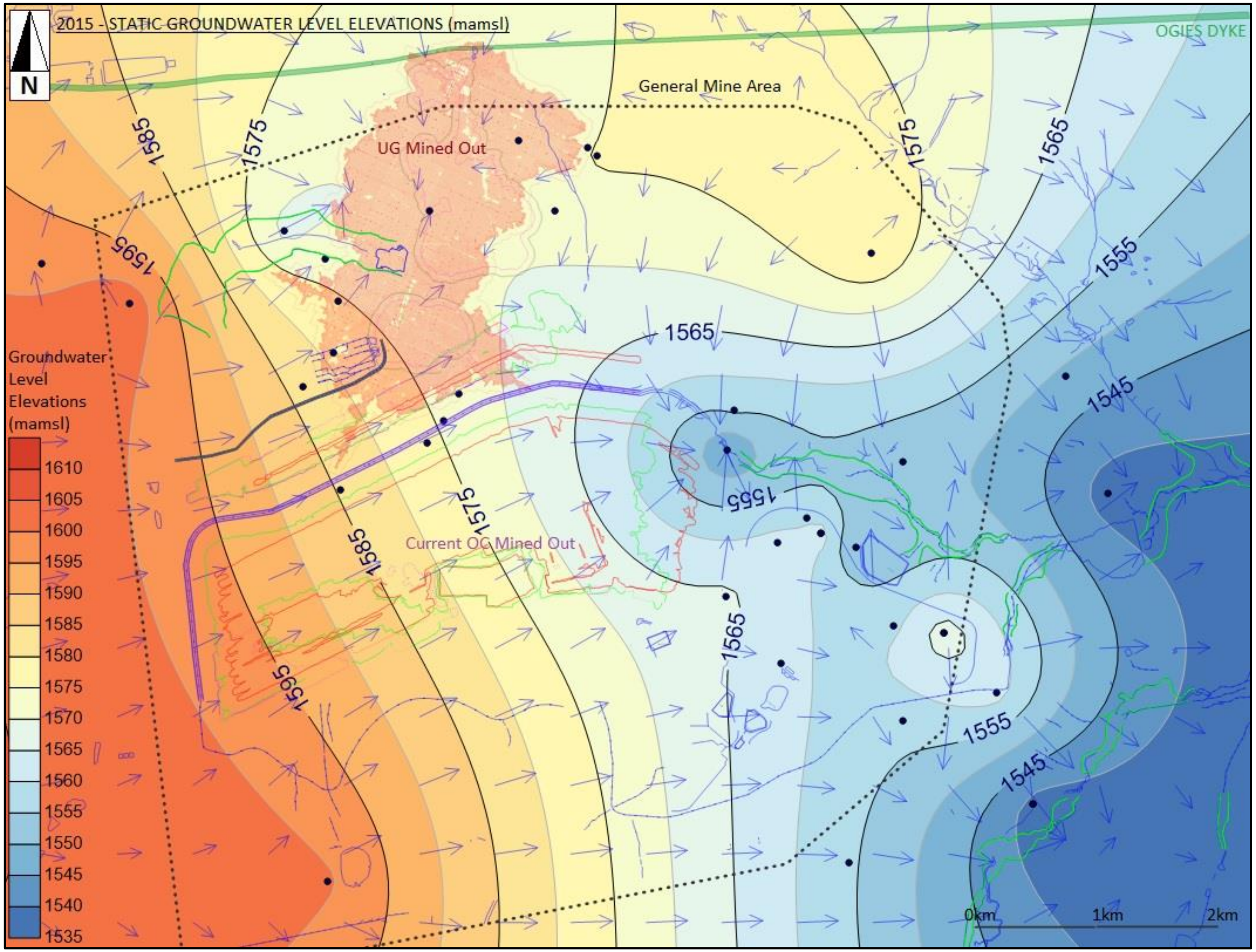


Figure 33. Static Groundwater Level Elevation Contours (mamsl) - 2015

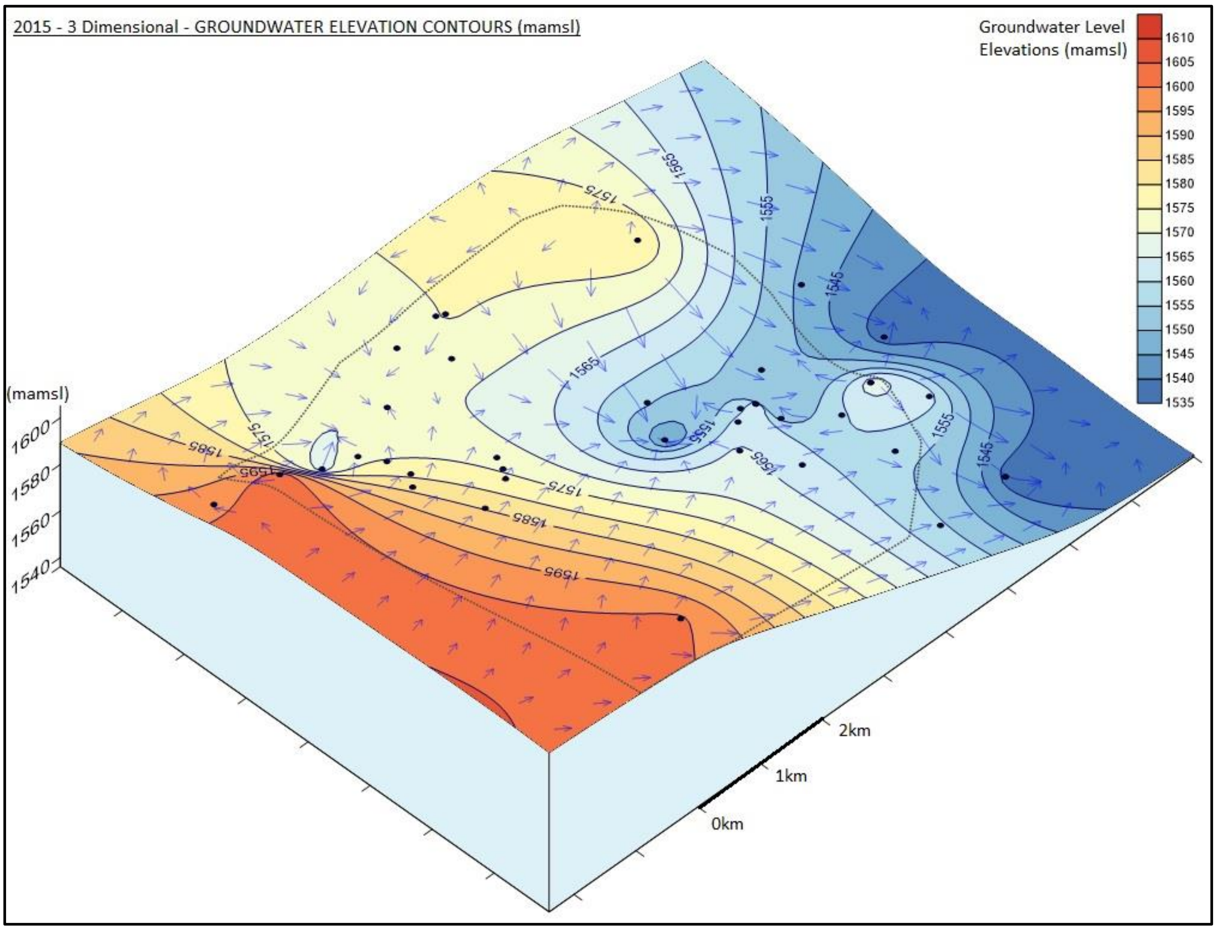


Figure 34. 3D Groundwater Elevation Contours Map (mamsl) – 2015

The groundwater elevations versus surface topography graph of all the available recorded groundwater level data for **2014** is presented in Figure 35. The variations in groundwater levels for 2014 share a close relationship with the surface elevation variations. The variables have a correlation coefficient of R^2 = 0.914 indicating that about 91% of the recorded groundwater elevations are related to surface topography. The 2014 groundwater levels mimic surface topography (like the groundwater levels datasets of 2015 and 2016). Boreholes BW32, BW38 and BW02 (shown with red circles on the graph) have irregular groundwater levels that do not fit the surface elevations trend.

The averaged groundwater level data for the 2014 wet season and dry season is presented in Figure 36 as a thematic map (in meters below the surface). The 2014 groundwater levels generally varied between 11.28 m and 0.36 m for the wet season and between 11.36 m and 0.36 m for the dry season. Groundwater depth levels for boreholes BW32, BW38 and BW02 fell outside of these general ranges for the 2014 wet and dry season. Borehole BW32 had groundwater depth measurements of 24 m for the wet season, and 24.12 m for the dry season. The groundwater depth levels measured for borehole BW38 were 17.12 m in the wet season and 16.91 m in the dry season. Borehole BW02 displayed groundwater depth levels of 16.66 m (wet season) and 16.58 m (dry season). BW06, BW39 and BW35 showed slightly deeper groundwater depths relative to the rest of the measured 2014 data (Figure 36). BW06 had groundwater depth levels of 8.36 m and 11.36 m for the wet and dry seasons respectively with BW35 containing wet season groundwater depth levels of 9.26 m and dry season depths of 10.93 m. Borehole BW39 exhibited deeper groundwater levels of 9.37 m (wet season) and 9.39 m (dry season).

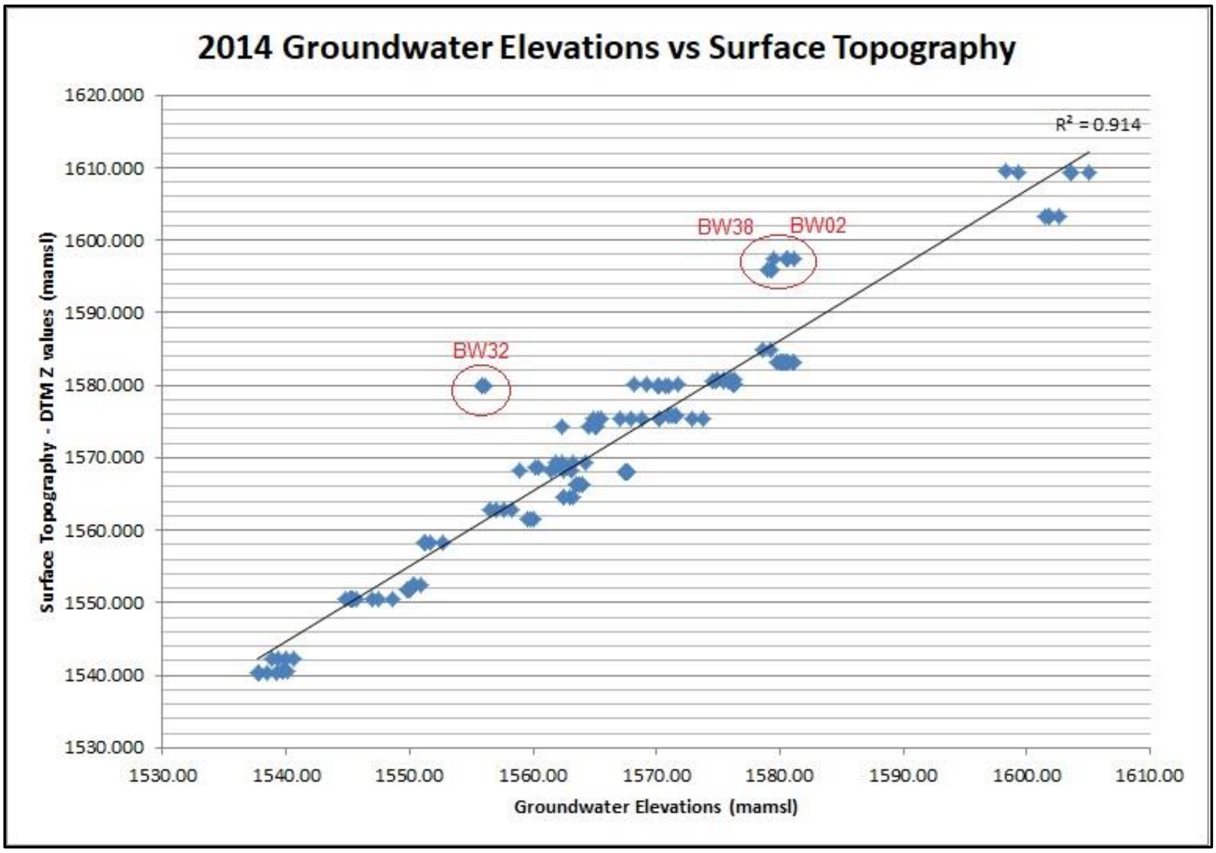


Figure 35. Groundwater Elevations vs Surface Topography for 2014 (compiled from all available recorded water level data for 2014)

Boreholes BW32, BW38, BW39, BW02 and BW06 were all drilled over or adjacent to, the historical mined out area (indicated in light red in Figures 36 and 37) situated within the north of the general mine area. The deeper groundwater levels recorded in these boreholes could be as a result of mine dewatering taking place with groundwater flowing into the old mined out underground workings. Boreholes BW38 and BW02 are in close proximity to the recent mined out opencast areas and these boreholes groundwater depths could also be influenced by dewatering into the rehabilitated opencast areas. The lowered groundwater levels found in borehole BW35 could be a result of pumping of water from this hole, as it is situated more than 2 km from any old or recent mine workings.

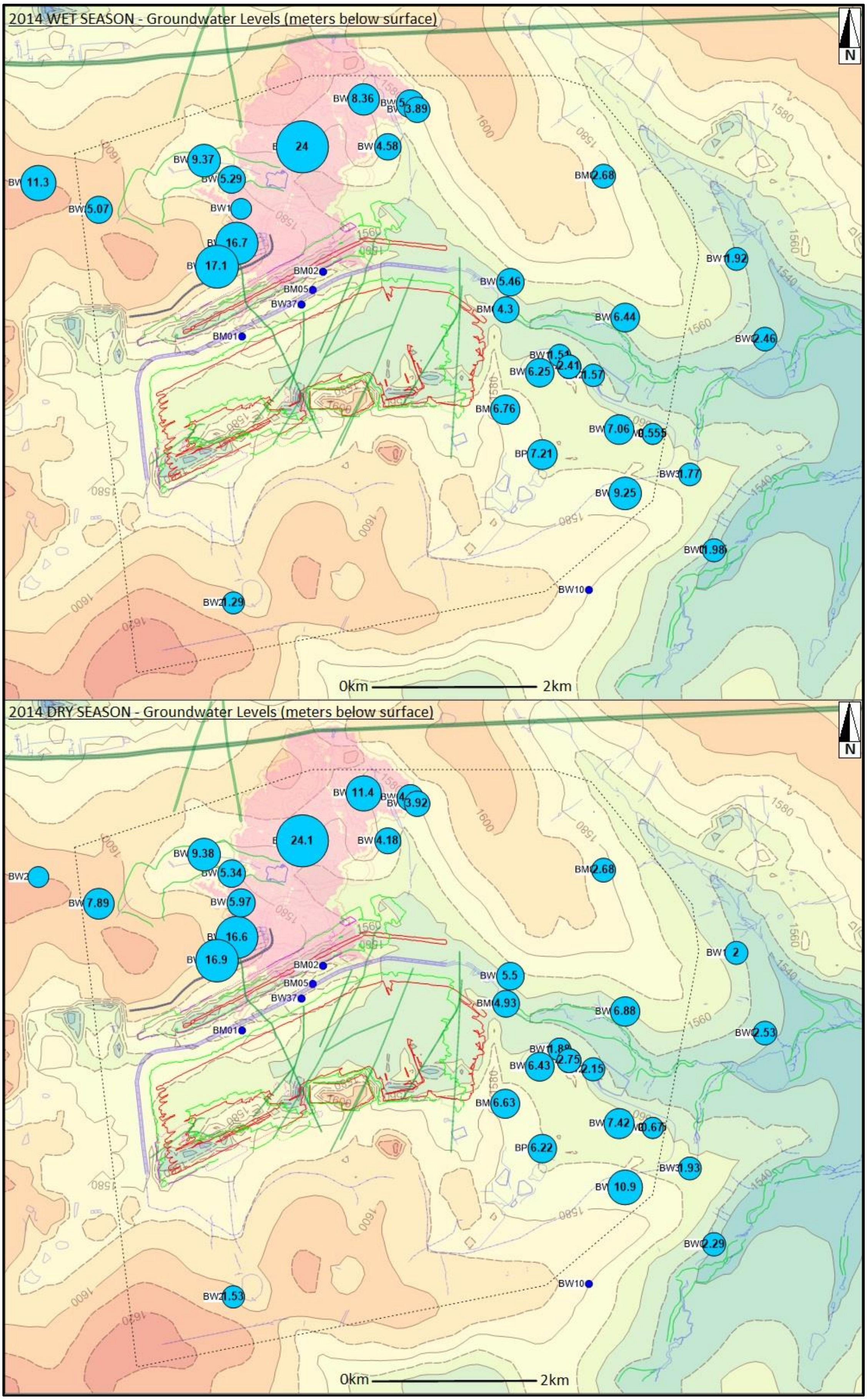


Figure 36. Wet and Dry Seasons Groundwater Depth Levels Thematic Map - 2014

The static groundwater elevations of the mine site for **2014** are indicated in Figure 37 (in mamsl). The overall trend in groundwater flow directions and groundwater elevations for 2014 are similar in relation to the 2015 and 2016 trends for the same variables. The highest groundwater elevations of above 1610 mamsl are present within the west and south-west border of the study area. The lowest groundwater elevations of below 1540 mamsl occur in the south-east corner of the study area. The high and low groundwater elevations occur at corresponding higher and lower surface elevations respectively. The mean of the groundwater elevations for 2014 over the entire project area was 1572.45 mamsl. Groundwater flow direction (indicated with arrows on Figure 37 and Figure 38) regionally occurs from the west and north towards the south-east of the site.

Inconsistent groundwater elevations not fitting the regional groundwater elevation trends were recognised within the following parts of the mine site:

- The historical mined out area (underlying boreholes BW32, BW02 and BW06, and next to boreholes BW38 and BW39) had a groundwater elevation of below 1565 mamsl at its centre (at hole BW32). This is much lower than the groundwater elevations of the monitoring borehole surrounding the old workings (Figure 38). These lower groundwater elevations over the historical mined out block is probably caused by groundwater abstraction from borehole BW32. The groundwater flow direction in the area is radially inward towards borehole BW32 (similar to the 2015 and 2016 datasets).

- At borehole BM03 lowered groundwater elevations are found, similar to the 2016 and 2015 data maps for this borehole. This could be caused by the pumping of groundwater from this borehole in order to dewater the current mining areas. Conversely borehole BM03 was drilled in a relative topographic low area (1550.490 mamsl), where the groundwater may be present closer to the surface than usual.

- Over borehole BW28, BW33, BF06, BW36, BW27, BF05 and BW12 abnormally higher groundwater elevations occur (between 1565 and 1560 mamsl), that could be the result of more water seeping into the groundwater system from the discard stockpile situated above these boreholes. Groundwater seems to be flowing radially outward from this part of the mine site.

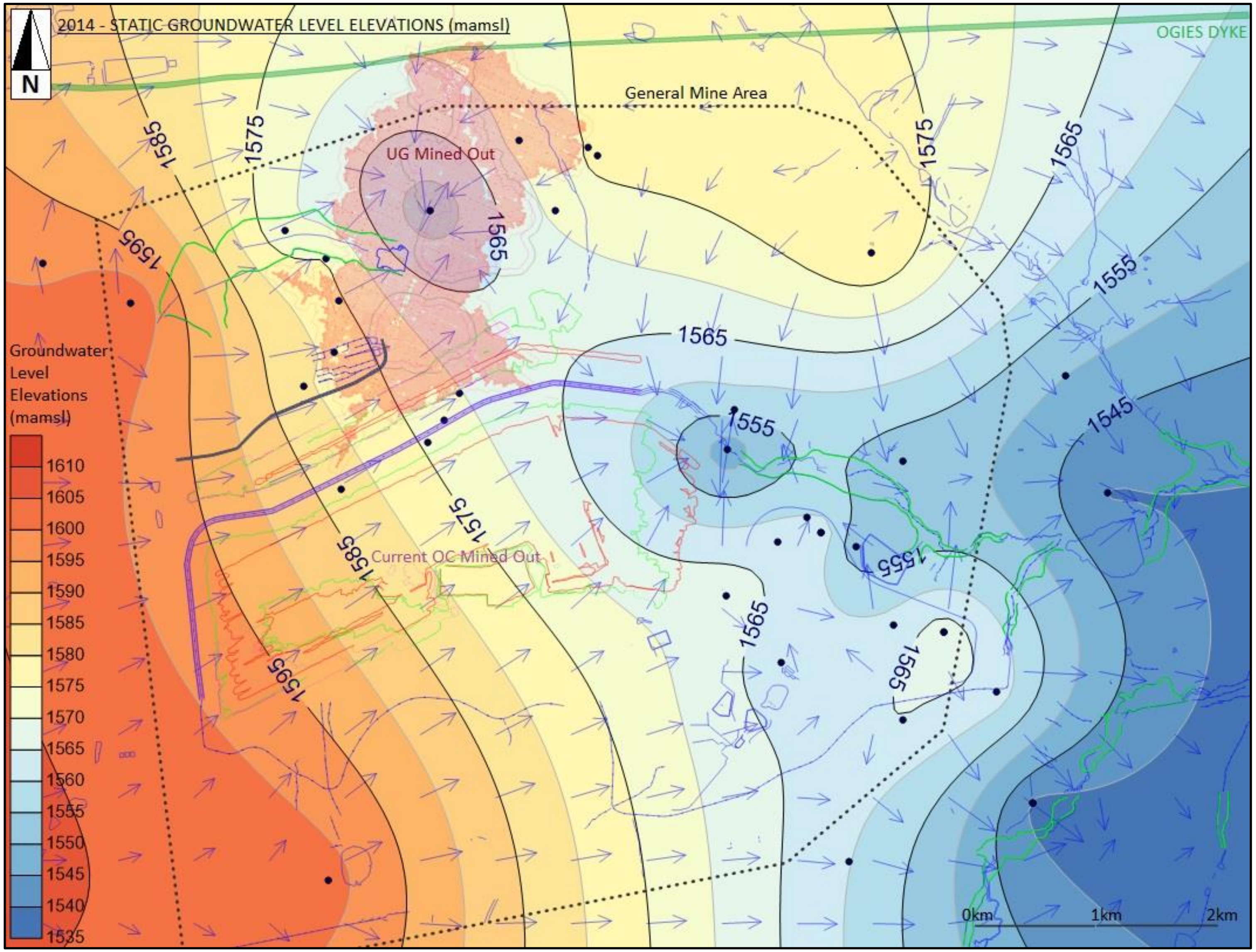


Figure 37. Static Groundwater Level Elevation Contours (mamsl) - 2014

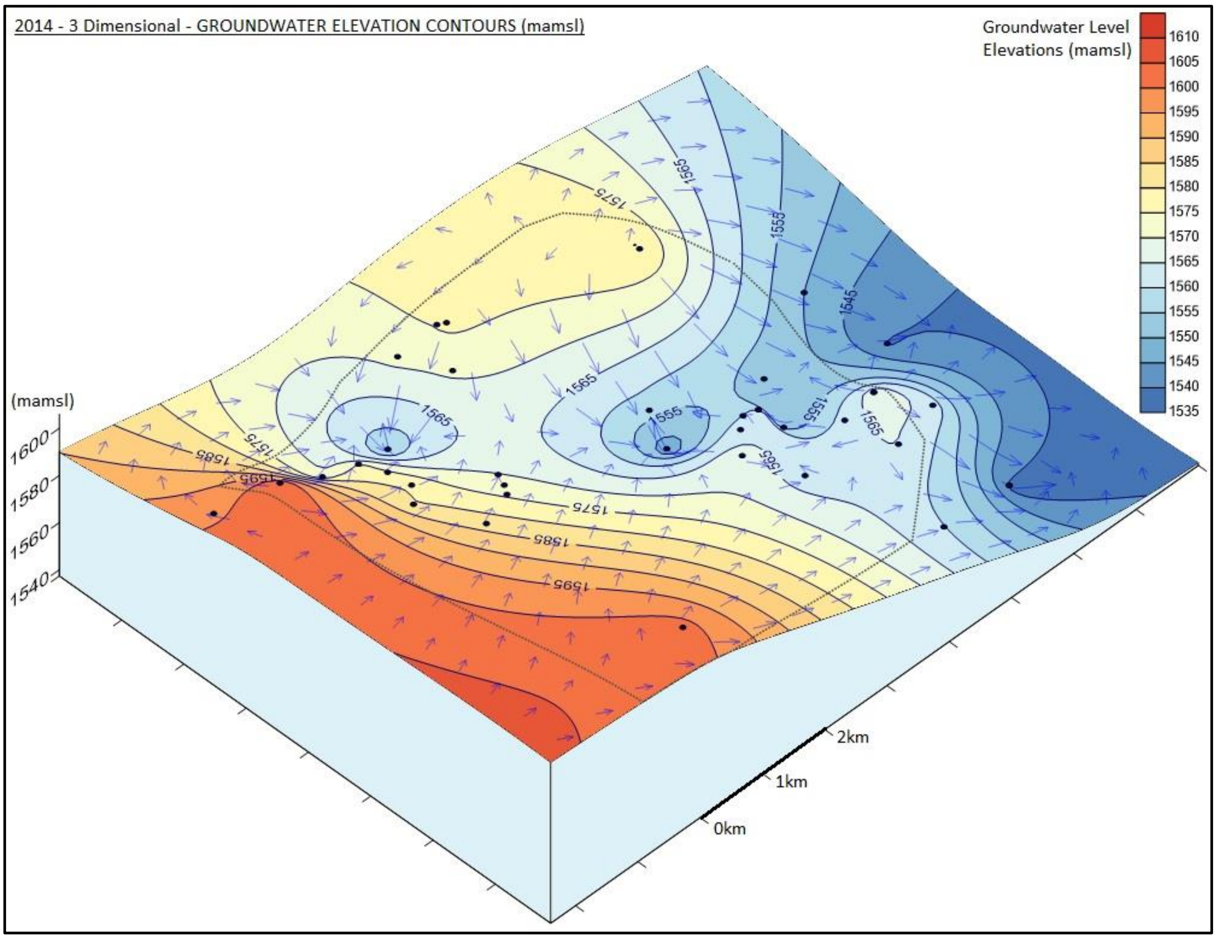


Figure 38. 3D Groundwater Elevation Contours Map (mamsl) – 2014

The groundwater elevations versus surface topography graph of all the available recorded groundwater level data for **2013** is illustrated in Figure 39. Clear differences between the 2013 correlations and the correlations for the years 2016, 2015 and 2015 are apparent. This is because the 2013 dataset contains data from boreholes BM01 and BM05 (shown with thick red circles on the graph) that were drilled in the recent mine workings, which were not present in the following year's datasets. When comparing all the groundwater elevations (including the data from borehole BM01 and BM05) to surface topography the data has a poor correlation of R^2=0.496. When removing the data form the two mine workings boreholes a correlation coefficient of R^2=0.8965 is estimated. This indicates that excluding boreholes BM01 and BM05, the remaining groundwater elevations share a close relationship (nearly 90% of recorded values) with variations in surface topography. The groundwater levels from boreholes BM01 and BM05 are influenced by processes unrelated to surface topography. Boreholes BW02, BW32 and BW38 (indicated with red circles on graph) also had groundwater level data that did not correlate well with the surface topography.

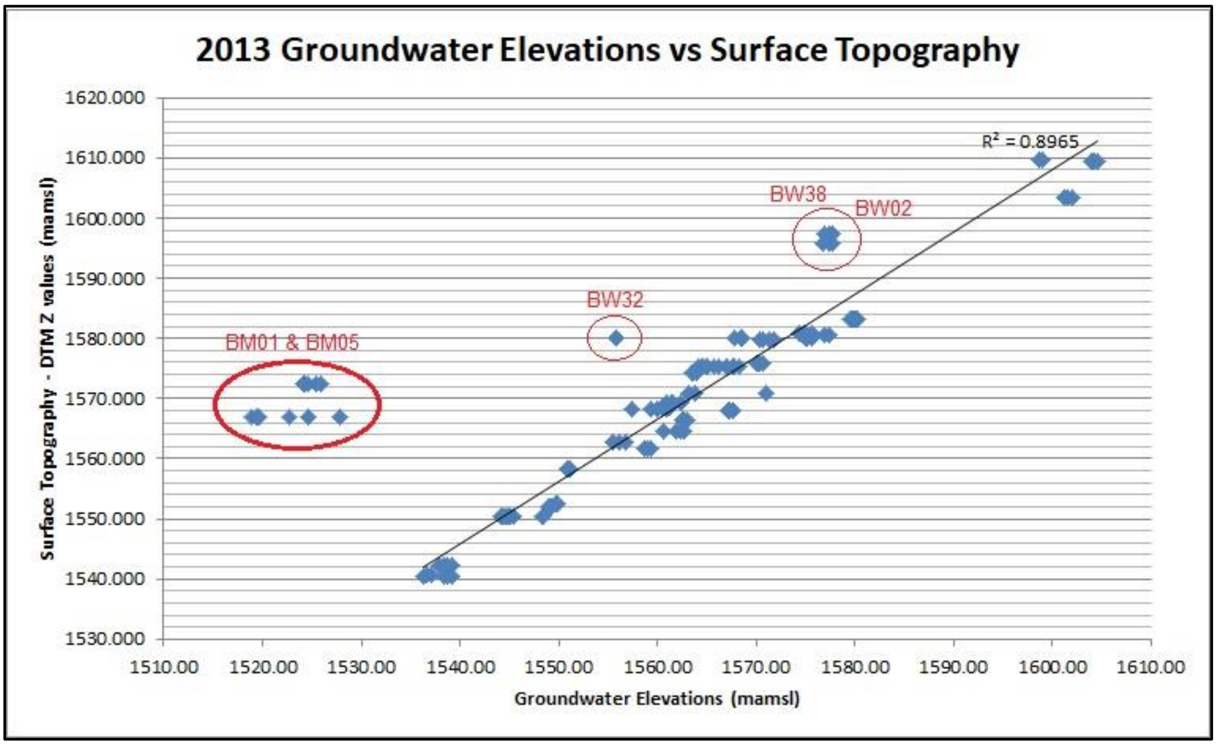


Figure 39. Groundwater Elevations vs Surface Topography for 2013 (compiled from all available recorded water level data for 2013)

The averaged groundwater level data for the 2013 wet season and dry season is summarised in Figure 40 as a thematic map (in meters below the surface). The 2013 groundwater levels largely fluctuated between 11.84 m and 0.45 m for the wet season and between 11.65 m and 0.49 m for the dry season. The groundwater level depths for boreholes BM01, BM05, BW02, BW32 and BW38 were much deeper than the general range maximum depths for the wet and dry seasons.

Boreholes BM01 and BM05 were drilled in the current mine workings within the central part of the general mine area (Figure 40). Pumping of these boreholes to dewater the active opencast mine workings is the reason that these boreholes have such pronounced lower groundwater levels. Borehole BM01 had a wet season groundwater depth of 46.7 m and dry season depth of 48 m. Borehole BM05 had a wet season groundwater depth of 40.6 m and dry season depth of 44.3 m.

Boreholes BW02 and BW32 were drilled over the old underground mine workings with borehole BW38 situated next to these old mine workings. Dewatering taking place into the old mine workings could cause the lower groundwater depths in the vicinity of these boreholes. The recent mined out opencast areas could also be influencing holes BW02 and BW38, as these holes are located near these rehabilitated areas.

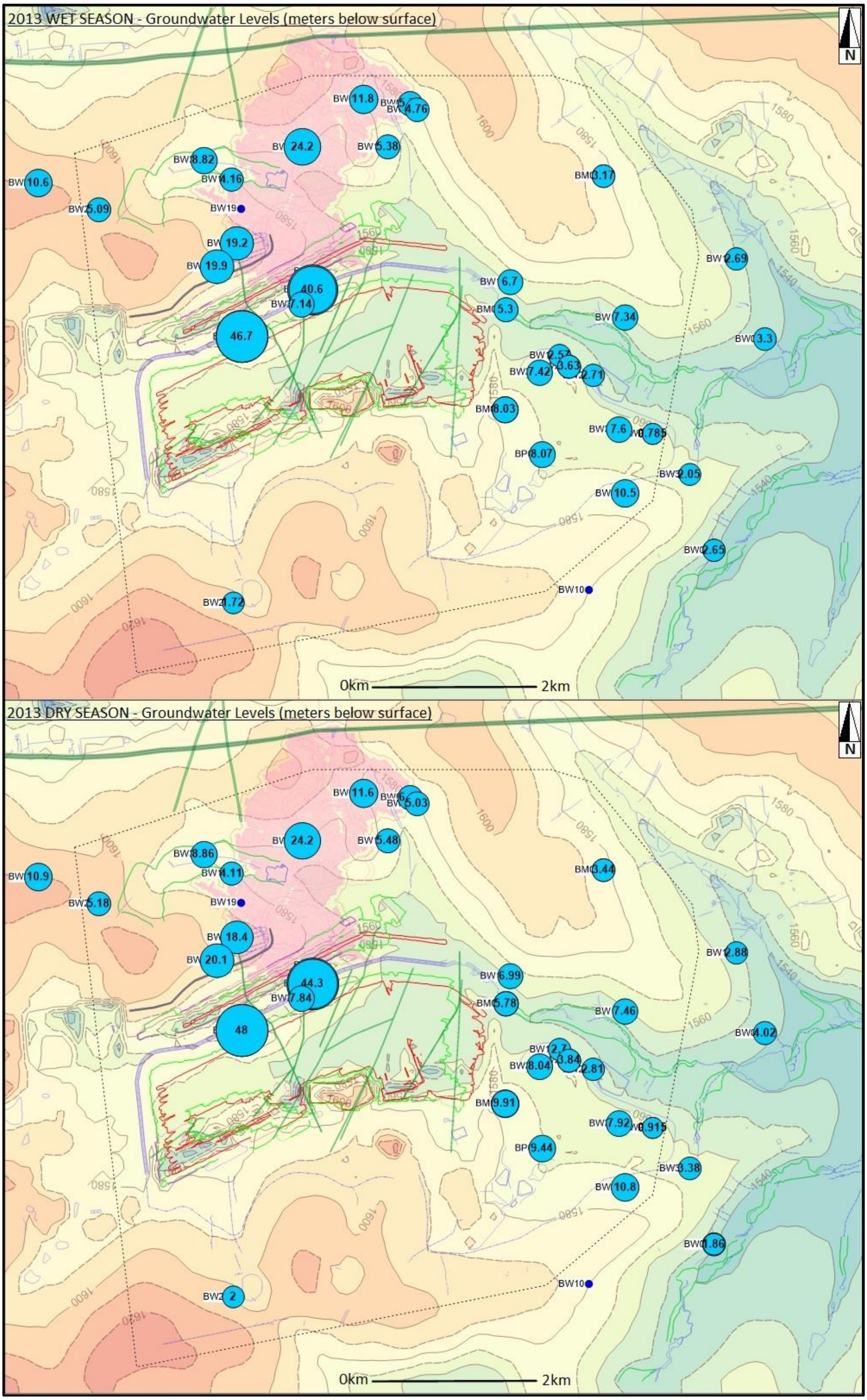


Figure 40. Wet and Dry Seasons Groundwater Depth Levels Thematic Map - 2013

The static groundwater elevations (in mamsl) for **2013** over the mine area are shown in Figure 41. The 2013 static groundwater elevations exhibit a trend that differs greatly from the groundwater elevations of the 2016, 2015 and 2014 datasets. The 2013 groundwater level dataset represents actual conditions within the mine site the best; as it contains the most complete monitoring borehole dataset (which includes the most boreholes drilled in the current mine workings). The highest groundwater elevations (above 1605 mamsl) occur in the north-west and south-western corners of the study area. The highest groundwater elevations correspond with the presence of the highest surface elevations in these parts of the site. The lowest groundwater elevations are situated within two distinct parts of the region. Towards the south-eastern parts of the study area lower groundwater elevations (of under 1540 mamsl) corresponding to lower surface elevations are found. Within the central portion of the mine site, where the current mining activities are taking place, a distinct lowering of groundwater elevations (below 1530 mamsl) is evident. These lower groundwater elevations form a cone of depression within the mining area, which is caused by the pumping of boreholes to dewater the mining blocks in this area. The mean of the groundwater elevations for 2013 over the entire site was 1566.89 mamsl (which is much lower than the corresponding groundwater elevation means for 2016, 2015 and 2014).

The overall groundwater flow direction appears to be radially inwards towards the central part of the mine site where the cone of depression formed (Figure 42). Pumping of groundwater within the actively mined area in the central part of the site caused this groundwater flow pattern. Towards the eastern regions of the site the groundwater flows from the north and west, towards the south-east following the natural drainage pattern of the region.

The following parts of the site have groundwater elevations that do not conform to what would be expected within a natural system:

- The recent mine workings within the central part of the mine site exhibit groundwater elevations of below 1530 mamsl forming a prominent local cone of depression. An explanation for this is that boreholes BM01 and BM05 are located in the mine workings and are most probably pumped to dewater the active mining areas during production, significantly lowering the water table. The lower groundwater levels in borehole BW02 and BW32 could also be effected by the dewatering of the active mine areas.
- Within the central part of the old mine workings (under borehole BW32) lowered groundwater elevations are encountered of less than 1560 mamsl. Interaction with

the old mined out underground workings could be responsible for the lower groundwater depths in this part of the mine site.

- Elevated groundwater levels (above 1565 mamsl) are present within parts along the south eastern border of the general mine area where boreholes: BW28, BW33, BF06, BP01, BW36, BW27, BF05 and BW12 are located. These higher groundwater elevations were present in 2014, 2015 and 2016, and are thought to be caused by the discard stockpile covering this area that gradually releases stored water into the groundwater system (artificial recharge), elevating the groundwater table.

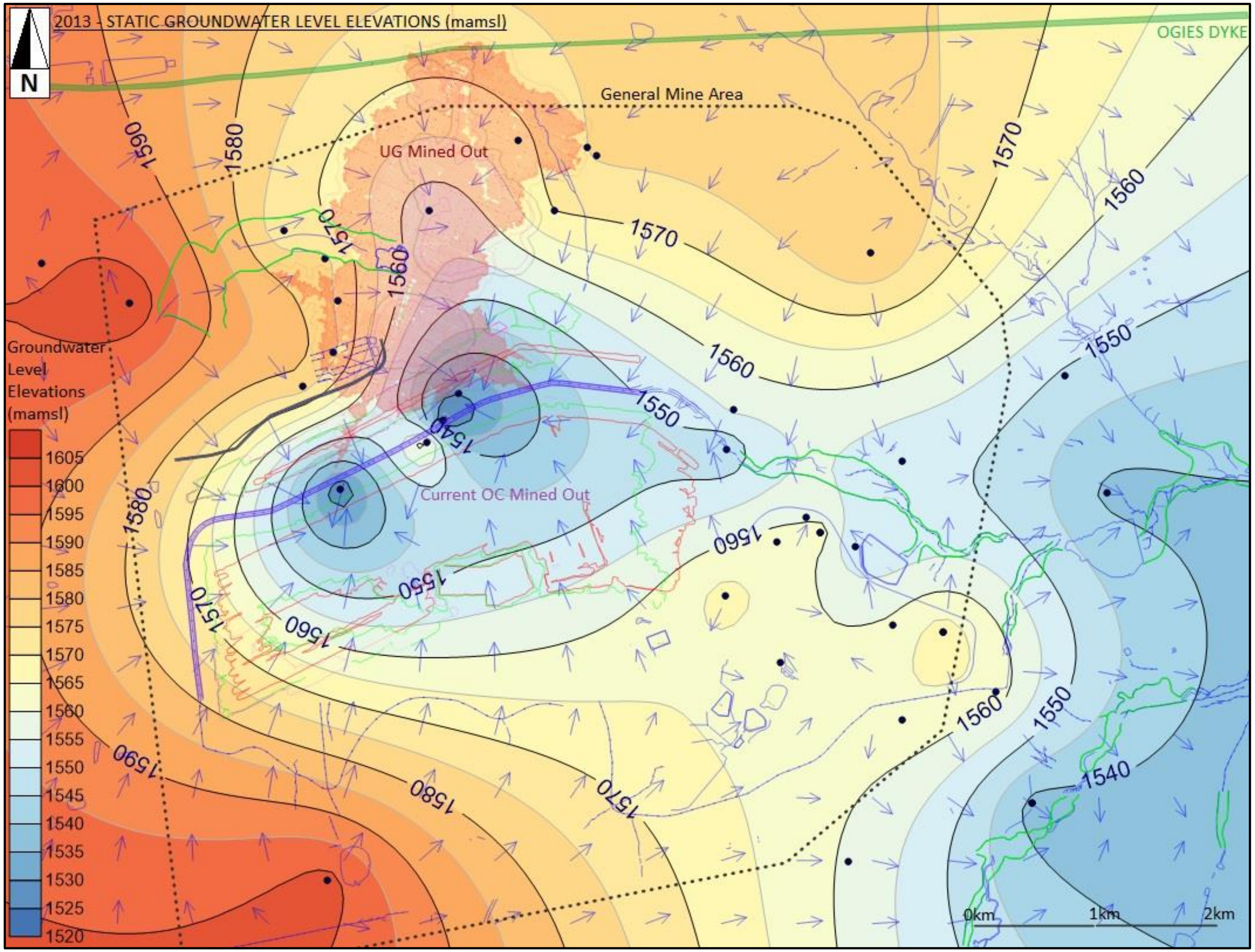


Figure 41. Static Groundwater Level Elevation Contours (mamsl) - 2013

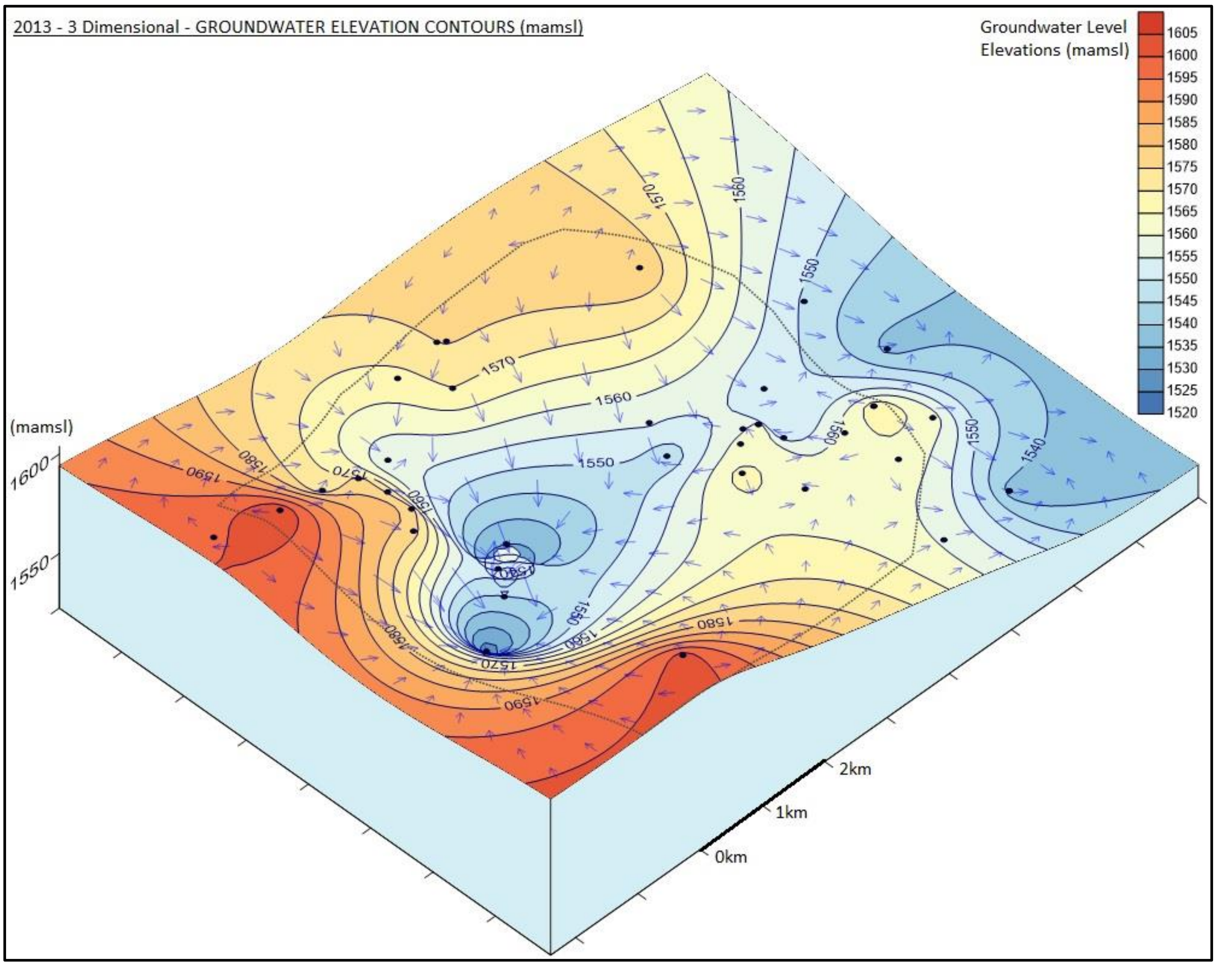


Figure 42. 3D Groundwater Elevation Contours Map (mamsl) – 2013

The groundwater elevations versus surface topography graph of all the available recorded water level data for **2012** is provided in Figure 43. Unlike the years following 2012, the dataset is poorly correlated with a correlation coefficient of only R^2=0.1926. This means that most of the recorded groundwater levels of 2012 are not related to the surface topography. The reason that there are such large differences between the 2012 dataset and the rest of the datasets is that the 2012 groundwater level data is made up of measurements from only 6 boreholes. These 6 boreholes are BM01, BM02, BM03, BM04, BM05 and BM06 and were all drilled within mine workings. The groundwater levels from these boreholes were all influenced by mining activities (active pumping of these holes for mine dewatering purposes) and not by the fluctuating surface topography within the mine site.

The averaged groundwater level data for the 2012 wet season and dry season is shown in Figure 44 as a thematic map (in meters below the surface). The groundwater level readings for the 2012 dataset varied between 2.78 m and 47.06 m for the wet season and from 3.12 m to 47.21 m for the dry season. Boreholes BM03, BM04 and BM06 had shallower groundwater levels between 2.78 m and 7.73 m (wet season) and 3.62 m to 10.01 m (dry season). These boreholes are located towards the east and north-east of the current mining area (Figure 44). Boreholes BM01, BM02 and BM05 had much deeper groundwater levels that fluctuated between 45.68 m and 47.06 m for the wet season and 45.55 m to 47.21 m for the dry season.

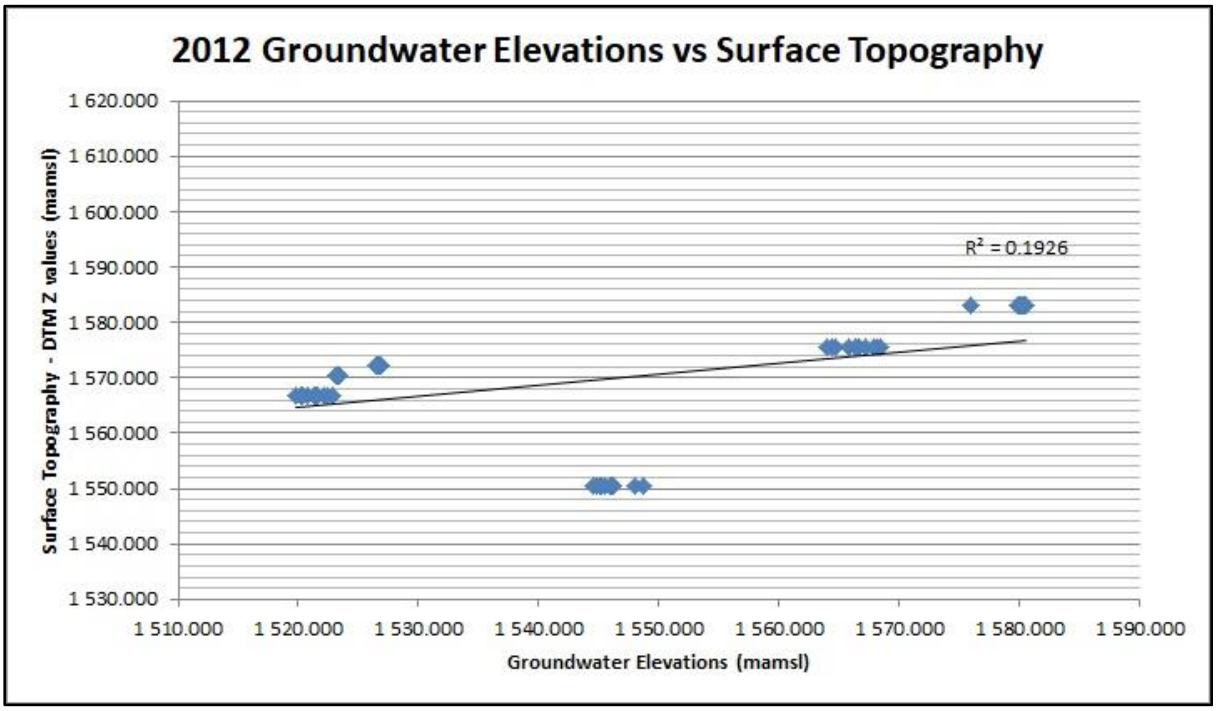


Figure 43. Groundwater Elevations vs Surface Topography for 2012 (compiled from all available recorded water level data for 2012)

Boreholes BM01, BM02, BM03, BM04, BM05 and BM06 were all influenced to varying degrees by mine dewatering. The boreholes closest to the current mine workings (BM01, BM02 and BM05) had the deepest groundwater levels indicating that these boreholes were pumped during active mining to dewater the opencast pit. Boreholes BM03, BM04 and BM06 are situated further away from the current mine workings, but it is clear that these boreholes have also been influenced by mine dewatering processes.

Not enough monitoring borehole data for 2012 was available to create a meaningful static groundwater elevation map or 3D groundwater elevation map for this year. The groundwater elevations mean for 2012 was 1553.62 mamsl, which is significantly lower than the means of the groundwater elevations for 2016, 2015, 2014 and 2013. The highest groundwater elevation of 1580.30 mamsl occurred in borehole BM06. The lowest groundwater elevation of 1521 mamsl was found in borehole BM05. The groundwater flow direction (according to the limited dataset) is from outside the general mine area towards the central part of the site where the deepest groundwater levels of boreholes BM01, BM02 and BM05 are located.

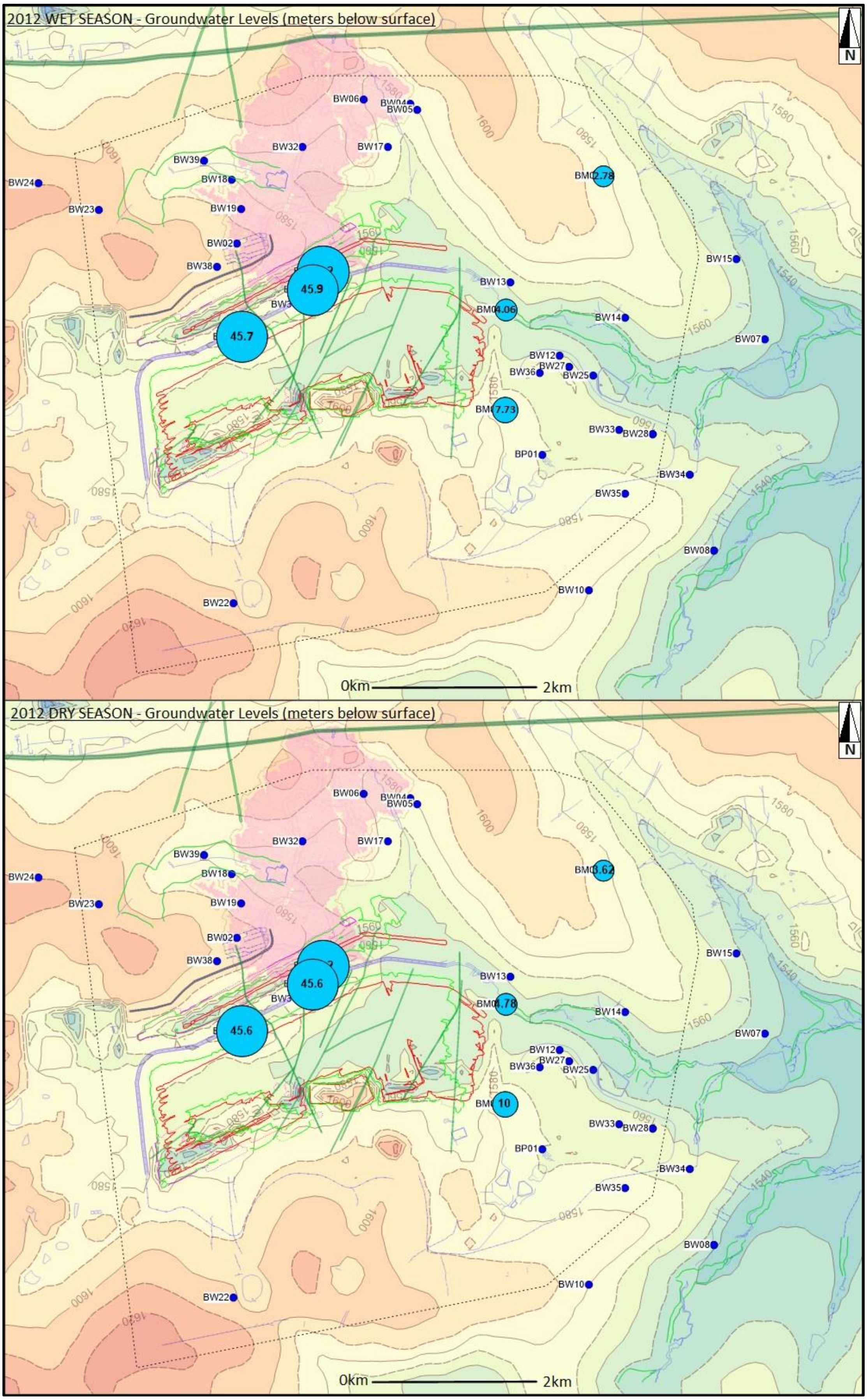


Figure 44. Wet and Dry Seasons Groundwater Depth Levels Thematic Map - 2012

6.2.4 Groundwater Chemistry

Groundwater chemistry data were made available as time-series readings from the groundwater monitoring programme of the mine for the years: 2016, 2015, 2014, 2013 and 2012. As with the groundwater levels data the average values for the wet season and dry season data were calculated to compile a total of 10 groundwater chemistry datasets (an average wet season values and average dry season values dataset for every year from 2012 – 2016).

The wet season was taken as January, February, March; October, November and December of a year; with the dry season being taken as April, May, June, July, August and September of each year.

Groundwater chemistry variables in boreholes with prefixes "BW', "BP" and "BF" were measured quarterly in March, June, September and December of each year (2012 – 2016). The groundwater chemistry variables in the boreholes with prefixes "BM" were recorded monthly during the year (2012 – 2016). The averaged seasonal groundwater datasets for each year (2012 – 2016) varied in regards to available groundwater chemistry data from the groundwater monitoring programme. Table 1 (in the Appendix, section 10) summarises the groundwater chemistry data available from each monitoring hole, for each year from 2016 to 2012.

A wide range of water quality variables were analysed for in the provided groundwater datasets. Groundwater chemistry variables were analysed by a SANAS accredited laboratory according to the obtained data. Only the relevant groundwater variables, as stipulated by the Witbank Dam Management Unit water quality objectives for the study area (contained within the groundwater chemistry databases), are listed below (Table 4):

- **Physico-chemical parameters:** pH, Electronic Conductivity (EC) and Total Dissolved Solids (TDS)

- **Major cations and anions:** Total Alkalinity (in mg $CaCO_3$/L), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl), Sulphate (SO_4), Fluoride (F), Barium (Ba), Boron (B) and Bromide (Br)

- **Metals:** Iron (Fe), Manganese (Mn) and Aluminium (Al)

The positions of the groundwater monitoring boreholes which contain groundwater chemistry data for the various years (2016 to 2012) have been presented in Figure 25 (in section

6.2.2). The following boreholes had relevant groundwater chemistry data for the averaged wet season and dry season datasets of each year (out of a total of 38 possible groundwater monitoring sites):

- **2016**: 24 boreholes (3 “BF”, 3 “BM” and 18 “BW” holes) with groundwater chemistry data (wet season and dry season) – approximately 63% of the available boreholes

- **2015**: 30 boreholes (3 “BF”, 3 “BM”, 1 “BP” and 23 “BW” holes) with groundwater chemistry data (wet season and dry season) – approximately 79% of the available boreholes

- **2014**: 32 boreholes (3 “BF”, 3 “BM”, 1 “BP” and 25 “BW” holes) with groundwater chemistry data (wet season and dry season) – approximately 84% of the available boreholes

- **2013**: 35 boreholes (3 “BF”, 5 “BM”, 1 “BP” and 26 “BW” holes) with groundwater chemistry data (wet season and dry season) – approximately 92% of the available boreholes. Boreholes BM01, BM03, BM04, BM05 and BM06 contained 2 sets of groundwater chemistry measurements because water was sampled from these holes at a shallow depth and a deeper depth (exact depths unknown).

- **2012**: 36 boreholes (3 “BF”, 6 “BM”, 1 “BP” and 26 “BW” holes), with groundwater chemistry data (for the wet season only) – approximately 95% of the available boreholes contained groundwater chemistry data for the 2012 wet season. Boreholes BM01, BM02, BM03, BM04, BM05 and BM06 contained 2 sets of groundwater chemistry measurements because water was sampled from these holes at a shallow depth and a deeper depth (exact depths unknown). No groundwater chemistry data for the 2012 dry season was present within the 2012 datasets.

The groundwater chemistry datasets were evaluated against the water quality objectives of the specific Witbank Dam Management Unit within which the mine site is located (Table 4). The South African National Standards (SANS) 241:2006 Drinking Water Standards is included with the relevant Witbank Dam Management Unit water quality objectives in Table 4, for comparison.

The SANS 241:2006 Drinking Water Standard indicates the “fitness of use” of water for human intake (Potgieter, 2015). The SANS 241:2006 Drinking Water Standard is indicated in two classes, with class 1 being the recommended limit, and class 2 being the maximum allowable limit for a set time period.

Water quality variable limits indicated in green have lower limits than the prescribed objectives, and have been self-imposed by the mine (the prescribed limits are shown in brackets). Water quality variables that do not have current water standards are designated with dashed lines in Table 4. The water quality goals of the applicable Witbank Dam Management Unit are more stringent than the SANS 241:2006 Drinking Water Standard (in most cases). The exceptions are the allowable concentrations for Fluoride, Iron and Manganese of the SANS 241:2006 Drinking Water Standard, which is less than what is required by the relevant Witbank Dam Management Unit standards.

Table 3. Comparison of the water quality guidelines of the relevant Witbank Dam Management Unit and the SANS 241:2006 Drinking Water Standards

Water Quality Variable (required for analyses by the relevant Witbank Dam Management Unit)	**Unit**	**Relevant Witbank Dam Management Unit Water Quality Requirements**	**SANS 241:2006 Drinking Water Quality Requirements (Class 1 - recommended limit)**	**SANS 241:2006 Drinking Water Quality Requirements (Class 2 - allowable for limited duration)**
Physical Requirements				
pH	-	6.50 - 8.40 (8.50)	5.00 - 9.50	4.00 - 10
Conductivity (EC)	mS/m	70.00	150.00	150.00 - 370.00
Chemical Requirements				
Total Alkalinity	$CaCO_3$ mg/L	-	-	-
Barium	Ba mg/L	0.50	-	-
Boron	B mg/L	0.50	-	-
Bromide	Br mg/L	1.00	-	-
Calcium	Ca mg/L	150.00	150.00	150.00 - 300.00
Chloride	Cl mg/L	25.00	200.00	200.00 - 600.00
Fluoride	F mg/L	1.50	1.00	1.00 - 1.50
Magnesium	Mg mg/L	70.00	70.00	70.00 - 100
Potassium	K mg/L	50.00	50.00	50.00 - 100
Sodium	Na mg/L	70.00	200.00	200.00 - 400.00
Sulphate	SO_4 mg/L	380.00 (400)	400.00	400.00 - 600.00
Total Dissolved Solids	TDS mg/L	650.00 (-)	1000.00	1000.00 - 2400.00
Dissolved Metals				
Iron	Fe mg/L	1.00	0.20	0.20 - 2.00
Manganese	Mn mg/L	0.50	0.10	0.10 - 1.00
Aluminium	Al mg/L	0.02 (0.10)	0.30	0.30 - 0.50

The groundwater chemistry for the years: 2016, 2015, 2014, 2013 and 2012 were evaluated by compiling data tables and piper plots of the combined wet and dry season datasets for each year. The methods and data used to make the groundwater chemistry data tables and piper plots are discussed below:

- **Groundwater chemistry data tables** were compiled in Microsoft Excel by combining the averaged wet season and dry season datasets for every year (2016 to 2012). All of the available water chemistry variables required by the water standards described in Table 4 was included in the tables for each year per monitoring borehole. Negative water chemistry values contained within the data tables indicated instances where the specific variable was below the detection limit of the analysis method used by the laboratory. The Witbank Dam Management Unit (WDMU) water quality limits for each variable was included in the data tables for comparison. Where water qualities surpassed these prescribed limits, the values were shaded in red within the data tables.

- **Piper plots** were constructed of the combined wet and dry season groundwater chemistry datasets for each year using GW Chart^{TM} water chemistry plotting software. Total alkalinity (in mg $CaCO_3$/L) was converted to Bicarbonate Alkalinity (in mg HCO_3^-/L) by dividing the Total Alkalinity (in mg $CaCO_3$/L) by 0.8202 (Hem, 1985). The equation for the conversion is as follows: *Bicarbonate Alkalinity (in mg HCO_3^-/L) = Total Alkalinity (in mg $CaCO_3$/L) / 0.8202*. It is then assumed that all of the alkalinity present within the provided water samples is present as Bicarbonate Alkalinity in mg HCO_3^-/L, which is mostly accurate when the pH of the water is below approximately 8.4 and above about 4.5 (Hem, 1985). The major chemical constituents (in mg/L): Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl) and Sulphate (SO_4) were used with the converted Bicarbonate Alkalinity (HCO_3^-) to produce piper plots for the years 2016 to 2012.

The groundwater chemistry data tables and piper plots were made from different available groundwater monitoring borehole datasets for the years 2016, 2015, 2014, 2013 and 2012, which are described in the beginning of this section. Refer to Figure 25 for the positions of the monitoring boreholes within the mine site. The groundwater chemistry datasets were evaluated by including the groundwater chemistry data tables and piper plots for every year (2016 to 2012), and then interpreting and discussing these water chemistry variables for each relevant year.

Acid mine drainage is a process that occurs within coal mining areas when sulphide mineral bearing lithologies (especially pyrite "FeS_2") come into contact with water or oxygen (Hodgson and Krantz, 1998). This negatively impacts the environment markedly lowering the pH of effected waters and causing metals and salts (which could harm the environment) to dissolve in the water (Hobbs et al., 2008; Barnes and Vermeulen, 2012). Focus is thus placed specifically on the pH, sulphate, iron, manganese and aluminium concentrations of the monitored boreholes during the evaluation of the groundwater chemistry.

The combined wet and dry season groundwater chemistry variables for **2016** are provided in Table 5. A total of 48 groundwater chemistry measurements (for each required variable) were included in the table from 24 monitoring boreholes.

The **pH** values ranged from 5.07 to 8.77 with an average pH value of 7.53 for all the data points. Borehole BM03 (situated just to the east of the current mine workings, at the end of the river diversion outlet) has elevated pH values of 8.77 (wet season) and 8.62 (dry season) that could be caused by runoff water from the planted fields (where chemicals like lime and chalk are possibly added to prepare the fields for planting). Boreholes BW14, BW12, BW34 and BF05 all displayed pH values below the recommended range. These boreholes are all situated close to or downstream from the discard stockpile of the mine (south-east portion of the study area). The **EC** values fluctuated between 8.04 mS/m and 138.50 mS/m, with an average of 43.09 mS/m. The **TDS** (total dissolved solids) ranged from 44.50 mg/L to 916 mg/L, with an average of 273.77 mg/L (indicating predominantly fresh water present within the site).

All of the 2016 **sulphate** values comply with the water quality standard except for boreholes BW28 and BF06 (which are twin holes that where drilled next to each other). These two boreholes are located next to the discard stockpile within the south eastern part of the general mining area and have sulphate values of over 500 mg/L for the wet and dry seasons, which could be due to acid mine drainage. The **chloride** values from six readings had values exceeding the prescribed WDMU limits in 2016. Only the chloride measurements from boreholes BW04 and BW05 also exceeded the class 1 category of the SANS 241:2006 standard (Table 5). BW04 and BW05 are located next to the old underground workings within planted fields (in the northern part of the mine site). Agricultural activities and runoff from old mine dumps around these boreholes could be causing the elevated chloride concentrations at these monitoring points.

Boreholes BW17 and BM04 have elevated **iron** concentration above the prescribed limit for the dry season only. BW17 was drilled above the old underground mine workings and BM04 was drilled between the recent opencast area and the discard stockpile. Elevated **aluminium** concentrations were recorded in boreholes BW17 and BM06 for the wet season. Borehole BM06 is situated within the north-east section of the study area. The **manganese** concentrations in boreholes BM04, BW04, BW05 and BW25 were higher than the water quality limits (for both seasons). Borehole BW25 was drilled next to the discard stockpile.

The prominent areas where degraded groundwater qualities exceeding acceptable limits were encountered were near the old underground workings and the discard stockpile close to the current mining activities. A total of 22 borehole readings out of 48 were completely compliant with the regional water standards with no variables that exceeded the water quality objectives.

Table 4. Groundwater Chemistry - 2016 (combined wet and dry season datasets)

Changed Site Name	Season	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Total ALK mg CaCO3/L	Total ALK mg HCO3 /L	Cl mg/l	SO4 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	B mg/l	Ba mg/l
WDMU	**WQ Limits**	**6.5 - 8.4**	**70**	**650**	**150**	**70**	**70**	**50**	**-**	**-**	**25**	**380**	**1.5**	**0.02**	**1**	**0.5**	**0.5**	**0.5**
BF03	WET SEASON	7.45	13.25	72.00	6.49	4.01	8.12	4.51	20.60	25.12	22.90	2.26	-0.47	-0.01	-0.01	0.08	-0.03	0.03
BF05	WET SEASON	7.40	13.00	83.00	7.47	6.63	4.70	4.34	55.20	67.32	4.80	-0.45	-0.47	-0.01	-0.01	0.33	-0.04	0.42
BF06	WET SEASON	8.34	89.30	775.50	77.90	86.25	19.90	10.07	84.40	102.93	2.23	521.05	-0.47	-0.01	-0.01	0.00	-0.03	-0.01
BM03 Bottom	WET SEASON	8.77	138.00	878.00	51.60	48.50	86.00	171.00	281.00	342.68	142.50	198.00	-0.47	-0.01	-0.01	0.17	-0.03	0.05
BM04 Bottom	WET SEASON	8.03	17.65	107.50	17.50	6.32	8.05	3.78	72.60	88.54	4.01	10.28	-0.47	-0.01	-0.01	1.21	-0.03	-0.01
BM06 Bottom	WET SEASON	8.10	14.70	103.00	13.95	6.83	4.11	2.50	61.60	75.12	2.27	2.01	-0.47	0.06	0.05	0.07	-0.03	-0.01
BW04	WET SEASON	7.97	74.30	405.00	50.45	25.85	50.85	12.10	118.00	143.90	131.00	42.45	-0.47	-0.01	0.17	1.40	-0.03	0.13
BW05	WET SEASON	7.43	138.50	742.50	84.85	47.70	109.10	21.10	8.35	10.18	458.50	9.18	-0.47	-0.01	0.08	1.25	-0.03	0.41
BW06	WET SEASON	8.32	90.20	685.00	95.15	51.25	34.50	5.59	142.00	173.17	7.28	363.00	-0.47	-0.01	-0.01	0.00	-0.01	-0.01
BW07	WET SEASON	7.57	8.04	50.50	4.68	3.11	2.60	3.89	26.05	31.77	-0.06	0.02	-0.47	-0.01	-0.01	0.01	-0.03	0.10
BW08	WET SEASON	7.94	20.50	108.00	19.40	6.28	7.28	5.52	60.50	73.78	23.35	-0.50	-0.47	-0.01	-0.01	0.00	-0.03	0.10
BW12	WET SEASON	7.70	13.50	100.00	6.05	4.81	6.67	4.83	10.33	12.59	3.10	8.94	0.01	-0.01	-0.01	0.00	-0.03	0.34
BW13	WET SEASON	8.14	30.20	225.00	23.30	13.40	17.90	2.88	89.00	108.54	21.50	-0.54	-0.47	-0.01	-0.01	0.00	-0.01	
BW14	WET SEASON	6.17	25.50	192.00	18.70	10.35	2.66	8.43	6.30	7.68	9.82	0.15	-0.47	-0.01	-0.01	0.06	-0.03	1.79
BW15	WET SEASON	7.98	10.70	61.00	9.24	2.90	4.35	3.57	38.25	46.65	3.46	1.41	-0.47	-0.01	-0.01	0.00	-0.03	0.03
BW17	WET SEASON	7.69	12.10	82.00	4.53	1.80	10.80	2.64	31.10	37.93	8.42	0.89	-0.47	0.11	-0.01	0.00	-0.03	0.10
BW22	WET SEASON	7.73	12.95	105.00	6.02	2.64	9.50	2.32	41.85	51.04	0.14	-0.50	-0.47	-0.01	0.01	0.00	-0.03	-0.01
BW23	WET SEASON	7.52	16.50	128.00	9.04	2.20	11.15	2.89	50.00	60.98	2.51	1.02	-0.47	-0.01	0.06	0.00	-0.03	0.02
BW25	WET SEASON	8.18	18.30	106.50	13.10	7.13	5.32	5.33	78.15	95.30	3.10	8.43	-0.47	-0.01	0.80	0.97	-0.03	0.21
BW27	WET SEASON	8.10	17.76	107.00	13.84	6.58	6.73	6.11	48.75	59.45	3.48	29.88	-0.47	-0.01	-0.01	0.23	-0.03	-0.01
BW28	WET SEASON	8.26	96.02	853.00	106.41	92.85	21.25	8.77	99.75	121.65	6.69	551.66	-0.47	-0.01	-0.01	0.00	-0.03	-0.01
BW32	WET SEASON	7.96	131.50	685.00	48.25	12.95	21.55	18.55	605.50	738.41	14.95	8.13	-0.47	-0.01	-0.01	0.12	-0.03	0.05
BW33	WET SEASON	7.95	29.70	189.00	18.85	14.30	12.55	3.95	39.45	48.11	18.60	38.15	-0.47	-0.01	-0.01	0.00	-0.03	0.05

BW34	WET SEASON	7.48	8.18	61.50	2.84	2.20	5.58	1.91	17.15	20.91	4.48	0.70	-0.47	-0.01	-0.01	0.00	-0.03	0.11
BF03	DRY SEASON	7.18	13.90	66.50	6.13	3.66	7.86	4.15	18.30	22.32	21.60	3.20	-0.47	-0.01	-0.01	0.05	-0.01	0.01
BF05	DRY SEASON	6.50	8.40	51.50	4.84	4.18	3.28	3.28	30.35	37.01	4.05	-0.50	-0.47	-0.01	0.37	0.23	-0.01	0.16
BF06	DRY SEASON	7.45	115.15	899.50	98.02	105.42	19.32	8.28	101.15	123.35	3.90	595.05	-0.47	-0.01	-0.01	0.25	-0.01	0.00
BM03 Bottom	DRY SEASON	8.62	100.00	521.50	25.20	24.20	49.85	122.50	185.00	225.61	95.10	84.70	-0.47	-0.01	-0.01	0.02	-0.01	0.00
BM04 Bottom	DRY SEASON	6.96	14.11	73.00	11.66	3.88	4.83	2.72	55.70	67.93	2.17	1.29	0.05	-0.01	1.25	1.03	-0.01	0.00
BM06 Bottom	DRY SEASON	7.85	13.40	89.00	11.90	6.29	4.33	1.37	56.70	69.15	2.30	-0.45	-0.47	-0.01	-0.01	0.00	0.00	0.00
BW04	DRY SEASON	6.88	95.95	461.00	59.30	26.55	59.55	12.25	43.45	52.99	235.00	26.02	-0.47	-0.01	-0.01	1.00	-0.01	0.14
BW05	DRY SEASON	7.42	95.40	480.00	52.65	29.55	65.90	14.10	54.10	65.98	248.50	22.86	-0.47	-0.01	-0.01	0.89	-0.01	0.06
BW06	DRY SEASON	8.10	85.25	576.00	79.85	41.70	29.95	4.66	120.50	146.95	6.95	304.50	-0.47	-0.01	-0.01	0.00	-0.01	0.00
BW07	DRY SEASON	7.43	8.25	44.50	4.35	2.16	1.91	2.96	16.27	19.84	0.00	2.85	-0.47	-0.01	-0.01	0.00	-0.01	0.07
BW08	DRY SEASON	7.92	21.15	109.00	18.60	5.87	6.85	5.15	60.30	73.54	24.30	0.58	-0.47	-0.01	-0.01	0.00	-0.01	0.10
BW12	DRY SEASON	6.37	14.55	103.00	6.37	5.21	7.39	5.18	12.85	15.66	0.37	15.60	-0.47	-0.01	-0.01	0.00	-0.01	0.41
BW13	DRY SEASON	7.04	33.60	208.00	24.00	13.15	17.40	2.74	76.35	93.11	22.45	2.37	-0.47	-0.01	-0.01	0.00	-0.01	0.04
BW14	DRY SEASON	5.07	27.05	163.50	17.70	9.85	2.22	7.95	6.30	7.68	10.92	0.54	-0.47	-0.01	-0.01	0.04	-0.01	1.77
BW15	DRY SEASON	7.98	11.40	58.00	9.56	2.79	3.85	3.38	41.90	51.10	3.50	-0.45	-0.47	-0.01	-0.01	0.00	0.00	0.04
BW17	DRY SEASON	7.09	17.95	123.00	12.45	4.29	10.45	2.66	49.85	60.79	5.15	7.88	0.17	-0.01	2.29	0.00	-0.01	0.08
BW22	DRY SEASON	7.71	13.15	112.00	7.13	2.90	10.11	2.25	50.95	62.13	-1.96	1.36	-0.47	-0.01	-0.01	0.00	-0.01	0.00
BW23	DRY SEASON	7.04	14.55	119.00	6.74	1.89	11.15	2.63	44.80	54.63	-0.20	2.26	-0.47	-0.01	-0.01	0.00	-0.01	0.01
BW25	DRY SEASON	7.46	18.65	106.00	13.10	7.25	5.36	5.59	68.90	84.02	0.34	15.50	-0.47	-0.01	-0.01	1.09	-0.01	0.26
BW27	DRY SEASON	7.26	10.09	57.00	6.03	2.74	4.19	4.44	38.25	46.65	0.38	-0.50	-0.47	-0.01	-0.01	0.25	-0.01	0.00
BW28	DRY SEASON	7.34	134.85	916.00	94.95	107.20	19.98	9.36	106.85	130.30	5.19	605.85	-0.47	-0.01	-0.01	0.30	-0.01	0.00
BW32	DRY SEASON	7.28	125.00	667.00	50.20	14.45	21.45	15.75	589.50	718.90	13.35	12.07	-0.47	-0.01	0.21	0.15	-0.01	0.05
BW33	DRY SEASON	7.26	27.45	178.00	17.00	12.85	12.15	3.70	34.40	41.95	20.80	34.65	-0.47	-0.01	-0.01	0.00	-0.01	0.03
BW34	DRY SEASON	6.22	8.96	54.00	2.21	1.88	5.00	1.99	13.80	16.83	4.87	0.11	-0.47	-0.01	-0.01	0.00	-0.01	0.10

The piper plot of the 2016 groundwater chemistry dataset is shown in Figure 45. The 2016 dataset has a dispersed hydrochemical image, with the majority of the water samples displaying a magnesium/calcium-bicarbonate hydrochemical facies (blue circle). A large part of the remaining samples had a magnesium/calcium-sulphate/chloride hydrochemical composition (yellow circle). A slight sodium/potassium-chloride water signature is identifiable between these two mentioned dominant water types. Clear mixing can be seen on the piper plot between the bicarbonate rich fresh water (blue circle) and the mine water contaminated by sulphate, with some chloride enrichment possibly caused by agricultural activities, municipal pollution or mine runoff (yellow circle). A clear distribution of anions from bicarbonate to sulphate and then chloride is visible on the anion triangle of the piper plot. This could indicate a strong evolutionary trend possibly caused by pollution. The cations transition from a magnesium/calcium rich water type to a sodium/potassium rich water type.

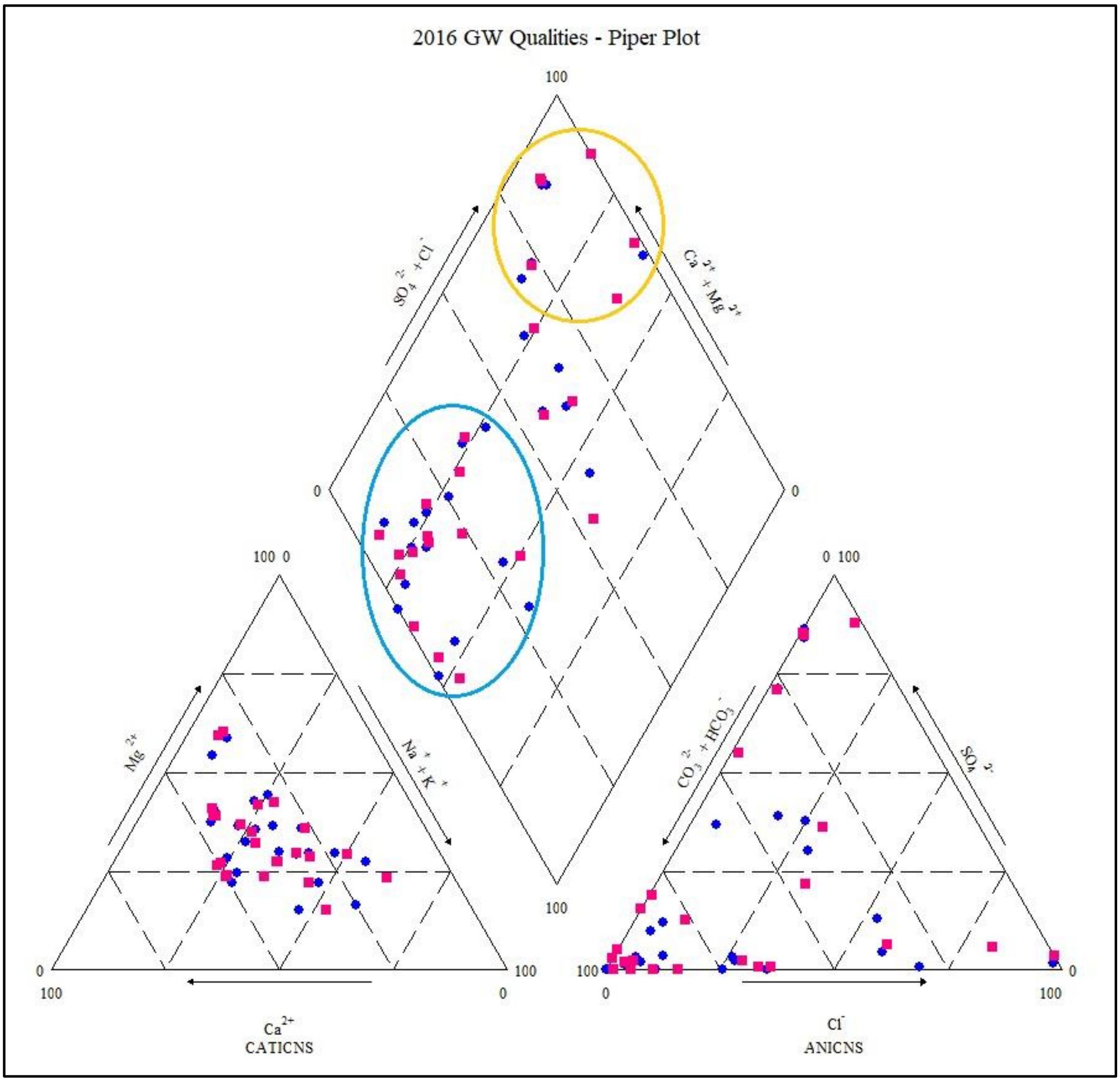


Figure 45. Piper Plot – 2016 Groundwater Chemistry (wet season in blue, dry season in pink)

The groundwater chemistry data table for **2015** is included in Table 6. The dataset contains 59 readings from 30 monitoring boreholes for each listed groundwater chemistry variable.

The **pH** values varied between 5.67 and 8.73 with an average pH value of 7.06 for the 2015 dataset. Boreholes BM03 and BM06 had elevated pH values of between 8.73 and 8.56 respectively, that could be due to interaction with alkaline waters from the agricultural areas (where chalk and lime were widely used on the planted fields). Boreholes BW14, BW12, BW34, BW35, BW36, BP01, BF03 and BF05 all contained pH values below the water quality limit. All of these monitoring boreholes are located in close proximity to the discard stockpile and downstream from the recent mine workings (Figure 25). Water that has interacted with the discard dump and rehabilitated mine areas could be causing the lower pH values in this region of the mine site. The **EC** readings varied between 5.74 mS/m and 163 mS/m, with an average EC measurement of about 34.82 mS/m. The total dissolved solids (**TDS**) for 2015 ranged from 34.50 mg/L to 1153.50 mg/L and had an average value of 224.46 mg/L. Only borehole BF06 had a TDS value of above 1000 mg/L indicating that the water was brackish in this borehole.

The **sulphate** concentration in boreholes BF06 and BW06 (all over 380 mg/L SO_4) were above the recommended maximum. BW06 was drilled over the old mine workings in the north of the mine site. Groundwater could be reacting with the old mine workings. Borehole BW06 is situated next to the discard dump and could be affected by high sulphate water from the mine dump. **Chloride** measurements from six boreholes (BW04, BW05, BW08, BW13, BM03 and BM04) had chloride values higher than the water quality objectives. Only boreholes BW04 and BW05 had chloride values that exceeded the class 1 drinking water standards (Table 4). These holes were drilled in a planted field (above the old mine workings) and could possibly be affected by high runoff taking place around these holes.

The **iron** concentration in boreholes BW24, BW25, BF06 and BM04 were higher than the allowable limit. BW24 is located outside the north-west boundary of the general mine area with the remaining holes all situated between or adjacent to the recent opencast area and the discard dump. No **aluminium** values exceeded the water quality limits within the 2015 dataset. **Manganese** concentration for boreholes BM04, BW04, BW05 and BW25 are all higher than the water quality limits (similar to the 2016 dataset). The elevated dissolved metal concentrations are probably caused by acid mine drainage processes. The south-eastern part of the mine site, downstream from the current mining blocks and close to the discard dump displayed the most groundwater quality issues in 2015 (similar to 2016). The 2015 dataset contained 27 measurements (out of 59) that were fully compliant with the water standards for every required variable.

Table 5. Groundwater Chemistry - 2015 (combined wet and dry season datasets)

Changed Site Name	Season	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Total ALK mg CaCO3/L	Total ALK mg HCO3 /L	Cl mg/l	SO4 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	B mg/l
WDMU	**WQ Limits**	**6.5 - 8.4**	**70**	**650**	**150**	**70**	**70**	**50**	**-**	**-**	**25**	**380**	**1.5**	**0.02**	**1**	**0.5**	**0.5**
BF03	WET SEASON	6.52	12.85	75.50	6.29	3.73	7.57	4.43	18.80	22.93	21.35	0.70	0.39	-0.01	0.45	0.03	0.01
BF05	WET SEASON	7.10	7.53	42.00	4.22	3.54	3.18	2.93	28.20	34.39	6.68	0.71	0.21	-0.01	-0.01	0.14	0.03
BF06	WET SEASON	7.75	104.15	793.50	91.45	90.85	26.50	11.38	128.00	156.10	8.38	480.00	-0.33	-0.01	-0.01	0.00	0.02
BM03 Bottom	WET SEASON	8.73	128.00	729.00	28.10	33.10	78.50	165.00	245.00	298.78	177.00	94.90	-0.47	-0.01	-0.01	0.08	0.05
BM04 Bottom	WET SEASON	6.66	14.40	88.50	14.15	3.94	4.77	2.38	54.40	66.34	6.12	5.42	-0.14	-0.01	4.30	1.68	0.02
BM06 Bottom	WET SEASON	8.60	9.50	58.50	8.85	3.42	4.94	1.76	38.90	47.44	4.97	2.17	-0.13	-0.01	-0.01	0.00	0.00
BP01	WET SEASON	6.53	9.18	92.00	5.58	2.63	3.86	4.75	9.33	11.38	4.05	0.22	0.22	-0.01	-0.01	0.00	0.02
BW04	WET SEASON	7.32	92.85	499.00	42.50	34.45	80.40	10.74	73.00	89.02	261.00	7.45	0.45	-0.01	0.69	1.37	0.00
BW05	WET SEASON	7.04	149.00	830.50	69.55	56.65	131.50	33.20	28.55	34.82	458.50	60.90	-0.33	-0.01	-0.01	0.75	0.01
BW06	WET SEASON	7.84	87.55	653.50	103.40	48.00	34.40	5.45	128.50	156.71	11.03	337.00	-0.33	-0.01	-0.01	0.00	0.08
BW07	WET SEASON	6.93	7.07	51.00	4.58	2.87	2.53	3.89	22.30	27.20	5.26	1.57	-0.04	-0.01	-0.01	0.00	0.01
BW08	WET SEASON	7.35	17.75	95.00	16.10	5.45	6.85	5.14	50.60	61.71	23.35	-0.56	-0.11	-0.01	0.01	0.00	0.01
BW12	WET SEASON	6.24	10.90	88.50	4.61	4.01	5.93	4.63	12.61	15.37	4.47	2.00	-0.33	-0.01	-0.01	0.00	0.01
BW13	WET SEASON	6.82	37.45	258.00	27.30	16.50	20.45	4.11	65.20	79.51	31.45	3.81	-0.04	-0.01	-0.01	0.00	0.00
BW14	WET SEASON	5.67	24.55	176.50	18.20	11.25	1.97	8.10	2.08	2.54	12.30	0.25	-0.13	-0.01	-0.01	0.14	0.00
BW15	WET SEASON	7.48	9.48	57.00	9.09	2.78	4.21	3.63	35.05	42.74	6.03	-0.56	-0.33	-0.01	-0.01	0.00	0.00
BW17	WET SEASON	6.66	13.30	108.00	6.58	2.68	7.44	2.67	41.30	50.37	4.20	-0.13	0.24	-0.01	0.37	0.00	-0.01
BW18	WET SEASON	7.50	27.40	195.00	36.30	6.36	12.90	3.48	148.00	180.49	3.80	-1.00	-0.47	-0.01	-0.01	0.00	0.02
BW22	WET SEASON	7.08	12.05	108.00	7.13	2.99	9.96	2.40	45.05	54.94	4.04	0.10	-0.13	-0.01	-0.01	0.02	0.00
BW23	WET SEASON	6.98	18.45	155.50	8.82	4.29	14.40	3.47	64.75	78.96	5.38	0.78	-0.14	-0.01	0.55	0.00	0.07
BW24	WET SEASON	7.60	25.55	193.50	25.50	10.95	10.34	9.30	125.50	153.05	4.93	4.07	-0.03	-0.01	0.18	0.05	0.01
BW25	WET SEASON	7.05	16.00	102.00	10.46	5.44	4.09	4.87	79.35	96.77	3.75	3.55	-0.13	-0.01	1.84	1.07	0.02
BW27	WET SEASON	6.89	8.07	59.50	4.20	3.03	6.17	4.60	30.85	37.62	3.49	3.37	-0.12	-0.01	0.30	0.47	0.00

BW28	WET SEASON	7.67	5.97	34.50	2.11	1.41	5.11	3.91	16.95	20.67	4.36	3.62	-0.13	-0.01	-0.01	0.00	0.00
BW33	WET SEASON	7.14	21.15	142.50	14.15	11.00	8.64	4.04	38.80	47.32	10.20	32.95	-0.13	-0.01	-0.01	0.00	0.01
BW34	WET SEASON	5.70	7.39	64.50	2.53	2.19	5.91	2.22	0.44	0.54	6.36	-0.56	-0.33	-0.01	-0.01	0.00	0.00
BW35	WET SEASON	6.79	100.34	520.50	30.51	8.68	14.50	14.26	435.37	530.94	13.92	4.57	-0.33	-0.01	-0.01	0.11	0.01
BW36	WET SEASON	6.09	8.86	76.00	3.13	2.95	4.91	3.94	8.26	10.07	4.91	0.30	0.21	-0.01	-0.01	0.00	-0.01
BW39	WET SEASON	8.37	21.10	187.00	14.30	8.00	19.80	4.81	107.00	130.49	5.71	1.07	-0.47	-0.01	-0.01	0.00	0.02
BF03	DRY SEASON	6.34	12.50	73.50	6.43	3.52	7.09	4.01	17.05	20.79	24.10	-0.96	0.12	-0.01	0.98	0.04	0.01
BF05	DRY SEASON	5.94	5.74	39.00	3.47	2.74	2.72	2.54	19.40	23.66	4.90	2.62	-0.47	-0.01	0.03	0.00	0.01
BF06	DRY SEASON	6.97	152.00	1153.50	134.50	131.50	29.20	13.10	179.50	218.90	5.16	723.50	-0.47	-0.01	1.82	0.54	0.01
BM03 Bottom	DRY SEASON	8.56	154.00	908.50	36.85	41.25	91.10	185.50	245.00	298.78	195.50	204.15	-0.47	-0.01	-0.01	0.07	0.04
BM04 Bottom	DRY SEASON	6.75	14.80	84.50	12.45	3.68	5.69	2.81	59.55	72.62	2.19	2.64	0.29	-0.01	1.31	1.41	0.02
BM06 Bottom	DRY SEASON	7.48	13.03	91.67	11.40	5.58	4.40	1.41	48.73	59.43	-0.16	0.99	-0.47	-0.01	-0.01	0.00	0.00
BP01	DRY SEASON	5.89	17.80	140.50	8.78	5.94	7.24	6.49	7.26	8.85	2.20	-0.96	-0.47	-0.01	-0.01	0.00	0.01
BW04	DRY SEASON	7.24	81.75	410.00	41.75	26.25	56.30	9.99	83.50	101.83	195.50	7.90	-0.47	-0.01	0.21	1.32	0.01
BW05	DRY SEASON	7.15	163.00	861.50	71.30	58.35	136.50	33.65	14.60	17.80	503.50	47.80	-0.47	-0.01	0.03	0.69	0.02
BW06	DRY SEASON	7.95	92.45	688.50	104.45	47.60	33.90	5.37	119.50	145.73	7.86	381.00	-0.47	-0.01	-0.01	0.00	0.08
BW07	DRY SEASON	7.23	7.84	47.50	4.81	2.72	2.44	3.83	24.90	30.37	0.07	-0.96	-0.47	-0.01	-0.01	0.00	0.00
BW08	DRY SEASON	7.44	17.10	90.50	15.25	4.91	6.53	4.78	43.55	53.11	25.15	-0.96	-0.47	-0.01	-0.01	0.00	0.01
BW12	DRY SEASON	6.32	11.50	89.50	4.83	4.07	5.96	4.54	14.85	18.11	2.45	2.68	-0.47	-0.01	-0.01	0.00	0.00
BW13	DRY SEASON	6.74	36.40	247.50	27.85	15.55	19.55	3.12	68.20	83.17	34.65	0.12	-0.47	-0.01	-0.01	0.00	0.00
BW14	DRY SEASON	5.81	25.30	167.00	18.50	10.45	1.95	7.89	6.18	7.54	10.85	-0.96	-0.47	-0.01	-0.01	0.09	0.00
BW15	DRY SEASON	7.57	10.95	57.50	10.35	2.94	3.49	3.57	40.35	49.21	1.71	-0.96	-0.47	-0.01	-0.01	0.00	0.00
BW17	DRY SEASON	8.04	21.68	79.00	1.24	1.88	10.28	3.92	31.30	38.17	7.80	-0.96	0.04	0.01	0.55	0.00	0.00
BW18	DRY SEASON	8.08	27.10	189.00	37.60	6.67	13.70	3.39	141.00	171.95	-0.78	-0.96	-0.47	-0.01	-0.01	0.00	0.02
BW22	DRY SEASON	7.28	11.60	104.50	7.29	2.78	9.57	2.42	44.35	54.09	2.71	1.45	-0.47	-0.01	0.05	0.00	0.00
BW23	DRY SEASON	7.34	12.90	120.00	6.10	1.84	9.08	3.22	46.40	56.59	1.65	1.26	-0.47	-0.01	0.29	0.00	0.01
BW24	DRY SEASON	7.36	26.65	188.00	26.55	10.35	10.30	8.43	145.00	176.83	0.34	-0.96	0.18	-0.01	1.03	0.06	0.03
BW25	DRY SEASON	7.29	16.40	84.50	9.64	4.90	3.64	4.84	68.30	83.29	1.42	1.38	0.17	-0.01	1.40	1.01	0.01
BW27	DRY SEASON	6.96	8.54	49.50	5.01	2.68	3.72	4.09	34.75	42.38	1.83	-0.96	-0.47	-0.01	-0.01	0.49	0.00

BW28	DRY SEASON	6.94	9.14	56.50	4.38	2.86	4.78	3.67	22.40	27.32	1.48	12.99	-0.47	-0.01	-0.01	0.19	0.00
BW33	DRY SEASON	7.17	19.15	120.50	11.90	8.84	7.85	3.73	45.90	55.98	6.28	21.15	-0.47	-0.01	-0.01	0.00	0.01
BW34	DRY SEASON	5.88	8.44	61.00	2.64	2.18	5.35	2.06	9.48	11.56	5.24	0.08	-0.47	-0.01	-0.01	0.00	0.00
BW35	DRY SEASON	5.75	8.73	64.00	3.44	3.26	4.15	2.61	6.18	7.54	4.30	-0.96	-0.47	-0.01	-0.01	0.00	0.00
BW36	DRY SEASON	6.10	10.78	81.00	3.62	3.32	5.18	4.09	6.18	7.54	1.61	2.81	-0.47	-0.01	-0.01	0.00	0.00
BW38	DRY SEASON	7.97	26.70	181.00	21.20	7.07	23.50	5.59	128.50	156.71	0.37	-0.96	-0.47	-0.01	-0.01	0.00	0.02
BW39	DRY SEASON	7.20	22.80	179.50	15.40	8.24	20.35	4.55	115.50	140.85	-0.78	-0.96	-0.47	-0.01	-0.01	0.00	0.01

A piper plot of the 2015 groundwater chemistry dataset was compiled and is provided in Figure 46. Most of the 2015 groundwater chemistry measurements (for the wet and dry season) exhibit a calcium/magnesium-bicarbonate hydrochemical signature (blue circle), which is similar to the 2016 dataset. This is characteristic of natural fresh waters. A prominent magnesium/calcium-sulphate/chloride hydrochemical facies is visible on the piper plot (yellow circle). The high sulphate samples are due to acid mine drainage contamination from the coal mine. Elevated chloride concentrations present are probably caused by agricultural activities and runoff from certain regions of the mine site. The cations show higher concentrations of calcium, sodium and potassium than in 2016, indicating higher levels of salts present in the water in 2015. Similar to 2016, the anions display an evolutionary trend from bicarbonate to sulphate and then to chloride, that is probably caused by pollution. Some slight mixing between the natural and contaminated waters is possible, but is not as apparent as in the 2016 dataset.

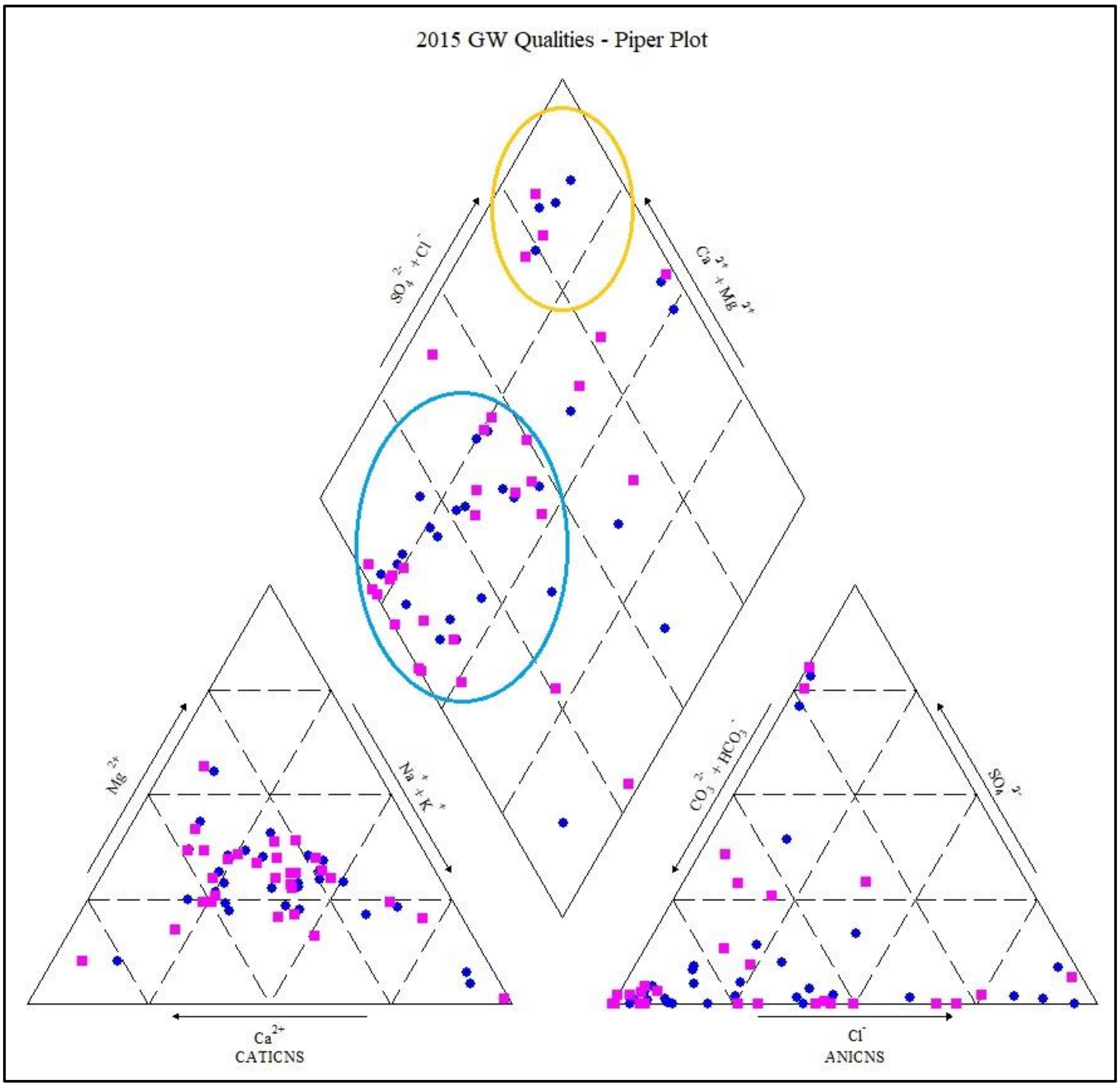


Figure 46. Piper Plot – 2015 Groundwater Chemistry (wet season in blue, dry season in pink)

The **2014** groundwater chemistry data from 64 measurements (from 32 boreholes) for different variables is presented in Table 7. The groundwater chemistry data is divided up into wet season and dry season datasets (like the previous years).

The **pH** readings of the 2014 dataset had a maximum value of 8.75 and a minimum value of 5.64. The average of the pH values was 7.44. Numerous boreholes (BM03, BW02, BW24, BW32 and BW39) had elevated pH values above 8.40 for the wet season. Boreholes BW02, BW24, BW32 and BW39 are all situated within fields to the north of the current mine workings. The higher pH values encountered in these boreholes (in the wet season) could possibly be caused by runoff during the wet season from planted fields that were treated with chalk and lime during farming practices. The high pH values recorded in BM03 (for the wet and dry seasons) were caused by runoff from these areas (to the north and west of the site), as this borehole is located at the outlet of the river diversion running through the current mine workings. A drop in pH values below 6.5 is once again encountered in the south eastern portion of the project area during the dry season (in boreholes BP01, BW12, BW14, BW34, BW35 and BW36). These boreholes are located close to or downstream from the discard dump, and receive water that has interacted with the mine spoils, lowering the pH values. The recorded **EC** values ranged from 5.90 mS/m to 862.50 mS/m with an average of 48.09 mS/m. The average **TDS** values were 284.59 mg/L with boreholes BM03, BW05 and BW19 having TDS measurements exceeding a 1000 mg/L indicating that the groundwater in these boreholes were brackish.

Borehole BW06 contained **sulphate** values of above the 380 mg/L limit during the wet and dry season. The remaining boreholes had sulphate values below this limit. Borehole BW06 appears to be close to an old mine dump and was drilled over the old underground workings. The elevated sulphate concentrations in this borehole could have been caused by groundwater interaction with these features. Boreholes BM03, BW02, BW04, BW05, BW13 and BW19 had **chloride** concentrations above the WDMU limits for 2014. These boreholes could be affected by runoff waters with a high concentration of salts, from agricultural fields and compacted areas on the mine site.

Elevated **iron** concentrations (above 1 mg/L) in boreholes BF03, BF05, BW17, BW32, BM03 and BM04 could be related to lower pH values within the majority of areas where these holes are located. Borehole BW19 had a dry season **aluminium** value of 0.03 mg/L just above the required limit. The **manganese** levels in boreholes BF05, BM04, BW04, BW05, BW25, BW27 and BW32 were all above the prescribed limit showing that acid mine drainage is probably causing the dissolution of manganese within these areas. Borehole BF03 (situated in the south-east corner of the mine site) had a dry season **fluoride** concentration of 2.10

mg/L exceeding the allowable SANS drinking water standard limit. In total 30 of the groundwater quality measurements (out of 64) for 2014 were totally compliant with the water quality standards.

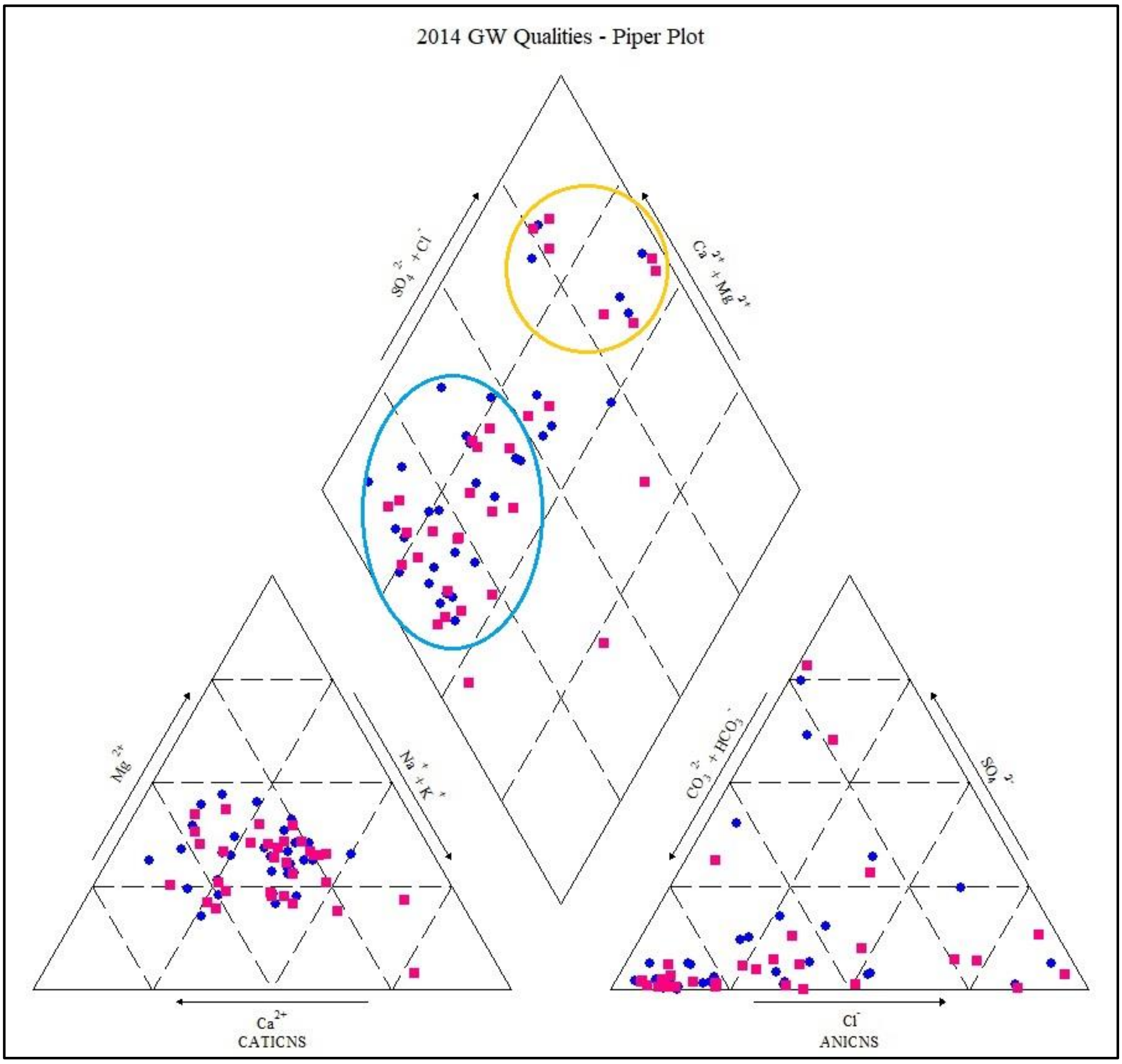


Figure 47. Piper Plot – 2014 Groundwater Chemistry (wet season in blue, dry season in pink)

The 2014 groundwater chemistry piper plot (Figure 47) shows that there are two prominent water types present. The most of the groundwater samples plot within a calcium/magnesium-bicarbonate water type range (blue circle). Groundwater plotting in the yellow circle on the piper plot is of a calcium/magnesium-sulphate/chloride water type. The high sulphate was attributed to the influence of mining activities with the elevated chloride possibly due to runoff from agricultural fields and compacted areas within some parts of the mine site. There seems to be mixing between the natural and contaminated water types (similar to the 2015 dataset). The cations of the 2014 dataset do not show pronounced elevated concentrations of calcium, sodium and potassium like the 2015 dataset. The evolutionary trend of the 2014 anions is similar to the 2016 and 2015 data and indicates possible pollution present within some of the groundwater boreholes.

Table 6. Groundwater Chemistry - 2014 (combined wet and dry season datasets)

Changed Site Name	Season	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Total ALK mg CaCO3/L	Total ALK mg HCO3 /L	Cl mg/l	SO4 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l
WDMU	WQ Limits	6.5 - 8.4	70	650	150	70	70	50	-	-	25	380	1.5	0.02	1	0.5
BF03	WET SEASON	7.13	12.05	80.50	6.14	3.37	6.61	4.28	24.40	29.76	20.30	1.97	0.63	-0.01	2.05	0.13
BF05	WET SEASON	8.25	15.70	79.00	7.50	6.21	7.24	5.02	65.50	79.88	7.70	-0.13	-0.18	-0.01	3.43	0.57
BF06	WET SEASON	8.36	31.95	179.00	17.80	16.00	12.69	6.40	84.60	103.17	7.23	60.95	-0.18	-0.01	-0.01	0.00
BM03 Bottom	WET SEASON	8.58	184.50	1178.00	48.23	56.28	111.15	258.50	264.50	322.56	253.75	283.00	0.30	-0.01	0.25	0.10
BM04 Bottom	WET SEASON	7.36	19.03	101.67	18.50	5.84	1.60	2.65	90.53	110.41	6.55	1.58	0.15	-0.01	7.05	2.37
BM06 Bottom	WET SEASON	7.60	11.96	74.50	11.64	4.61	2.40	2.03	44.20	53.90	5.08	3.36	-0.18	-0.01	-0.01	0.01
BP01	WET SEASON	7.36	9.52	82.00	4.28	2.38	2.96	4.87	8.26	10.07	4.10	0.93	-0.18	-0.01	-0.01	0.00
BW02	WET SEASON	8.50	53.15	329.50	28.30	19.05	34.00	10.10	125.50	153.05	42.55	38.35	0.00	-0.01	-0.01	0.00
BW04	WET SEASON	7.90	113.50	576.50	51.05	37.25	90.00	12.85	78.20	95.37	322.00	6.91	-0.18	-0.01	-0.01	1.34
BW05	WET SEASON	7.17	205.00	1076.00	118.25	69.55	145.00	41.75	43.80	53.41	613.00	58.10	-0.18	-0.01	0.04	0.84
BW06	WET SEASON	7.87	107.00	825.00	121.00	62.10	36.80	5.87	146.00	178.05	11.70	459.00	-0.18	-0.01	-0.01	0.00
BW07	WET SEASON	7.51	8.20	48.50	4.31	2.57	2.28	3.75	20.75	25.30	4.61	3.58	0.25	-0.01	-0.01	0.00
BW08	WET SEASON	7.68	17.40	82.00	14.50	4.78	6.08	4.61	46.10	56.22	18.30	0.80	0.28	-0.01	-0.01	0.06
BW12	WET SEASON	7.64	11.80	74.00	4.06	3.14	3.77	4.23	21.70	26.46	5.40	4.01	-0.18	-0.01	-0.01	0.00
BW13	WET SEASON	7.58	43.35	272.00	30.95	17.45	19.00	3.71	87.10	106.22	31.60	5.41	-0.18	-0.01	-0.01	0.00
BW14	WET SEASON	7.05	27.35	159.50	17.25	11.00	1.68	7.49	28.84	35.17	11.65	0.80	-0.18	-0.01	-0.01	0.22
BW15	WET SEASON	7.81	10.16	57.00	9.09	2.52	3.64	3.52	34.75	42.38	6.33	0.83	-0.18	-0.01	-0.01	0.00
BW17	WET SEASON	7.44	15.15	126.00	7.72	2.51	7.63	2.84	56.65	69.09	6.49	0.33	0.95	-0.01	4.05	0.01
BW18	WET SEASON	8.17	20.30	123.00	20.98	4.03	9.42	3.38	95.65	116.65	2.84	2.16	-0.18	-0.01	0.23	0.00
BW22	WET SEASON	7.84	12.65	117.00	8.60	3.16	8.46	2.61	47.70	58.17	4.70	0.77	-0.18	-0.01	-0.01	0.00
BW23	WET SEASON	8.06	18.45	154.50	11.15	4.54	14.85	3.20	60.60	73.90	4.64	1.68	-0.18	-0.01	-0.01	0.00
BW24	WET SEASON	8.44	26.70	198.00	24.50	11.10	8.99	9.85	129.00	157.32	5.26	8.86	0.35	-0.01	-0.01	0.13
BW25	WET SEASON	8.04	15.80	84.00	9.96	4.58	3.45	5.68	53.70	65.49	6.53	3.83	-0.18	-0.01	-0.01	2.24
BW27	WET SEASON	8.06	11.00	56.00	5.40	3.06	3.27	4.85	38.50	46.95	3.32	0.16	-0.18	-0.01	0.46	0.77

BW28	WET SEASON	7.93	8.40	35.00	3.55	2.43	3.93	3.62	21.90	26.71	4.11	0.78	-0.18	-0.01	-0.01	0.00
BW32	WET SEASON	8.48	35.65	238.00	39.15	10.36	12.25	7.23	174.00	212.20	11.40	4.46	0.51	-0.01	0.78	0.50
BW33	WET SEASON	7.85	32.45	204.50	21.70	16.80	8.34	4.43	34.70	42.32	9.29	72.65	-0.18	-0.01	-0.01	0.01
BW34	WET SEASON	7.49	9.98	68.00	4.63	2.39	5.16	2.13	2.37	2.89	7.18	3.93	-0.18	-0.01	-0.01	0.00
BW35	WET SEASON	7.15	9.94	63.50	3.39	3.34	3.54	2.81	8.26	10.07	7.00	0.71	-0.18	-0.01	-0.01	0.00
BW36	WET SEASON	7.26	9.84	75.50	3.31	2.88	3.95	3.82	8.26	10.07	4.66	2.58	-0.18	-0.01	-0.01	0.00
BW38	WET SEASON	7.94	26.75	176.50	16.70	7.97	14.50	7.71	66.70	81.34	11.05	1.27	0.00	-0.01	-0.01	0.00
BW39	WET SEASON	8.42	26.50	185.00	15.45	9.12	19.15	5.04	108.50	132.32	7.75	2.39	0.35	-0.01	-0.01	0.00
BF03	DRY SEASON	6.33	12.80	79.00	5.50	3.20	5.69	3.09	23.65	28.84	18.90	5.28	2.10	-0.01	7.22	0.04
BF05	DRY SEASON	6.97	8.67	51.00	4.94	2.83	4.13	2.99	31.20	38.05	6.13	0.59	0.40	-0.01	0.66	0.36
BF06	DRY SEASON	7.34	28.20	168.00	19.30	14.41	15.35	5.89	91.90	112.07	6.74	44.06	-0.18	-0.01	-0.01	0.10
BM03 Bottom	DRY SEASON	8.75	153.75	952.50	33.93	38.85	99.68	215.75	236.50	288.41	213.00	203.03	0.13	-0.01	-0.01	0.03
BM04 Bottom	DRY SEASON	6.84	10.29	52.75	9.69	2.52	2.38	1.22	42.10	51.34	3.25	1.03	0.32	-0.01	1.29	1.99
BM06 Bottom	DRY SEASON	7.87	13.92	88.00	11.98	5.35	4.15	1.66	49.85	60.79	3.78	3.34	0.01	-0.01	-0.01	0.03
BP01	DRY SEASON	6.47	7.92	73.00	4.68	1.72	2.89	4.10	1.82	2.22	4.74	0.61	-0.18	-0.01	-0.01	0.00
BW02	DRY SEASON	7.54	46.30	290.00	26.80	17.60	29.70	6.54	95.80	116.83	38.40	21.20	0.25	-0.01	-0.01	0.02
BW04	DRY SEASON	8.11	116.00	575.50	41.80	37.25	88.70	15.65	78.80	96.10	324.00	1.40	0.02	-0.01	-0.01	1.36
BW05	DRY SEASON	6.91	183.00	984.50	80.75	66.65	144.50	43.15	33.05	40.30	516.50	110.00	0.05	-0.01	0.26	0.85
BW06	DRY SEASON	7.82	97.00	759.50	105.50	51.75	35.35	5.82	117.00	142.68	8.76	443.00	-0.18	-0.01	-0.01	0.21
BW07	DRY SEASON	7.24	7.69	46.50	4.19	2.67	2.40	3.62	19.95	24.33	5.07	1.57	0.36	0.01	-0.01	0.00
BW08	DRY SEASON	7.41	17.05	86.00	14.80	4.79	6.46	4.52	47.15	57.50	19.45	0.64	0.20	-0.01	-0.01	0.00
BW12	DRY SEASON	6.19	10.34	76.00	4.33	3.59	4.93	4.04	17.70	21.59	5.27	1.21	-0.18	-0.01	-0.01	0.00
BW13	DRY SEASON	7.28	36.55	226.50	24.25	14.10	16.25	8.54	58.55	71.40	26.65	5.82	-0.18	-0.01	-0.01	0.00
BW14	DRY SEASON	6.01	26.65	171.00	19.25	10.95	1.77	7.74	5.17	6.31	10.29	1.48	0.06	0.00	0.25	0.24
BW15	DRY SEASON	7.47	10.60	59.50	8.86	2.67	4.01	3.55	36.20	44.15	5.18	0.74	-0.18	-0.01	-0.01	0.00
BW17	DRY SEASON	6.86	46.60	267.50	7.14	3.04	11.46	8.67	183.65	223.96	7.82	3.51	0.46	-0.01	0.09	0.03
BW18	DRY SEASON	7.61	22.85	140.00	22.55	5.38	10.88	3.16	106.30	129.63	4.69	2.33	0.05	-0.01	0.19	0.07
BW19	DRY SEASON	7.69	862.50	4516.00	26.85	3.48	62.75	116.50	2547.00	3106.10	1233.00	0.06	0.61	0.03	0.19	0.01
BW22	DRY SEASON	7.17	11.45	99.00	7.54	2.84	8.82	1.74	42.80	52.20	3.38	0.28	-0.18	-0.01	-0.01	0.00

BW23	DRY SEASON	7.65	16.65	150.50	10.62	3.75	13.30	2.99	63.00	76.83	5.78	2.39	-0.18	-0.01	-0.01	0.00
BW25	DRY SEASON	7.12	12.35	69.00	9.49	4.39	3.41	4.02	49.60	60.49	4.81	0.37	-0.18	-0.01	-0.01	1.05
BW27	DRY SEASON	6.90	8.17	44.50	4.14	3.03	3.63	3.26	27.70	33.78	5.54	0.22	-0.18	-0.01	-0.01	0.48
BW28	DRY SEASON	7.06	5.90	37.00	2.75	1.67	4.02	3.29	19.55	23.84	3.93	0.26	0.29	-0.01	0.52	0.10
BW32	DRY SEASON	7.05	38.55	247.00	38.55	8.80	12.50	19.95	178.00	217.07	15.65	2.01	0.33	-0.01	0.79	0.69
BW33	DRY SEASON	6.97	27.50	169.50	18.25	12.65	8.33	3.41	21.15	25.79	10.45	52.25	-0.18	-0.01	-0.01	0.08
BW34	DRY SEASON	5.64	9.57	66.00	3.66	2.87	5.74	1.75	0.31	0.38	6.69	0.35	-0.18	-0.01	-0.01	0.00
BW35	DRY SEASON	5.95	8.83	58.50	3.43	3.17	3.90	2.25	8.26	10.07	6.18	0.22	-0.18	-0.01	-0.01	0.00
BW36	DRY SEASON	6.11	9.42	72.50	3.46	2.73	4.57	3.78	10.80	13.17	3.78	1.19	-0.18	-0.01	-0.01	0.00
BW38	DRY SEASON	7.27	25.20	174.50	19.45	6.81	18.30	6.66	84.85	103.48	9.50	0.55	-0.18	-0.01	-0.01	0.00
BW39	DRY SEASON	6.90	24.10	184.00	15.75	8.40	20.45	4.76	114.00	139.02	6.17	1.23	0.30	-0.01	-0.01	0.00

The groundwater chemistry dataset of **2013** has been presented in Table 8, and contains 80 records from 35 boreholes, for the various relevant water chemistry variables (for the wet and dry season). The dataset has 36 borehole records (from a total of 80) that comply fully with the water quality objectives for the region. The 2013 groundwater quality dataset contained data for the most monitoring boreholes from all of the year's datasets from 2016 to 2012.

The average **pH** of the 2013 dataset is 7.08, with a minimum recorded value of 5.43 and a maximum of 8.50. Boreholes BM01, BM05 and BW37 located over the current mine area had pH values of below 6.43 (Table 8), which could be caused by acid mine drainage reactions within the mine area. Borehole BW05 had pH values of 5.99 (wet season) and 6.12 (dry season) and was drilled over the old underground mine workings. Groundwater interaction with the historic mine workings or nearby old mine dumps could have caused the low pH values in this borehole. Boreholes BP01, BW34, BW35, BW36, BW12 and BW14 within the south-east portion of the mine site had pH values below 6.5. The low pH measurements in these boreholes was probably due to water that reacted with the large discard stockpile situated near or just upstream from these boreholes. Boreholes BM03 and BM06 had pH measurements above 8.40, that were probably caused by agricultural activities in the vicinity of these holes, like adding chalk and lime to prepare fields for planting.

The average **EC** values of the 2013 dataset were 37.56 mS/m with 11 measurements above the 70 mS/m limit requirements. The 2013 EC values varied from 5.43 mS/m to 252 mS/m. **TDS** values ranged between 16.50 mg/L and 1795.5 mg/L with 6 recorded TDS values above 1000 mg/L (indicating brackish water from these sites). The highest TDS values (above 1300 mg/L) were from borehole BM03 (located at the river diversion outlet) which is influenced by runoff from the mine site and surrounding fields.

Sulphate values exceeding the drinking water guideline limits were encountered in boreholes BM03 and BW06 (like in 2014). Borehole BW06 is possibly influenced by the old underground workings below it and by water from the old mine dumps near the site. The elevated sulphate values in borehole BM03 could be caused by water flowing through rehabilitated mine workings on its way to this borehole. High **chloride** values are present in boreholes BM03, BW13, BW4 and BW5. Boreholes BM03 and BW13 (above the old underground workings) are near each other and are influenced by mine runoff from the north and west of these boreholes. Boreholes BW04 and BW05 are close to old mine dumps and agricultural fields that could have caused elevated chloride values in the area.

Acid mine drainage reactions could have caused the higher dissolved **iron** concentration in boreholes BW04, BW05, BW08, BW24, BW25 and BW28. The majority of higher iron concentration was recorded in the dry season when less water was available to dilute the dissolved metal content within the affected areas. Borehole BW02 had a **fluoride** concentration of above 1.5 mg/L for the wet and dry seasons. Elevated **aluminium** levels were found within the central part of the current mine workings (in boreholes BM06 and BW02) in the dry season. Acid mine drainage within the current mine workings probably caused the higher aluminium values in these holes. Boreholes BW14 and BW07 (situated in the eastern part of the project area) had wet season aluminium values above the water quality limit. These boreholes are located downstream from the current mine workings and discard dump, with higher aluminium concentrations possibly due to acid mine water from these places affecting the boreholes. Dissolved **manganese** concentrations over 0.5 mg/L were found in boreholes BM04, BW04, BW05, BW25 and BW32. These borehole localities had low pH values that could have caused the elevated manganese concentrations.

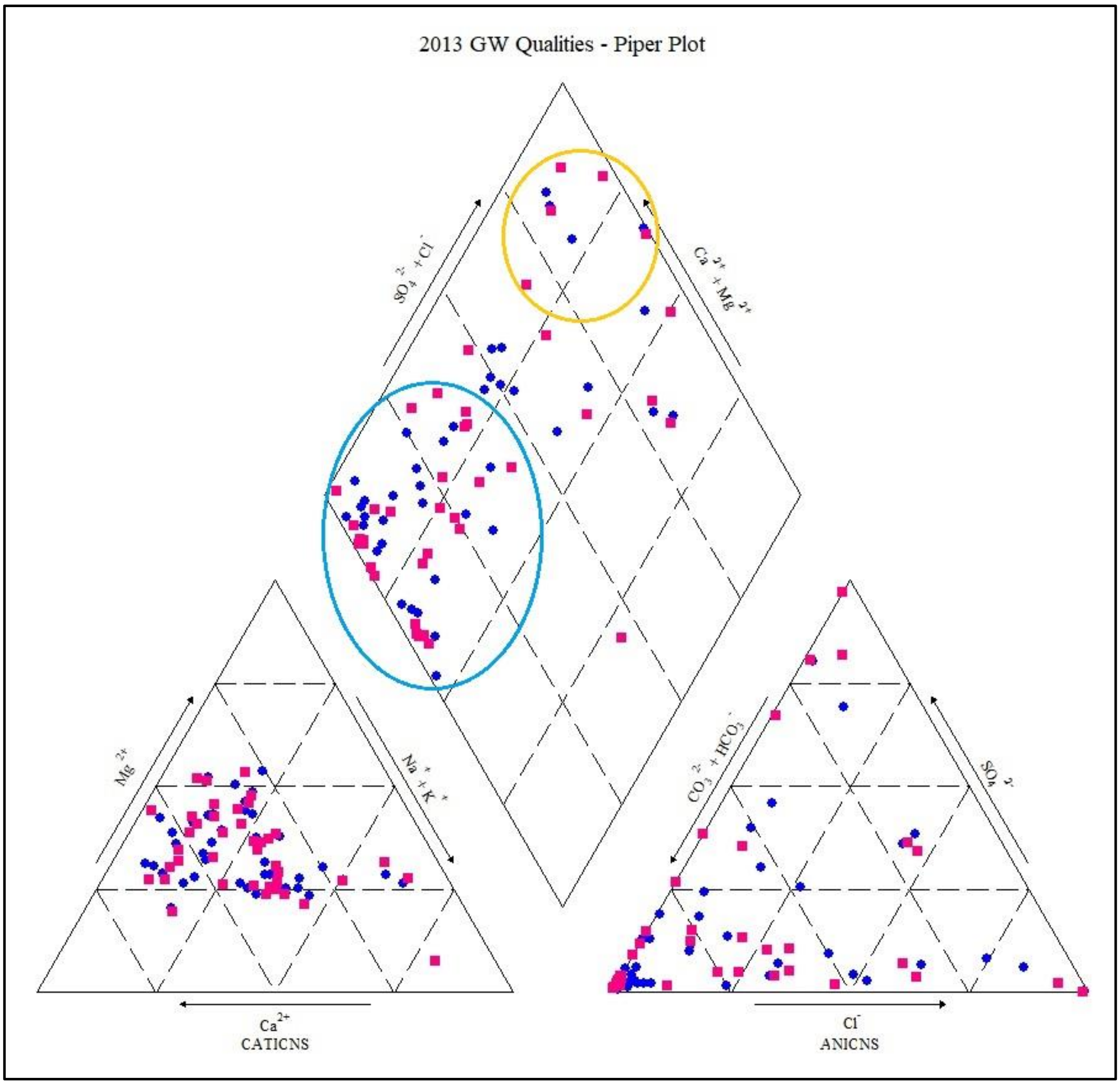


Figure 48. Piper Plot – 2013 Groundwater Chemistry (wet season in blue, dry season in pink)

The predominant water type discernible from the piper plot of the 2013 dataset (Figure 48) is a calcium/magnesium-bicarbonate groundwater facies (blue circle). This groundwater composition is characteristic of fresh groundwater (as the site does not contain carbonate rocks). A prominent calcium/magnesium-sulphate/chloride groundwater type that represents water polluted by mining and agricultural activities is also present (yellow circle). There appears to be a large degree of mixing between the fresh water and contaminated water taking place (more than in 2014 and 2015). The 2013 cation triangle displays an enrichment of calcium and sodium that could be caused by elevated levels of salts in the groundwater. The anion evolutionary trend (possibly due to pollution) remains similar to the 2016, 2015 and 2014 datasets. Higher chloride levels in the dry season shows the influence of dilution during the wet season when more water is available.

Table 7. Groundwater Chemistry - 2013 (combined wet and dry season datasets)

Changed Site Name	Season	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Total ALK mg CaCO3/L	Total ALK mg HCO3 /L	Cl mg/l	SO4 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l
WDMU	**WQ Limits**	**6.5 - 8.4**	**70**	**650**	**150**	**70**	**70**	**50**	**-**	**-**	**25**	**380**	**1.5**	**0.02**	**1**	**0.5**
BF03	WET SEASON	7.38	13.85	69.50	13.90	3.99	3.35	2.86	28.95	35.30	21.35	2.49	0.39	-0.01	0.57	0.03
BF05	WET SEASON	6.88	11.00	48.50	6.66	5.55	0.34	2.80	33.80	41.22	7.38	0.64	0.25	-0.01	0.03	0.28
BF06	WET SEASON	7.38	18.90	110.00	9.40	11.86	6.77	3.28	50.20	61.22	6.44	37.65	0.00	-0.01	-0.01	0.00
BM01 Bottom	WET SEASON	6.56	14.08	73.25	7.00	5.51	4.11	2.85	13.60	16.59	7.99	2.47	-0.06	-0.01	-0.01	0.00
BM03 Bottom	WET SEASON	8.42	223.17	1412.25	55.37	75.38	131.23	282.50	246.83	301.02	360.50	405.83	0.21	-0.01	-0.01	0.09
BM04 Bottom	WET SEASON	6.88	14.90	68.25	15.30	4.68	1.59	1.89	61.15	74.57	2.05	1.23	0.30	-0.01	0.44	1.32
BM05 Bottom	WET SEASON	7.23	19.05	98.25	12.30	4.34	8.01	4.07	23.80	29.02	8.60	2.61	0.15	-0.01	-0.01	0.00
BM06	WET SEASON	8.47	9.25	34.00	6.55	2.71	1.09	0.85	29.10	35.49	-1.41	1.69	0.07	-0.01	-0.01	0.00
BM06 Bottom	WET SEASON	7.45	12.85	71.25	11.74	5.65	0.83	0.68	43.85	53.48	0.72	2.74	0.01	-0.01	-0.01	0.00
BM01	WET SEASON	6.30	14.07	42.00	6.06	5.89	3.00	3.11	3.59	4.38	10.99	1.64	-0.18	-0.01	-0.01	0.00
BM03	WET SEASON	8.09	192.00	1300.00	38.03	60.80	120.67	265.67	173.33	211.38	313.67	367.33	0.20	-0.01	-0.01	0.19
BM04	WET SEASON	6.88	17.07	77.00	18.33	5.62	1.34	1.98	72.03	87.85	0.09	1.22	0.76	-0.01	0.55	1.64
BM05	WET SEASON	6.43	17.70	49.00	7.63	3.54	8.80	4.27	8.26	10.07	11.37	1.65	-0.05	-0.01	-0.01	0.00
BP01	WET SEASON	6.03	9.08	54.50	5.37	2.60	0.91	2.77	8.26	10.07	0.63	2.80	0.00	-0.01	-0.01	0.00
BW02	WET SEASON	7.92	61.35	359.00	38.65	20.85	56.50	4.71	128.50	156.71	22.40	129.85	2.84	-0.01	-0.01	0.00
BW04	WET SEASON	6.94	105.65	590.00	47.60	35.10	92.10	12.75	55.75	67.99	321.50	31.50	0.54	-0.01	1.05	1.70
BW05	WET SEASON	5.99	191.00	1146.50	144.00	68.30	137.00	34.95	7.07	8.62	747.00	1.84	1.02	-0.01	11.60	1.64
BW06	WET SEASON	7.84	89.10	757.00	107.50	57.40	29.60	4.58	106.50	129.88	9.14	464.00	-0.18	-0.01	-0.01	0.00
BW07	WET SEASON	6.93	7.47	35.00	4.71	2.88	0.52	2.30	20.15	24.57	0.25	2.93	0.36	0.03	-0.01	0.00
BW08	WET SEASON	6.73	13.60	60.00	9.90	3.97	2.93	2.78	24.60	30.00	20.30	1.41	0.42	-0.01	0.49	0.00
BW12	WET SEASON	6.23	9.52	48.50	4.13	3.48	1.55	2.46	9.48	11.56	2.04	5.14	-0.18	-0.01	-0.01	0.00
BW13	WET SEASON	6.95	40.60	203.00	29.45	16.85	14.00	2.29	83.75	102.13	28.70	4.99	0.01	-0.01	-0.01	0.00
BW14	WET SEASON	6.46	26.05	143.50	17.35	11.20	11.55	6.57	22.07	26.92	8.80	11.25	0.21	0.05	-0.01	0.00
BW15	WET SEASON	7.38	9.30	44.00	8.87	2.61	0.88	2.02	34.20	41.71	0.59	0.75	-0.18	-0.01	-0.01	0.00

BW17	WET SEASON	7.08	86.82	365.50	12.54	5.66	13.38	12.83	357.90	436.46	2.86	1.84	0.43	-0.01	0.12	0.03
BW18	WET SEASON	7.67	22.35	147.50	29.80	5.99	8.55	2.62	124.00	151.22	2.09	1.21	-0.18	-0.01	-0.01	0.00
BW22	WET SEASON	7.06	11.40	77.50	8.72	3.15	5.81	1.56	46.65	56.89	-1.41	1.36	-0.18	-0.01	-0.01	0.00
BW23	WET SEASON	7.43	16.60	110.50	10.80	4.40	13.20	1.64	60.45	73.72	1.59	1.59	0.00	-0.01	-0.01	0.00
BW24	WET SEASON	7.25	24.90	128.00	24.20	10.30	7.09	5.98	121.00	147.56	2.02	5.22	0.45	-0.01	0.42	0.00
BW25	WET SEASON	7.13	12.20	63.00	11.05	4.96	0.74	2.61	53.60	65.37	2.35	1.15	0.41	-0.01	0.40	0.92
BW27	WET SEASON	7.11	8.63	39.00	5.31	3.36	0.78	2.62	30.70	37.44	1.78	0.65	0.01	-0.01	0.04	0.28
BW28	WET SEASON	7.22	5.66	19.00	2.29	1.05	0.99	2.29	11.00	13.41	-1.41	1.56	0.23	-0.01	0.11	0.03
BW32	WET SEASON	7.20	30.85	177.00	31.90	10.17	10.82	4.08	109.55	133.60	11.20	13.08	0.29	-0.01	0.07	0.22
BW33	WET SEASON	6.53	33.40	184.50	23.90	19.15	5.34	2.78	19.50	23.78	11.65	76.85	0.01	-0.01	-0.01	0.00
BW34	WET SEASON	5.76	7.72	33.00	2.39	1.82	2.34	0.98	8.26	10.07	0.73	1.98	-0.18	-0.01	-0.01	0.00
BW35	WET SEASON	5.88	9.24	38.50	3.62	3.33	1.09	1.63	8.26	10.07	0.83	1.17	-0.18	-0.01	-0.01	0.00
BW36	WET SEASON	5.78	8.70	42.00	3.31	2.57	1.09	2.23	8.26	10.07	0.04	1.87	-0.18	-0.01	-0.01	0.00
BW37	WET SEASON	5.95	13.30	38.00	5.81	2.54	6.02	2.59	14.30	17.44	2.58	2.66	0.20	-0.01	-0.01	0.00
BW38	WET SEASON	7.60	24.15	147.00	21.05	7.15	16.80	4.72	103.55	126.28	2.26	2.62	0.22	-0.01	-0.01	0.00
BW39	WET SEASON	6.97	25.30	165.50	19.20	10.04	17.55	3.51	128.50	156.71	2.46	2.52	0.36	-0.01	-0.01	0.00
BF03	DRY SEASON	7.50	16.50	72.00	16.90	5.44	1.93	4.08	34.80	42.44	21.65	1.07	0.25	-0.01	-0.01	0.00
BF05	DRY SEASON	7.44	9.13	36.50	6.34	4.96	-0.03	2.39	24.60	30.00	5.91	1.54	0.04	-0.01	-0.01	0.00
BF06	DRY SEASON	7.04	23.45	123.00	12.85	14.03	6.42	3.55	32.05	39.09	0.74	64.50	-0.18	-0.01	0.15	0.06
BM01 Bottom	DRY SEASON	6.94	14.50	55.00	8.38	5.32	5.97	3.55	38.45	46.89	3.33	0.63	0.22	-0.01	-0.01	0.00
BM03 Bottom	DRY SEASON	8.20	252.00	1795.50	63.10	106.85	163.50	351.50	280.50	342.07	444.00	497.00	0.01	-0.01	-0.01	0.06
BM04 Bottom	DRY SEASON	6.85	11.65	46.50	10.90	2.86	0.85	1.90	43.65	53.23	0.32	0.62	0.86	-0.01	1.17	0.87
BM05 Bottom	DRY SEASON	7.69	20.00	70.50	12.09	4.89	9.84	5.46	24.90	30.37	9.80	4.34	0.23	0.06	-0.01	0.00
BM06	DRY SEASON	8.16	10.22	43.50	9.25	3.63	1.63	1.53	37.78	46.07	-1.41	3.60	-0.18	-0.01	-0.01	0.00
BM06 Bottom	DRY SEASON	7.51	14.15	56.50	13.35	6.64	0.12	0.86	51.90	63.29	-1.41	1.48	-0.18	-0.01	-0.01	0.00
BM01	DRY SEASON	7.14	14.10	54.00	7.98	5.53	6.20	3.90	29.50	35.98	5.52	1.79	0.13	-0.01	-0.01	0.00
BM03	DRY SEASON	8.50	210.25	1394.00	35.45	70.40	131.00	305.75	204.50	249.39	368.50	359.25	-0.08	-0.01	-0.01	0.09
BM04	DRY SEASON	7.29	12.43	60.75	13.90	3.84	1.65	3.22	60.08	73.26	-0.58	0.66	0.40	-0.01	0.81	0.76
BM05	DRY SEASON	6.95	17.50	56.00	8.59	3.32	10.00	5.79	8.45	10.30	9.75	1.61	-0.18	-0.01	-0.01	0.00

BP01	DRY SEASON	6.13	13.25	33.50	6.78	4.58	2.33	4.27	8.26	10.07	-1.41	2.90	0.01	-0.01	-0.01	0.00
BW02	DRY SEASON	8.35	72.75	432.00	18.80	6.70	135.50	1.21	195.00	237.80	24.90	120.00	7.16	-0.01	-0.01	0.15
BW04	DRY SEASON	7.44	113.00	587.50	44.50	32.45	107.00	13.35	28.65	34.94	354.00	10.31	0.28	-0.01	0.67	0.81
BW05	DRY SEASON	6.12	217.50	1143.00	138.00	69.25	142.00	37.40	8.26	10.07	743.00	1.51	1.49	-0.01	10.79	1.51
BW06	DRY SEASON	8.05	90.65	687.00	96.30	51.60	29.10	4.41	102.30	124.76	5.41	436.00	0.03	-0.01	-0.01	0.00
BW07	DRY SEASON	7.37	7.41	32.00	5.01	3.13	0.29	3.31	26.50	32.32	-1.41	3.37	0.36	-0.01	-0.01	0.00
BW08	DRY SEASON	6.63	12.45	49.50	6.46	3.97	3.50	3.61	15.45	18.84	19.95	1.53	0.88	-0.01	2.38	0.07
BW12	DRY SEASON	6.31	9.73	28.50	4.51	3.37	1.22	2.83	0.19	0.23	-1.41	6.15	-0.18	-0.01	-0.01	0.00
BW13	DRY SEASON	7.09	41.15	172.50	33.15	18.80	16.65	2.84	77.35	94.33	31.50	6.25	0.03	-0.01	-0.01	0.00
BW14	DRY SEASON	6.92	27.40	92.50	17.50	9.82	0.20	8.32	26.57	32.40	9.54	1.58	0.19	-0.01	-0.01	0.06
BW15	DRY SEASON	7.63	10.70	39.50	8.52	3.00	0.67	3.06	36.30	44.27	-1.41	1.00	0.20	-0.01	-0.01	0.00
BW17	DRY SEASON	6.75	11.85	51.00	6.93	2.82	6.81	2.24	47.40	57.80	-1.41	1.85	0.21	-0.01	0.53	0.00
BW18	DRY SEASON	7.86	24.25	128.50	31.35	6.02	9.27	2.84	128.00	156.10	-1.41	1.13	0.04	-0.01	-0.01	0.00
BW22	DRY SEASON	7.43	10.22	42.50	6.36	2.84	6.58	1.50	39.30	47.93	-1.41	1.01	0.02	-0.01	-0.01	0.00
BW23	DRY SEASON	7.76	17.90	78.50	12.05	4.75	14.15	2.04	62.75	76.52	-1.41	2.38	0.03	-0.01	-0.01	0.00
BW24	DRY SEASON	7.34	25.90	146.00	27.80	11.80	8.92	8.92	143.00	174.39	-1.41	1.06	0.48	-0.01	0.16	0.14
BW25	DRY SEASON	7.21	14.75	70.50	11.75	5.66	0.75	4.84	69.90	85.24	-1.41	1.36	0.72	-0.01	1.87	1.21
BW27	DRY SEASON	7.20	8.89	35.00	5.41	3.73	0.48	2.94	34.60	42.20	-1.41	0.72	0.14	-0.01	1.34	0.48
BW28	DRY SEASON	7.07	5.43	18.50	2.23	1.28	0.69	2.30	14.95	18.23	-1.41	2.44	0.24	-0.01	1.02	0.14
BW32	DRY SEASON	7.32	34.10	167.50	30.30	10.05	11.13	13.21	113.75	138.72	10.95	17.15	0.32	-0.01	-0.01	0.52
BW33	DRY SEASON	7.39	37.45	193.50	27.15	21.70	6.09	3.45	14.97	18.25	7.52	110.30	0.01	-0.01	-0.01	0.00
BW34	DRY SEASON	5.90	7.82	16.50	2.47	1.88	1.94	1.60	8.26	10.07	1.86	1.60	-0.18	-0.01	-0.01	0.00
BW35	DRY SEASON	6.06	9.10	21.50	3.48	3.23	1.55	2.04	8.26	10.07	2.59	1.31	0.01	-0.01	-0.01	0.00
BW36	DRY SEASON	6.00	8.97	23.50	3.74	3.20	0.91	3.29	8.26	10.07	-1.41	4.95	-0.18	-0.01	-0.01	0.00
BW37	DRY SEASON	6.18	12.40	41.00	6.98	2.63	4.66	2.77	22.20	27.07	1.90	4.21	0.19	0.03	0.10	0.00
BW38	DRY SEASON	7.74	26.05	130.00	21.45	7.71	18.90	5.91	111.00	135.37	0.61	1.81	0.22	-0.01	-0.01	0.00
BW39	DRY SEASON	7.12	25.75	135.50	19.30	10.45	20.00	4.31	124.00	151.22	0.32	4.17	0.35	-0.01	-0.01	0.00

The **2012** groundwater chemistry dataset contained data for the 2012 wet season period only (Table 9). A total of 42 groundwater chemistry records (for each relevant variable) are present in the table from 36 monitoring boreholes. Overall 21 of the groundwater chemistry measurements (out of 42) had fully compliant results for all of the required variables.

Borehole BM03 had an elevated **pH** of above 8.40 (as in 2013, 2014, 2015 and 2016) that could be due to agricultural runoff from the north and west of the site that flows to this borehole through the river diversion. Farmers use chalk and lime when preparing their fields for planting, with these substances possibly elevating the water pH from these areas. The pH values of boreholes BW34, BW35, BW36, BW37, BW05, BW14, BW12, BW08 and BP01 were all below 6.5 for the 2012 wet season. Most of these boreholes are situated near or downstream from the current mining area and discard dump, where acidic water could be flowing from, towards these boreholes. Borehole BW05 is located to the north of the current mine workings, near old mine dumps and the historical underground mine areas. Acid mine drainage from these areas could be decreasing the pH values in this borehole. Borehole BW37 was drilled in the current mine area and is most probably influenced by acidic mine water flowing from the mine workings. The 2012 wet season pH values vary from 5.53 to 8.67, with an average value of 7.14 (Table 9).

The 2012 dataset contained 6 **EC** measurements exceeding the 70 mS/m water standard limits, with an average EC value of 43.11 mS/m for 2012. The 2012 EC values for the wet season ranged between a minimum of 5.56 mS/m and a maximum of 280.50 mS/m. **TDS** values fluctuated from 12 mg/L to 1954.5 mg/L with 3 TDS readings with values above 1000 mg/L (showing brackish water present in these boreholes). Similar to 2013 and 2014, the maximum TDS values (above 1600 mg/L) were measured in borehole BM03 (located at the river diversion outlet) which is influenced by runoff from the mine site and surrounding agricultural lands.

Sulphate levels above the required limit were encountered in borehole BM03 and BW06 (as in 2013 and 2014). Acid mine water runoff with high sulphate concentrations, from the west and north of borehole BM03, could be the cause of the elevated sulphate levels in this borehole. Interaction with the old mine dumps and old underground areas probably caused the higher sulphate concentrations in BW06 (located to the north of the current mine workings). All of the remaining sulphate values within the 2012 dataset comply with the water standards of the region. Boreholes BM03, BM02, BW02, BW04 and BW05 had **chloride** concentrations above the prescribed limit of 25 mg/L. Boreholes BM03, BM02 and BW02 were drilled in and close to the recent mine workings, where runoff from compacted areas around the mine site and farming areas north of these boreholes possibly contributed to high chloride measurements in these holes. Boreholes BW04 and BW05 were drilled nearby each other above the old mine workings. Old mine dumps near these holes could have influenced the higher chloride values present. Boreholes BW04 and BW05 also had elevated dissolved **iron** concentrations with a maximum of 26.40 mg/L dissolved iron in borehole BW05. Acid mine drainage reactions are clearly present and influencing the region around these two boreholes.

Boreholes BW07, BW017 and BM05 displayed **aluminium** values above the 0.02 mg/L limit. BW017 is situated downstream from boreholes BW04 and BW05, and could be influenced by acidic contaminated water from these sites. Borehole BM05 (within the recent mine workings) was probably effected by acidic mine water from the rehabilitated and current mine workings. Borehole BW07 had an aluminium concentration of 0.10 mg/L, and is located downstream (to the east) of the discard stockpile and recent mine workings. Low pH waters from these areas could be causing elevated aluminium concentrations in this borehole. All of these boreholes however have aluminium concentrations that are compliant to the SANS drinking water standards.

Higher **manganese** concentrations (corresponding to areas with low pH values), of above 0.5 mg/L were found in boreholes BM04, BW04, BW05 and BW25. Acid mine drainage waters from the mine discard dump effected the dissolved manganese concentrations in boreholes BM04 and BW25. Low pH waters from the old mine dumps and possibly the old underground workings could have influenced the manganese levels in boreholes BW04 and BW05. All of the 2012 groundwater quality measurements had **fluoride** values that comply with the set water standards for the area.

Table 8. Groundwater Chemistry - 2012 (wet season dataset only)

Changed Site Name	Season	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Total ALK mg CaCO3/L	Total ALK mg HCO3 /L	Cl mg/l	SO4 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l
WDMU	**WQ Limits**	**6.5 - 8.4**	**70**	**650**	**150**	**70**	**70**	**50**	**-**	**-**	**25**	**380**	**1.5**	**0.02**	**1**	**0.5**
BF03	WET SEASON	7.39	15.00	59.00	12.00	4.45	0.81	3.75	29.80	36.34	18.80	1.19	0.27	-0.01	-0.01	0.00
BF05	WET SEASON	7.39	7.86	21.00	2.14	2.03	1.46	2.42	19.20	23.41	-1.41	1.35	-0.18	-0.01	-0.01	0.00
BF06	WET SEASON	7.12	16.60	74.00	6.81	7.53	7.47	3.77	43.10	52.56	-1.41	21.50	-0.18	-0.01	-0.01	0.00
BM01 Bottom	WET SEASON	6.60	14.30	49.50	7.05	5.11	4.62	3.73	18.00	21.95	7.17	5.72	0.02	-0.01	-0.01	0.00
BM02 Bottom	WET SEASON	7.20	25.20	106.00	22.60	5.37	9.07	4.06	59.70	72.80	32.55	13.95	0.09	-0.01	-0.01	0.01
BM03 Bottom	WET SEASON	8.67	280.50	1954.50	66.45	117.65	183.00	405.50	270.00	329.27	490.33	473.00	0.14	-0.01	-0.01	0.23
BM04 Bottom	WET SEASON	7.01	16.15	73.00	17.25	4.68	1.94	2.31	80.00	97.56	22.76	6.73	0.10	-0.01	0.31	2.26
BM05 Bottom	WET SEASON	7.49	20.75	81.00	12.85	5.56	12.20	5.11	25.83	31.50	13.53	11.62	0.23	0.12	-0.01	0.00
BM06	WET SEASON	8.05	10.15	31.50	6.87	2.45	1.74	1.21	29.53	36.02	4.46	7.36	0.02	-0.01	-0.01	0.00
BM06 Bottom	WET SEASON	7.55	12.45	39.00	8.73	4.07	1.78	1.14	30.07	36.67	0.03	2.46	0.01	-0.01	-0.01	0.02
BM01	WET SEASON	6.60	14.45	59.50	6.93	5.08	7.40	4.46	19.40	23.66	7.56	10.18	0.02	-0.01	-0.01	0.00
BM02	WET SEASON	7.25	25.10	109.00	22.80	6.34	9.22	4.05	63.15	77.01	12.35	8.98	0.10	-0.01	-0.01	0.00
BM03	WET SEASON	8.67	252.50	1654.50	43.70	96.35	161.00	357.00	218.67	266.67	423.00	382.67	0.12	-0.01	-0.01	0.04
BM04	WET SEASON	7.01	16.25	74.00	17.60	4.82	2.04	2.35	78.80	96.10	1.97	4.01	0.17	-0.01	0.22	2.26
BM05	WET SEASON	7.49	20.55	75.00	12.80	5.03	10.75	4.63	21.80	26.59	9.84	8.04	0.22	0.00	-0.01	0.00
BP01	WET SEASON	6.16	10.70	25.00	4.94	3.20	0.65	4.69	8.26	10.07	-1.41	2.03	-0.18	-0.01	-0.01	0.00
BW02	WET SEASON	8.00	54.90	250.00	34.20	19.80	36.10	10.80	103.00	125.61	29.00	37.00	0.99	-0.01	-0.01	0.00
BW04	WET SEASON	7.01	142.00	758.00	54.40	45.30	135.00	16.00	65.80	80.24	428.00	29.30	0.59	-0.01	1.12	2.27
BW05	WET SEASON	5.53	196.00	1067.00	147.00	52.10	96.30	36.90	82.50	100.61	652.00	1.39	0.25	-0.01	26.40	1.42
BW06	WET SEASON	8.20	87.70	646.00	96.00	52.20	26.10	4.25	114.00	139.02	3.08	394.00	-0.18	-0.01	-0.01	0.00
BW07	WET SEASON	7.20	7.55	14.00	2.11	1.69	0.26	1.10	11.00	13.41	-1.41	2.04	0.34	0.10	-0.01	0.00
BW08	WET SEASON	6.41	11.20	39.00	5.67	3.31	1.16	3.25	12.00	14.63	16.20	1.25	-0.18	-0.01	-0.01	0.00
BW10	WET SEASON	8.29	25.50	143.00	37.00	8.00	0.52	6.05	146.00	178.05	-1.41	2.02	0.59	-0.01	-0.01	0.00
BW12	WET SEASON	6.31	9.32	26.00	3.40	3.28	0.90	3.31	8.26	10.07	-1.41	5.94	-0.18	-0.01	-0.01	0.00

BW13	WET SEASON	7.10	37.40	165.00	29.70	17.10	13.70	2.44	103.00	125.61	23.50	9.23	-0.18	-0.01	-0.01	0.00
BW14	WET SEASON	5.63	24.20	69.00	18.70	11.20	0.54	7.60	8.26	10.07	4.49	1.02	-0.18	-0.01	-0.01	0.00
BW15	WET SEASON	7.76	10.30	29.00	7.48	1.87	0.52	2.66	25.70	31.34	-1.41	-0.13	-0.18	-0.01	-0.01	0.00
BW17	WET SEASON	7.77	211.00	877.00	14.20	10.10	23.50	38.70	929.00	1132.93	9.79	6.89	0.84	0.03	-0.01	0.00
BW22	WET SEASON	7.14	12.70	52.00	10.60	3.84	4.58	1.71	48.50	59.15	-1.41	1.88	-0.18	-0.01	-0.01	0.00
BW23	WET SEASON	7.77	18.40	75.00	12.30	4.76	13.10	1.84	62.00	75.61	-1.41	0.16	-0.18	-0.01	-0.01	0.00
BW24	WET SEASON	7.74	27.90	137.00	26.60	11.20	4.91	8.26	141.00	171.95	-1.41	0.26	0.40	-0.01	-0.01	0.00
BW25	WET SEASON	7.23	12.70	56.00	11.30	5.27	0.52	3.50	55.70	67.93	-1.41	1.43	0.20	-0.01	-0.01	0.82
BW27	WET SEASON	7.46	9.47	25.00	3.07	2.99	0.23	2.75	25.10	30.61	-1.41	-0.13	-0.18	-0.01	-0.01	0.19
BW28	WET SEASON	7.09	5.56	12.00	1.07	0.63	0.54	3.42	9.15	11.16	-1.41	0.59	-0.18	-0.01	-0.01	0.00
BW32	WET SEASON	7.80	36.20	169.00	35.50	12.80	11.80	5.01	102.00	124.39	3.29	32.10	0.27	-0.01	-0.01	0.00
BW33	WET SEASON	6.82	23.10	94.00	14.80	12.70	2.32	2.80	8.26	10.07	6.87	43.80	0.20	-0.01	-0.01	0.00
BW34	WET SEASON	5.83	7.76	14.00	2.85	1.91	0.57	0.63	8.26	10.07	-1.41	3.36	-0.18	-0.01	-0.01	0.00
BW35	WET SEASON	6.04	9.09	18.00	3.76	3.54	0.54	1.82	8.26	10.07	-1.41	0.43	-0.18	-0.01	-0.01	0.00
BW36	WET SEASON	5.85	8.32	18.00	3.02	2.57	0.75	2.66	8.26	10.07	-1.41	2.78	-0.18	-0.01	-0.01	0.00
BW37	WET SEASON	6.12	12.40	35.00	5.62	2.69	5.08	3.52	14.20	17.32	-1.41	2.30	0.25	-0.01	-0.01	0.00
BW38	WET SEASON	6.73	22.40	84.00	17.90	7.01	6.71	7.66	20.30	24.76	10.80	2.31	-0.18	-0.01	-0.01	0.00
BW39	WET SEASON	7.33	28.90	147.00	21.60	11.10	18.90	4.18	138.00	168.29	2.38	3.52	0.36	-0.01	-0.01	0.00

The piper plot of the 2012 wet season groundwater chemistry dataset (Figure 49) indicates the same two prominent water types present as in the succeeding years (2013 to 2016), with a calcium/magnesium-bicarbonate water facies (blue circle) predominating. A calcium-sulphate/chloride water type indicative of water contaminated by acid mine drainage is also present (yellow circle). Some mixing is visible between these two water types on the piper plot. The anion and cation evolutionary trends are similar to the 2013 dataset.

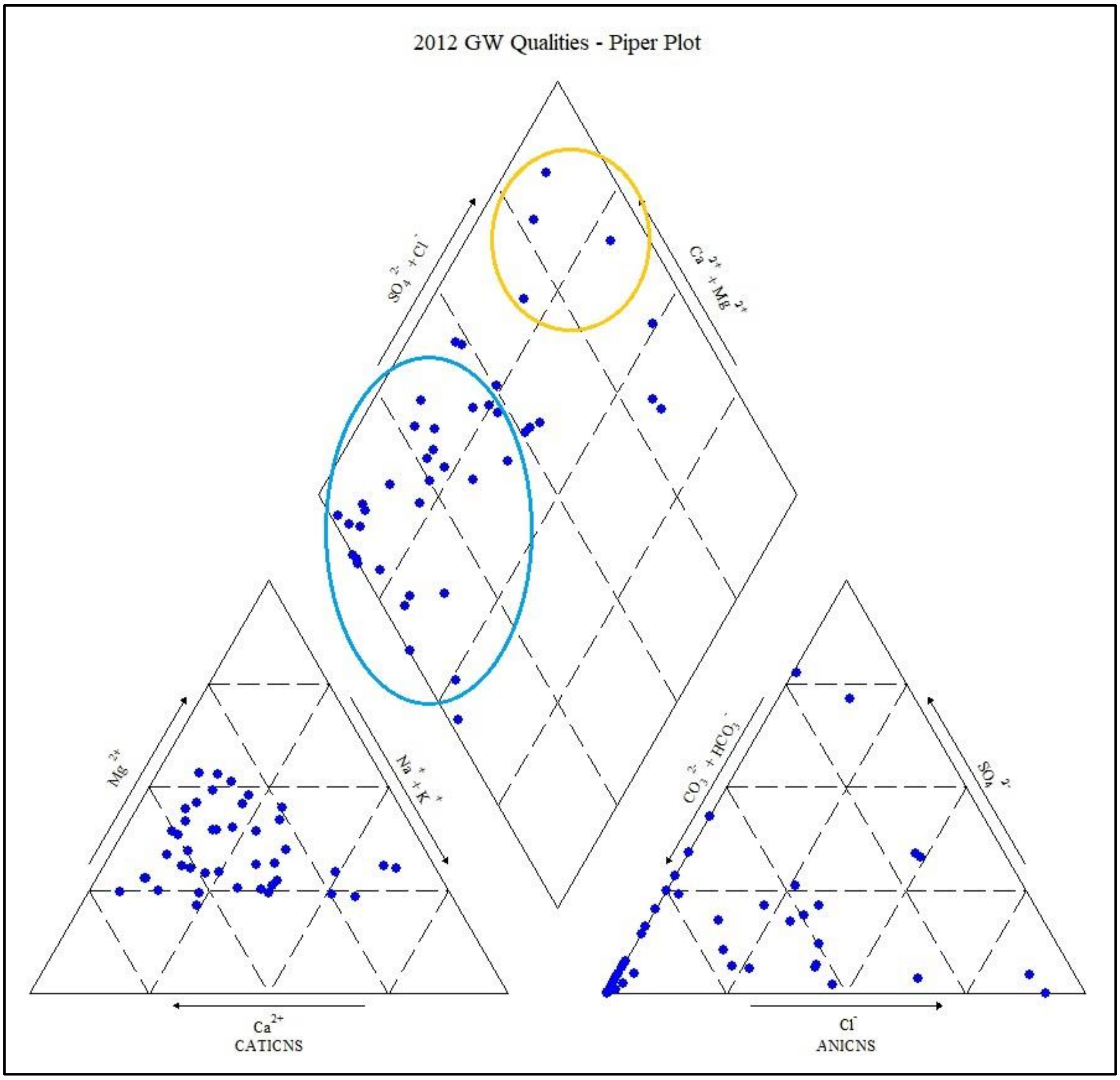


Figure 49. Piper Plot – 2012 Groundwater Chemistry (for the wet season only, in blue)

6.2.5 Conceptual Hydrogeological Site Model

The conceptual hydrogeological site model of the project area was based on the understanding gained after the data evaluation stage was completed. A two dimensional conceptual cross-section of the study area was made to illustrate important aspects of the conceptual hydrogeological site model (Figure 50). This cross-section was not constructed to scale and does not represent any specific part of the mine site, but was included as a graphical representation of the major components of the conceptual model developed through the data analysis performed on the site.

The conceptual hydrogeological site model is divided into the following parts:

- Local Karoo aquifer descriptions
- Disturbed groundwater system (opencast coal mine and rehabilitated mine workings) description
- Groundwater elevations and flow characteristics
- Groundwater chemistry

Reference should be made to Figure 50 during the discussion of the various parts of the conceptual site model (where these components are illustrated).

Local Karoo Aquifers

The local aquifers identified within the study area are:

- Shallow weathered zone aquifer (unconfined)
    - The aquifer is associated with the weathering zone and is composed of weathered Vryheid Formation lithologies
    - The aquifer thickness ranges from intersecting the surface (0 m) to approximately 40 m, with an average thickness of around 11.72 m
    - Groundwater occurs close to surface. Groundwater depths below surface vary between 0.66 m and 22.75 m, with an average depth of about 6.68 m
    - The aquifer is unconfined receiving rainfall recharge and making the aquifer vulnerable to contamination by various pollution sources

- Fractured zone aquifer (unconfined to semi-confined)
    - This aquifer is made up of fresh sandstone, siltstone, shale and coal seams, and underlies the weathered zone aquifer
    - Intersected by only a few boreholes within the site situated within the south-east corner of the project where the aquifer is possibly closer to surface
    - Groundwater flow is controlled by fracture flow (double porosity aquifer type) with water flowing from interstitial pores and fractures within the rock
    - Groundwater depths below surface range from 0.47 m to 3.40 m, with an average depth of approximately 1.94 m

Disturbed Groundwater System

- Disturbed groundwater system (opencast coal mine and rehabilitated mine workings)
    - The disturbed groundwater flow system is present in areas affected by the recent mining activities and includes the current opencast mine areas and rehabilitated mine areas. Coal mining occurs up to the base of the Number 2 Seam within the mine site affecting the area from the floor of this seam to the surface. The shallow weathered zone aquifer and the fractured zone aquifer were disturbed during coal mining activities within the opencast coal mine
    - Groundwater depths below surface within the current mine workings fluctuate between 3.14 m and 24.10 m, with an average depth of roughly 12.97 m. Mine dewatering during active coal mining could cause the lowered groundwater levels within the boreholes drilled in the mine workings
    - The disturbed groundwater system contains numerous connected voids formed during coal mining, which creates large zones with higher porosity than the surrounding undisturbed (natural) areas
- The unsaturated zone thickness (depth to groundwater level within the monitoring borehole datasets) varied between a minimum depth of around 2.68 m and a maximum depth of about 48.15 m.
- The saturated zone thickness (general aquifer thickness) was estimated during various studies within the mine site to range between 8 m and 40 m.

Groundwater elevations and flow characteristics

The 2013 groundwater elevations (estimated from the groundwater level dataset for the year) most accurately depicts the actual conditions within the mine site (section 6.2.3). This is because the 2013 dataset contains the most complete groundwater monitoring borehole dataset received from the mine.

The regional groundwater flow trend appears to be radially inwards towards the central portions of the mine site (over the current mine workings) where a prominent cone of depression is present (caused by mine dewatering). Towards the eastern regions of the site the groundwater flows from the north and west, towards the south-east following the natural drainage pattern of the region.

In general the regional groundwater table follows the same trend as the surface topography and correlates well with the surface elevations. This indicates that the upper weathered aquifer has high porosity with recharge taking place uniformly within this aquifer. The groundwater elevations versus surface topography graph for 2013 had a correlation coefficient of R^2 = 0.8965. Notable exceptions occurred in the groundwater elevations of boreholes drilled within the current mine workings and above the old underground mine workings. Mine dewatering and groundwater abstraction from these sites caused lower groundwater levels than the surrounding data points. Elevated groundwater levels were consistently identified beneath the discard stockpile of the mine site (within the south-east part of the general mine area). Artificial recharge from the discard stockpile caused the higher groundwater elevations within this area. Pumping of groundwater from boreholes for agricultural and domestic use lowered the groundwater elevations at certain localities over various lengths of time.

Groundwater Chemistry

Acid mine drainage reactions influenced most of the groundwater quality issues within the study area. Lowered pH coupled with high concentrations of sulphate and dissolved metals (iron, aluminium and manganese) were encountered within: the current (and rehabilitated) mine workings, the north of the mine site (over the old underground workings and near old mine dumps) and adjacent to, or downstream from, the mine discard stockpile (south-east portion of the mine site).

High chloride concentrations found in some monitoring boreholes were caused by runoff from agricultural areas and the mine within the region. High pH values were due to agricultural practices (adding chalk and lime to fields to prepare for planting) within certain parts of the site. The area surrounding the river diversion outlet consistently displayed groundwater qualities with variables that exceed the required water quality guidelines. This area is situated just to the east of the current mine workings and receives runoff from this entire part of the mine site.

Substantial mixing between contaminated water and fresh water was evident from all of the groundwater quality datasets (2016 – 2012). The anion evolutionary trend showed a clear distribution of anions from bicarbonate to sulphate and then to chloride within most of the piper plots. This strong anion evolutionary trend could possibly be caused by pollution of the groundwater within certain parts of the site.

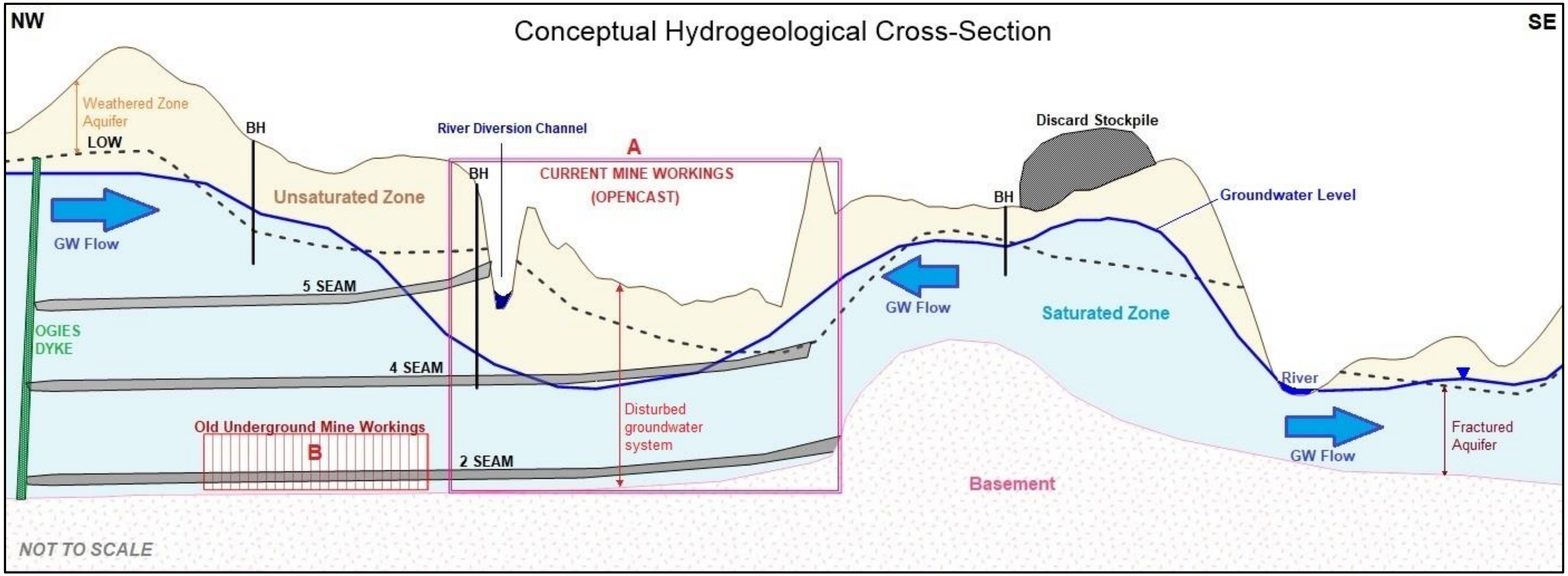


Figure 50. Conceptual Hydrogeological Cross-Section of the study area (North West to South East) – Not to Scale

<u>Conceptual Hydrogeological Cross-Section description</u>: *A – current mine workings, B – Old underground mine workings, LOW – Limit of weathering (dashed line), Static groundwater level – thick blue line, "BH" – groundwater monitoring boreholes, coal seams indicated – 5 Seam, 4 Seam and 2 Seam, Weathered zone aquifer – indicated with orange arrows, Fractured aquifer – indicated with dark red arrows, Disturbed groundwater system – indicated with red arrows, Unsaturated zone – shaded light brown, Saturated zone – shaded light blue, Ogies dyke – thick near vertical green line, Groundwater flow directions – large blue arrows indicate general direction (radially inward towards mine workings and away from higher groundwater elevations), Discard stockpile (with elevated groundwater levels beneath it) – shaded in dark grey, natural river – shown in blue, river diversion channel – shown in dark blue, basement – shaded in pink.*

7. CONCLUSIONS

A Groundwater Impact Assessment was compiled for the mine site by evaluating the existing groundwater level and groundwater chemistry datasets for the years 2016, 2015, 2014, 2013 and 2012. Data is presented within the research report in such a way that the non-disclosure agreement signed with the mine is adhered to throughout.

The conceptual hydrogeological site model incorporated the data evaluation results, and a conceptual hydrogeological cross-section of the study area was constructed. The study acted as a review of the current hydrogeological understanding of the mine site.

In summary the mine site contains a shallow weathered zone aquifer, fractured aquifer and disturbed groundwater system (opencast coal mine and rehabilitated mine workings). The 2013 groundwater level and groundwater chemistry datasets provide the most accurate representation of the actual conditions present within the study area (as it contains the most complete datasets). The regional groundwater flow trend appears to be radially inwards towards the central portions of the mine site (over the current mine workings) where a prominent cone of depression is present that is caused by active mine dewatering (see Figures 40, 41 and 42 in section 6.2.2). Towards the eastern regions of the site the groundwater flows from the north and west, towards the south-east following the natural drainage pattern of the region. The regional groundwater trend differs from what would be expected from a natural groundwater system within this region. The variations in the regional groundwater trend are most probably caused by active mine dewatering and groundwater abstraction within the study area.

Acid mine drainage reactions influenced most of the groundwater quality issues within the study area. Lowered pH coupled with high concentrations of sulphate and dissolved metals (iron, aluminium and manganese) were encountered within: the current (and rehabilitated) mine workings, the north of the mine site (over the old underground workings and near old mine dumps) and adjacent to, or downstream from, the mine discard stockpile (south-east portion of the mine site). High chloride concentrations found in some monitoring boreholes were caused by runoff from agricultural areas and from the mine site within the region. Substantial mixing between contaminated water and fresh water was evident from all of the groundwater chemistry datasets (2016 – 2012). The anion evolutionary trend showed a clear distribution of anions from bicarbonate to sulphate and then to chloride within most of the piper plots. This strong anion evolutionary trend could possibly be caused by pollution of the groundwater within certain parts of the site.

8. RECOMMENDATIONS

Certain points were identified that need to be considered:

- The groundwater monitoring programme should be reviewed and updated on a regular basis as it is an essential groundwater management tool.

- The monitoring sites within the mine workings provide valuable data on the influence that mining is having on the groundwater regime. New monitoring boreholes should be drilled within the active mine workings, as numerous monitoring boreholes within these workings have been destroyed during active mining. Additional boreholes could be drilled within areas where there is a low coverage of monitoring sites in the south-west and north-east of the project area.

- Existing monitoring boreholes should be maintained so that accurate data can be retrieved from these sites for as longs as possible.

- A detailed study of the areas affected by poor groundwater qualities should be considered in order to delineate any possible pollution plumes, identify the specific sources of the groundwater contamination and to evaluate possible mitigation strategies of these at risk areas.

- The possible influence of neighbouring coal mines on the local groundwater system and groundwater chemistry within the mine site should be evaluated.

9. REFERENCE LIST

Agricultural Research Council (ARC), Institute for Soil, Climate and Water (ISCW) (2018). Agricultural Geo-referenced Information System (AGIS) database.

Barnes, M.R. and Vermeulen, P.D. (2012). Technical Note: Guide to groundwater monitoring for the coal industry. Water SA, 38, 831 – 835.

Bell, F.G., Bullock, S.E.T., Hälbich, T.F.J. and Lindsay, P. (2001). Environmental impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. International Journal of Coal Geology. 45, 195 – 216.

Bordy, E.M., Bumby, A., Catuneanu, O., Eriksson, P.G. (2004). Advanced Early Jurassic termite(Insecta: Isoptera) nests: evidence from the Clarens Formation in the Tuli Basin, Southern Africa. Palaios. 19, 68 – 78.

Botha, J.F., Verwey, J.P., van der Voort, I., Vivier, J.J.P., Buys, J., Colliston, W.P., Loock, J.C. (1998). Karoo Aquifers – Their Geology, Geometry and Physical Properties, Water Research Commission, 487/1/98. Water Research Commission, South Africa.

Cadle, A.B. (1982). Controls on coal distribution. In: Cadle, A.B. (Ed.), Coal Exploration, Economics and Assessment. University of the Witwatersrand, Johannesburg, p. 36.

Cairncross, B. (2001). An overview of the Permian (Karoo) coal deposits of southern Africa. Journal of African Earth Science. 33, 529 – 562.

Cairncross, B. and Cadle, A.B. (1988). Palaeoenvironmental control on coal formation, distribution and quality in the Permian Vryheid Formation, East Witbank Colfield, South Africa. Int. J. Coal Geol. 9, 343 – 370.

Catuneanu, O., Hancox, P.J. and Rubidge, B.S. (1998). Reciprocal flexural behaviour and contrasting stratigraphies: a new basin development model for the Karoo retroarc foreland system, South Africa. Basin Res. 10, 417 – 439.

Chief Directorate: National Geo-spatial Information (1995). Topographical Map Series of South Africa. 1:50 000 Topographical Map Sheets.

Department of Environmental Affairs and Tourism (DEAT), University of Pretoria & GIS Business Solutions (2000). Environmental Potential Atlas for the Mpumalanga Province – Mean Annual Precipitation Map.

Department of Environmental Affairs and Tourism (DEAT), University of Pretoria & GIS Business Solutions (2000). Environmental Potential Atlas for the Mpumalanga Province – Mean Annual Runoff Map.

Department of Water Affairs and Forestry. (1999). 2526 Johannesburg sheet 1:500 000 Hydrogeological Map Series of the Republic of South Africa. Associated Printing, Cape Town.

Falcon, R.M.S. (1986). Classification of coals in southern Africa. In: Anhaeusser, C.R., Maske, S. (Eds.), Mineral Deposits of Southern Africa, vol. II. Geological Society of South Africa, Johannesburg, pp. 1899 – 1921.

Geo Pollution Technologies (2012). Hydrological Report for the proposed Keldoron Colliery, New Castle KwaZulu-Natal. pp 1 – 65.

Geological Survey of South Africa. (1986). 2628 East Rand sheet 1:250 000 Geological Map Series. The Government Printer.

Hancox, P.J. (2016). The Coalfields of South-Central Africa: A Current Perspective. IUGS Episodes. 39 (2), 413 – 415.

Hancox, P.J. and Götz, A.E. (2014). South Africa's coalfields – a 2014 perspective. International Journal of Coal Geology. 132, 170 – 254.

Hem, J D. (1985). Study and interpretation of the chemical characteristics of natural water, 3rd Edition, US Geological Survey Water Supply Paper 2254, 55 – 56.

Hobbs, P., Oelofse, S.H.H. and Rascher, J. (2008). Management of Environmental Impacts from Coal Mining in the Upper Olifants River Catchment as a Function of Age and Scale. Water Resources Development, 24 (3), 417 – 431.

Hodgson, F.D.I, Grobbelaar, R., Usher, B., Cruywagen, L.M. and de Necker, E. (2004). Long-term impact of intermine flow from collieries in the Mpumalanga Coalfields. Water Research Commission, 1056/1/04. Water Research Commission, South Africa.

Hodgson, F.D.I. and Krantz, R.M. (1998). Investigations into Groundwater Quality Deterioration In The Olifants River Catchment Above The Loskop Dam With Specialised Investigation In The Witbank Dam Sub-Catchment. WRC Report No. 291/1/98. Water Research Commission, Pretoria.

Holland, M., and Witthüser, K. (2016). Hydrogeological Study for the Setlabotsha Coal Mine Project. Delta H Water System Modelling. pp. 30 – 36.

Huisamen, A. and Wolkersdorfer, C. (2016). Modelling the hydrogeochemical evolution of mine water in a decommissioned opencast coal mine, International Journal of Coal Geology. http://dx.doi.org/10.1016/j.coal.2016.05.006.

Jeffrey, L.S., (2005). Characterization of the coal resources of South Africa. Journal of The South African Institute of Mining and Metallurgy, 105, 95 –102.

Johnson, M.R., Van Vuuren, C.J., Visser, J.N.J., Cole, D.I., Wickens, H. De V., Christie, A.D.M., Roberts, D.L. and Brandl, G. (2006). Sedimentary rocks of the Karoo Supergroup. In: Johnson, M.R., Anhaeusser, C.R. and Thomas, R.J. (Eds.), The Geology of South Africa, Geological Society of South Africa, Johannesburg/Council for Geosciences, Pretoria. pp. 461 – 499.

Potgieter, J. (2015). Groundwater Management Dynamics for Coal Mines in South Africa; a step-by-step outline. Unpublished MSc Thesis, University of the Free State. pp 1 – 175.

Smith, D.A.M. (1970). The distribution of coal quality in the Witbank and Highveld coalfields of South Africa. Proceed. 2nd Int. Gondwana Symposium (IUGS). CSIR, Pretoria, pp. 461 – 468.

Smith, D.A.M. and Whittaker, R.R.L.G. (1986). The coalfields of southern Africa: an introduction. In: Anhaeusser, C.R., Maske, S. (Eds.), Mineral Deposits of Southern Africa, vol. II. The Geological Society of South Africa, pp. 1875 – 1878.

Snyman, C.P. (1998). Coal. In: Wilson, M.G.C., Anhaeusser, C.R (Eds.), The Mineral Resources of South Africa, sixth ed. Council for Geoscience, Pretoria.

South African National Standard 241. 2006 Edition 6.1. Drinking Water. Standards Act, 1982 (Act 30 of 1982).

South African Weather Service (2018). Witbank Automatic Weather Station climatic data records (1993 – 2016).

Thomas, L. (2013). Coal Geology, Chapter: Hydrogeology of Coal, John Wiley & Sons, Ltd. West Sussex, UK. pp 254 – 269.

10. APPENDIX

Table 9. Groundwater Monitoring Boreholes Data Summary (compiled from mine data)

BH_ID (All Borehole Names Changed)	BH Type	Groundwater Level (depth below surface) Data (X indicates data type present in provided database)					Groundwater Quality Data (X indicates data type present in provided database)					Demolished / Discontinued
	BF - Deep Fractured Aquifer; BW - Shallow Weathered Zone Aquifer; BM - Mine Workings Monitoring Borehole	2016	2015	2014	2013	2012	2016	2015	2014	2013	2012	Date Demolished
BF01	Deep Fractured Aquifers											September 2011
BF02	Deep Fractured Aquifers											March 2011
BF03	Deep Fractured Aquifers	X	X	X	X		X	X	X	X	X	
BF04	Deep Fractured Aquifers											September 2011
BF05	Deep Fractured Aquifers	X	X	X	X		X	X	X	X	X	
BF06	Deep Fractured Aquifers	X	X	X	X		X	X	X	X	X	
BF07	Deep Fractured Aquifers											September 2011
BF08	Deep Fractured Aquifers											September 2011
BF09	Deep Fractured Aquifers											September 2011
BP01	Perched Aquifer		X	X	X			X	X	X	X	December 2015
BW01	Shallow Weathered Zone Aquifer				X					X	X	December 2013
BW02	Shallow Weathered Zone Aquifer			X	X				X	X	X	
BW04	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW05	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW06	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW07	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW08	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW09	Shallow Weathered Zone Aquifer											September 2011
BW10	Shallow Weathered Zone Aquifer										X	
BW11	Shallow Weathered Zone Aquifer											Date Not Known
BW12	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW13	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW14	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW15	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW16	Shallow Weathered Zone Aquifer											Date Not Known
BW17	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW18	Shallow Weathered Zone Aquifer		X	X	X			X	X	X		
BW19	Shallow Weathered Zone Aquifer			X					X			
BW20	Shallow Weathered Zone Aquifer											September 2011
BW21	Shallow Weathered Zone Aquifer											December 2009
BW22	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW23	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW24	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW25	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW26	Shallow Weathered Zone Aquifer											September 2011
BW27	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW28	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW29	Shallow Weathered Zone Aquifer											September 2011
BW30	Shallow Weathered Zone Aquifer											September 2011
BW31	Shallow Weathered Zone Aquifer											September 2011
BW32	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW33	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW34	Shallow Weathered Zone Aquifer	X	X	X	X		X	X	X	X	X	
BW35	Shallow Weathered Zone Aquifer		X	X	X			X	X	X	X	
BW36	Shallow Weathered Zone Aquifer	X	X	X	X			X	X	X	X	
BW37	Shallow Weathered Zone Aquifer				X					X	X	December 2013
BW38	Shallow Weathered Zone Aquifer		X	X	X			X	X	X	X	December 2015
BW39	Shallow Weathered Zone Aquifer	X	X	X	X			X	X	X	X	
BW40	Shallow Weathered Zone Aquifer											January 2012
BM01	Mine Workings Monitoring Borehole				X	X				X	X	
BM02	Mine Workings Monitoring Borehole					X					X	July 2014
BM03	Mine Workings Monitoring Borehole	X	X	X	X	X	X	X	X	X	X	
BM04	Mine Workings Monitoring Borehole	X	X	X	X	X	X	X	X	X	X	
BM05	Mine Workings Monitoring Borehole				X	X				X	X	March 2014
BM06	Mine Workings Monitoring Borehole	X	X	X	X	X	X	X	X	X	X	