

Water Use Licence Application Randfontein Estate Limited: Doornkop Mine



Hydrogeological Report
HAR05

WU29548

Harmony Gold Mining Company Limited

Niara Environmental Consultants (Pty) Ltd
Registration no.: 2012/018290/07
Cell: +27827672786; Fax: 0865314434

www.niara.co.za
info@niara.co.za

KwaZulu Natal Office:
59 Beaumont Road,
Bluff, Durban, 4052

Gauteng Office:
Office 1 Palm Place Office Park
22 Bram Fischer Drive, Linden,
Johannesburg, 2195

Mpumalanga Office:
16 Birkholtz Avenue,
Witbank Ext 16,
eMalahleni, 1034

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Prepared For:	Harmony Gold Mining Company Limited Thabo Sithole Snr Environmental Officer PO Box 2 Randfontein, 1760 T: +27 (0)11 278 6973 Email: Thabo.Sithole@Harmony.co.za
Prepared By:	Charles Rikhotso Hydrogeologist Niara Environmental Consultants (Pty) Ltd Office 1 Palm Place Office Park 22 Bram Fischer Drive, Linden Johannesburg, 2194 Mobile: 082 767 2786 Email: info@niara.co.za



Executive Summary

Introduction and Background

- ✔ Niara Environmental Consultants (Pty) Ltd has been appointed by Harmony Gold Mining Company Limited (Randfontein Estates Limited) to conduct a specialist hydrogeological study for Doornkop Mine.
- ✔ The mine is located within the City of Johannesburg Metropolitan Municipality of the Gauteng Province, approximately 30 km west of Johannesburg.
- ✔ The scope of work for the hydrogeological study entails conducting a hydrogeological study in line with regulatory requirements.
- ✔ The main objective of the study is to conduct a hydrogeological study that includes a baseline impact assessment.

Methodology

- ✔ Desktop Study: A comprehensive desktop study was conducted, entailing the gathering of information from maps, reports and previous studies conducted for Doornkop Mine and in the vicinity of the mine site.
- ✔ Geophysical survey: Resistivity method was used for the survey. In total, six traverses were conducted with a 10 m electrode spacing.
- ✔ All traverses were interpreted where weathering zones, moist zones and geological structures were identified.
- ✔ In total, six drilling targets have been selected for drilling of monitoring boreholes.
- ✔ Groundwater sampling and analysis is conducted in a quarterly basis for groundwater quality.
- ✔ Groundwater recharge was calculated using the groundwater recharge program developed by van Tonder and Xu (2000).
- ✔ Groundwater modelling was constructed based on Model Muse and Modflow 6.
- ✔ Six waste samples were collected and submitted to the laboratory for determination of Paste pH, Total Sulphur (%) (LECO), Acid Potential (AP) (kg/t), Neutralization Potential (NP), Nett Neutralization Potential (NNP), Neutralising Potential Ratio (NPR) (NP: AP), Net Acid Generation and Rock Type.

Result and interpretation

Groundwater recharge calculations

- ✔ Groundwater recharge was calculated using the groundwater recharge program developed by van Tonder and Xu (2000). This program provides the basis for estimation of groundwater recharge.
- ✔ Estimated recharge for the study area ranges from 3% to 20% of the annual rainfall, with an average of 5%. This translates to 32 mm recharge per annum.



Geochemical assessment

- ☛ Paste pH: the method only classifies TSF DTSF 3 as potential acid generating material. This samples have a pH of less than 4.5 which shows that the sample is acid generating. All other samples namely, DTSF 1, DTSF 2, DWRD 1, HW 2300m below and Footwall 2300m BS are characterised by high pH of more than 4.5 (Neutral to alkaline pH). This indicates non-acid generating.
- ☛ NNP: All samples collected have NNP of less than zero which suggest that the samples have a potential to generate acid.
- ☛ NPR: All samples collected have NPR of less than 1 which indicates that the samples have a potential to generate acid mine drainage. These results support the NNP result which suggest that the TSF and WRD have a potential for acid mine drainage generation.
- ☛ Rock Type: The method has shown that the TSF and the waste rock are classified as Type I and II which has a potential to form acid.
- ☛ NAG pH: DTSF 3 is classified as non-acid generating while the remaining samples are acid generating.
- ☛ %S and NPR Method: The method has classified all samples as acid generating.

Groundwater quality

- ☛ The concentration of Mn was found at high concentration above the SANS 2015 limit at borehole DKP 4, DKP 7, DKP 8 and DKP 13.

Hydrochemical facies

- ☛ Groundwater in the study area is classified into: Shallow fresh groundwater, Mixed water sources, Deeper fresh groundwater, Evaporation water source and Acid Mine drainage influence.

Aquifer Characterisation

- ☛ Groundwater vulnerability: Dolomite is classified as high or most vulnerable to contamination while the fractured and intergranular aquifer is classified as moderate vulnerability.
- ☛ Aquifer classification: Dolomite is classified as major aquifer while fractured and intergranular aquifer is classified as minor aquifer.
- ☛ Aquifer susceptibility: Dolomite aquifer is classified as strictly non degradation while fractured and intergranular aquifer is classified as medium.

Results of the model

- ☛ Steady state groundwater level varies from 1611 mamsl to 1625 mamsl across the model boundary.
- ☛ The groundwater level is slightly deep compared to shallow perched groundwater level occurring within the mine.
- ☛ Groundwater level during operational phase shows a slight variation compared to steady state simulation.



- ✔ Drawdown in groundwater level is observed, with average groundwater level of 1619 mamsl.
- ✔ Simulation suggest that the two dewatering boreholes do not have major impact on groundwater level.
- ✔ Simulated plume result shows contamination within the footprint of the TSF, RWD and Evaporation dam, and immediate surrounding area.
- ✔ Monitoring boreholes DKP 3, DKP 7 and DKP 8 are located within the predicted plume area.
- ✔ Post closure impacts was simulated using 50- and 100-years projections. 50- and 100-year contamination plume will continue to spread to the south and south east.
- ✔ Borehole DKP 3, DKP 4, DKP 7 and DKP 8 will be affected by both the 50- and 100-year plume migration.
- ✔ Current inflow into Doornkop Mine is estimated as 6.4Mℓ/d. The mine is currently pumping approximately 8.44 Mℓ/d which suggest that there may be unknown water sources that infiltrates into mine working.



List of Acronyms

°C	Degree Celsius
ABA	Acid Base Accounting
AMD	Acid Mine Drainage
AP	Acid Potential
ARD	Acid Rock Drainage
DWAF	Department of Water Affairs and Forestry
DEM	Digital Elevation Model
DRD	Durban Roodepoort Deep
DWS	Department of Water and Sanitation
GQM	Groundwater Quality Management
GUI	Graphical user interface
GWF	Groundwater Flow
GWT	Groundwater Transport
ha	Hectare
Harmony	Harmony Gold Mining Company Limited
km ²	Square kilometer
K	Hydraulic conductivity
km	Kilometer
l/s	Liter Per Second
m	Meter
m.a.m.s.l.	Meters above mean sea level
m.b.g.l	Meters below ground level
MAP	Mean Annual Precipitation
mm	Millimeter
m/s	Meter per second
m ² /day	Square meters per day
m ³ /day	Cubic meter per day
mg/l	Milligram per liter
mS/m	Milli siemens per meter
Me/d	Megaliters per day
NNP	Net Neutralization Potential
NP	Neutralization Potential



NPR	Neutralization Potential Ratio
PCD	Pollution Control Dam
SANS	South African National Standards
SABS	South African Bureau of Standards
SWL	Static Water Level
SRMR	South Roodepoort Main Reef
T	Transmissivity
TSF	Tailing Storage Facility
USGS	United States Geological Survey
VCR	Ventersdorp Contact Reef
WHO	World Health Organization
WRB	West Rand Basin
WRD	Waste Rock Dump
WWTP	Wastewater Treatment Plant



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DOCUMENT CONTROL

PROJECT DETAILS:	
Report Title	Hydrogeological study
Project Name	WULA and Associated Specialist Studies for Randfontein Estate Limited: Doornkop Mine
Local Municipality	City of Johannesburg Metropolitan Municipality
Client:	Harmony Gold Mining Company Limited
WULA Reference Number:	WU29548
Project Code:	HAR05
Date Submitted:	18 August 2023
Author(s):	Charles Rikhotso
Reviewer:	Vumile Ribeiro

Prepared For:	Harmony Gold Mining Company Limited Thabo Sithole (Project Manager) Senior Environmental Officer Email:
Prepared By:	Charles Rikhotso Hydrogeologist Niara Environmental Consultants (Pty) Ltd 16 Birkholtz Avenue Witbank Ext 16 eMalaheni, 1034 Email: info@niara.co.za
Reviewed By:	Vumile Ribeiro Director: Environmental Management Services Niara Environmental Consultants (Pty) Ltd Email: vumile@niara.co.za




Specialist Declaration of Independence

Niara Environmental Consultants (Pty) Ltd
Office 1 Palm Place Office Park
22 Bram Fischer Drive, Linden
Johannesburg, 2194
info@niara.co.za

I, Charles Rikhotso, as duly authorised representative of Niara Environmental Consultants (Pty) Ltd., hereby confirm my independence and declare that I:

- ✔ I act as the independent specialist in this application;
- ✔ I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- ✔ I declare that there are no circumstances that may compromise my objectivity in performing such work;
- ✔ I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity;
- ✔ I will comply with the Act, regulations and all other applicable legislation;
- ✔ I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- ✔ I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the application by the competent authority; and the objectivity of any report, plan, or document to be prepared by myself for submission to the competent authority.
- ✔ all the particulars furnished by me in this form are true and correct; and
- ✔ I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of Section 24F of the Act.

Signature of the Specialist:	
Designation:	Hydrogeologist
Qualifications:	MSc Hydrogeology, Masters Environmental Management
Name of company:	Niara Environmental Consultants (Pty) Ltd
Experience (years):	12 Years
Date:	18 August 2023



1. Introduction

1.1. Project Background

Niara Environmental Consultants (Pty) Ltd has been appointed by Harmony Gold Mining Company Limited (Randfontein Estates Limited) to conduct specialist hydrogeological study for Doornkop Mine. This report forms part of the specialist studies conducted in support of the water use licence application.

Doornkop Mine is currently holding a mining right (Ref No. GP 30/5/1/1/1/09 MR) which permits mining and mining related activities. The mine focus is on gold mining through conventional underground mining. Currently, mining activities occurs at the depth of 2300 m below ground. Average gold production is approximately 1 642 639 tons per annum, with total production of approximately 19 327 597 tons processed.

The mine has various infrastructures that support the entire operation. This includes but not limited to; underground shaft, tailing storage facility (TSF), waste rock dump (WRD), mine water containment facilities, processing plant, Sludge settling Ponds and sewage transfer station. Extracted gold ore is processed at Doornkop carbon-in-pulp plant where the material is screened, crushed, and subjected to leach, adsorption, and elusion process to recover gold product. The plant has a thickener which is used for mine water storage.

Liquid waste or slurry (residue) is transported to the TSF. Doornkop Mine have one operational TSF which is used for tailing storage and management of mine residue. Mine water at Doornkop is managed through two sludge settling ponds, one evaporation dam (storm water dam), one return water dam (RWD), two process water dams, four storage tanks and TSF settling dams.

Therefore, this study seeks to provide hydrogeological aspects and impacts associated with the mining activities (including the above facilities). The report was compiled in line with regulation 267, Regulations regarding the procedural requirements for water use licence applications and appeals (Gazette No. 40713, GoR. 267, 24 March 2017).

1.2. Regional Setting and Location of Activity

Doornkop Mine is located within the City of Johannesburg Metropolitan Municipality of the Gauteng Province, approximately 30 km west of Johannesburg. The mine lies between 26°11'46" and 26°13'41" south latitude and between 27°46'19" and 27°48'48" east longitude. The mine is located specifically on the farm: Vlakfontein 238, Doornkop 239, Zuurbult 240 and Farm No 241. Access to the mine is through the R548 provincial road. It is bounded by several township, with Dobsonville in the southeast, Tshepisoong in the northeast and Rietvlei in the northwest (Figure 1-1).



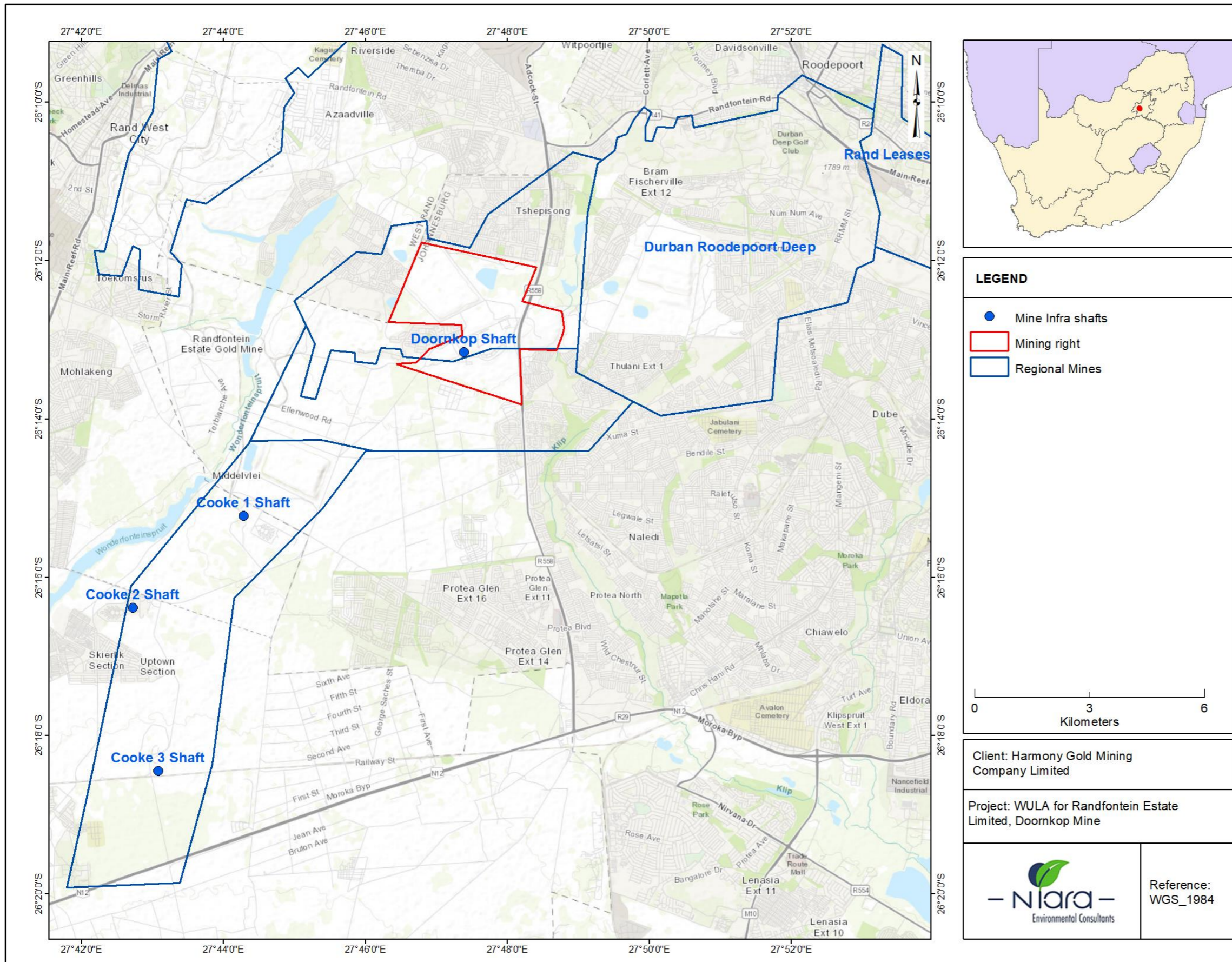


Figure 1-1: Locality Plan

2. Geographical setting

2.1. Topography and drainage

The area has a surface landform of hills and gently undulating topography (Figure 2-1). Elevation varies from 1 640 m to 1 680 m above mean sea level (mamsl). Although the mine is located within the water divide with high elevation, northern and eastern site of the mining right area is characterised by high elevation. Elevation in these regions reaches a maximum of 1 720 mamsl, decreasing towards the mining right area (Figure 2-2).

The mine is located within the western boundary of C22A quaternary catchment of the Vaal Water Management Area (WMA). Surface drainage from the mine is towards the east, south and west (Figure 2-2 and Figure 2-3). Large portion of the mine area drains towards the south and east. The area is drained by two main perennial rivers, namely, the Klip River in the east and Wonderfontein spruit River in the west. The Klip River flows from north to south for approximately 65 km where it drains into the Vaal River south of the mining area. The Wonderfontein spruit flows from northeast to southwest where its confluence with the Mooi River approximately 28 km southwest of the mine. All these rivers are tributaries of the Vaal River.

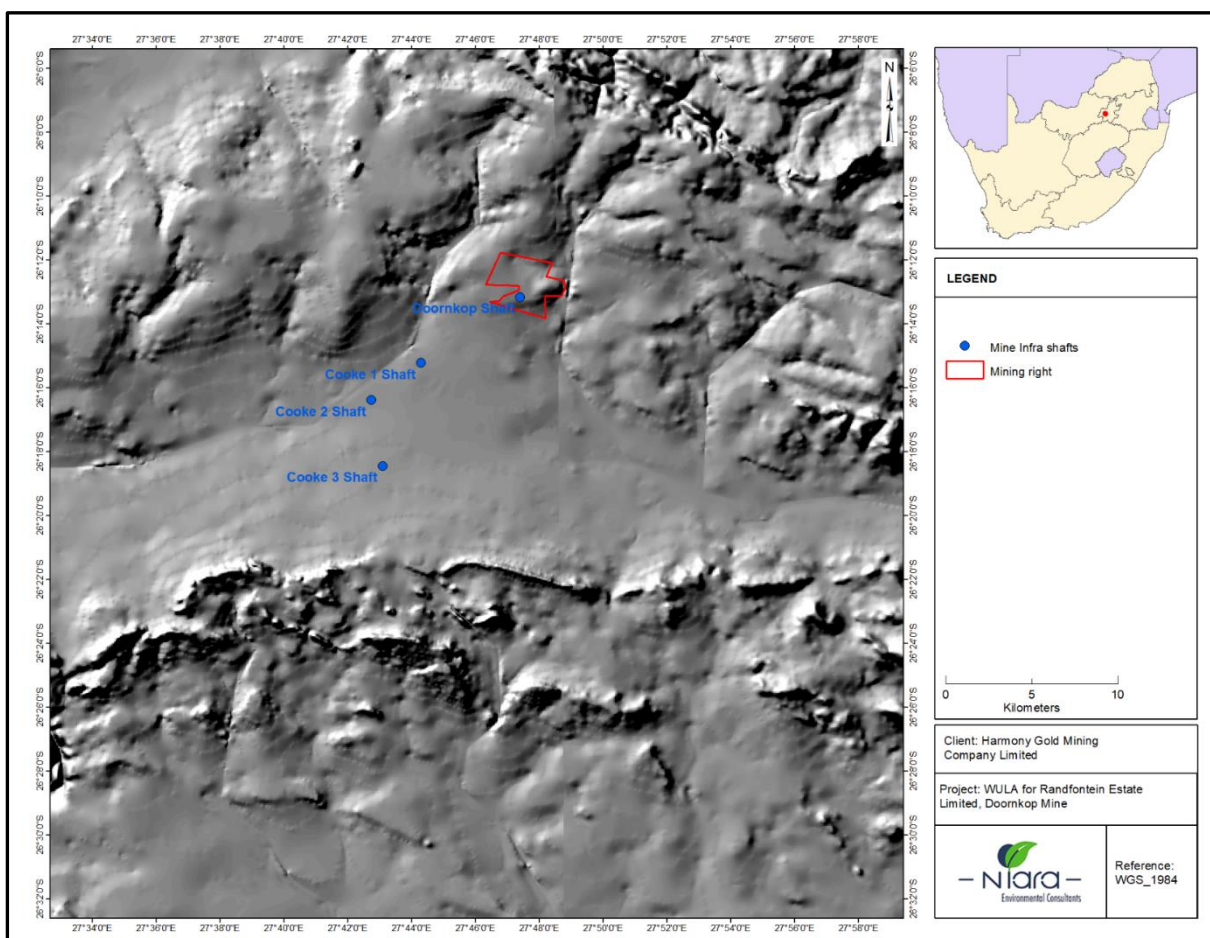


Figure 2-1: Surface elevation (a).

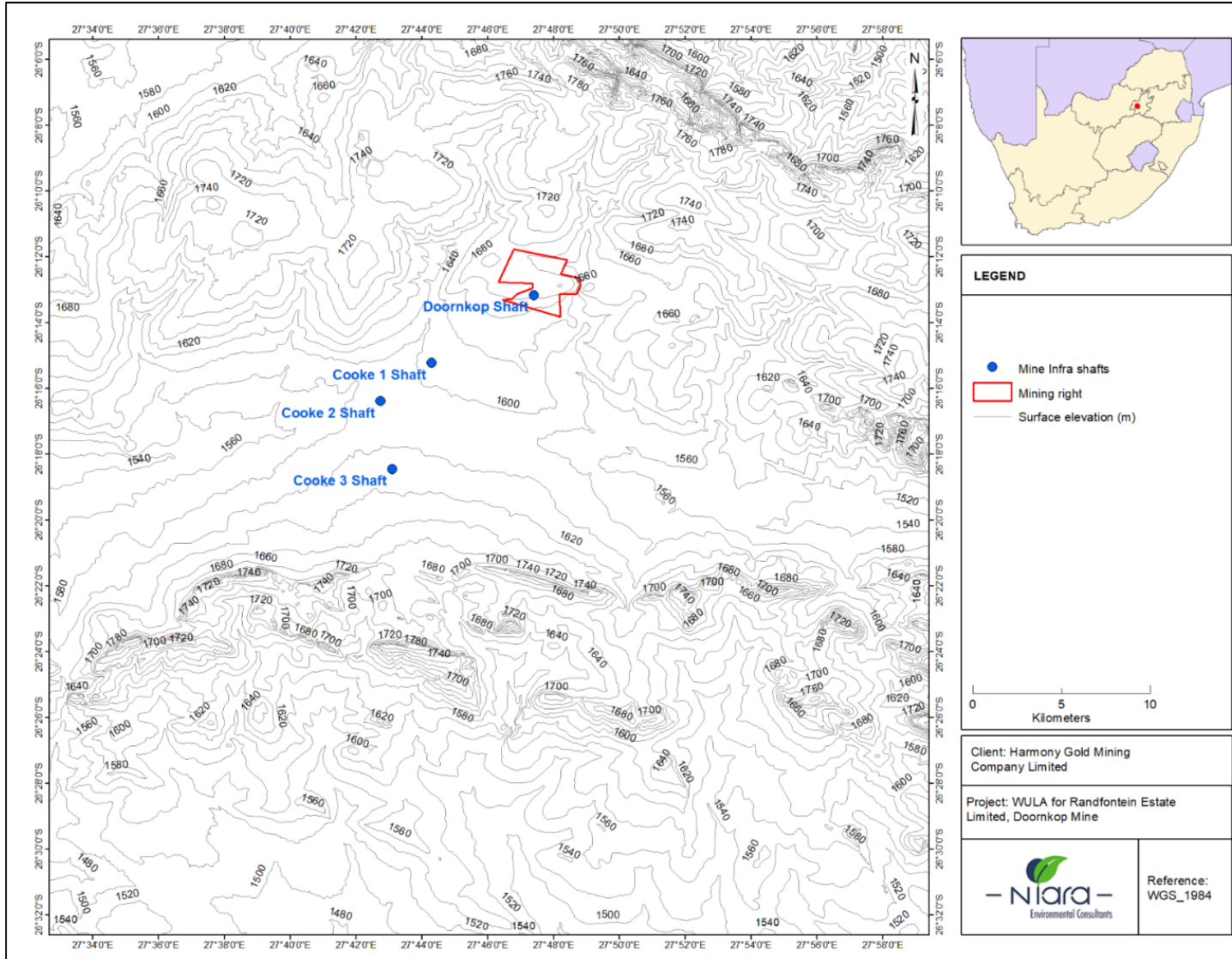


Figure 2-2: Surface elevation (b).



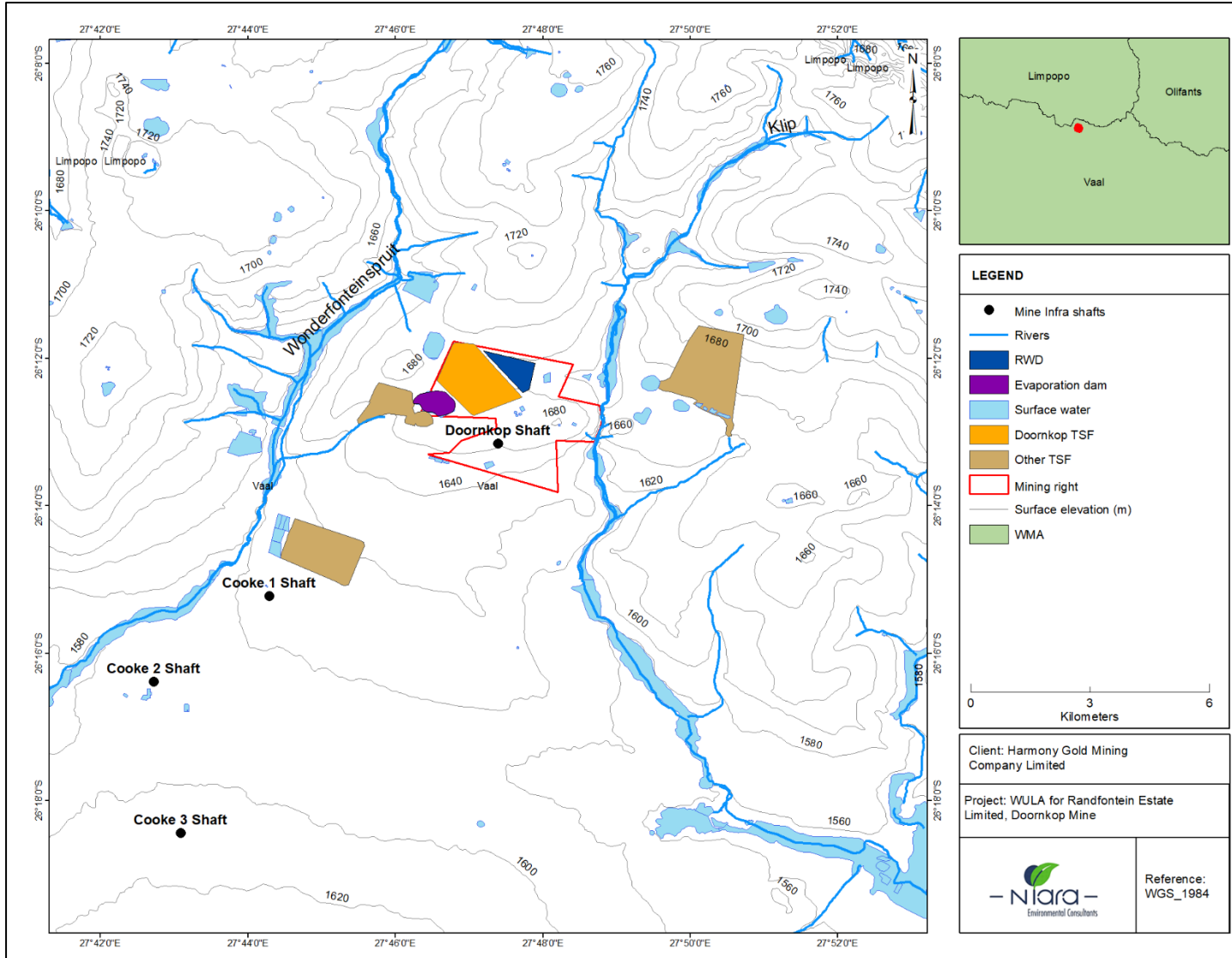


Figure 2-3: Map showing drainage features.



2.2. Climate

Doornkop Mine falls in the Southern African Highveld climate region. The area is classified as a warm temperate climate zone with dry winters. Summer in the region is characterised by warm to hot temperature while winter is cold with warm sunny days and frosty night. Temperature reaches a minimum of -3 °C and a maximum of 16 °C in July. Temperature is high and hot during the month of January, with a minimum of 15.5 °C and maximum of 29.9 °C. Average monthly temperature varies from 6.5 °C to 22.7 °C during the months of July and January respectively (Table 2-1 and Figure 2-4).

Table 2-1: Mean monthly, maximum, and minimum temperatures.

Months	*Minimum (°C)	*Maximum (°C)	Average (°C)
January	15.5	29.9	22.7
February	12.6	27.1	19.85
March	7.1	25.1	16.1
April	7.1	23.6	15.35
May	3.1	21	12.05
June	-1.4	18.1	8.35
July	-3	16	6.5
August	-0.6	22.4	10.9
September	5.5	25.3	15.4
October	10.4	26.6	18.5
November	9.1	29.1	19.1
December	13.1	29.8	21.45

*de Giessen, 2021

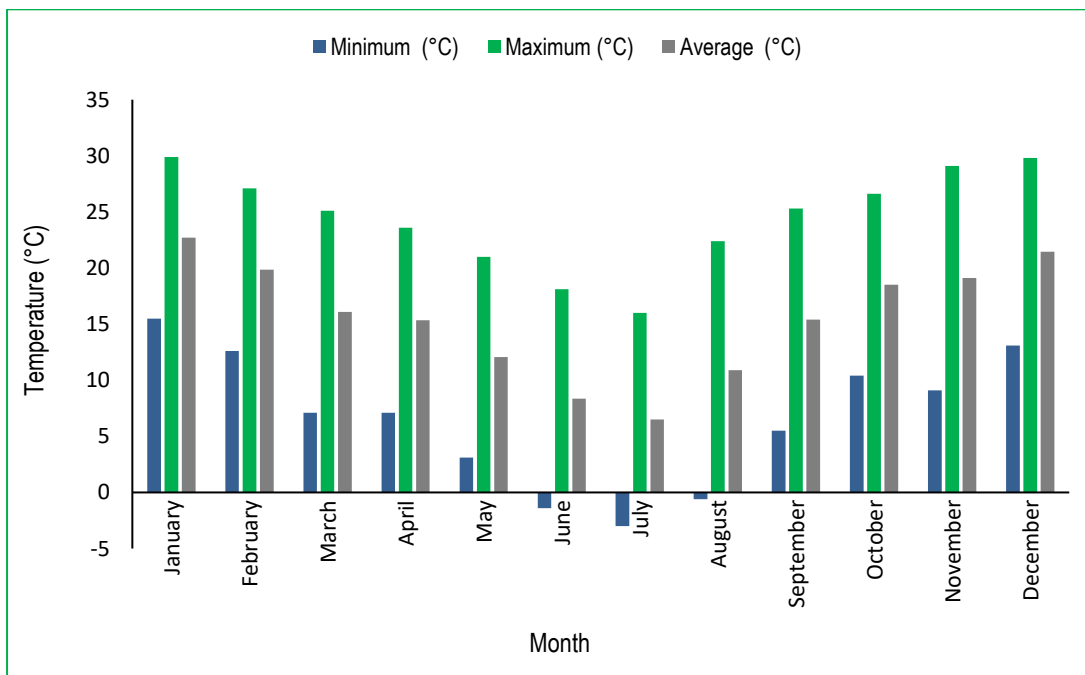


Figure 2-4: Mean monthly, maximum, and minimum temperatures.



The region falls in the summer rainfall area, with average annual rainfall of 675 mm/annum. 85% of rainfall in the region occurs between October and March, with the highest rainfall of 120 mm recorded in January. Evaporation varies from 88 mm in June to 265 mm in December, with annual evaporation of 2054 mm/annum. The region has an annual evaporation that exceeds annual rainfall (Table 2-2 and Figure 2-5).

Table 2-2: Mean monthly rainfall and evaporation ("A" pan) (Shangoni, 2008; Van Biljon, 2013).

Months	Average monthly rainfall (mm)	Average monthly evaporation (mm)
January	120	214
February	95	182
March	81	173
April	49	125
May	15	109
June	7	88
July	4	100
August	7	144
September	20	204
October	69	240
November	100	210
December	108	265
Annual Total	675	2054

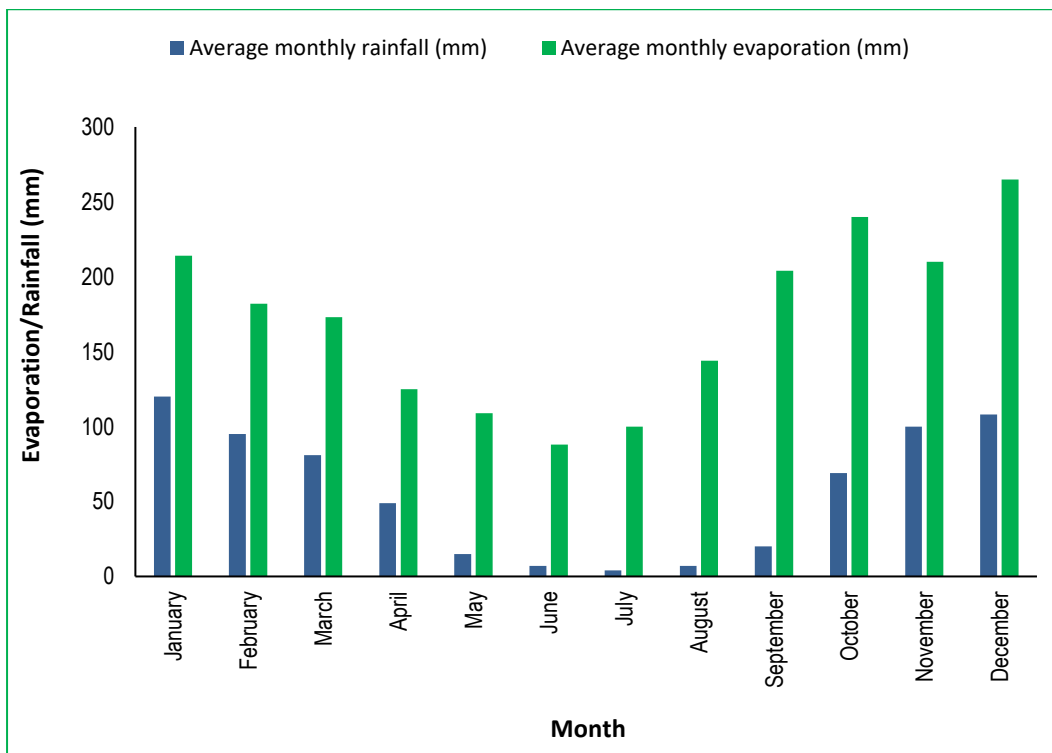


Figure 2-5: Mean monthly rainfall and evaporation ("A" pan).



3. Scope of Work

3.1. Scope of Work

The scope of work for the hydrogeological study entail conducting hydrogeological study in line with regulatory requirements. The following scope of work was covered:

- ✔ Introduction and background of the study – objectives, scope of work, methodology and description of the study area.
- ✔ Description of the climate, rainfall, evaporation, temperature, topography, and drainage.
- ✔ Description of the geological setting including regional geology, local Geology, and structural Geology.
- ✔ Description of the hydrogeology including aquifer type, aquifer yield, groundwater level, groundwater flow and groundwater quality and aquifer parameters
- ✔ Characterisation and description of the groundwater potential contaminants including contamination sources, pathways, and receptors.
- ✔ Characterisation of acid generation material, groundwater quality and associated impacts.
- ✔ Description of geophysical survey results, drilling results and pump testing data.
- ✔ Description of aquifer characterisation including aquifer classification, aquifer vulnerability and aquifer Susceptibility.
- ✔ Description of groundwater monitoring plan including monitoring network, monitoring frequency and monitoring parameters.
- ✔ Conduct groundwater modelling.
- ✔ Description of post closure management plan, groundwater potential contaminants, geohydrological Impacts and groundwater environmental management programme.

3.2. Study Objectives

The main objective of the study is to conduct hydrogeological study that includes a baseline impact assessment. The following objectives were critical for the study.

- ✔ To compile geological and hydrogeological aspects of the mine.
- ✔ To simulate groundwater model focusing on impact predictions.
- ✔ To evaluate the status of groundwater quality and associated impacts.
- ✔ To evaluate potential impacts associated with the mine activities.
- ✔ To identify gaps and update the current hydrogeological study.



4. Methodology

4.1. Desk study

A comprehensive desktop study was conducted, entailing the gathering of information from maps, reports and previous studies conducted for Doornkop Mine and in the vicinity of the mine site. The aim of this task was to collect and review available information regarding hydrogeological and associated aspects. Reports, journal, and publicly available documents were reviewed. This included reviewing information that includes (but not limited to):

- ✔ Hydrogeological maps, data, brochures, reports, shapefiles, journals article and related information.
- ✔ Geological map, data, brochures, reports, shapefiles, journals article and related information.
- ✔ Previous geophysical data, information, and reports.
- ✔ Topographic maps.
- ✔ Satellite images (Google Earth).
- ✔ Drilling, core logs and overall geology information.
- ✔ Groundwater data and information.
- ✔ Borehole data and coordinate.
- ✔ Water chemistry and natural background concentration.
- ✔ 1:50 000 Topographic Map.
- ✔ 1:250 000 Geology Map Series.
- ✔ 1:500 000 General Hydrogeological Map Sheet.
- ✔ 1:500 000 General Hydrogeological Map Brochure.

Detail references regarding all sources which were used for this assessment are included in the reference section. This data and information were reviewed where data gaps were identified. Available information was then used in the compilation of the draft and final hydrogeological impact assessment study that highlight potential impacts.

4.2. Hydro –census

Hydro census survey was not conducted as part of the investigation. The mine has an existing monitoring borehole network with groundwater level and chemistry data, which was provided for review. Drilling logs for the monitoring boreholes that shows water strikes, depth and static water level were reviewed. The following provide summary of boreholes (Table 4-1):



Table 4-1: Available borehole

Borehole ID	Latitude	Longitude	Elevation (mamsl)	Depth (m)	SWL (mbgl)	SWL (mamsl)	Purpose
DKP1	-26.19135	27.77329	1677	36	3.21	1669.37	Monitoring
DKP3	-26.21286	27.78848	1671	27	2.41	1662.94	Monitoring
DKP4	-26.22042	27.7995	1661	30	9.98	1644.88	Monitoring
DKP6	-26.22458	27.78913	1656	18	13.84	1649.24	Monitoring
DKP7	-26.20712	27.77593	1671	33	11.85	1640.27	Monitoring
DKP8	-26.20797	27.79432	1664	21	4.18	1660.48	Monitoring
DK 13	-26.2056	27.802	1655		2.11	1651.7	Monitoring

4.3. Geophysical survey and results

A geophysical survey was conducted at the operation. For the detailed assessment, methodology, interpretation, and recommendations, refer to Appendix 1.

4.3.1. Objectives of the study

- ☛ The main objectives of the study were to conduct a geophysical survey for monitoring boreholes in line with DWS recommendations.
- ☛ Conduct a geophysical survey to expand the current monitoring program.

4.3.2. Methodology

The survey followed a general approach which is to conduct a series of desktop studies of literature review, field investigation, interpretations, and recommendations. The following provide a summary of the field survey:

- ☛ Investigation was conducted with the aim to identify preferential flow paths and geological structures such as weathering and fracturing.
- ☛ The resistivity method was used for the survey. The mine is partially located within residential areas which limits the number of methods to be used for the survey.
- ☛ In total, six traverses were conducted where a 10 m electrode spacing was used (Figure 4-1).
- ☛ These traverses were conducted at different orientation.
- ☛ The traverse line was placed perpendicular to the targeted geological structure.
- ☛ The results were interpreted using a 2D resistivity model.





Figure 4-1: Resistivity traverse's map.



4.3.3. Geophysical results

Traverse DOK 1

- 🌿 Survey was conducted for a traverse line of 400 m on the northern side of TSF area.
- 🌿 Weathering or moist zones were identified which was associated with less resistivity.
- 🌿 Target for drilling was identified which correspond with station 240.
- 🌿 The following diagram depict the model result for Traverse DOK 1.

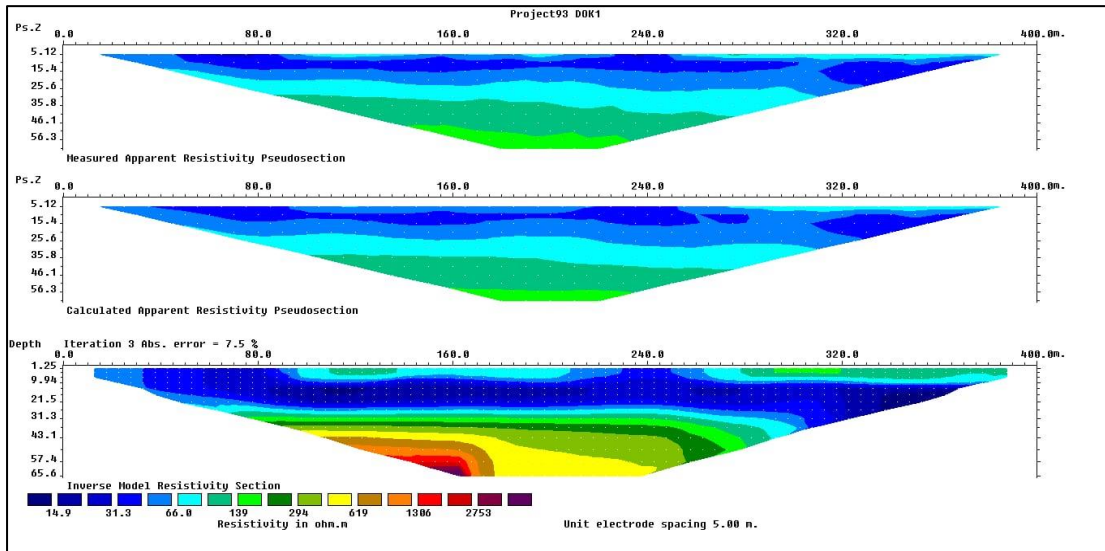


Figure 4-1: Traverse DOK1 profile

Traverse DOK 2

- 🌿 The survey was conducted for a traverse line of 400 m on the western side of the TSF.
- 🌿 Weathered zone or moist zones was identified at traverse station number 350.
- 🌿 Drilling target was selected at this point, traverse station number 350.
- 🌿 The following diagram depict the result of this survey line.



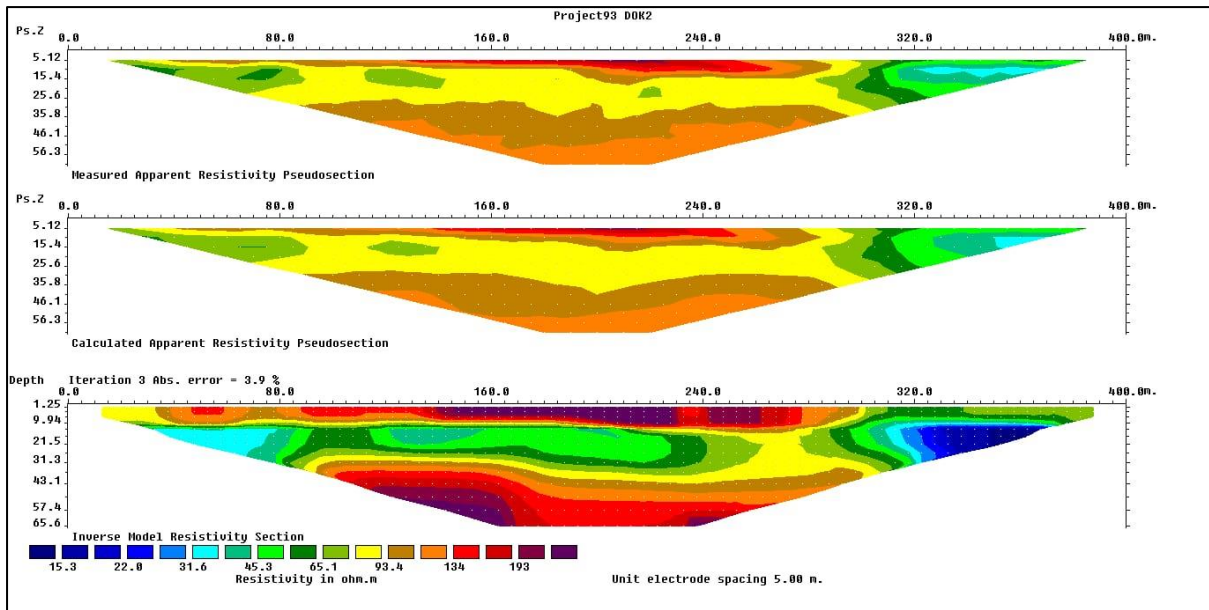


Figure 4-2: Traverse DOK 2 profile

Traverse DOK 4

- 🌿 This survey was conducted to the south of evaporation pan.
- 🌿 The survey line or traverse line was approximately 500 m in length from west to east.
- 🌿 Less resistivity zones that are interpreted as moist zones or weathered zones were identified at station 220.
- 🌿 This zone was selected as a target for drilling of a monitoring borehole.

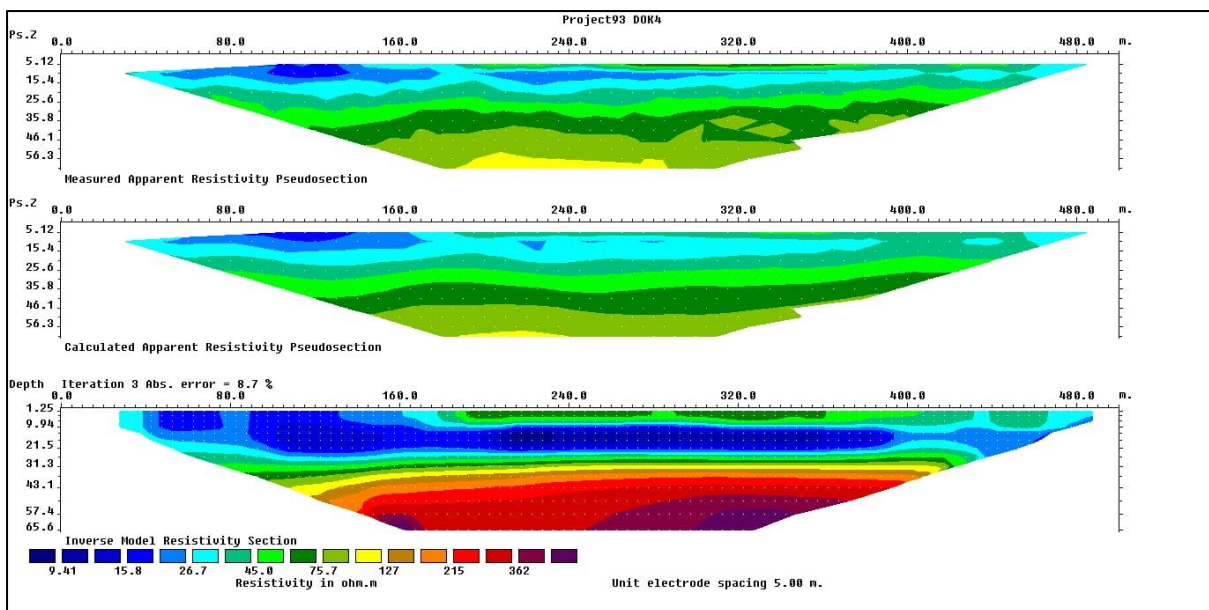


Figure 4-3: Traverse DOK 4 profile.



Traverse DOK 5

- ✔ Traverse DOK 5 was about 400 m in length, which was conducted to the east of the TSF.
- ✔ A geological structure was identified which was intersected with the survey.
- ✔ This structure is located between the traverse station number 200 to 240.
- ✔ Least resistivity zone was also identified within the same traverse line between station number 250 to 400.
- ✔ These zones are interpreted as weathered zones or zones characterised by moist zones.
- ✔ Traverse station number 320 was selected as a target for drilling of a monitoring borehole.
- ✔ The following diagram shows the survey results.

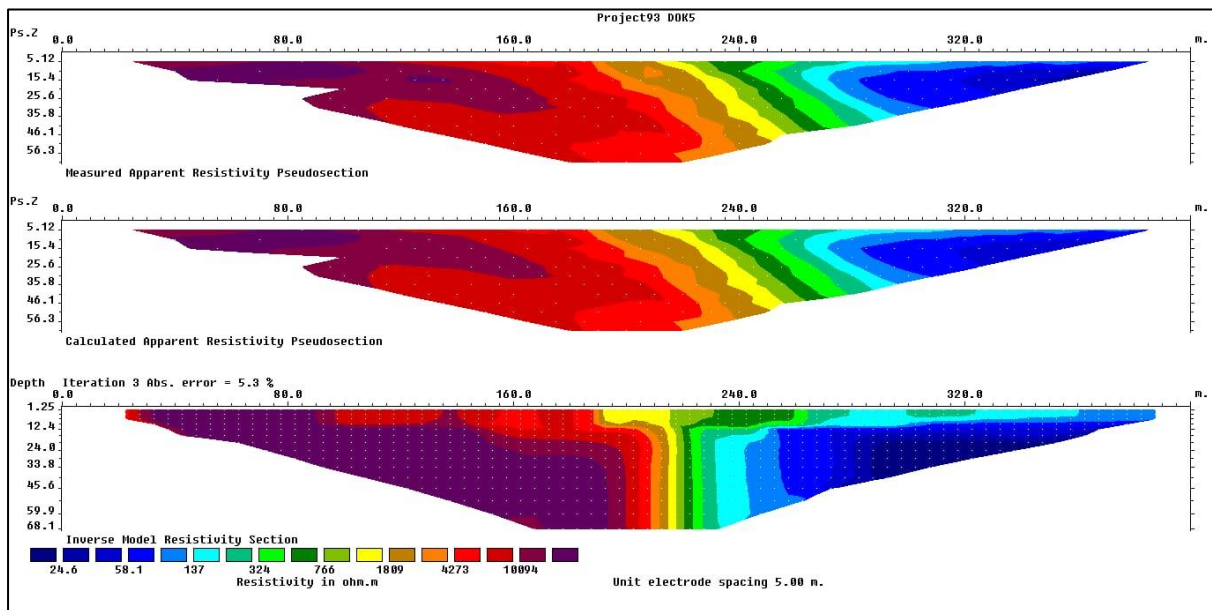


Figure 4-4: Traverse DOK 5 profile

Traverse DOK 6

- ✔ A short traverse line compared to other traverse was conducted for 300 m.
- ✔ This traverse was conducted to the east of the TSF, with an orientation from south to north.
- ✔ Geological structures such as contact zones of rocks was detected by the survey.
- ✔ Drilling target was selected at traverse station number 100.
- ✔ The survey results are shown in the following diagram.



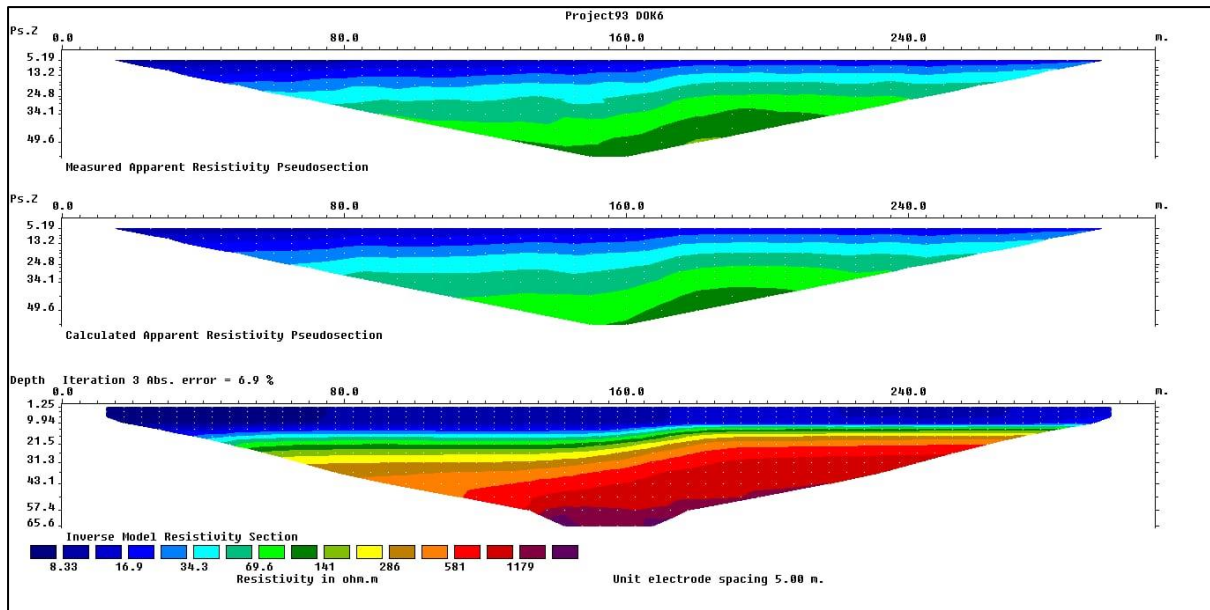


Figure 4-5: Traverse DOK 6 profile

Traverse DOK 8

- 🌿 The final traverse line was conducted north of the RWD.
- 🌿 The traverse was conducted for a line of 600 m from east to west.
- 🌿 Moist or weathered zones were identified because of low resistivity.
- 🌿 Survey station number 240 was selected as a drilling target.
- 🌿 The following diagram depict the survey result of this traverse line.

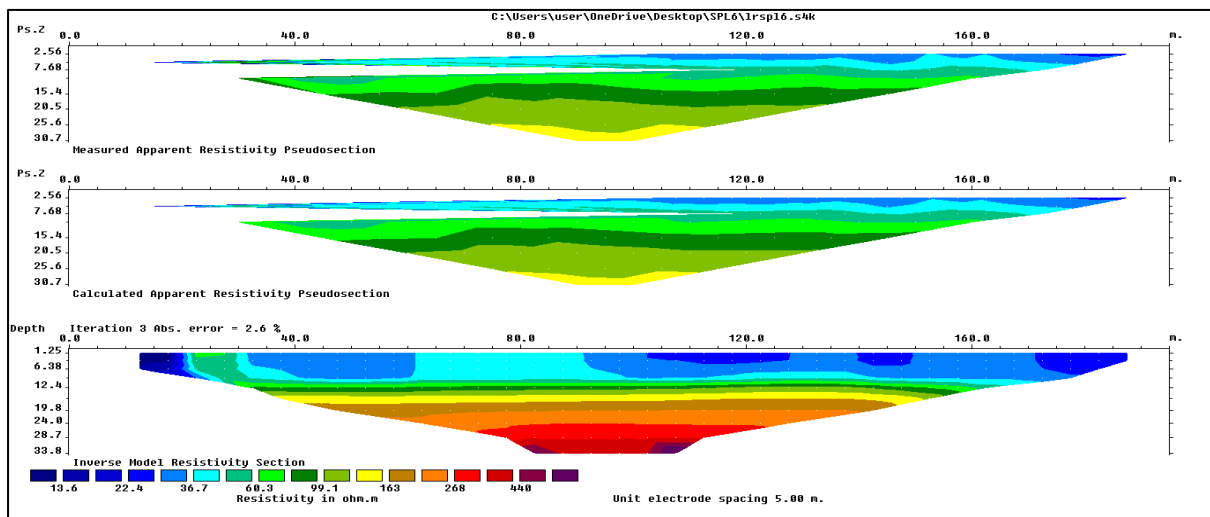


Figure 4-6: Traverse DOK 8 profile



4.3.4. Drilling target

In total, six drilling target have been selected for drilling of monitoring boreholes. Table 4-2 shows the traverse name together with a latitude-longitude coordinate system. These sites have been recommended by the geophysical survey report for drilling of monitoring boreholes.

Table 4-2: Summary of proposed drilling targets

Traverse	Longitude	Latitude	Geophysics Peg	Borehole Number
DOK1	27.78620	-26.19755	240	HDKBH1
DOK2	27.77704	-26.20098	350	HDKBH2
DOK4	27.77957	-26.21343	220	HBKBH4
DOK5	27.80028	-26.21087	320	HDKBH5
DOK6	27.81142	-26.20673	100	HDKBH6
DOK8	27.79712	-26.19974	220	HDKBH7

4.3.5. Geophysical survey recommendations

- ☛ Rotary air percussion must be used for drilling. The work must be done in accordance with DWS minimum standards.
- ☛ Drilling must be supervised by a professional hydrogeologist.
- ☛ Information to be collected must include drilling chip logging and water strikes.
- ☛ The boreholes must be tested after drilling.

4.4. Aquifer testing

Table 4-3 provides a summary of calculated transmissivity and hydraulic conductivity (Appendix 3). In general, hydraulic conductivity of the site varies from 0.04 m/day to 0.39 m/day. Transmissivity of the site varies from 1.1 m²/day to 3.5 m²/day. The site is characterised by low aquifer parameters based on the calculations. Two boreholes are located within the quartzite while three are located within the lava. These parameters are the driving force behind groundwater flow and contaminant transport. Doornkop area is characterised by very low aquifer parameters, which translates to slow movement of groundwater and spread of contamination plume.

Table 4-3: Transmissivity and hydraulic conductivity of the site.

Borehole ID	Depth (m)	T (m ² /day)	K (m/day)	Aquifer material
DKP1	36	1.1	0.04	Quartzite
DKP3	27	1.1	0.06	Lava
DKP4	30	3.5	0.35	Quartzite
DKP6	18	3.5	0.39	Lava
DKP8	21	3	0.19	Lava
Min	18	1.1	0.04	
Max	36	3.5	0.39	



4.5. Sampling and chemical analysis

Doornkop Mine has an ongoing groundwater monitoring program (Refers to monitoring section for additional details). Groundwater sampling and analysis is conducted in a quarterly basis for groundwater quality. All seven boreholes are currently being monitored. Samples are collected and submitted to an accredited laboratory for determination of physical, chemicals and microbiological parameters. The lab results are then compared to the South African National Standards of Drinking water (SANS) (SABS, 2006; 2015). Table 4-4 and Table 4-5 provides the summary of the standard limits.

Table 4-4: Standard limits for physical, chemical microbiological determinands (SABS, 2006; 2015).

Physical and chemical determinands		
	Unit	Standard Limits
pH @ 25°C	pH	5.0 - 9.7
Electrical conductivity (EC) @ 25°C	mS/m	170
Total Dissolved solids @ 180°C	mg/l	1200
Sulphate (SO ₄)	mg/l	500
Fluoride (F)	mg/l	1.5
Ammonium (NH ₄) as N	mg/l	1.5
Ammonia	mg/l	1.5
Nitrate (NO ₃) as N	mg/l	11
Iron (Fe)	mg/l	0.3
Sodium (Na)	mg/l	200
Magnesium (Mg)	mg/l	100
Calcium (Ca)	mg/l	300
Chloride (Cl)	mg/l	300
Manganese (Mn)	mg/l	0.1
Boron (B)	mg/l	2.4
Free chlorine (Cl ₂)	mg/l	5
Chromium (Cr)	mg/l	0.005
Aluminium (Al)	mg/l	0.3
Copper (Cu)	mg/l	0.01
Cadmium (Cd)	mg/l	0.07
Iron (Fe)	mg/l	5
Lead (Pb)	mg/l	0.01
Nickel (Ni)	mg/l	0.07
Zinc (Zn)	mg/l	5
Arsenic (As)	mg/l	0.01
Mercury (HG)	mg/l	0.006
Dissolved Uranium (U)	mg/l	0.03
Free Cyanide (CN)	mg/l	-
Cyanide WAD (CN)	mg/l	-
Chemical oxygen demand (COD)	mg/l	0.2
Dissolved oxygen (DO)	mg/l	-



Table 4-5: Standard limits for physical, chemical microbiological determinands (SABS, 2015).

Microbiological determinands		
Total coliform	CFU/100ml	10
E. coli	CFU/100ml	0

4.6. Groundwater recharge calculations

Groundwater recharge was calculated using the groundwater recharge program developed by van Tonder and Xu (2000). This program provides the basis for estimation of groundwater recharge. The amount of rainfall that enters or reaches the water table is dependent on various factors such as the amount of rainfall or precipitation, topography, vegetation, land use, soil characteristics and geology. The groundwater recharge program was developed based on these characteristics. The following is the summary of parameters considered.

- 🌿 Geology: recharge based on rock types.
- 🌿 Soil: recharge based on soil, %clay and vegetation.

Historical recharge has been conducted by various scientists and these were also considered. This includes:

- 🌿 Groundwater recharge by Vegter (1995) and Schulze.
- 🌿 ACRU recharge by Roland Schulze.
- 🌿 Harvest potential of South Africa.

Estimated recharge for the study area ranges from 3% to 20% of the annual rainfall, with an average of 5%. This translates to 31.77 mm recharge per annum. Doornkop Mine falls under C22A quaternary drainage region. According to the Department of Water Affairs and Forestry (DWA, 2005), this quaternary catchment is characterised by groundwater recharge of 32.62 mm/a (Table 4-6).

Table 4-6: Groundwater recharge calculations.

Name of Expert	% Recharge	Recharge (mm/a)	Weight (1 - 5)
Soil	20	135	1
Geology	3.6	24.3	4
Vegter	4.7	31.725	3
Acru	3	20.25	4
Harvest Potential	3.7	24.975	4
Average =	4.7	31.77	



4.7. Groundwater modelling

Groundwater modelling was constructed based on Model Muse and Modflow 6. The detail methodology is provided under the groundwater modelling section. The aim of conducting groundwater modelling is to predict current and future impacts associated with mining activities. The following steps were considered in the construction of the model:

- ✔ Development of the conceptual model.
- ✔ Simulation of groundwater flow model.
- ✔ Simulation of contamination plume/contaminant transport.
- ✔ Prediction of mine water inflow.

The model was constructed based on site specific data and information. This model incorporated site-specific information and data such as:

- ✔ Aquifer deposit in the form of layers.
- ✔ Groundwater recharge.
- ✔ Evapotranspiration.
- ✔ Hydraulic conductivity.
- ✔ Porosity.
- ✔ Concentration of SO₄.
- ✔ Aquifer thickness.
- ✔ Rivers.

Based on the available and previous data, reports, maps, current monitoring data and information, a numerical model was developed to provide a detailed understanding of the flow, contamination plume and possible pathways or preferential flow path of the contamination in the area. This model was then calibrated based on available data.



5. Prevailing groundwater conditions - site specific

5.1. Geology

5.1.1. Regional geology

Regional geology of the area is chronologically divided into:

- ✔ Witwatersrand Supergroup.
- ✔ Ventersdorp Supergroup.
- ✔ Transvaal Supergroup.
- ✔ Karoo Supergroup.

5.1.1.1. Witwatersrand Supergroup

The Witwatersrand Supergroup was deposited between 2300 Ma and 2800 Ma. The supergroup extends to a depth of more than 4 000 m, with angle of between 10° and 50° which dips towards the south. Angle of up to 80° was recorded in mine workings close to gold reef exposure (SACS, 1980). The Witwatersrand Supergroup overlies and covers the basement rocks, especially the Archaean granitoids sequence as well as the Dominion Group (Johnson et al., 2006). The supergroup is overlain by the Ventersdorp, Transvaal, and Karoo Supergroup. The Witwatersrand Supergroup is covered by rocks of the Transvaal and Karoo Supergroups in most of its occurrence (Visser, 1989). According to SACS (1980), the supergroup is divided into West Rand Group and Central Rand Group.

West Rand Group

The West Rand Group is classified as the older and lower deposit at the base of the Supergroup. The group consist of Jeppestown, Government and Hospital Hill Subgroups. Hospital Hill Subgroups attains a thickness of 1 500 m. The Orange Grove Formation forms the base of the group and is composed of quartzite and subordinate shale. The Orange Grove Formation is overlain by Parktown Formation which consist of shale at the base and quartzite at its top. Brixton Formation is composed of three quartzite unit separated by shale deposit (SACS, 1980; Visser, 1989; Johnson et al., 2006). The bonanza Formation marks the top deposit with thin conglomerate.

The Government Subgroup is characterised by wide diversity of deposit that attains a maximum thickness of 1 930 m. The Subgroup is composed by Promise Formation at the base. This formation comprises of quartzite, thin bed of shale and Promise Reef, a conglomerate layer. Promise Formation is followed by Coronation Formation which consist of back strongly magnetic shale. This formation is followed by Tusscheinin, Palmietfontein, Elandslaagte and Afrikander Formation which forms the top (Johnson et al., 2006). These formations consist of shale and quartzite.



The Jeppestown Subgroup form the top deposit of the West Rand Group. The subgroup has a thickness of 1 140 m and is subdivided into Koedoeslaagte at the base, followed by Rietkuil, Babrosco, Crown, Roodepoort and Maraisburg Formation which forms the top. The Koedoeslaagte Formation is characterised by conglomerate followed by the quartzite and shale unit of the Rietkuil Formation. The quartzite deposit of the Babrosco Formation is covered by 250 m thick deport of Crown Formation. This unit is dominated by basaltic andesite which covers most of West Rand outcrop (Johnson et al., 2006). This formation is followed by the quartzite unit of the Roodepoort and Maraisburg Formation.

Central Rand Group

The Central Rand Group is composed of quartzite, conglomerate, and shale. The group differs fundamentally from the West Rand Group. Unlike the West Rand Group with quartzite: shale ration of 1, the Central Rand Group has a quartzite: shale ratio of 12:6. Conglomerate of the Central Rand Group has produced most of the gold extracted from the Witwatersrand Basin apart from the Ventersdorp Contact Reef (Johnson et al., 2006). The Central Rand Group is classified as the top or upper deposit of the Witwatersrand Supergroup. The group is subdivided into Johannesburg and Turffontein Subgroup.

The Johannesburg Subgroup is composed predominantly of quartzite. Blyvooruitzicht Formation Form the base with conglomerate deposit. This formation is overlain by the Main Formation comprising of conglomerate beds namely the main reef, leader reef and south reef. These reefs deposit was followed by series of erosive episode where the erosive channel was filled with exposed Jeppestown sediments. This event resulted in the deposition of Randfontein, Luipaardvlei and Krugersdorp Formation. These formations consist of quartzite. The Booyens Formation which forms the top is composed of shale that separate the Johannesburg and Turffontein subgroups (Johnson et al., 2006).

The Turffontein Subgroup represent the final phase of deposition. This subgroup is subdivided into Kimberly, Elsburg and Mondeor Formation (Johnson et al., 2006). The Kimberly Formation is composed of conglomerate beds where the Kimberly reef occurs towards the top. This formation is followed by quartzite of the Elsburg Formation where the UE1A/Composite Reefs has developed. The upper deposit consists of coarse conglomerate of the Mondeor Formation (Visser, 1989; Johnson et al., 2006).

5.1.1.2. Ventersdorp Supergroup

The Ventersdorp Supergroup is approximately 750 m long and 350 km wide with an extent of approximately 300 000 km² (Johnson et al., 2006). The supergroup rests unconformably on the Witwatersrand Supergroup. It is divided into Klipriviersberg Group and Rietgat Formation. The Klipriviersberg group overlies the Turffontein Subgroup of the Central Rand Group and forms the base of the supergroup (Table 5-1 and Figure 5-1). The group attains a thickness of approximately 1831 m consisting of tholeiitic basalt (SACS, 1980). The Klipriviersberg group is subdivided into Venterspost, Westonaria, Alberton, Orkney, Loraine, and Edenville Formation (Johnson et al., 2006). Rietgat Formation form part of the Platberg Group. The formation rest unconformably on the Klipriviersberg



Group and attains a thickness of approximately 1 700 m. The formation comprises of Chert and tuff (SACS, 1980; Johnson et al., 2006).

Transvaal Supergroup

The Transvaal Supergroup rests conformably on the older rocks of the Ventersdorp Supergroup. The supergroup was deposited on the eroded surface of the underlying Ventersdorp Supergroup. This supergroup is subdivided into the Black Reef Formation, Wolkberg, Godwana, Chuniespoort and Pretoria Groups (Hartzer, 1995). In the study area, only the Black Reef Formation and Malmani Subgroup of the Chuniespoort Group which are deposited. Surface exposure of this deposit is evident in the south of the mining right area, with large outcrop of Malmani Subgroup (Table 5-1 and Figure 5-1).

The Black Reef Formation rests unconformably on the rocks of the Ventersdorp Supergroup. This formation consists of quartzite, conglomerate, and shale. The formation attains a thickness of 35 m, with 9 m thickness measured near Krugersdorp (SACS, 1980; Kafri et al., 1986). It is characterised by unit of conglomerate at the base and shale at the top. The Black Reef Formation comprises of shallow dips.

Malmani Subgroup, also referred to as Malmani dolomite of the Chuniespoort Group, consist predominantly of dolomite. The subgroup also comprises of chert, carbonaceous shale, limestone, and quartzite. The subgroup attains a thickness of approximately 1 200 m (Swart et al., 2003; Lin et al., 2014). It is subdivided into Oaktree, Monte Christo, Lyttelton, Eccles and Frisco Formation. Oaktree Formation attains a thickness of 10 m to 200 m consisting of shale, dolomite, and quartzite. The unit forms the base, overlying the Black Reef Formation (Johnson et al., 2006).

The Christo Formation is composed of dolomite rocks and overlies the Oaktree Formation. The formation has a thickness of 300 m to 500 m. This formation is followed by quartzite, shale, and dolomite deposit of the Lyttelton Formation. The formation has a thickness that varies from 100 m to 200 m. It is followed by Eccles Formation with a thickness of up to 600 m. The Eccles Formation comprises of breccia that separate the formation with the top deposit, the Frisco Formation which forms the upper formation of the Malmani Subgroup. The formation has a thickness of up to 400 m of dolomite that becomes more shale towards the top (Johnson et al., 2006).

Karoo Supergroup

The Karoo Supergroup forms the youngest geological deposit in the Doornkop Mining right area. The Supergroup consist of the Main Karoo Basin and significant deposit which include Tuli, Springbok flats, Tshipise and Elliras Basin. The supergroup has a thickness of 12 km mainly in the southeastern portion of the Main Karoo Basin. Large geological portion of the supergroup is covered by the Main Karoo with an area of approximately 700 000 km². These basins range in age from late carboniferous to middle Jurassic (Johnson et al., 2006).



The Karoo Supergroup is subdivided into different geological groups that includes Drakensberg and Lebombo Groups, Molteno, Elliot and Clarens Formations, Beaufort Group, Eccca Group and Dwyka Group. Only Dwyka Group which is present in the study area. The Dwyka Group is composed of diamictite, shale and mudrocks. The Group form the base of the Karoo Supergroup. The occurrence of this group in some locality is patchy and consist of uneven floor. The group attains a thickness of approximately 15 m thick. In the study area, Dwyka Group covers rocks of the Transvaal Supergroup.

5.1.2. Local geology

Surface outcrop occurring within the area includes:

- ✔ Jeppestown Subgroup.
- ✔ Johannesburg Subgroup.
- ✔ Turffontein Subgroup.
- ✔ Klipriviersberg Group.
- ✔ Rietgat Formation.
- ✔ Black Reef Formation.
- ✔ Malmani Subgroup (Dolomite).
- ✔ Vaalian diabase.
- ✔ Dwyka Group.

Table 5-1 shows lithostratigraphic units while Figure 5-1 shows the distribution of these geological outcrops. Jeppestown Subgroup shows an outcrop north of the mining right area. This subgroup occurs below the Johannesburg Subgroup within the shaft area. An outcrop of Johannesburg Subgroup occurs to the north and centre of the mining right area. Large portion of surface outcrop within the mining right area is covered by Klipriviersberg group and Malmani subgroup (dolomite).

Table 5-1: Lithostratigraphic unit and surface geology.

Lithostratigraphic Unit		Major lithology
Karoo Supergroup	Dwyka Group	Diamictite, shale, mudstone
Transvaal Supergroup	Vaalian diabase	Diabase
	Malmani Subgroup	Dolomite, chert, carbonaceous shale, limestone, and quartzite
	Black Reef Formation	Quartzite, conglomerate, shale
Ventersdorp Supergroup	Rietgat Formation	Chert and tuff
	Klipriviersberg Group	Tholeiitic basalt
Witwatersrand Supergroup	Turffontein Subgroup	Quartzite and conglomerate
	Johannesburg Subgroup	Shale, quartzite, lava, conglomerate
	Jeppestown Subgroup	Shale, quartzite, lava, and conglomerate
Dominion Group and Archaean granitoids sequence		



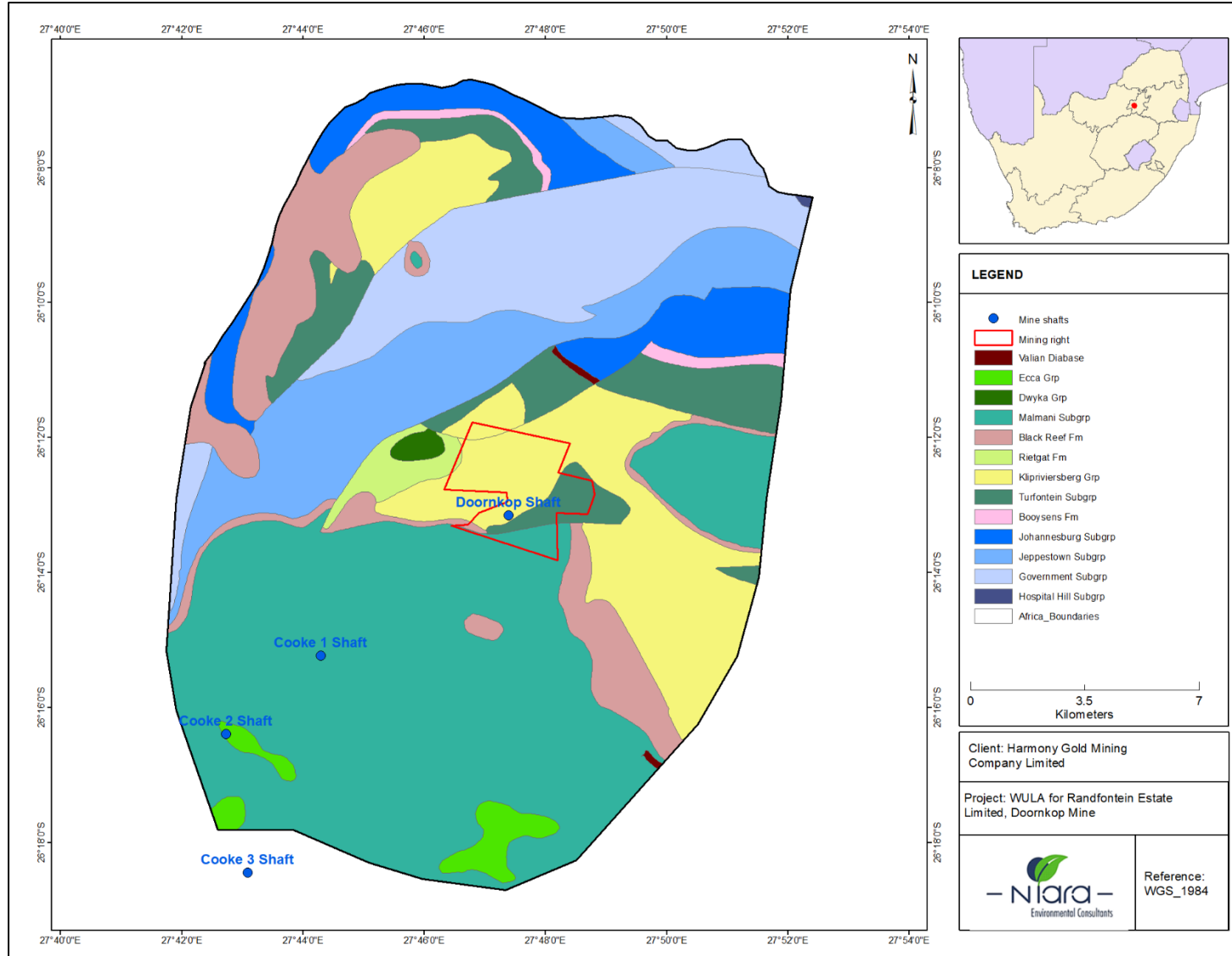


Figure 5-1: Map showing surface geology.



Dolomite covers the southern portion of the mining right area. This deposit covers the upper portion of the mining right area to the south (Figure 5-1 and Figure 5-2). According to Balta and Gravea (2007), surface overburden is characterised by decomposed dolomite and leached chert. Oxidised dolomite was noted on the first 200 m of dolomite deposit. This dolomite is underlain by a layer of decomposed shale in the area (Black Reef Formation). On the northern portion, the Klipriviersberg group overlies the Turfontein subgroup whereas the Black Reef shale separates the dolomite and Turfontein subgroup. Black Reef shale directly overlies the Turfontein subgroup.

The underlying geology is characterised by major zones or reefs of the Witwatersrand Basin due to the occurrence of upper Witwatersrand deposit (Figure 5-2). The Witwatersrand Supergroup remains one of the well documented and well studied geological deposit. This is due to extensive mining activities and its rich gold deposit that has attracted much attention. The supergroup host one of the largest goldfields in the world, the Witwatersrand Basin which yielded more than 52 000 tonnes of gold to date.

The economic reefs are present in the mining right area. These are:

-  Upper Elsburg
-  Middle Elsburg
-  The Kimberleys.
-  The Black Reef.
-  The Livingstone Reefs.
-  The Ventersdorp Contact Reef (the “VCR”).
-  The South Reef.

These reefs consist of fine to coarse grained pyritic mineralisation. The Kimberley Reef and South Reef are considered viable for mining. These reefs have been mined at depth between 500 m and 2 000 m below surface. The Kimberly Reefs occurs in the Vlakfontein Member of the Westenaria Formation. This formation comprises of four complex deposits, all characterised by upper conglomerate and lower quartzite of variable grades (Harmony, 2009).

Mining commenced with the Kimberly Reef on the upper level and expanded to South Reef which is approximately 900 m below the Kimberly Reef. The South Reef is deposited above the Main Reef and is between 7.5 m to 60 m above the Main Reef. The hanging wall and footwall of the South Reef is characterised by siliceous quartzite. Strike direction of the reefs is from east to west, with an angle that varies from 5° to 15° (Harmony, 2021).



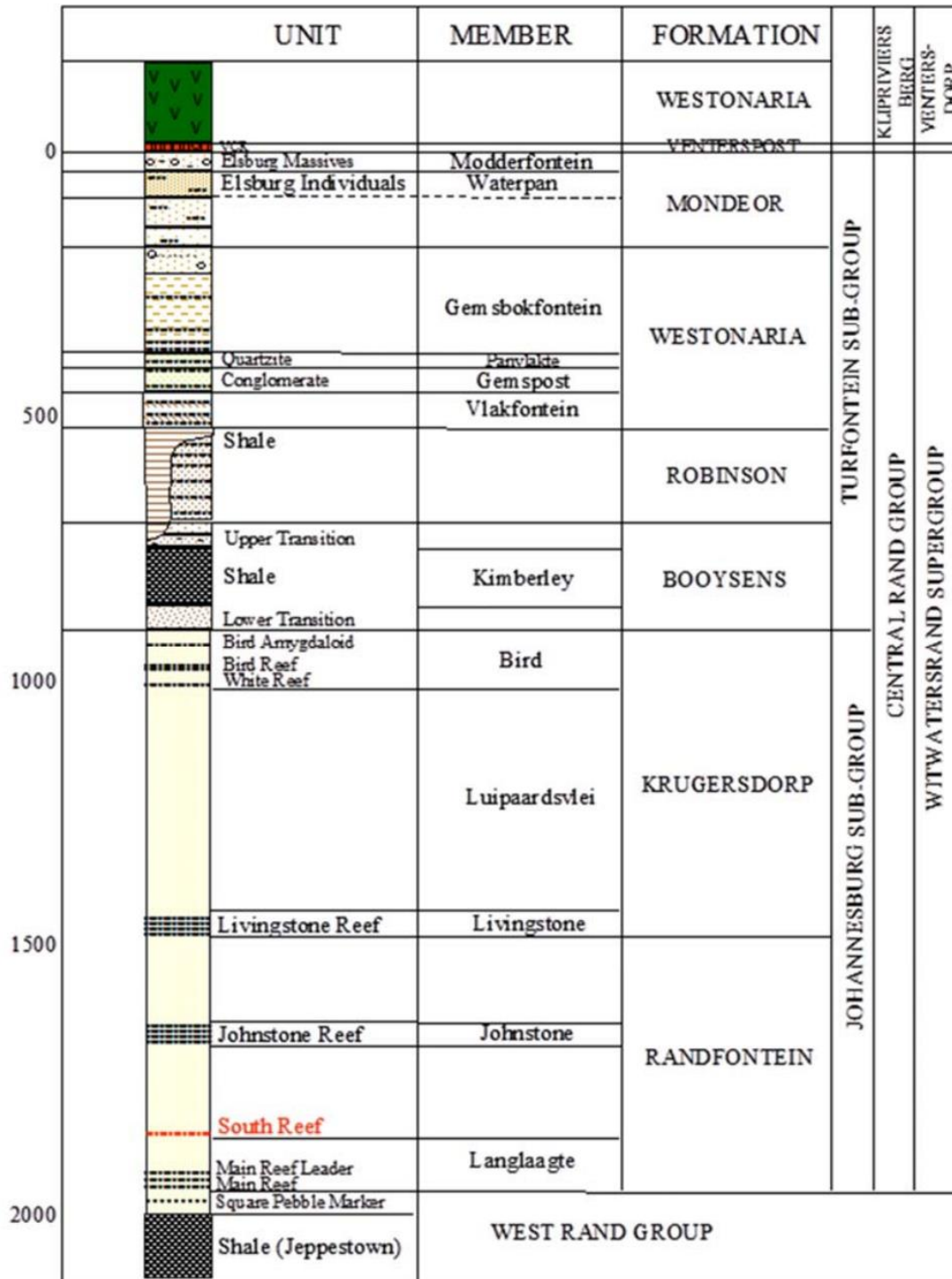


Figure 5-2: Stratigraphy of Doornkop Mine showing the main reefs (Bevelander, 1996; Van Biljon).



5.1.3. Structural geology

Doornkop Mine area is dominated by major structural geological features that includes faults and dykes. A set of faults occurs within the Doornkop Mine area and these faults reflects characteristics that suggest possible reactivation (van Biljon, 2014). Strike slip fault and folding are common within the mine area. The area has undergone complex history of folding that resultant in the formation of Roodepoort Fault, Saxon Faults, Doornkop Fault, and the Black Duck Dyke. These structures are steeply dipping and are characterised by East-West and North-South orientation. It is characterised by downthrows between 250 m and 550 m, with smaller scale faults characterised by downthrows ranging from 20 m to 150 m (Tucker et al., 2016). Figure 5-3 to 5-5 shows structural orientation and distribution within the Doornkop Area.

Roodepoort Fault

The Roodepoort Fault forms the southern margin of the Witpoortjie Horst. The fault is characterised by north-easterly striking and dips to the south. The fault defines the western margin of the Central Rand Basin. According to Dankert and Hein (2010), this fault is classified as a normal fault characterised by a rollover fold in the hanging-wall. The Roodepoort Fault becomes the east-dipping Panvlakte Fault in the southern continuation. Panvlakte Fault merge with steeply east-dipping north east orientation faults and becomes a fault complex.

Doornkop Fault

Doornkop Fault marks the northern limit between Witwatersrand and Ventersdorp Supergroup from the Malmani Dolomite (Chunniespoort Group) which dips to the south. This dolomite occurs to the south of the mining right area. Doornkop Fault is trending East-West which dips to the south at an angle of 52°. Investigation have revealed a downthrow of 150 m and vertical downthrow of up to 250 m to the south.

According to Killick (2014), this fault has displaced the Black Reef Quartzite Formation. The displacement that occurred was associated with listric faulting, growth faulting or strike-slip movement. Doornkop Fault has been intersected at level 106 between Doornkop shaft and Cooke 1 shaft. The exposed outcrop contains quartzite and shale. Doornkop Anticline was observed in the area north of Doornkop Fault. Reverse fault was also mapped in the area. Investigations have revealed an upthrow of 150 m to the north associated with this fault. This fault becomes a normal fault in the north.

Saxon Faults

The Roodepoort fault splays to form the Saxon fault (Dankert and Hein, 2010). This fault has a north-east strike which dips to the south at an angle of 65°. This fault is approximately 9 km which was traced in southeasterly direction (Killick, 2014). This fault occurs as a synthetic fault in the hanging wall of the Roodepoort fault (Killick, 2014). Displacement of this fault was correlated to that of the Witpoortjie fault. The fault marks an abrupt



termination between the Kimberly and Birds reefs. Synclinal remnant of the Ventersdorp lava occurs in the area between Roodepoort and Saxon Fault. Surface outcrop of conglomerate occurs in the southern portion of the fault.

Black Duck Dyke

Figure 5-5 shows the location and direction of the Black Duck Dyke in the area. The Black Duck Dyke occurs to the south east of the mining area. This dyke strikes parallel to the Doornkop fault, with orientation towards southeast. Investigation have identified dykes of Ventersdorp age within the Cooke section. According to Tucker et al. (2016), Ventersdorp age dykes and sills act as conduit for mineralised fluid. The Black Duck Dyke is known for groundwater occurrence. Boreholes drilled have intersected some water strikes.

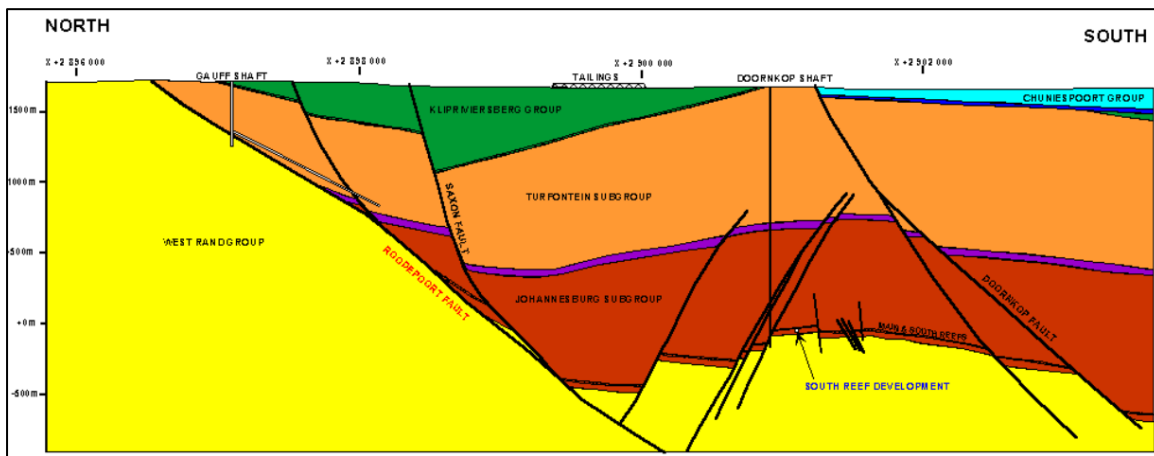


Figure 5-3: Schematic North-South section through Doornkop mine (van Biljon, 2013).

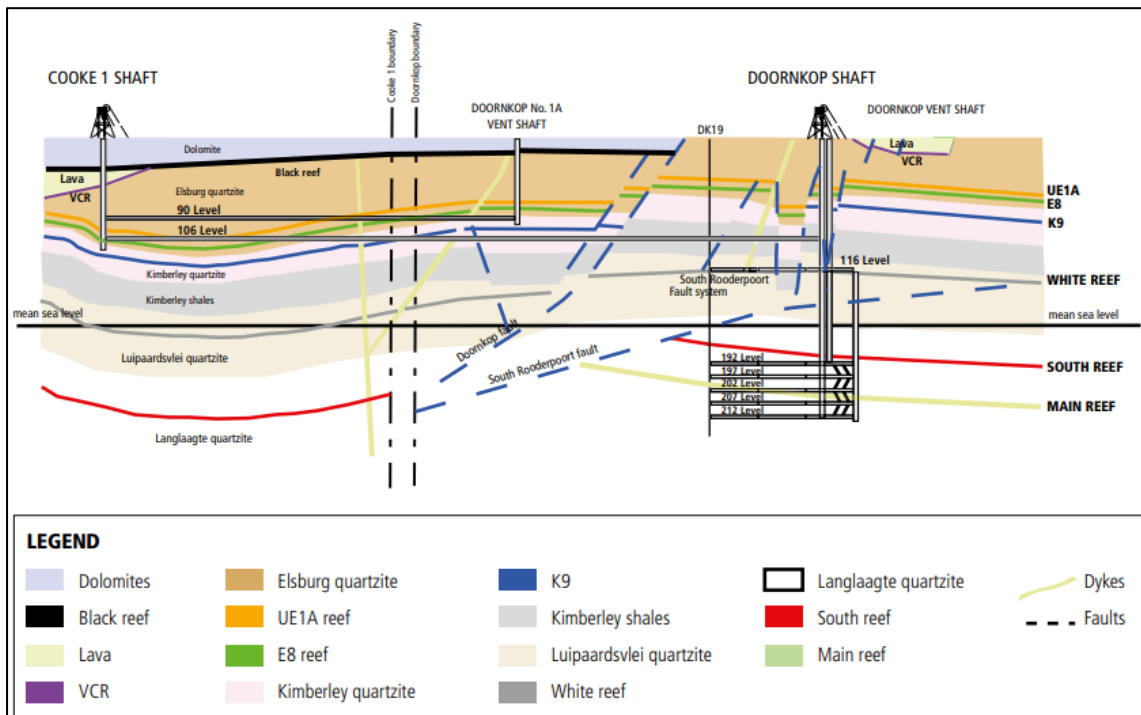


Figure 5-4: Schematic North-South section showing Doornkop Mine infrastructure and geology (Harmony, 2020).



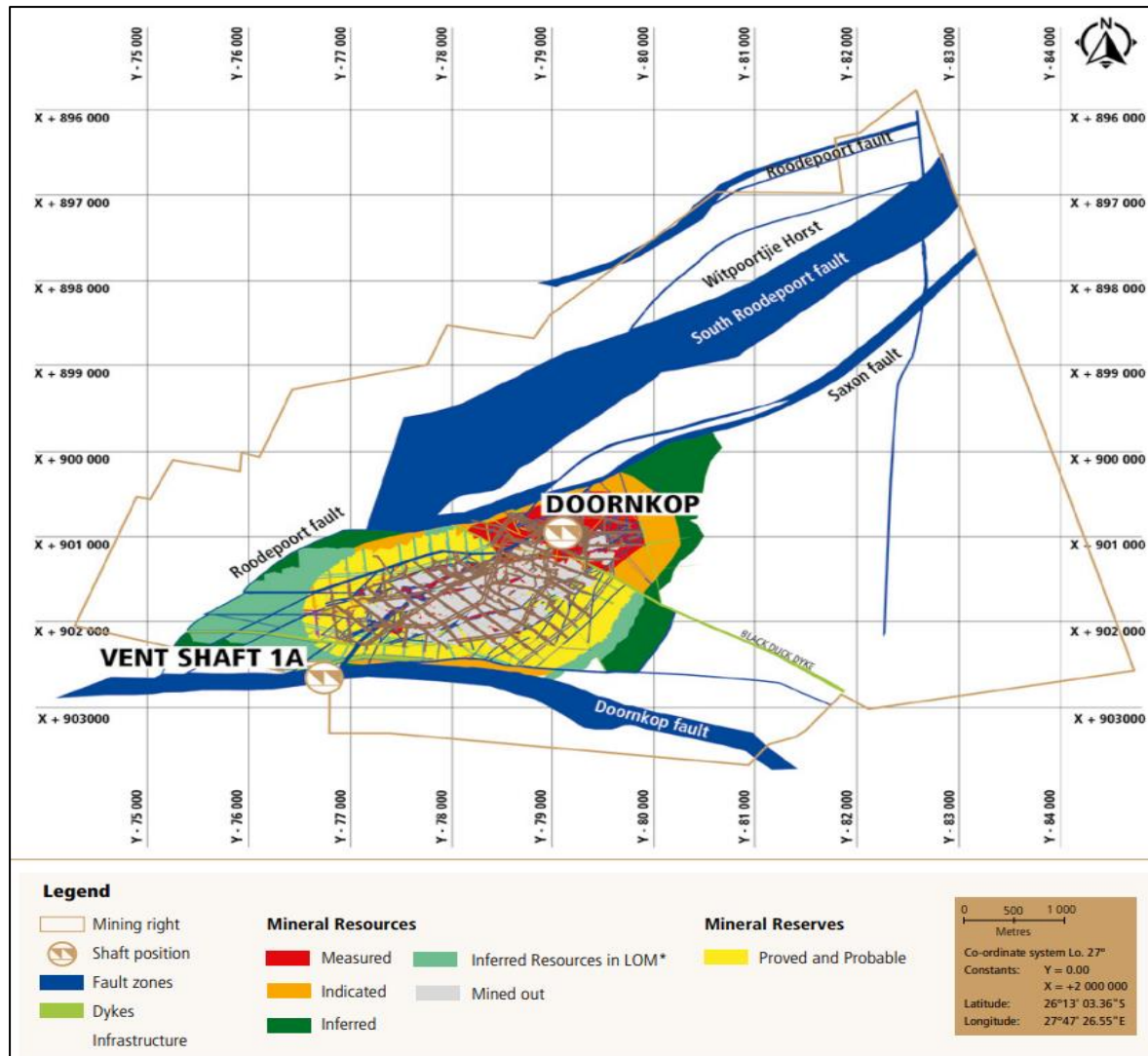


Figure 5-5: Mine structural geological map showing faults and dykes (Harmony, 2020).



5.2. Acid generation capacity

5.2.1. Leach Test

The following leach test analysis was conducted:

- ☛ pH Value at 25 °C and Total Dissolved Solids at 180 °C.
- ☛ Inorganic Anions: Chloride (Cl), Sulphate (SO₄), Nitrate (N), Nitrite (N), Fluoride (F), Total Cyanide (CN), Hexavalent Chromium (Cr⁶⁺).
- ☛ ICP Elements: As, B, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, V and Zn.

5.2.2. Acid-Base Accounting

ABA is the most used technique for predicting the water quality likely to result from a mining operation (Smith & Brady, 1990). It is also a cost-effective means of predicting acid rock drainage (ARD) potential. Acid-base accounting illustrates the ultimate acidity or basicity of different rock zones in the overburden (Skousen et al., 1971). According to Price (2010), ABA is a series of compositional analyses and calculations which entail the:

- ☛ Analysis of pH.
- ☛ Analysis of sulphur species and calculation of the Acid Potential (AP).
- ☛ Analysis of Neutralization Potential (NP).
- ☛ Calculation of NP/AP (Neutralization Potential Ratio, NPR) and NP-AP (Net Neutralization Potential, NNP).

Therefore, the following parameters were selected for analysis:

- ☛ Paste pH.
- ☛ Total Sulphur (%) (LECO).
- ☛ Acid Potential (AP) (kg/t).
- ☛ Neutralization Potential (NP).
- ☛ Nett Neutralization Potential (NNP).
- ☛ Neutralising Potential Ratio (NPR) (NP: AP).
- ☛ Rock Type.

5.2.3. Net Acid Generation

NAG is one of the static test methods used for geochemical assessment. The method assists in assessing and predicting the potential of the rock to generate acid during mining and after closure. The method can be used separately to characterise the acid generation potential of the rock or waste. However, it can also be used to predict acid generation potential as a supplementary method to ABA. The following parameters were analysed to assist in the prediction:



- ✔ NAG pH: (H₂O₂).
- ✔ NAG (kg H₂SO₄ / t).

5.2.4. Sulphur Speciation

Sulphur speciation is one of the critical components of acid mine drainage formation. The presence of sulphur in waste material has major environmental risk and impact. One of the common impacts is the potential to generate acid mine drainage. The parameters have been analysed to support the ABA and NAG method. The following parameters were critical for the study:

- ✔ Total Sulphur (%) (ELTRA).
- ✔ Sulphate Sulphur as S (%).
- ✔ Sulphide Sulphur (%).

5.2.5. X-Ray Diffraction

XRD is critical in the identification of material structure of the rock or waste material. The method is used to assess and identify individual minerals in the waste material. In mining, it is commonly used to understand the mineralogical composition of geology, TSF and WRD. This is critical in identifying mineral that contribute to the formation of acid mine drainage.

5.2.6. Criterial and threshold for classification

The following classification was used to assess geochemical characteristics of the waste material.

Table 5-2: Classification according to Neutralization Potential Ratio (NPR) (Price et al., 1997; Usher et al., 2003).

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	< 1:1	Likely AMD generating
Possibly	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity



Table 5-3: Classification according to rock type

TYPE I	Potentially Acid Forming	Total S (%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate	Total S (%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S (%) < 0.25% and NP:AP ratio 1:3 or greater

Table 5-4: Classification according to Nett Neutralisation Potential (NNP) (Usher et al., 2003).

Potential	Values	Comments
Potential to generate acid	NNP (NP – AP) < 0	The sample has the potential to generate acid
Potential to neutralise acid produced	NNP (NP – AP) > 0	The sample has the potential to neutralise acid produced
Potential acid-generating	NNP < 20	Is potential acid-generating
Might not generate acid	NNP > -20	Might not generate acid

Net Acid Generation (NAG) analysis is used to support the ABA result. Often, ABA tests are assessed for geochemical characterisation while NAG test are used in association with the ABA results. The general criteria are described below:

- 🌿 NAG pH < 4.5: Is usually defined as potential acid generation.
- 🌿 NAG pH > 4.5: Is usually defined as non-acid generation.

Paste pH is a relatively rapid and simple method used to measure a mixture of soil and deionized water that form a slurry or paste. As part of the paste pH test rock samples are crushed and pulverized. The air-dried sample is mixed with deionized water at a 1:1 ratio and the pH is then measured with a pH meter, calibrated at pH 4.00-7.00. The pH is then measured after 24 hours. Because the test is of short duration and non-vigorous (deionized water), only soluble salts and reactive minerals are assessed (Chotpantarat, 2011).

Minerals typically assumed to be assessed by paste pH tests include acid generating sulphate salts such as melanterite, reactive sulphides such as greigite, and high surface area pyrite and carbonate. Paste pH provides no indication of the sample's total capacity to generate acidity or alkalinity, but rather, provides an indication of the immediate pH characteristics of the sample should it be mixed with water (Weber et al., 2006). The criteria are summarised as follows:

- 🌿 pH < 3.5: Potential Acid Generation.
- 🌿 pH 3.5 -5.5: Uncertain/ Inconclusive.
- 🌿 pH > 5.5: Non-Potential Acid Generation.



The criteria for classification according to sulphur content (%S) and Neutralising Potential Ratio (NPR) is provided below:

- ✔ For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed.
- ✔ Values below this can yield acidity but it is likely to be only of short-term significance.
- ✔ From these facts, and using the NPR values, several rules can be derived:
 - Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
 - NPR ratios of >4:1 is considered to have enough neutralising capacity.
 - NPR ratios of 3:1 to 1:1 is considered inconclusive.
 - NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998; Usher et al., 2003).

5.2.7. Results

5.2.7.1. X-Ray Diffraction (XRD)

General composition of the TSF and waste rock shows quartzite as a dominant mineral in all samples. Pyrite was not detected in all other samples collected. Table 5-5 and 5-6 provide the analysis and mineralogical composition present in the TSF and WRD material (Appendix 4).

Table 5-5: XRD analysis showing rock mineralogy.

Analyses	Sample Identification:					
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650
Mineral	Composition (%) [o]					
Amount (weight %)						
Quartz	82.2	83.6	86.2	77.1	84.3	86.8
Pyrophyllite	8.7	4.1	2.7	2.2	2.9	6.1
Chloritoid	5.3	10.9	10.1	10.0	11.0	5.8
Chlorite	1.5	0.6	0.5	2.7	0	0
Muscovite	2.4	1.0	0.5	8.0	0.6	1.4
Pyrite	0	0	0	0	1.2	0



Table 5-6: Ideal Mineral compositions.

Compound Name	Chemical Formula
Chlorite	(Mg, Fe) ₅ Al (AlSi ₃ O ₁₀) (OH) ₈
Chloritoid	FeAl ₂ SiO ₅ (OH) ₂
Muscovite	KAl ₂ ((OH) ₂ Al Si ₃ O ₁₀)
Pyrite	FeS ₂
Pyrophyllite	Al (Si ₂ O ₅) (OH)

5.2.7.2. Acid generation assessment

Table 5-7 present the analysis of the ABA while Table 5-8 present the analysis of the NAG (Appendix 5 and 6). Based on the NNP obtained from the ABA analyses of the collected samples, it can be inferred that all TSF and WRD samples have the potential to generate acid, as their NNP values are less than zero. To confirm if this is indeed the case, it is important to correlate the NNP results with the results from paste pH analysis and the results from the calculated

According to Price et al. (1997), and Usher et al. (2003), material with potential to generate acid has NPR of less than 1. All samples collected has NPR of less than 1 which indicates that the samples have a potential to generate acid mine drainage. These results support the NNP result which suggest that the TSF and WRD has a potential for acid mine drainage generation

Paste pH of the analysis shows that one (DTSF 3) of the three samples collected at the TSF has a potential to generate acid mine drainage. This sample has a paste pH of less than 3.5. Two other TSF samples (DTSF 1 and DTSF 2) have higher pH which place the samples under non-acid generation based on paste pH. The sample collected from the WRD and underground are characterised by higher paste pH of more than 5.5 which suggest that the samples are non-acid generation (DWRD 1, HW 2300m below and Footwall 2300m BS).

The host rock or rock type was also identified from the laboratory. The criteria established for geochemical classification based on rock type suggest that all samples have intermediate to high potential to form acid mine drainage. Rock Type I and Type II are classified as potential acid generation while rock Type III are classified as non-acid generation.

NAG tests remain one of the static test methods which is used for acid mine drainage prediction. The method is used either as a stand-alone prediction method or supplementary method to verify or support other findings. NAG pH of less than 4.5 is usually defined as potential acid generation. Five of the six samples collected at Doornkop Mine are characterised by NAG pH of less than 4.5. This observation indicates that the five samples have a potential to generate acid mine drainage. These samples are: DTSF 1, DTSF 2, DWRD 1, HW 2300m below and Footwall 2300m BS (Appendix 6).



Table 5-7: Acid base accounting

Acid – Base Accounting	Sample Identification						
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Modified Sobek (EPA-600)							
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
Paste pH	7.6	7.4	3.2	7.2	5.5	7.2	7.1
Total Sulphur (%) (LECO)	0.27	0.24	0.07	0.34	1.20	0.37	0.37
Acid Potential (AP) (kg/t)	8.39	7.37	2.27	11	37	12	12
Neutralization Potential (NP)	2.28	1.77	-0.755	0.255	-0.755	0.255	0.508
Nett Neutralization Potential (NNP)	-6.11	-5.60	-3.02	-10	-38	-11	-11
Neutralising Potential Ratio (NPR) (NP: AP)	0.271	0.240	0.333	0.024	0.020	0.022	0.044
Rock Type	I	II	II	I	I	I	I

Table 5-8: Net Acid Generation

Net Acid Generation	Sample Identification: pH 4.5						
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
NAG pH: (H ₂ O ₂)	4.0	3.2	5.1	3.1	2.5	3.1	3.1
NAG (kg H ₂ SO ₄ / t)	4.70	4.51	<0.01	5.49	23	6.86	6.66

Net Acid Generation	Sample Identification: pH 7.0						
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
NAG pH: (H ₂ O ₂)	4.5	4.5	5.1	4.5	4.5	4.5	4.5
NAG (kg H ₂ SO ₄ / t)	1.57	1.37	2.35	1.37	3.53	1.37	1.57



According to Soregaroli & Lawrence (1998) and Usher et al. (2003), the combination of NPR of less than 1 and Sulphite-S of more than 3% are potentially acid generation. Sustainable long term acid generation is characterised by Sulphite-S of more than 0.3%. The following table and figure show the result of the TSF and WRD samples collected. Result of Total Sulphur (%) shows that all TSF samples, namely DTSF 1, DTSF 2 and DTSF 3 has potential to generate acid in a short term. All waste rock samples namely, DWRD 1, HW 2300 m below and Footwall 2300 m BS are acid generating (Figure 5-6). These samples were collected at the surface WRD and underground working particularly at the footwall and hanging wall (Table 5-9 and Appendix 7).

Table 5-9: Sulphur speciation.

Analysis	Sample Identification						
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300M below	Footwall 2300m BS	Footwall 2300m BS
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
Total Sulphur (%) (ELTRA)	0.27	0.24	0.07	0.34	1.20	0.37	0.37
Sulphate Sulphur as S (%)	0.08	0.04	0.02	0.06	0.06	0.07	0.05
Sulphide Sulphur (%)	0.19	0.20	0.05	0.28	1.13	0.31	0.32

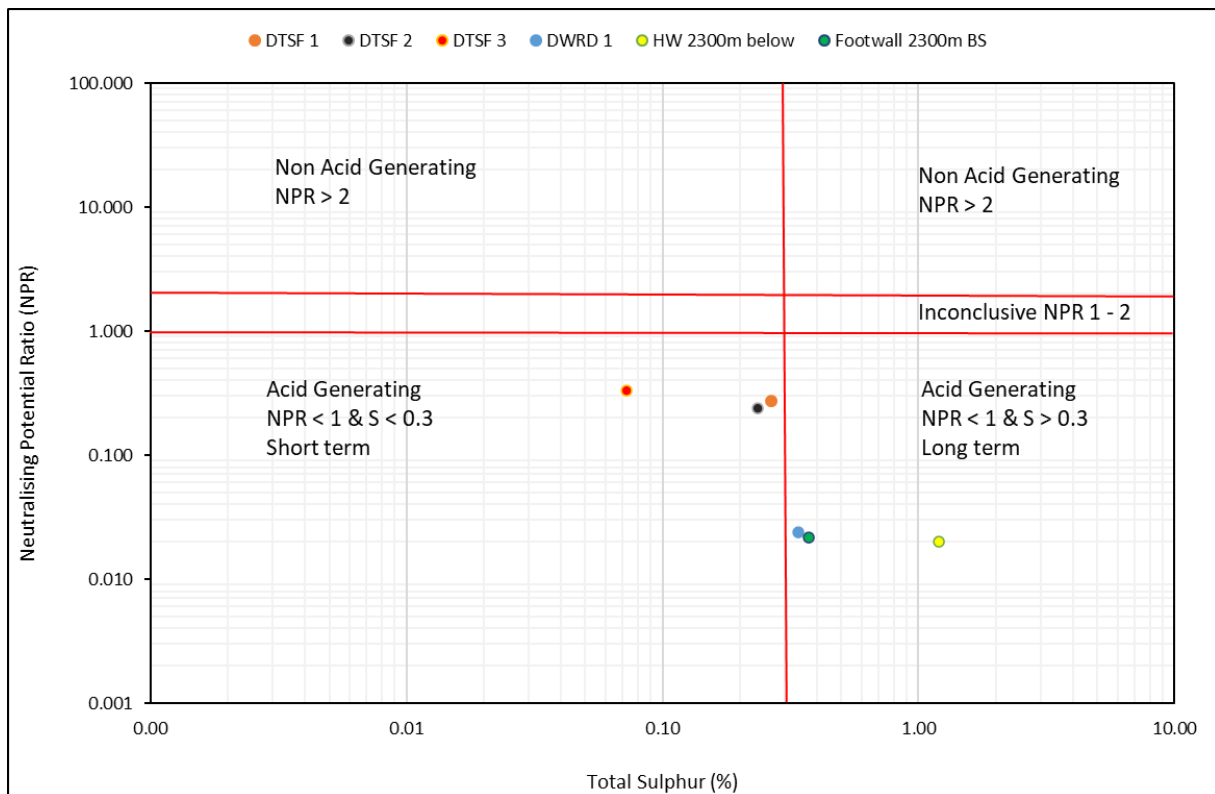








Figure 5-6: Total Sulphur (%) and Neutralization Potential Ratio (NPR).



The following conclusion is drawn from the laboratory result and classification criteria (Table 5-10):

-  Paste pH: the method only classifies TSF DTSF 3 as potential acid generating material. This sample has a pH of less than 4.5 which shows that the sample is acid generating. All other samples namely, DTSF 1, DTSF 2, DWRD 1, HW 2300m below and Footwall 2300m BS are characterised by high pH of more than 4.5 (Neutral to alkaline pH). This indicates non-acid generating.
-  NNP: All samples collected has NNP of less than zero which suggest that the samples have a potential to generate acid.
-  NPR: All samples collected has NPR of less than 1 which indicates that the samples have a potential to generate acid mine drainage. These results support the NNP result which suggest that the TSF and WRD has a potential for acid mine drainage generation.
-  Rock Type: The method has shown that TSF and waste rock are classified and Type I and II which has a potential to form acid.
-  NAG pH: DTSF 3 is classified as a non-acid generating while the remaining samples are acid generating.
-  %S and NPR Method: The method has classified all samples as acid generating.

In general, five methods have classified the TSF and waste rock samples as acid generating. Therefore, TSF and waste rock sample collected at Doornkop have potential to generate acid.

Table 5-10: Classification of acid generating potential

	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Paste pH	NAG	NAG	PAG	NAG	NAG	NAG	NAG
Nett Neutralization Potential (NNP)	PAG	PAG	PAG	PAG	PAG	PAG	PAG
Neutralising Potential Ratio (NPR) (NP : AP)	PAG	PAG	PAG	PAG	PAG	PAG	PAG
Rock Type	PAG	PAG	PAG	PAG	PAG	PAG	PAG
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
NAG pH	PAG	PAG	NAG	PAG	PAG	PAG	PAG
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
%S and NPR Method	PAG	PAG	PAG	PAG	PAG	PAG	PAG
PAG: Potential Acid Generating			NAG: Non-Acid Generating				



5.2.7.3. Leachate Tests and Total Element Analysis

All samples were subjected to leach test analysis. Leach test analysis provide information related to potential contaminant which may be released from the waste facility. This assessment assumed the process to be occurring under field condition or natural condition. Laboratory assessment and determination of parameters is conducted using Inductively coupled plasma mass spectrometry (ICP-MS) and inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES). These methods are used for detection of parameters and measurement of parameters at trace level.

The following leach parameters were detected in all samples:

- ✔ pH Value at 25°C and Total Dissolved Solids at 180 °C.
- ✔ Inorganic Anions: Chloride (Cl), Sulphate (SO₄), Nitrate (N), Nitrite (N), Fluoride (F), Total Cyanide (CN), Hexavalent Chromium (Cr⁶⁺).
- ✔ ICP Elements: As, B, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, V and Zn.

These parameters were compared to the drinking water quality guideline, namely:

- ✔ South African National Standards of Drinking water (SANS 241; 2006; 2015).
- ✔ World Health Organisation (WHO) guidelines for drinking-water quality (WHO, 2011).

Table 5-11 provides detailed analysis which are compared to drinking water guideline (Appendix 8 and 9). Based on the information provided in Table 5-11, the following conclusion can be made:

- ✔ pH: All samples are characterised by acidic pH that varies from 4.9 to 5.
- ✔ As: The concentration of As is detected at high concentration above guideline values in TSF sample namely DTSF 1 and DTSF 2. The concentration of As is also detected at high level above guideline value in sample collected from underground footwall (Footwall 2300m BS). All these samples exceed both SANS limit and WHO limit.
- ✔ Mn: Samples collected at TSF (DTSF 1 and DTSF 2) and waste rock (DWRD 1, HW 2300m below and Footwall 2300m BS) shows exceedance in terms of Mn guideline values. These samples are characterised by high concentration above WHO and SANS limit.
- ✔ Ni: TSF samples namely DTSF 1 and DTSF 2 shows guideline exceedance in terms of Ni concentration. These samples have exceeded both SANS and WHO guideline limit.
- ✔ Pb: High concentration of Pb above SANS and WHO guideline was detected in five samples that includes DTSF 1, DTSF 2, DWRD 1, HW 2300m below and Footwall 2300m BS.

Therefore, the TSF and waste rock have a potential to release contaminant into the environment.



Table 5-11: Leach test result.

Analyses	pH Value at 25 °C	Total Dissolved Solids at 180 °C	Chloride as Cl	Sulphate as SO ₄	Nitrate as N	Nitrite as N	Fluoride as F	Total Cyanide as CN [o]	As	B	Ba
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/l	mg/l	mg/l
SANS 241 2006 & 2015 operational	5.0 - 9.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SANS 241 2015 Aesthetic	N/A	≤ 1200	≤300	≤ 250	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SANS 241 2015 Acute Health	N/A	N/A	N/A	≤ 500	≤ 11	≤ 0.9	N/A	≤ 0.2	N/A	N/A	N/A
SANS 241 2006 & 2015 Chronic Health	N/A	N/A	N/A	N/A	N/A	N/A	≤ 1.5	N/A	≤ 0.01	≤ 2.4	≤0.7
WHO standard	6.5-8.5	N/A	250	250	11	0.9	1.5	N/A	0.01	2.4	0.7
DTSF 1	4.9	390	4	73	0.5	<0.05	<0.2	<0.07	0.043	<0.025	0.037
DTSF 2	5.0	112	3	18	0.3	<0.05	<0.2	<0.07	0.033	<0.025	<0.025
DTSF 3	4.9	58	<2	25	<0.1	<0.05	<0.2	<0.07	0.001	<0.025	<0.025
DWRD 1	5.0	132	<2	7	7.8	<0.05	<0.2	<0.07	0.006	<0.025	0.026
HW 2300m below	4.9	50	<2	<2	0.6	<0.05	<0.2	<0.07	0.008	<0.025	<0.025
Footwall 2300m BS	4.9	100	<2	2	4.4	<0.05	<0.2	<0.07	0.015	<0.025	<0.025
Analyses	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Sb	Se	Zn
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241 2006 & 2015 operational	N/A	≤ 0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SANS 241 2015 Aesthetic	N/A	N/A	N/A	N/A	N/A	≤ 0.1	N/A	N/A	N/A	N/A	≤ 5
SANS 241 2015 Acute Health	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SANS 241 2006 & 2015 Chronic Health	≤ 0.003	≤ 1	≤ 0.05	≤ 2	≤ 0.006	≤ 0.4	≤ 0.07	≤ 0.01	≤ 0.02	≤ 0.04	
WHO standard	0.03	N/A	0.05	2	0.006	N/A	0.07	0.01	N/A	0.04	N/A
DTSF 1	<0.001	0.072	<0.025	0.085	<0.001	1.03	0.171	0.031	0.004	0.002	0.130
DTSF 2	<0.001	0.027	<0.025	0.023	<0.001	0.561	0.094	0.054	0.001	0.001	0.047
DTSF 3	<0.001	<0.025	<0.025	0.020	<0.001	0.052	0.030	0.001	<0.001	0.004	<0.025
DWRD 1	<0.001	<0.025	0.027	0.037	<0.001	0.644	0.038	0.017	0.001	<0.001	0.104
HW 2300m below	<0.001	<0.025	0.030	0.037	<0.001	1.04	0.061	0.026	0.001	<0.001	0.038
Footwall 2300m BS	<0.001	<0.025	0.031	0.020	<0.001	0.961	0.046	0.029	0.001	<0.001	0.027
Acidic		Above limit									



5.3. Hydrogeology

5.3.1. Unsaturated zone

The unsaturated zone defines the subsurface zone above the water table. This zone is composed of soil and rocks containing water and air in pore spaces. This zone plays a critical role related to the rate of recharge, flow rate/infiltration or percolation rate and movement of contaminant to the aquifer. Unsaturated zone within the area is composed by various rock that belong to Jeppestown Subgroup, Johannesburg Subgroup, Turffontein Subgroup, Klipriviersberg Group, Rietgat Formation, Black Reef Formation, Malmani Subgroup (Dolomite), Vaalian diabase and Dwyka Group. These rocks weathers and decompose to form various soil type that occurs within the top layer of the unsaturated zone. The thickness of unsaturated zones in the area varies from 2 m to 13 m from surface.

5.3.2. Saturated zone

The hydrogeology of the mine site is characterised by various aquifer systems that control groundwater occurrence. These aquifers are classified as:

- 🌿 Intergranular and Fractured aquifer: Dwyka Group, Klipriviersberg Group and Rietgat Formation.
- 🌿 Fractured aquifer system: Jeppestown Subgroup, Johannesburg Subgroup, Turffontein Subgroup and Black Reef Formation.
- 🌿 Karst Aquifer: Malmani Subgroup (Malmani Dolomite).

5.3.2.1. Intergranular and Fractured aquifer

Intergranular and Fractured Aquifer system is constituted by Dwyka Group, Klipriviersberg Group and Rietgat Formation that dominate the central portion forming an outcrop.

Dwyka Group

The Dwyka Group is classified as an intergranular and fractured aquifer system comprising of diamictite, mudstones and shale rocks. According to Woodford and Chevallier (2002), Dwyka aquifers are classified as aquitards rather than aquifers. This is due to low hydraulic conductivity and low porosity. However, some localities can yield sufficient water for household water supply due to weathering and fracturing which have improved aquifer storage.

Table 5-12 provide the summary of aquifer types and yield. The Dwyka aquifer is classified as low yielding aquifer, with boreholes drilled yielding less than 2 l/s. Historical borehole record reviewed by Barnard (2020) has shown that approximately 76% of boreholes produce less than 2 l/s. Only 23.5% of boreholes that produce between 2 – 5 l/s, with no boreholes producing more than 5 l/s.



Table 5-12: Aquifer type and yield classes (Barnard, 2000).

Aquifer Type	Geology	Borehole yield class (L/s)					Max Yield (l/s)
		<0.1	0.1 - 0.5	0.5 - 2	2 - 5	> 5	
		<i>No of boreholes (%) per class</i>					
Intergranular and Fractured Aquifer	Dwyka Group	2.9	29.4	44.1	23.5	0	4.4
	Rietgat Formation	1	21	32.4	36.5	9.5	15
	Klipriviersberg Group	4.8	37.2	39	12.8	6	20
Fractured Aquifer	Black Reef Formation	6.3	15.8	50.7	20.6	6.3	6.3
	Central Rand (Johannesburg, Turffontein)	4.6	19.3	56.8	11.9	7.3	25
	West Rand (Jeppestown Subgroup)	1.3	18.8	44.4	13.3	22.2	30
Karst Aquifer	Malmani Dolomite (Malmani Subgroup)	3.2	7.2	23.6	15.1	50.5	126

Klipriviersberg Group

The Klipriviersberg Group is classified as an intergranular and fractured aquifer system. Groundwater occurrence is associated with weathering zones, transition zones, contacts zones, faults, fractures and contact zones between dykes and lava (Barnard, 2002). Drilling of monitoring boreholes at Doornkop have intersected lava on several boreholes. The Klipriviersberg Group is characterised by low borehole yield with approximately 80% of tested boreholes producing less than 2 l/s (Table 5-12). 6% of tested boreholes are classified as high yielding boreholes and produce more than 5 l/s with a maximum of 20 l/s.

Rietgat Formation

The Rietgat Formation is classified as intergranular and fractured aquifer system. Groundwater occurrence is associated with weathering, brecciation, jointing and contact zone between host rock and dyke. According to Barnard (2000), structural features of the aquifer is associated with the mode of extrusion. Such extrusion and deposition occurred at different time which had an influence on the degree, mode, and depth of weathering. Groundwater yield potential is low. Approximately 50% of boreholes yield less than 2 l/s, with 36% boreholes yielding between 2 l/s to 5 l/s. Maximum borehole yield was estimated as 15 l/s (Table 5-12).



5.3.2.2. Fractured aquifer system

Black Reef Formation

The Black Reef Formation is classified as a fractured aquifer system. This aquifer is composed of quartzite, conglomerate, and shale. The top layer of the Black Reef Formation consists of 10 m thick transition zone, composed of carbonaceous shale. Surface outcrop occurs to the north and east of the dolomite. The formation occurs below Malmani Dolomite aquifer which covers the southern portion of the mine. Due to low aquifer properties, the Black Reef Formation is classified as a barrier or impermeable layer that exist between the dolomite on top and the Witwatersrand deposit below the Black Reef Formation. This aquifer is classified as low yielding aquifer on the basis that 73% of boreholes produce less than 2 l/s (Table 5-12). Maximum yield estimated for this aquifer is about 6.3 l/s.

Central Rand Group

The Central Rand Group is classified as fractured aquifer system composed of quartzite, shale, and conglomerate. Geological structures in this aquifer serves as a target for groundwater exploration. This includes structures such as faults, deeply weathered zones, contact zones, weathered shale, bedding planes, fractured zones shear zones, contact zones between sediments and dykes. Weathering of the arenaceous and rudaceous rocks result in the formation of sandy soil, which generally improves local recharge (Barnard, 2000). Groundwater yield potential for this aquifer is low. Approximately 80% of boreholes yield less than 2 l/s with maximum yield of 25 l/s. 7.3% of boreholes produce more than 5 l/s.

West Rand Group

The West Rand Aquifer is classified as fractured aquifer system. This aquifer is composed of quartzite, shale, lava, and conglomerate. Groundwater occurrence within the aquifer is associated with secondary structures such as dykes, fault, fractures, weathered zones, contact between structures and host rock (Barnard, 2002). Depressions and valley locations consist of shales and diabase which forms the floor.

Sediment deposit of the West Rand fractured aquifer have been intruded by dykes and sills. These structures are characterised by high groundwater yield, especial when boreholes have intersected the upper and lower contacts with the host rocks. Deeply weathered shale formation produces high volume. Low lying area are favourable for groundwater occurrence. Contacts of host rocks and bending planes in these locations are weathered, which improves the storage capacity of the aquifer (Barnard, 2000). Table 5-12 provide the summary of historical borehole yield. Approximately 65% of historical boreholes drilled in West Rand aquifer yield less than 2 l/s, which suggest low borehole yield. Historical record has shown that this aquifer can produce a maximum of 30 l/s. 22.2% of boreholes tested produce more than 5 l/s.

5.3.2.3. Karst Aquifer

The Karst aquifer system is composed of dolomite rocks that belong to the Malmani Subgroup, a subdivision of the Chiniespoort Group. This aquifer is known as Zuurbekom Dolomite compartment in terms of dolomite



subdivision of the area. The aquifer occupies the southern part of the mine area where it forms an outcrop geology. The boundary of the Zuurbekom Dolomite compartment is marked by dykes in the east, south and west, namely the Kliprivier, the Panvlakte and the Magazine Dyke respectively. Dolomite outcrop that borders the Doornkop fault marks the northern boundary (Van Biljon, 2013).

The dolomite aquifers are characterised by high to very high aquifer storage. Open caves and cavities form the characteristics of the dolomite aquifers. This forms because of weathering or karstification. Lithostratigraphy was cited as one of the main factors controlling the weathering and leaching which result in the formation of large permeable zones and large storage. The dolomite in the area known for large groundwater availability which in instances, inflow of dolomite water into mine working becomes a challenge particularly, in the mining occurring the south.

In the Doornkop area, the dolomite is underlain by the Black Reef Formation which act as a barrier towards groundwater flow. The existence of this barrier limits the amount of dolomite water that flows into mine working. The dolomite borders the Doornkop fault in the northern portion. This fault is down thrown to the south and serves as a pathway that potential allow water to flows through. The fault is regarded as a conduit for groundwater flow, allowing groundwater from dolomite the infiltrate into the underlying mine voids.

According to Barnard (2000), the storage capacity of the dolomite decreases with increasing depth of dolomite. Reports have shown that 9.1% storage was recorded within the depth of 61 m below surface. This storage capacity has reduced to 1.3% storage at the depth of 146 m. Geological structures like dykes, especially impermeable vertical or sub-vertical dykes that prevent water to flow through usually interrupt the continuity. This allows water to accumulate in storage resulting in the development of compartment. In low lying areas, where dykes are weathered near surface, leakage through the dyke exist, resulting in the loss of water from one compartment to another.

Figure 5-7 shows the gravity survey depicting the base of the dolomite within Doornkop area. Dark green in the map suggest area of deep weathering within the dolomite. Groundwater occurrence in the dolomite aquifer is associated deep weathering or paleo-karst valley (Van Biljon, 2013). High recharge within the dolomite is associated with low density of surface drainage features (Barnard, 2000). The occurrence of springs such as structural controlled springs is common within the dolomite. The contact between the dolomite and dykes at low elevation forms the springs in some localities. Such springs are associated with high discharge volume. Dolomite aquifer is characterised by high borehole yield. Groundwater yield potential is high. 51% of boreholes drilled in this aquifer yield more than 5 l/s. Maximum yield predicted for this aquifer is about 126 l/s.



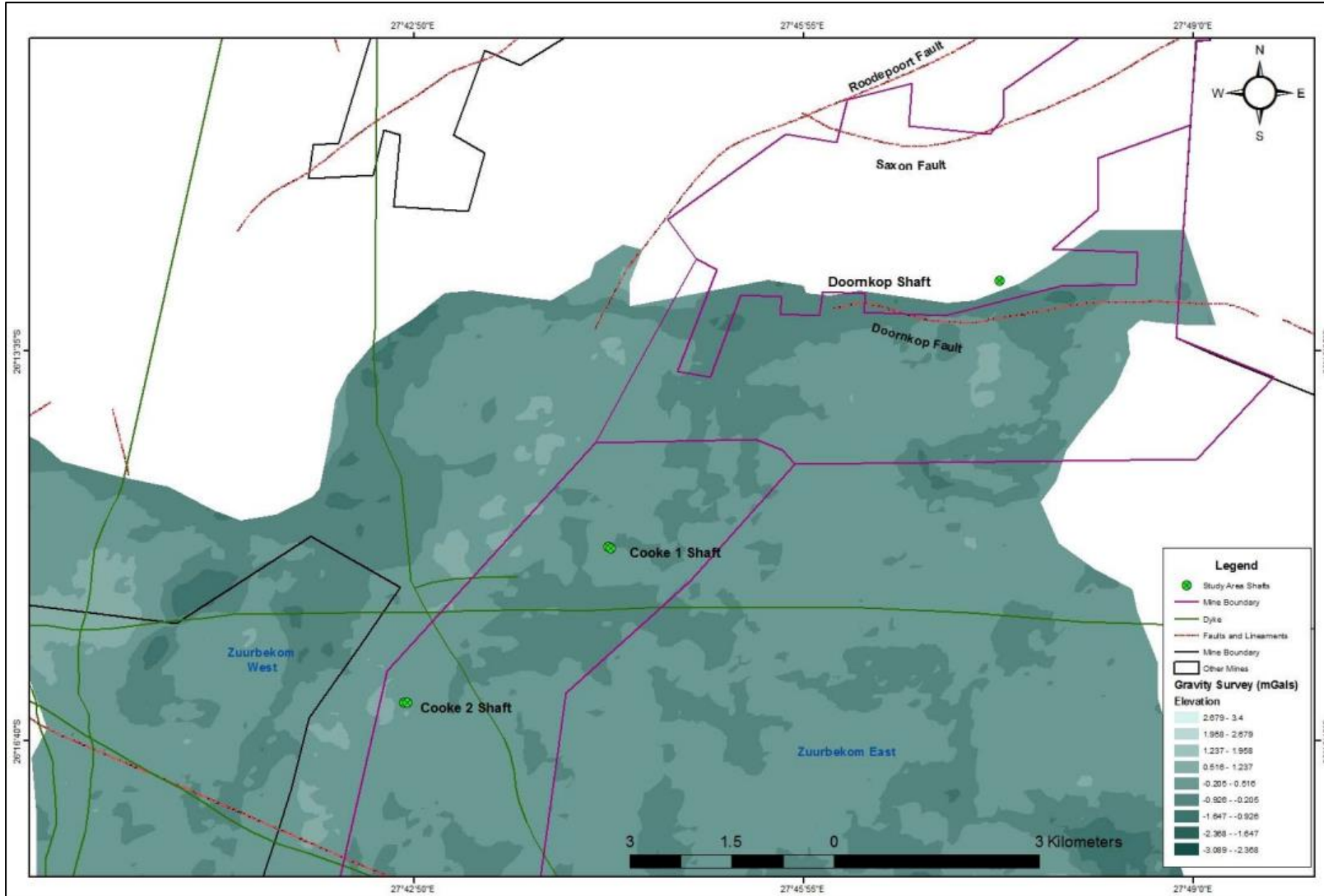


Figure 5-7: Geomorphology of the weathered dolomite aquifer.



5.3.3. Hydraulic conductivity

Table 5-13 provides the summary of aquifer types and associated hydraulic conductivity. Groundwater occurrence in the Witwatersrand Supergroup is associated with secondary fractures. Target for groundwater occurrence includes weathered zones, shear zones, intrusive rock formations, contact zones between weathered lithology and intrusive sills and bedding planes, and fault and fractured zones (Lourens, 2013). According to Barnard (2000), weathering of the rocks in the Witwatersrand Supergroup generally produce sandy soil. The occurrence of sandy soil within the area generally improves recharge rate and permeability. In some localities, it has been estimated that recharge is approximately 6.5% of the average annual rainfall.

The Witwatersrand Supergroup is composed of perched, unconfined, and confined aquifer system. Groundwater within the perched aquifer occurs in a residual and weathered quartzite. The hydraulic conductivity of this aquifer varies from 4.0×10^{-5} to 7.4×10^{-6} m/s. Weathered quartzite is classified as unconfined aquifer. The hydraulic conductivity of this aquifer is between 7.0×10^{-6} and 8.2×10^{-7} m/s. Fresh fractured rocks of the Witwatersrand Supergroup is classified as confined aquifer. This aquifer with hydraulic conductivity of 10^{-7} m/s is composed of fractured quartzite.

Table 5-13: Summary of types of aquifers and associated aquifer permeability (Lin et al., 2014; Kafri et al., 1986; Fleischer, 1981; Woodford and Chevallier, 2002).

Geological setting	Aquifer media	Aquifer type	Hydraulic conductivity (m/s)
Dwyka Group	Diamictite and shale		$\sim 10^{-11}$ to 10^{-12}
Witwatersrand supergroup	Residual and weathered quartzite	Perched	$4.0 \times 10^{-5} \sim 7.4 \times 10^{-6}$
	Weathered quartzite	Unconfined	$7.0 \times 10^{-6} \sim 8.2 \times 10^{-7}$
	Fractured quartzite	Confined	10^{-7}
Ventersdorp lava	Weathered shale	Perched	$4.2 \times 10^{-6} \sim 7.45 \times 10^{-7}$
	Residual and weathered lavas	Unconfined	$1.15 \times 10^{-6} \sim 7.45 \times 10^{-7}$
	Fractured lavas	Confined	$10^{-7} \sim 10^{-8}$
Malmani dolomite	Weathered	Unconfined	$5.0 \times 10^{-3} \sim 2.7 \times 10^{-3}$
	Fractured	Confined	$7.3 \times 10^{-4} \sim 6 \times 10^{-3}$
	Weathered and fractured		$2 \times 10^{-3} \sim 1.1 \times 10^{-4}$

Target for groundwater in Ventersdorp Supergroup includes contact zones, transitional zones, fault planes, contact zones of dykes, weathered zones, and fractures. Decomposed rocks result in the formation of spongy material with high storage capacity. In some localities, weathering of lava result in the formation of clay soil. This clay soil is characterised by low permeability. Transition zones of fractured and jointed lava are highly permeable and contain significant amount of groundwater (Barnard, 2000).

Weathered shale of the Ventersdorp Supergroup result in the formation of perched aquifer. This aquifer has a hydraulic conductivity that varies from 4.2×10^{-6} to 7.45×10^{-7} m/s. Residual and weathered lava of this supergroup



is classified as unconfined aquifer with hydraulic conductivity ranging from 1.15×10^{-6} to 7.45×10^{-7} m/s. Fresh fractures developed in the lava produce a confined fractured aquifer. The hydraulic conductivity of this aquifer ranges from 10^{-7} ~ 10^{-8} m/s (Table 5-13).

Malmani dolomite aquifer is characterised by high to very high groundwater storage capacity. The aquifer is associated with high permeability due to fractures, faults, and cavities. These cavities and fractures are filled by permeable residual material that allow groundwater storage. Weathering of this dolomite and formation of highly permeable zones is controlled by Lithostratigraphy (Barnard, 2000). This aquifer is composed of karstified dolomite which is covered by residual soil.

Weathered zone in Malmani dolomite result in the formation of unconfined groundwater storage characterised by hydraulic conductivity of 5.0×10^{-3} ~ 2.7×10^{-3} m/s. Fractured aquifer is classified as confined with hydraulic conductivity of 7.3×10^{-4} ~ 6×10^{-3} m/s. Aquifer zones that are composed by weathered and fractured material has hydraulic conductivity ranging from 2×10^{-3} ~ 1.1×10^{-4} m/s.

The Black Reef Formation is characterized by low porosity and permeability (Lin et al., 2014). The formation is classified as a regional barrier for groundwater movement due to low transmissivity (Lourens, 2013). Rocks of the Dwyka Dwyka Group tend to act as an aquitard than aquifer (Woodford and Chevallier, 2002). The aquifer is characterised by very low permeability due to poorly sorted material, resulting in low primary porosity. Hydraulic conductivity of this group is low, ranging from 10-11 to 10-12 m/s.

Hydraulic conductivity calculated for Doornkop Mine varies from 0.04 m/day to 0.35 m/day in quartzite aquifer and 0.06 m/day to 0.39 m/day in aquifer associated with lava (Table 5-14). Corresponding transmissivity for these rocks varies from 1.1 m²/day to 3.5 m²/day.

Table 5-14: Summary of hydraulic conductivity transmissivity, Doornkop Mine.

Borehole ID	T (m ² /day)	K (m/day)	S	Aquifer material
DKP1	1.1	0.04	0.00249	Quartzite
DKP3	1.1	0.06	0.00228	Lava
DKP4	3.5	0.35	0.00418	Quartzite
DKP6	3.5	0.39	0.00418	Lava
DKP8	3	0.19	0.00633	Lava

5.4. Groundwater levels

Available groundwater level and elevation for Doornkop Mine area is summarised in Table 5-15 while water strikes are summaries in Table 5-16. General groundwater level of the study area varies from 2.11 mbgl to 13.84 mbgl. Water strikes recorded in some boreholes varies from 6 mbgl to 29 mbgl. The depth of the boreholes varies ranges from 18 mbgl to 36 mbgl.



Borehole DKP1 is drilled within the outcrop of the Jeppestown Subgroup (West Rand Group) north east of the mine. The borehole has a shallow groundwater level of 3.21 mbgl. This borehole is drilled within the quartzite rock and has a depth of 36 mbgl with groundwater intersected at 29 mbgl.

Borehole DKP3, DKP8 and DKP13 are located downstream of the TSF. These boreholes are drilled in the outcrop of the Klipriviersberg Group, particularly lava. General water level in these boreholes is shallow. Groundwater level in borehole DKP3, DKP8 and DKP13 was recorded as 2.41 mbgl, 4.18 mbgl and 2.11 mbgl respectively. Borehole DKP3 has a depth of 27 mbgl while borehole DKP8 has a depth of 21 mbgl. Water strikes were recorded as 21 mbgl and 16 mbgl in borehole DKP3 and DKP8, respectively.

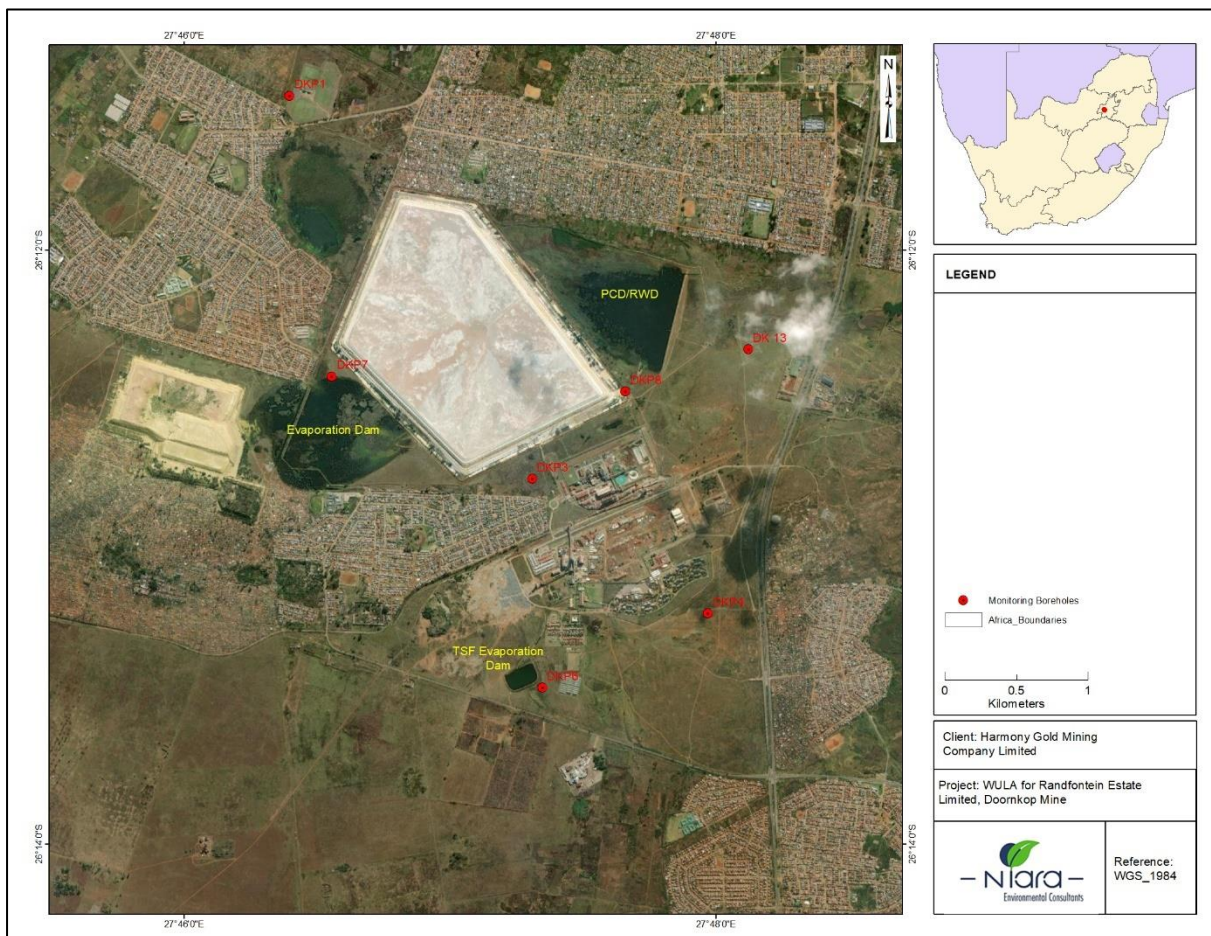


Figure 5-8: Distribution of boreholes.

Table 5-15: Summary of groundwater level and groundwater elevation.

Borehole ID	Elevation (mamsl)	Groundwater level (mbgl)	Groundwater elevation (mamsl)
DKP1	1677	3.21	1673.79
DKP3	1671	2.41	1668.59
DKP4	1661	9.98	1651.02
DKP6	1656	13.84	1642.16
DKP7	1671	11.85	1659.15
DKP8	1664	4.18	1659.82
DK 13	1655	2.11	1652.89
Min	1655	2.11	1642.16
Max	1677	13.84	1673.79
Average	1665.00	6.80	1658.20

Table 5-16: Monitoring borehole depth and water strike the study area.

Borehole ID	Depth (m)	Water strike (m)	Aquifer material
DKP1	36	29	Quartzite
DKP3	27	21	Lava
DKP4	30	27	Quartzite
DKP6	18	6	Chert, Lava
DKP7	33	27	Lava
DKP8	21	16	Lava
Min	18	6	
Max	36	29	

Borehole DKP4 has a shallow groundwater level, but slightly deeper than borehole DKP1, DKP3, DKP8 and DKP13. This borehole is drilled within the quartzite of the Turfontein Subgroup, downstream of the office complex. Groundwater level recorded in this borehole is 9.98 mbgl. The borehole is 30 m deep and has a water strike of 27 mbgl. Borehole DKP6 is located between the TSF and Evaporation dam. This borehole is 33 m deep and has a water strike of 27 mbgl with shallow groundwater level of 11.85 mbgl.

Borehole DKP6 has a shallow groundwater level but deeper than all the boreholes within the mine. Groundwater level in this borehole is 13.84 mbgl. This borehole is located within the northern edge of the dolomite. Lithological log shows that residual Chert fragment and decomposed Lava was intersected in this borehole. This may suggest that the borehole is drilled within the transition zone between the dolomite (Malmani Subgroup) and lava Klipriviersberg Group. The borehole is located downstream of the TSF evaporation dam. DKP6 is 18 m deep with water strike intersected at 6 mbgl.



The Bayesian Correlation was used to assess correlation between surface elevation and groundwater elevation (Figure 5-9). Groundwater levels within the project area mimic surface topography. Therefore, groundwater within the project area will follow topographic elevation from high to low topographic areas

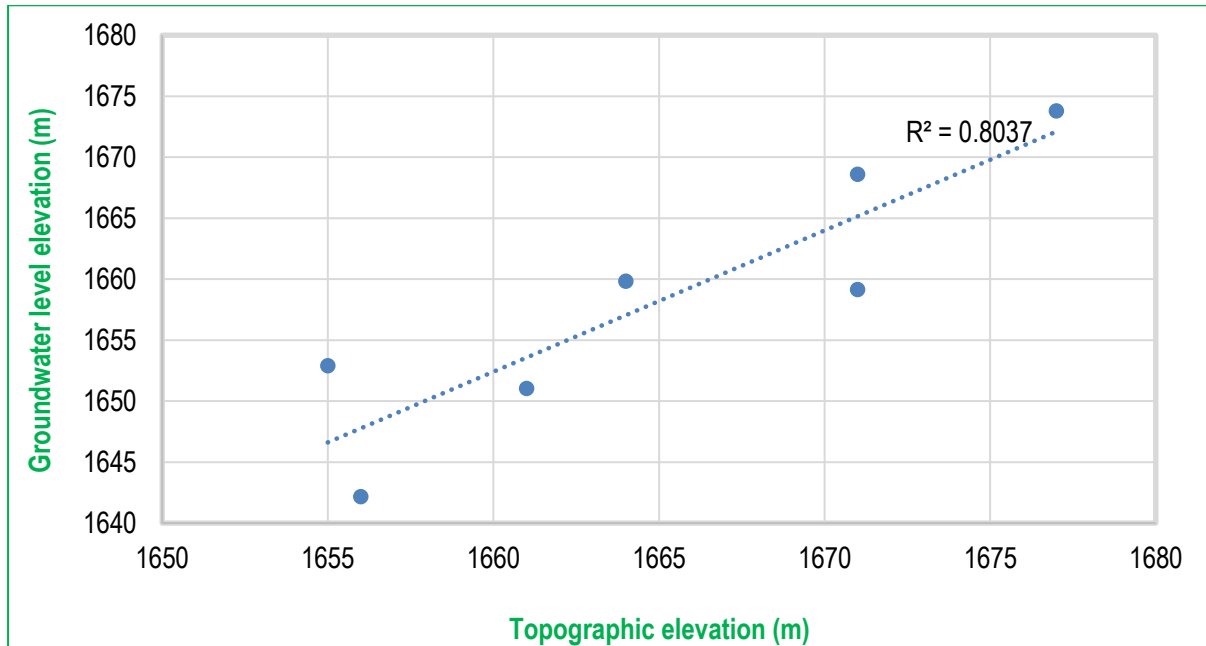


Figure 5-9: Correlation between surface topography and groundwater elevation

5.5. Groundwater potential contaminants

A risk based approach focusing on; source pathways and receptor was adopted to describe groundwater potential contaminants that exist within Doornkop Mine. This approach is critical to identify mitigation measures for the mine. The approach entails the following:

- 🌿 Assessment and identification of contamination sources. This refers to sources which generate contaminants which could affect the environment and other receptors.
- 🌿 Assessment and identification of route which contaminants could follow.
- 🌿 Assessment and identification of receptors. This is a receiving environment which could be exposed to contamination or being affected by contamination.

In general, mining operations are characterised by impacts which must be properly managed. Hence groundwater management strategies and mitigation measures are critical for any mining operation. Doornkop Mine has a water management strategy that aim in protecting water resources, preventing pollution and remediation of contamination. Figure 5-10 shows the distribution of the contamination sources at Doornkop Mine.



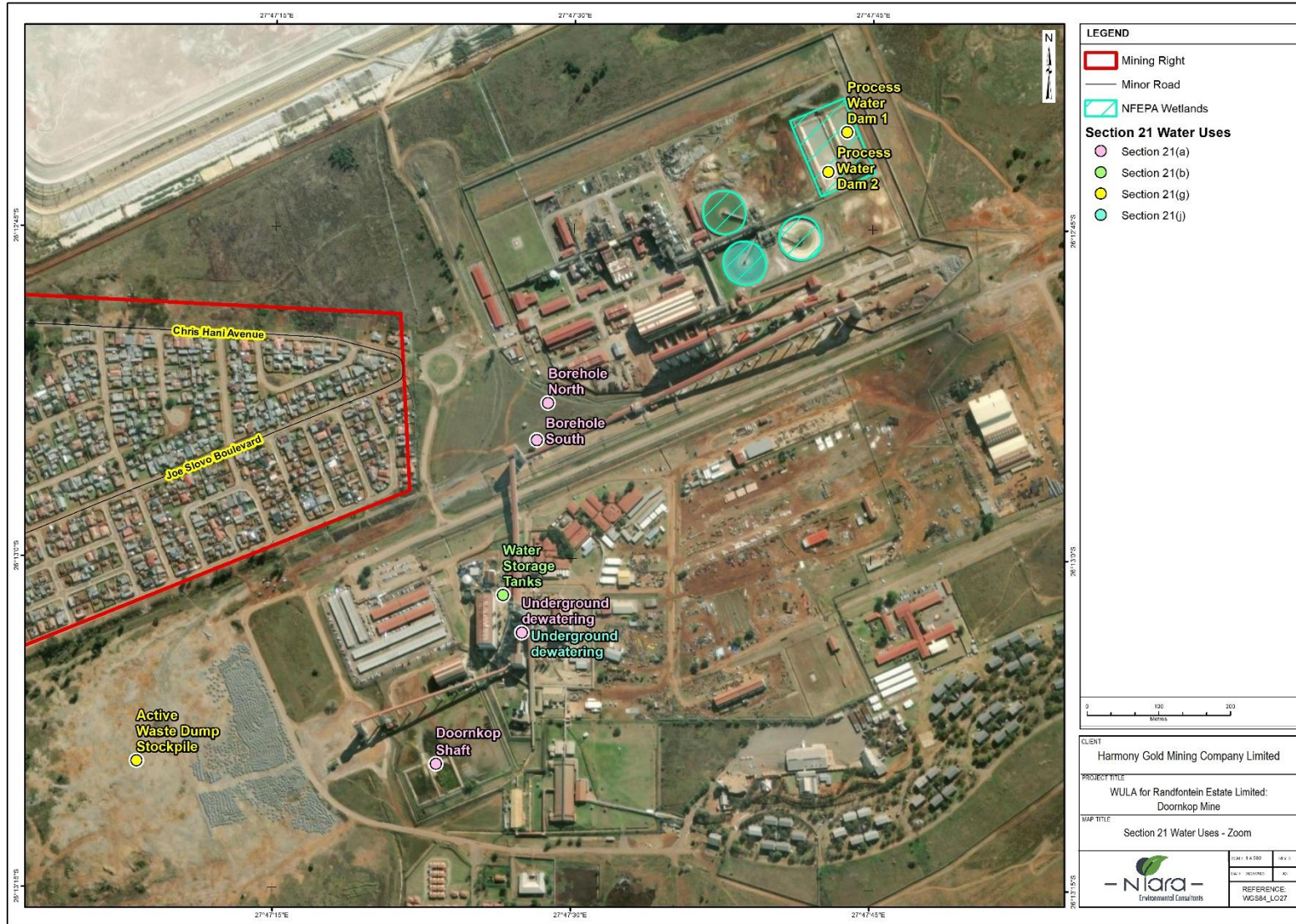


Figure 5-10: Pollution sources and location mine infrastructures.



5.5.1. Contamination sources

The contamination sources that are likely to contaminate surface and groundwater resources if not properly managed are:

- ☛ Tailings Storage Facility (TSF).
- ☛ Reclaimed Waste Rock Dump (WRD).
- ☛ Wastewater Treatment Plant (WWTP).
- ☛ Sludge Settling Ponds.
- ☛ Return Water Dam (also called Pollution Control Dam (PCD)).
- ☛ Underground Mine.
- ☛ Underground Discharge.
- ☛ Attenuation Dam.
- ☛ Evaporation Dam.
- ☛ Farmer's Dam.

These are mine infrastructures with potential for surface and groundwater contamination. Poor management of these infrastructures may result in surface and groundwater deterioration. Seepage of contaminated mine water from these facilities will eventually drains and affect the receiving environment. This will most likely have an impact on surface and groundwater quality. Increased salt load due to these sources is a concern which must be addressed through water management strategies focusing on prevention, mitigation, and remediation.

5.5.2. Pathways

The main pathways that are likely to transport contaminants within the mine site will be:

- ☛ Runoff and infiltration through soil or vadose zone.
- ☛ Fault and dykes occurring within the study area.
- ☛ Groundwater or aquifer.
- ☛ Surface water or streams.

Runoff and infiltration through soil or vadose zone

Runoff as a pathway for transporting contaminants from the mine is likely to occur during wet or rainy season. Hence, storm water management is critical to manage potential impacts during rainy season. In this case, separation of dirty and clean storm water must form priority and must be monitored to ensure that such measures are critical. Contaminated mine water must be prevented from flowing into receiving environment. A large portion of the mine and its surface drainage slopes towards the streams. Infiltration of contaminants through soil and vadose zone will form part of the pathways, affecting soil, surface water and groundwater resources.



Fault and dykes occurring within the mine

The mine area has undergone deformation which result in the occurrence of faults and intrusion of dykes. These faults are:

- Roodepoort Fault.
- Saxon Faults.
- Doornkop Fault.
- The Black Duck Dyke.

In most cases, geological structures that act as preferential flow path due to high hydraulic conductivity are likely to transport contaminant to groundwater resources. The structure within the site intersects with streams in the area, meaning if high conductivity exists within these structures, then streams may also be contaminated. Structure which acts as a barrier is likely to prevent horizontal groundwater flow. However, vertical groundwater flow within this structure may exist, particularly from the direction of groundwater flow.

Groundwater or aquifer

Doornkop Mine area is characterised by shallow groundwater level 2.11 mbgl to 13.84 mbgl. This is due to low vertical hydraulic conductivity which reduces infiltration and percolation rate, forming unconfined and perched aquifer. If contaminants from contamination sources migrate to groundwater within the mine, such contaminant will dilute and continues to spread towards downstream. Contaminant from the waste rock dump will most likely spread during rainy season, whereas contamination from the TSF and dams will be continuous.

Hydraulic conductivity within the vadose zone and aquifer together with hydraulic gradient are the driving forces for groundwater flow. If these parameters are high, contaminants will be transported fast from surface to groundwater with short residence time. Furthermore, contamination of the aquifer along the riverbank of the streams is likely to contribute to the contamination of the stream.

Shallow aquifer zones within the mine are fractured and weathered. In some locality, shallow water strikes were intersected. Deep aquifer is characterised by weathered zones, fractures and joint which improves permeability. These structures allow the storage and transportation of groundwater which may become a pathway for contaminant. Hence, groundwater management through monitoring, remediation and lining of new facilities is critical to reduce the impacts.

Surface water or streams

Two perennial rivers occur in the vicinity of the mine, with Klip River in the east and Wonderfonteinspruit River in the west. Any runoff, seepage and overland flow are likely to drain into the stream. Where the stream is interconnected with the aquifer, contamination of the stream is likely to contaminate groundwater within the aquifer. Implementation of storm water management is crucial to reduce the impacts.



5.5.3. Receptors

The Klip and Wonderfonteinspruit Rivers are the water courses which may potentially be affected by contaminants emanating from the sources. Groundwater resource downstream and underneath of the contamination sources is also a receptor and will potentially be affected by seepage, infiltration, runoff, and overflow of contaminated water. The contamination of surface and groundwater can lead to serious health problems for consumers, as well as the integrity and survival of surface and groundwater dependent ecosystems. Thus, surface and groundwater users as well as ecological dependent ecosystems serve as receptors.

5.6. Groundwater quality

5.5.1. Groundwater quality

Table 5-17 provide the summary of groundwater quality results. Detailed analyses are shown in Appendix 10. The concentration of Zn, Fe, Cu, U, Free cyanide, WAD cyanide and Total cyanide are below detection limit. In general, groundwater quality within the mine comprises of boreholes with good water quality and boreholes that shows exceedance in some parameters.

pH value within the mine generally varies from 6.39 to 8.29. All monitoring boreholes are confined within the SANS 2015 drinking water limit of 5.0 to 9.7. The presence of electrical conductivity in water may be associated ionised substances, excessive hardness, and contamination. EC of groundwater sample at Doornkop Mine ranges from 9.8 mS/m to 95.9 mS/m. These samples are well below the SANS limit of 170 mS/m. Total Dissolved Solids relates to all solids dissolved in water such as cations and anions. TDS values in the study area were found below permissible limits prescribed by SANS 2015.

The concentration of cations (Na, Mg, K, Ca, and anions (Cl, SO₄) in the study area are recorded at very low concentration. All monitoring boreholes are well within the recommended SANS limit. SO₄ in gold mine is very crucial indicator for contamination. High concentration of this parameter together with low pH, high Fe, Al, and metals may be an indication of acid mine drainage. It must be noted that these parameters in monitoring boreholes were recorded below SANS limit with the concentration of Fe, Zn and Cu recorded below detection limit.

Mn concentration at Doornkop Mine present a concern in monitoring boreholes. This is because the parameter was recorded at concentration above the SANS 2015 limit at borehole DKP 4, DKP 7, DKP 8 and DKP 13. DKP 4 also comprises of high concentration of Al above SANS 2015 limit. DKP 4 is located downstream of the mine while DKP 7, DKP 8 and DKP 13 are located downstream of TSF and RWD. Common sources of Mn in groundwater are industrial effluent, acid-mine drainage, and sewage facilities. High Mn concentration may result from weathering of Fe and Mn bearing minerals.



Table 5-17: Summary of groundwater quality analysis results.

BH ID	Variables	pH	EC	TDS	Sulphate	Manganese	Magnesium	Calcium	Sodium	Potassium	Chloride	Fluoride	Aluminium
		pH	EC	TDS	SO ₄	Mn	mg/l	Ca	Na	K	Cl	F	Al
	Units		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DKP1	Mar-23	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
	Jun-23	6.78	9.8	80	16.5	<0,001	5.74	6.93	13.1	4.31	8.14	<0,263	0.004
DKP3	Mar-23	7.61	19.2	154	8.5	0.024	11.3	15.8	8.65	4.58	9.08	<0,263	<0,002
	Jun-23	7.85	20	114	5.26	<0,001	11	14.9	7.35	3.1	12.8	<0,263	<0,002
DKP4	Mar-23	7.2	33.5	208	36.2	0.95	7.85	40.5	17.9	13	17.2	<0,263	0.525
	Jun-23	7.79	32.7	194	38	<0,001	5.66	44.8	16.4	8.75	19.3	<0,263	<0,002
DKP7	Mar-23	6.39	14.8	142	5.05	0.724	2.17	3.55	25.4	0.304	18.3	0.324	<0,002
	Jun-23	6.57	14.7	94	5.18	0.635	2.22	2.98	21.7	0.244	20.3	<0,263	<0,002
DKP8	Mar-23	7.61	62	506	242	<0,001	42.7	60.5	19.3	3.05	16.8	<0,263	<0,002
	Jun-23	7.99	65	398	244	0.217	34.5	63.1	19.6	3.07	20.3	<0,263	0.004
DKP13	Mar-23	7.83	95.9	856	312	0.779	79.3	99	26.6	9.49	49.2	<0,263	<0,002
	Jun-23	8.29	67.6	384	105	0.166	38.3	40	24.7	4.67	78.6	<0,263	<0,002

Notes: *** Within limit; Above Limit



Long term water quality trends at Doornkop Mine suggest a huge improvement in groundwater quality. Historical assessment of groundwater quality reflects concentration of impacted groundwater within the mine. Figure 5-11 and Figure 5-12 shows water quality trends for SO₄ and TDS at Doornkop Mine. Groundwater quality within Doornkop were impacted mainly within the TSF, evaporation dam and RWD area. DKP 8 and DKP 13 were characterised by high concentration of SO₄ and TDS between June 2014 and March 2019. These boreholes have shown great improvement in terms of water quality from 2021, which suggest a significant improvement in water quality improvement.

Groundwater quality at Doornkop Mine is shallow. This is associated with perched water table that result from perched aquifer system. A perched aquifer within Doornkop do exist due to low hydraulic conductivity and permeability which restrict groundwater movement, percolation, and infiltration. This results in the formation of perched aquifer system characterised by shallow water level. This type of aquifer generally recharges through direct rainfall due to weathered material close to surface.

A sudden decrease from impacted monitoring points to permissible limit suggest that the boreholes receive direct recharge. This recharge is characterised by short residence travel time, which suggest high dilution from fresh rainwater. It is possible that impact at Doornkop was associated with impacted runoff and impacted stormwater that enters the boreholes from the surface. This is because impacted groundwater does not change from high impact from one months to permissible limit on the following monitoring months.

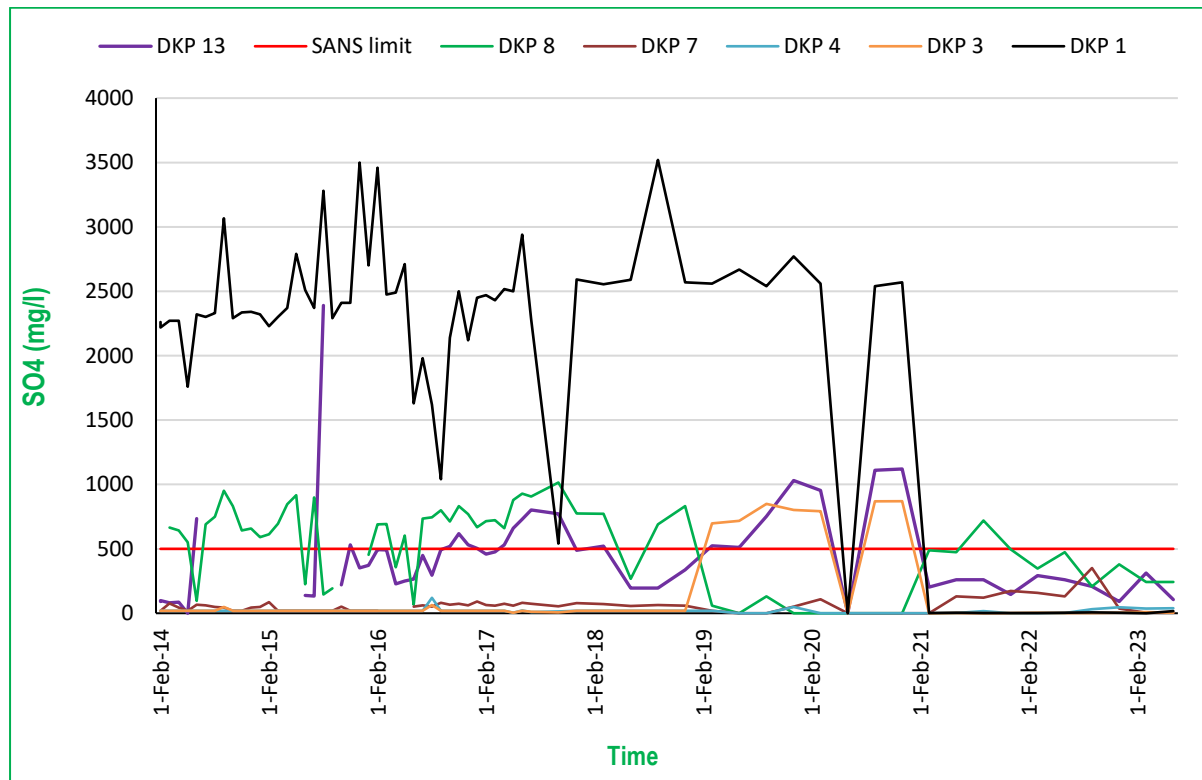


Figure 5-11: SO₄ concentration from February 2014 to June 2023.



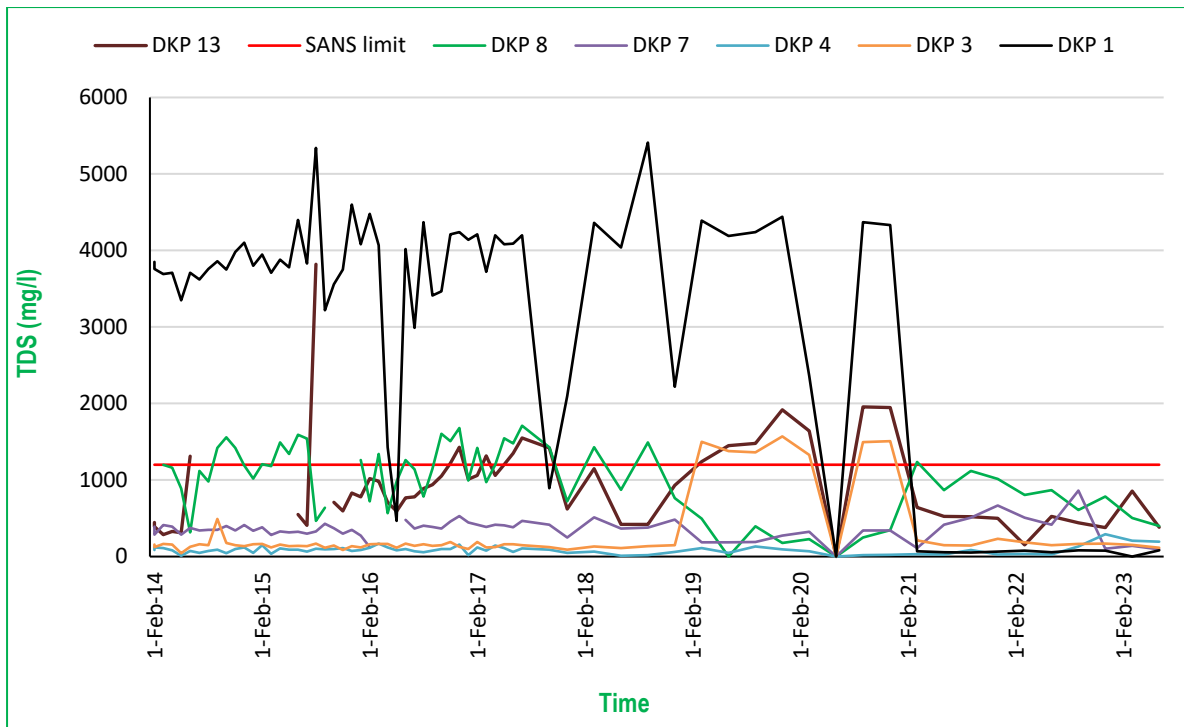


Figure 5-12: TDS value from February 2014 to June 2023.

Shallow groundwater is directly impacted by surface activities during rainy seasons, overflow of dams and deposition of tailings or waste material. Surface water and groundwater interaction may be high, especially between a perched aquifer and evaporation dams. Improvement in the containment of stormwater may have direct influence in the improvement of groundwater quality. Prevention of overflow which may flow towards the boreholes may also improve water quality for boreholes shallow groundwater level.

5.5.2. Hydrochemical facies

The piper diagram was used to understand the geochemical signature of groundwater at Doornkop. This diagram is compiled using the concentration of major cations and anion. The location of the samples that are plotted on a piper diagram is used to determine the facies of groundwater. The piper geochemical classification is shown in Figure 5-13, with water types that exist within the mine shown in Table 5-18. Based on the diagram, groundwater sampled at Doornkop Mine are classified into six hydrogeochemical facies, which are typically of:

- Shallow fresh groundwater: DKP 3.
- Mixed water sources: DKP1.
- Deeper fresh groundwater: DKP 7.
- Evaporation water sources.
- Mine drainage influence: DKP 4, DKP 8, DKP 13.



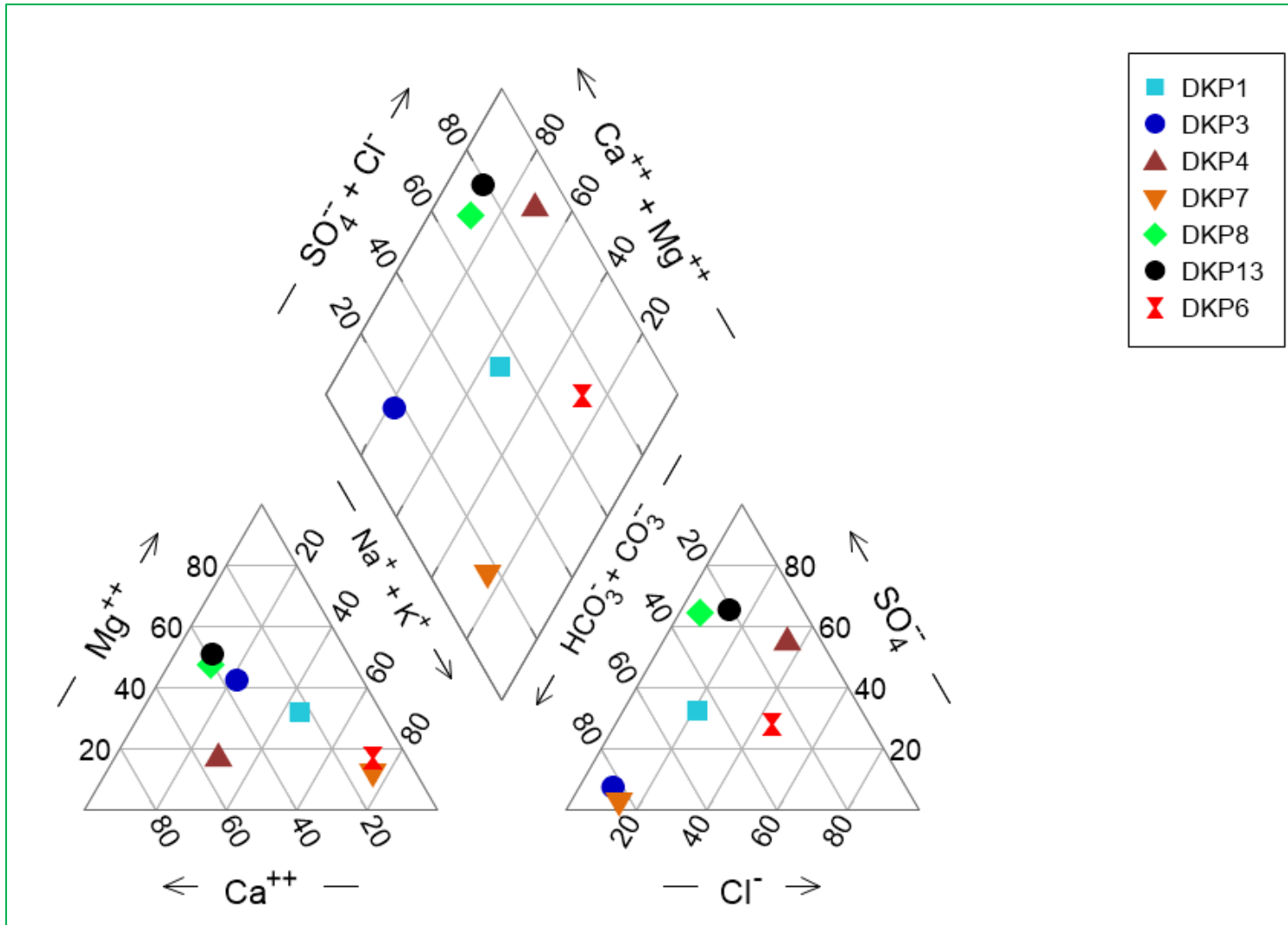


Figure 5-13: Piper diagram for hydrogeochemical facies.



Table 5-18: Table showing water types.

BH ID	Water type
DKP1	Na-Mg-Ca-HCO ₃ -SO ₄
DKP3	Mg-Ca-HCO ₃
DKP4	Ca-Na-Mg-SO ₄
DKP7	Na-HCO ₃ -Cl
DKP8	Mg-Ca-SO ₄ -HCO ₃
DKP13	Mg-Ca-SO ₄
DKP6	Na-Cl-SO ₄ -HCO ₃

DKP 3 is classified as shallow fresh groundwater. This is groundwater which recently have recharged. It is characterised by Mg-Ca-HCO₃ water type. The borehole is dominated by high HCO₃, low Cl with no dominant cation. Groundwater collected from DKP 7 is classified as deep water influenced by ion exchange. The ion exchange process occurs during groundwater flow to deeper aquifer system. This borehole consists of Na-HCO₃-Cl water type and is dominated by high Na+K and High HCO₃.

DKP 1 is classified as mixed water sources. This borehole comprises of different water source. This could be fresh groundwater sources, mine groundwater sources or deep groundwater sources. The borehole has Na-Mg-Ca-HCO₃-SO₄ water type. It is located within a zone with no dominant cation and anion.

DKP 6 comprises of water influenced by evaporation. Groundwater in this borehole is dominated by high Na+K with average Cl concentration. This influence may be associated with either; (1) lack of rainfall penetration or lack of dilution with rainwater, resulting in an increased concentration of Na and Cl, (2) direct recharge from surface water influenced by evaporation, and (3) dissolution processes or salt deposits.

The influence of mining activities is apparent in monitoring borehole DKP 4, DKP 8 and DKP 13. Although these boreholes comprise of concentration within permissible limit (Not polluted), piper classification suggest that the chemical composition is being influenced (Contaminated) by mine related activities. These boreholes are located downstream of the TSF and RWD. It consists of Ca-Na-Mg-SO₄, Mg-Ca-SO₄-HCO₃ and Mg-Ca-SO₄ water type dominated by high SO₄ concentration.



6. Aquifer Characterisation

6.1. Groundwater vulnerability

Vulnerability is defined as the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. There are many methods that are used to assess aquifer vulnerability. However, the most widely used method is DRASTIC method. This method has been developed by Aller et al., (1987) and has been used in several areas by different researchers and consultants. The method is based in evaluating seven parameters denoted by the acronym:

- Depth to groundwater.
- Recharge.
- Aquifer media.
- Soil media.
- Topography.
- Impact on vadose zone.
- Hydraulic Conductivity.

Based on this assessment, the mine area is classified as moderate vulnerability. This class results in a point scoring system of 2 as presented in Table 6-1. All mine infrastructures are located within this aquifer (Figure 6-1). The dolomite aquifer is classified as Most vulnerable to contamination as shown in Figure 6-1. This class results in a point scoring system of 3. Dolomite aquifer is often characterised by higher aquifer parameters than the aquifer located north of the dolomite where mine infrastructures is located. Depth of the groundwater level within the dolomite area is also shallow, with groundwater level that varies from 11.86 mbgl to 20.12 mbgl.

Table 6-1: Rating for the Aquifer Vulnerability Classification.

Aquifer Vulnerability Classification			
Class	Points	Mine Infrastructure area	Dolomite Aquifer
Most	3		3
Moderate	2	2	
Least	1		



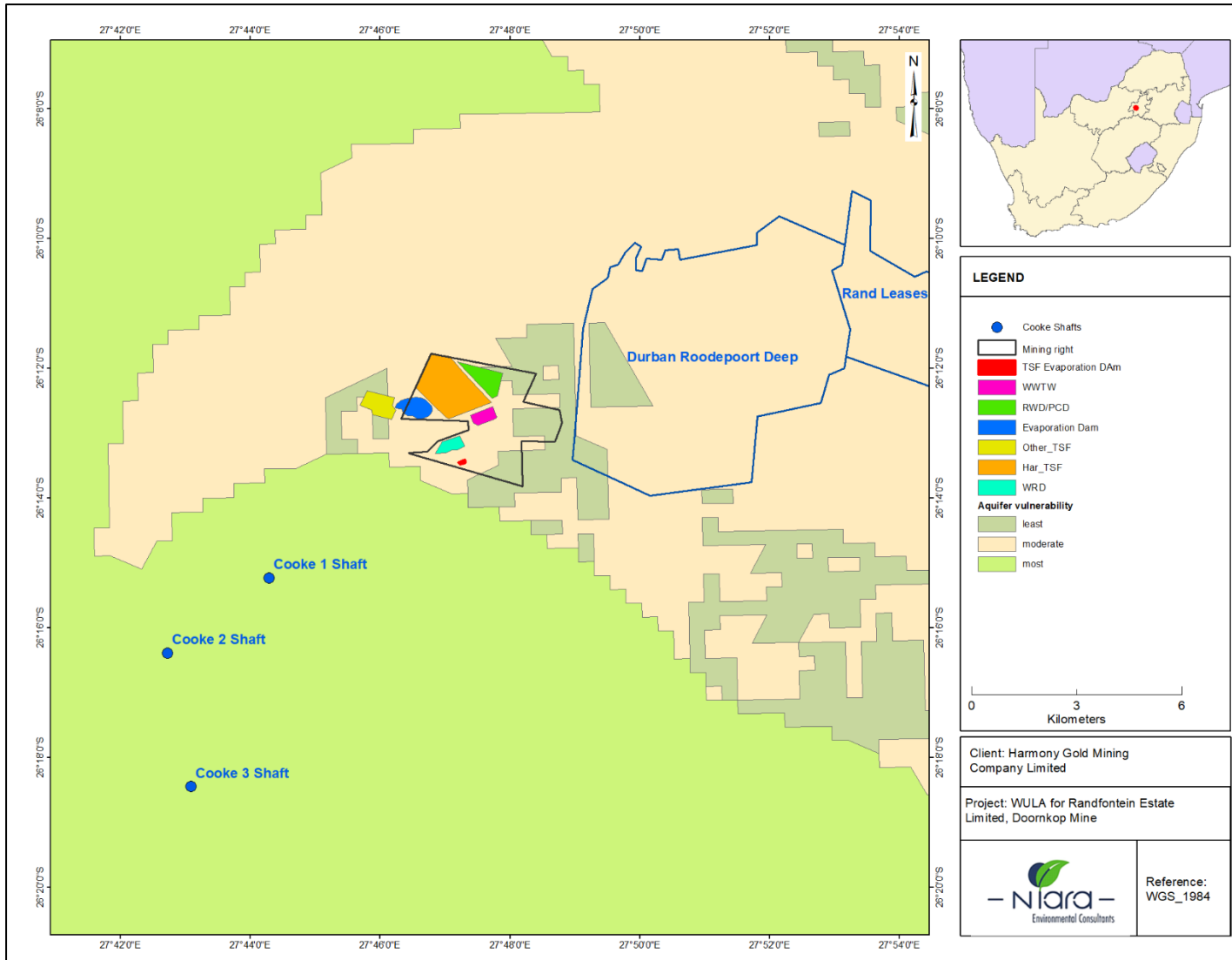


Figure 6-1: Aquifer classification map.



6.2. Aquifer classification

The Parsons' and Conrad (1995) aquifer system management classification was used in the assessment of aquifer class in the study area. Based on the classification method, the following types of aquifer systems are recognised:

- ☛ Sole Aquifer System - An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- ☛ Major Aquifer System - Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- ☛ Minor Aquifer System - These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- ☛ Non-Aquifer System - These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although 37 imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
- ☛ Special Aquifer System - An aquifer designated as such by the Minister of Water Affairs, after due process.

Base on this classification procedure and the information obtained from DWA (2012), the aquifer within the study area is classified as minor aquifer system. To achieve the Aquifer System Management, a point scoring system as presented in Table 6-2 was used. Figure 6-2 shows the distribution of aquifer class in the study area.

Table 6-2: Ratings for the Aquifer System Management.

Aquifer System Management Classification			
Class	Points	Mine infrastructure area	Dolomite Aquifer
Sole Aquifer System	6		
Major Aquifer System	4		4
Minor Aquifer System	2	2	
Non-Aquifer System	0		
Special Aquifer System	0 – 6		



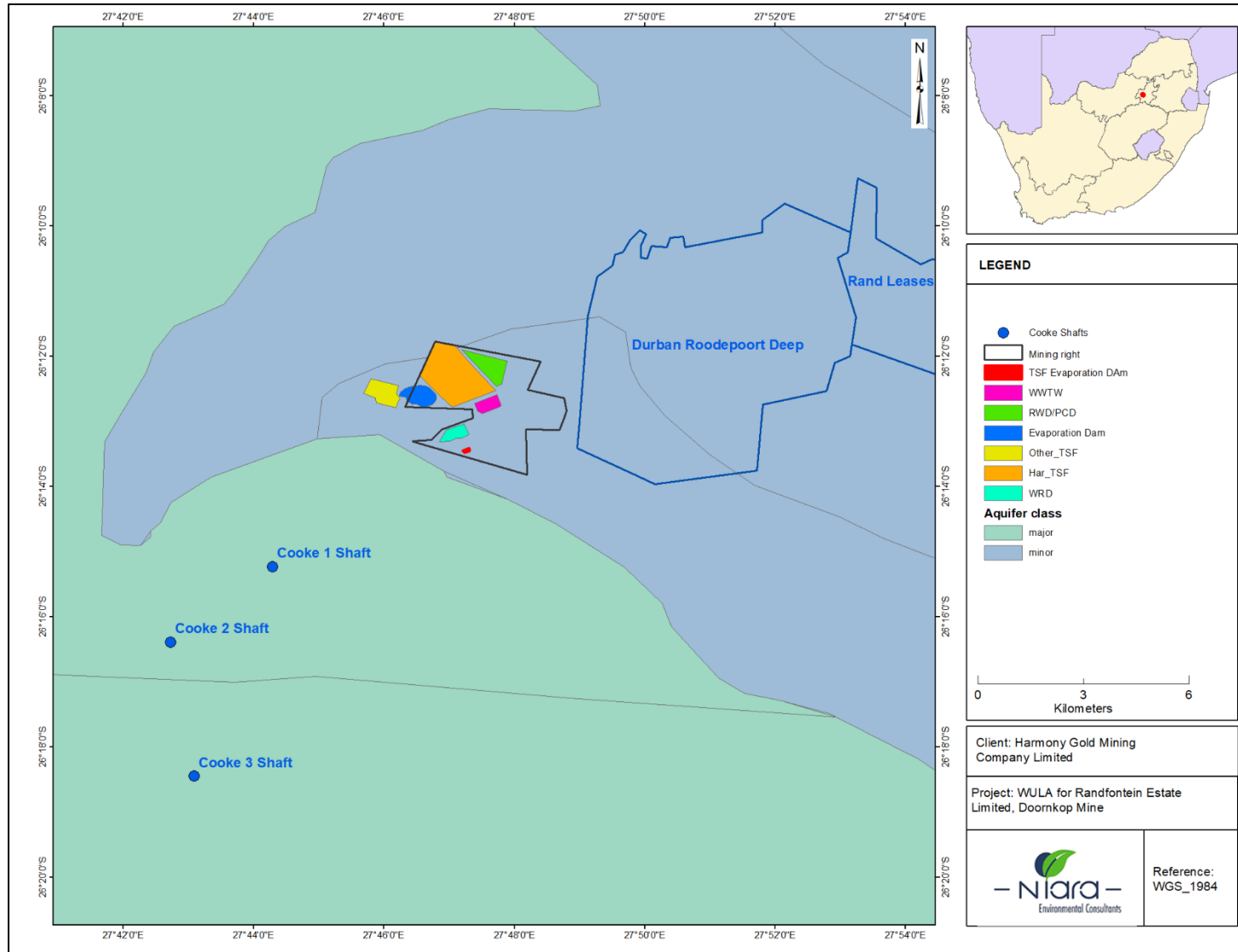


Figure 6-2: Aquifer classification map.



6.3. Aquifer protection classification

As part of the aquifer protection classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability (Table 6-3).

Table 6-3: Rating for Groundwater Quality Management Classification System.

Mine infrastructure area			
Aquifer System Management Classification		Aquifer Vulnerability Classification	
Class	Points	Class	Points
Sole Aquifer System	6	Most	3
Major Aquifer System	4	Moderate	2
Minor Aquifer System	2	Least	1
Non-Aquifer System	0		
Special Aquifer System	0 – 6		
Dolomite Aquifer			
Aquifer System Management Classification		Aquifer Vulnerability Classification	
Class	Points	Class	Points
Sole Aquifer System	6	Most	3
Major Aquifer System	4	Moderate	2
Minor Aquifer System	2	Least	1
Non-Aquifer System	0		
Special Aquifer System	0 – 6		

Table 6-4: Rating for the GQM Index for the Study Area.

GQM Index	Level of Protection	Mine infrastructure area	Dolomite Aquifer
<1	Limited		
1 - 3	Low Level		
3 - 6	Medium Level	4	
6 – 10	High Level		
>10	Strictly Non-Degradation		12

GQM Index = Aquifer System Management x Aquifer Vulnerability

The points scoring system for GQM index for the study area is presented in Table 6-4 where GQM is equal to 4. Based on the assessment, the mine area where infrastructure is located requires medium level of groundwater management activities within the dolomite area requires strict groundwater management.



7. Groundwater Modelling

7.1. Software model choice

Groundwater model was simulated using the ModelMuse, a graphical user interface (GUI) for modelflow packages. These software package have been developed by U.S. Geological Survey (USGS). ModelMuse provides a GUI for development and construction of groundwater flow and transport model. Version 4 of the package was modified to support Modflow 6. The package can support three dimensional (3D) and can specify spatially variable anisotropy in hydraulic conductivity (Winston, 2019).

Modflow 6 is a latest version of groundwater modelling software developed by USGS. The code is based on finite different method. It is capable of simulating both Groundwater Flow (GWF) and Groundwater Transport (GWT) modeling. Modelflow 6 has most of the features and capabilities which were included in previous version of mudflow in terms of flow packages, stress packages, approach for water table aquifer, features for regular and unstructured grid and solute transport. These features were available in different modelflow packages. All these features are built into Modelflow 6. The code support multiple models in one simulation.

7.2. Model set-up and boundaries

Model boundary was adopted from previous investigation and model conducted for Doornkop Mine. This boundary has an extent of 10 km by 7.3 km. The model boundary is bounded by Klip River and Wonderfontein River on the east and west of the mine.

7.3. Groundwater elevation and gradient

The northern section of the model boundary has high elevation (1720 mamsl) while the southern boundary has low elevation (1620 mamsl). The mine area consists of shallow groundwater level associated with perched water table. These groundwater levels mimic topographic elevation with general flow towards the east and south. Regional groundwater level associated with deeper aquifer is unknown. All boreholes are characterised by shallow groundwater level.

7.4. Geometric structure of the model

The initial model grid is composed of 10 columns and 10 rows with a column and row width of 100. The model consists of 8 layers with model top marked by surface elevation (DEM). These layers are classified as convertible confined-unconfined aquifer system. Table 7-1 shows the summary of the layers and assigned geology. Layer 1 and 2 are composed of various geology. Dolomite aquifer occurs to the south of the study area, forming the top deposit, while Ventersdorp lava and Eslburg covers the central portion to the north. The Black Reef formation occurs directly below the dolomite. This formation is classified as a barrier or impermeable layer that prevent vertical flow of groundwater from dolomite to underground working.



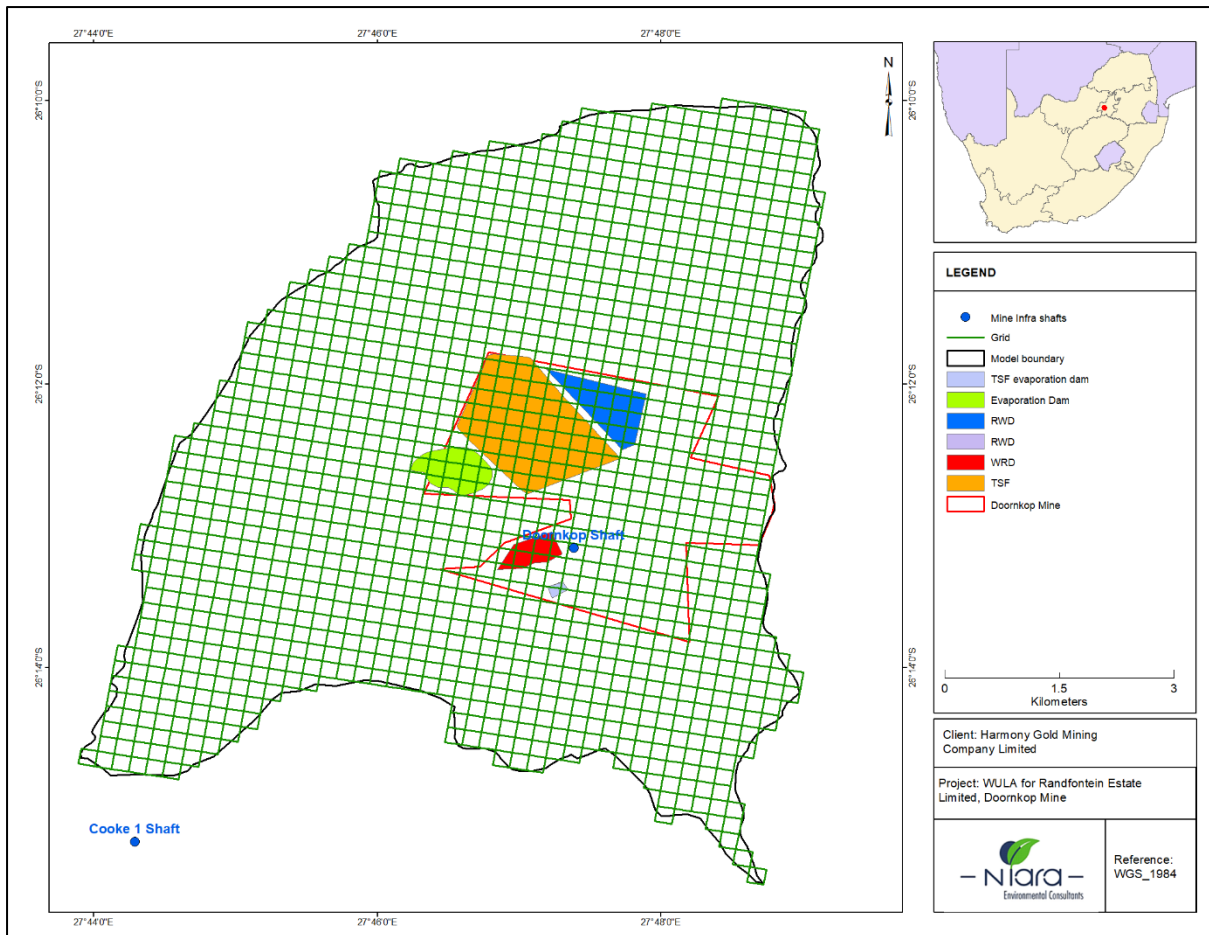


Figure 7-1: Model boundary and grid.

Table 7-1: Arrangement of modelled layers from the surface to the bottom with elevation.

Model layer	Elevation (m)	Notes
Model Top	Surface elevation (DEM)	DEM was used for model top
1, bottom	1450	Dolomite, Elsburg and Ventersdorp lava
2, bottom	1415	Black Reef, Elsburg
3, bottom	1150	Elsburg quartzite
4, bottom	900	Kimberly quartzite
5, bottom	650	Kimberly shale
6, bottom	150	Luipaardsvlei quartzite
7, bottom	-270	Langlaagte quartzite
8, bottom	-400	Jeppestown



7.5. Groundwater sources and sinks

The following boundary conditions were accommodated into the model:

- ☛ Drainage network.
- ☛ Contamination sources.
- ☛ Abstraction/dewatering points.
- ☛ Underground working.

Drainage network was incorporated into the model. This includes the Klip River and Wonderfontein River. The two rivers occur in the east and west of the mine, flowing from north to south. Tributaries of these rivers which direction drains surface water from mine was also accommodated. These boundaries were classified as drains. Underground working was incorporated into the model as drain package.

Sources and sinks in the form of contamination sources were specified. This included all contamination sources such as TSF, waste rock dump, PCD, attenuation dam and evaporation dam. Initiation concentration (SO₄) for these boundary conditions is summarised as follows:

- ☛ TSF: 1500 mg/l.
- ☛ Dams: 1200 mg/l.
- ☛ WRD: 500 mg/l.

Dewatering of aquifer above the mine working occurs using two deep boreholes. These boreholes were incorporated as dewatering points. Each borehole will abstract about 400 m³/day. Dewatering of mine water underground was simulated based on 6 000 m³/day. Recharge within the area was calculated as 31.77 mm/a or 4.77%. This recharge rate was specified for this groundwater model.

7.6. Conceptual model

As part of the study, conceptual model was constructed based on available information. The following provide a summary of the conceptual model which was constructed based on Figure 7-2 and available site information.

- ☛ Geology: Dolomite, Ventersdorp lava and quartzite form surface geology. From top to bottom, It is followed by Black reef, Elsburg quartzite, Kimberly shale, Kimberly quartzite, Luipaardsvlei quartzite, Langlaagte quartzite and Jeppestown below the mine. Black Reef occurs directly below the dolomite rocks.
- ☛ Aquifers: Karst (Dolomite) Aquifer occurs to the south of the mine. Large portion of the mine is covered by Fractured aquifer, Fractured and Intergranular aquifer.
- ☛ Groundwater level: Groundwater level is shallow and varies from 2.11 mbgl to 13.84 mbgl. Groundwater generally flows from north to south and towards south east.



- Hydraulic conductivity: Hydraulic conductivity of Ventersdorp lava and Elsburg quartzite is low and varies from 0.06 m/day to 0.39 m/day. Dolomite has hydraulic conductivity ranging from $2 \times 10^{-3} \sim 1.1 \times 10^{-4}$ m/s.
- Contamination sources: The following infrastructures are contamination sources; TSF, WRD, RWD/PCD, evaporation dam, TSF evaporation dam.
- Contamination pathways: The main pathways include runoff and infiltration through soil or vadose zone, fault and dykes occurring within the study area, unsaturated zone, groundwater or aquifer, and surface water or streams (Klip River and Wonderfontein River).
- Receptors: This includes the Klip and Wonderfontein spruit River, groundwater resource downstream and underneath contamination sources.
- Water sources: recharge through precipitation remain one of the major sources of water flowing into the study area.
- Location of infrastructure: Most infrastructures like contamination sources are located within the lava and quartzite rocks with low hydraulic conductivity. Ventilation shaft occurs within the dolomite. There is an impermeable barrier below the dolomite (Black Reef), that prevent vertical flow from the dolomite to underlying aquifer and mine void. The influence of dolomite could only take place through leakages occurring within the ventilation. Faults serving as a conduit or preferential flow may also transport water from the dolomite to the mine working.

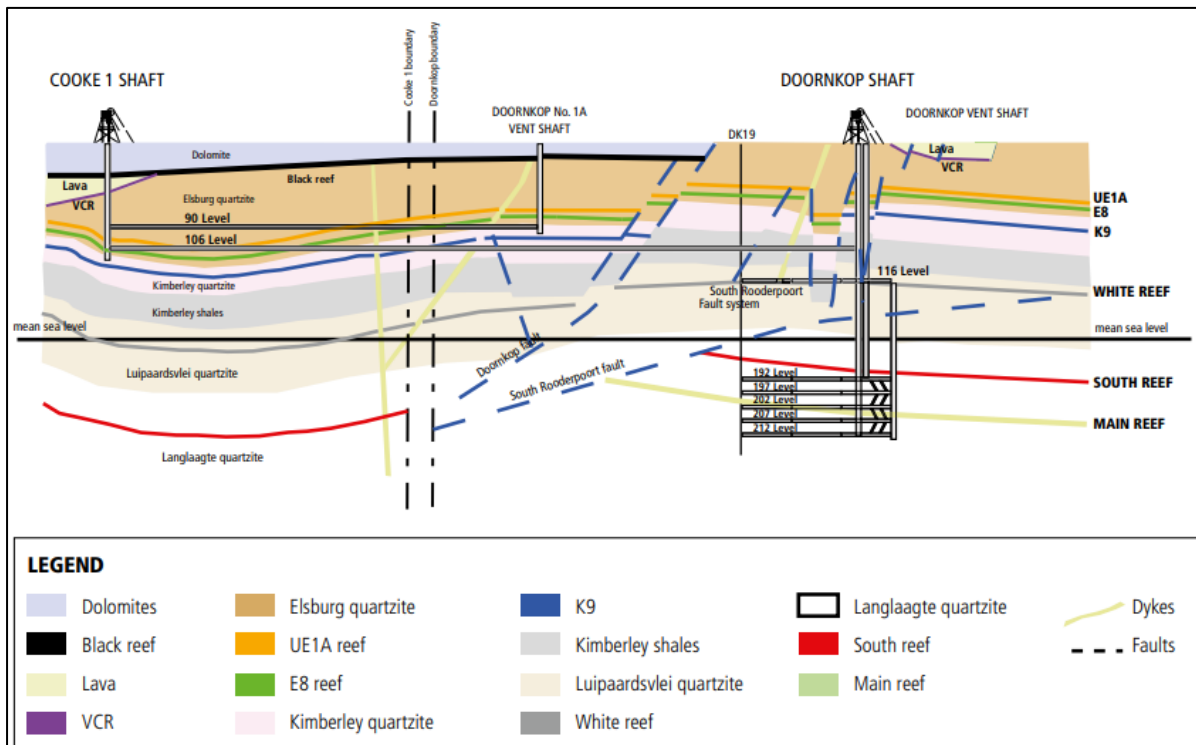


Figure 7-2: Schematic North-South section showing Doornkop Mine infrastructure and geology (Harmony, 2020).



7.7. Numerical model

8.7.1. Numerical groundwater flow and transport

Modflow 6 utilise a control volume finite different method for simulation of groundwater flow. Finite different equation that incorporates isotropic and anisotropic forms assist in simulating both vertical and horizontal flows. The code also has a finite different equation for head-dependent and specific boundary flows.

Steady state numerical model was simulated. The model was then converted into transient model to make long term predictions related to change in groundwater level, migration of plume within the mine and long-term impacts associated with dewatering and contamination sources. Converting of steady state mode to transient model required that a storage is activated. Horizontal Flow Barrier Package (HFB) package was used mainly for known faults that are incorporated in the model. Contaminant transport and migration of plume was assumed to take place under advection and dispersion package. Migration of contamination plume was assumed to occurs without reactions, adsorption, and decay along flow path.

Numerical groundwater flow model has been simulated to represent the natural condition at Doornkop Mine. Geology in terms of deposit and layering was incorporated into numerical model. Groundwater level from monitoring boreholes have been used to calibrate the model. Hydraulic conductivity and recharge calculated for Doornkop Mine have all been calibrated. The three-dimension numerical approach for groundwater flow is described by Darcy's Law. The following parameters were used for calibration of hydraulic conductivity.

Table 7-2: Hydraulic conductivity

Model layer	Rock type	Kx or Ky (m/s)
1	Dolomite	0.001
	Ventersdorp lava	6.94E-7
	Elsburg quartzite	4.05E-6
2, bottom	Black Reef	5.787E-10
	Elsburg quartzite	4.05E-6
3, bottom	Elsburg quartzite	4.05E-6
4, bottom	Kimberly quartzite	4.05E-6
5, bottom	Kimberly shale	2.525E-6
6, bottom	Luipaardsvlei quartzite	10E-7
7, bottom	Langlaagte quartzite	10E-7
8, bottom	Jeppestown	4.63E-7

Horizontal and vertical hydraulic conductivity was assumed to be the same. Modflow initial head boundary was considered as model top represented by DEM. Recharge of 0.03177 m/a was applied mainly in the top active layer.



7.8. Results of the model

7.8.1. Pre -facility

Figure 7-3 shows simulated steady state groundwater level. This result reflects simulated groundwater level prior to incorporation of all mine related activities. During this stage, the model shows regional groundwater level deeper than the monitoring boreholes. This groundwater level reflects the possible groundwater level pre mining. Steady state groundwater flow model suggest that groundwater will flow perpendicular to the flow line, towards the south and south east of the mine.

Steady state groundwater level varies from 1611 mamsl to 1625 mamsl across the model boundary. This groundwater level compared comparable with historical modelled groundwater level in the area. The groundwater level is slightly deep compared to shallow perched groundwater level occurring within the mine. It is important to note that monitoring boreholes are characterised by shallow groundwater level that result from perched water table that formed due to low infiltration rate.

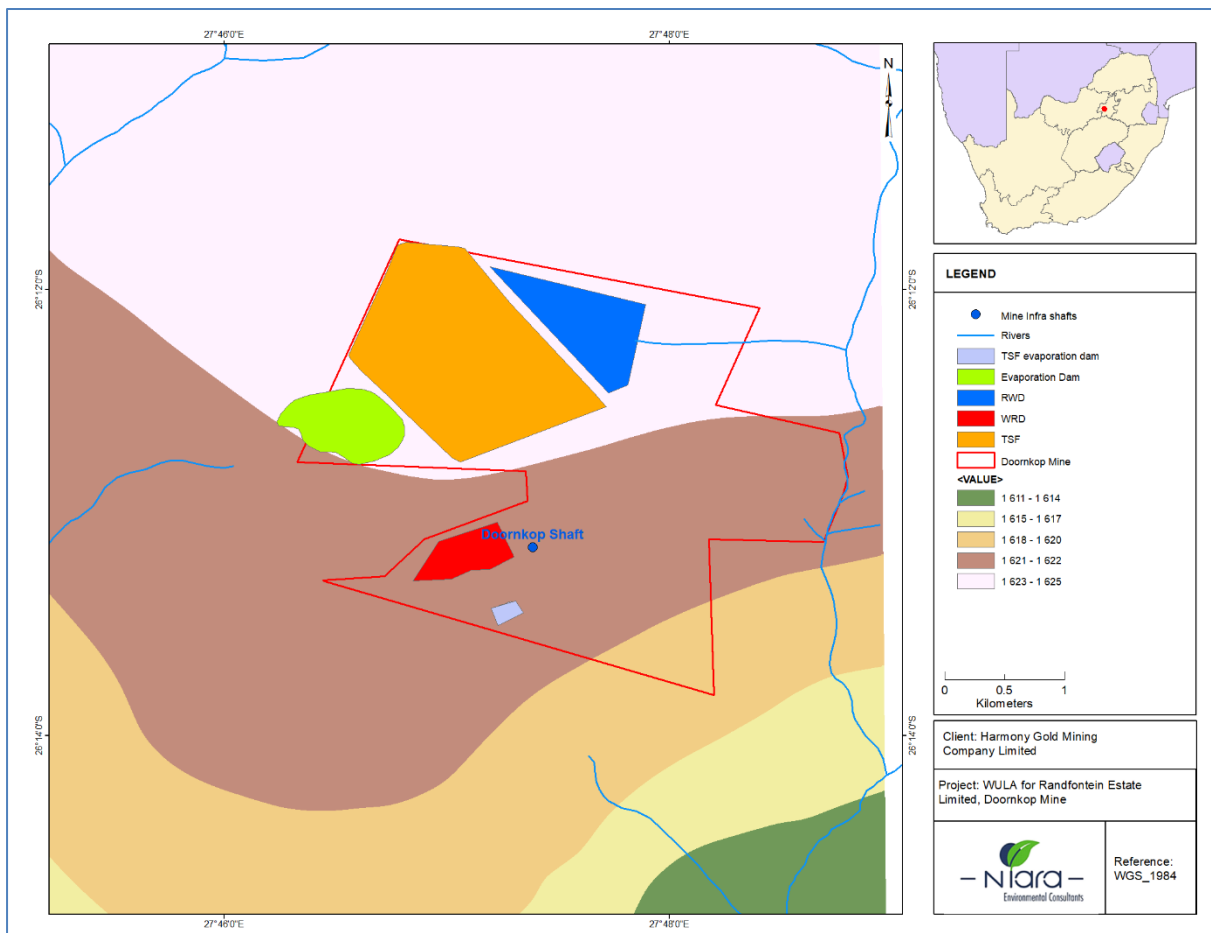


Figure 7-3: Simulated groundwater level



7.8.2. During facility operations

Operational phase was simulated based on transient simulation using mine related activities. This includes incorporation of mine contamination sources, abstraction from the boreholes and dewatering of underground working. This simulation incorporated the status since operation commenced and predicted impact related to the remaining life of mine

Groundwater level during operational phase shows a slight variation compared to steady state simulation. This is due to simulated abstraction from the two dewatering boreholes. Drawdown in groundwater level is observed, with average groundwater level of 1619 mamsl. Simulation suggests that the two boreholes do not have major impacts on groundwater level. This is because the boreholes are pumping at the depth of approximately 200 m below surface. Low hydraulic conductivity that exists within the surrounding rock unit may also contribute in reducing flow into the two boreholes. Geological deposit within Doornkop Mine is associated with faulting, which may also contribute to changing groundwater flow direction or preventing horizontal flow if such faults are sealed.

Simulation of dewatering of underground void does not show any impact on groundwater level above the mine. This is because the mine void starts at approximately 500 m below surface (1170 mamsl). Impermeable horizontal deposit such as the Black Reef and overlying lava may reduce the interaction between underlying voids and geology.

Surface contamination and spread of plume was simulated for operational phase that includes understanding the status of contamination migration and spread. Figure 7-4 shows the status of contamination plume while Figure 7-5 shows contamination plume at mine closure. Simulated result shows contamination within the TSF, RWD and Evaporation dam, and immediate surrounding area. Water table within the TSF area is relatively flat and decreases toward the south. This results in a contamination plume that spreads in all directions in the immediate surrounding of the TSF.

Monitoring boreholes DKP 3, DKP 7 and DKP 8 are located within the predicted plume area. The existence of this plume within this zone would suggest that the boreholes are supposed to be contaminated. This is not the case as the boreholes do not show any sign of major contamination plume. Only Mn and Al were detected in these boreholes. Plume associated with gold TSF and mine water is likely to have high SO_4 as one of the major indicators. This parameter is within the limit in these boreholes. This only suggests that the plume migrates through regional water table. All boreholes are shallow and comprise of shallow groundwater level. Historical assessment and reports at Doornkop have shown that the area has a perched aquifer system. TSF area was specifically cited as one of the sites with perched aquifer system.



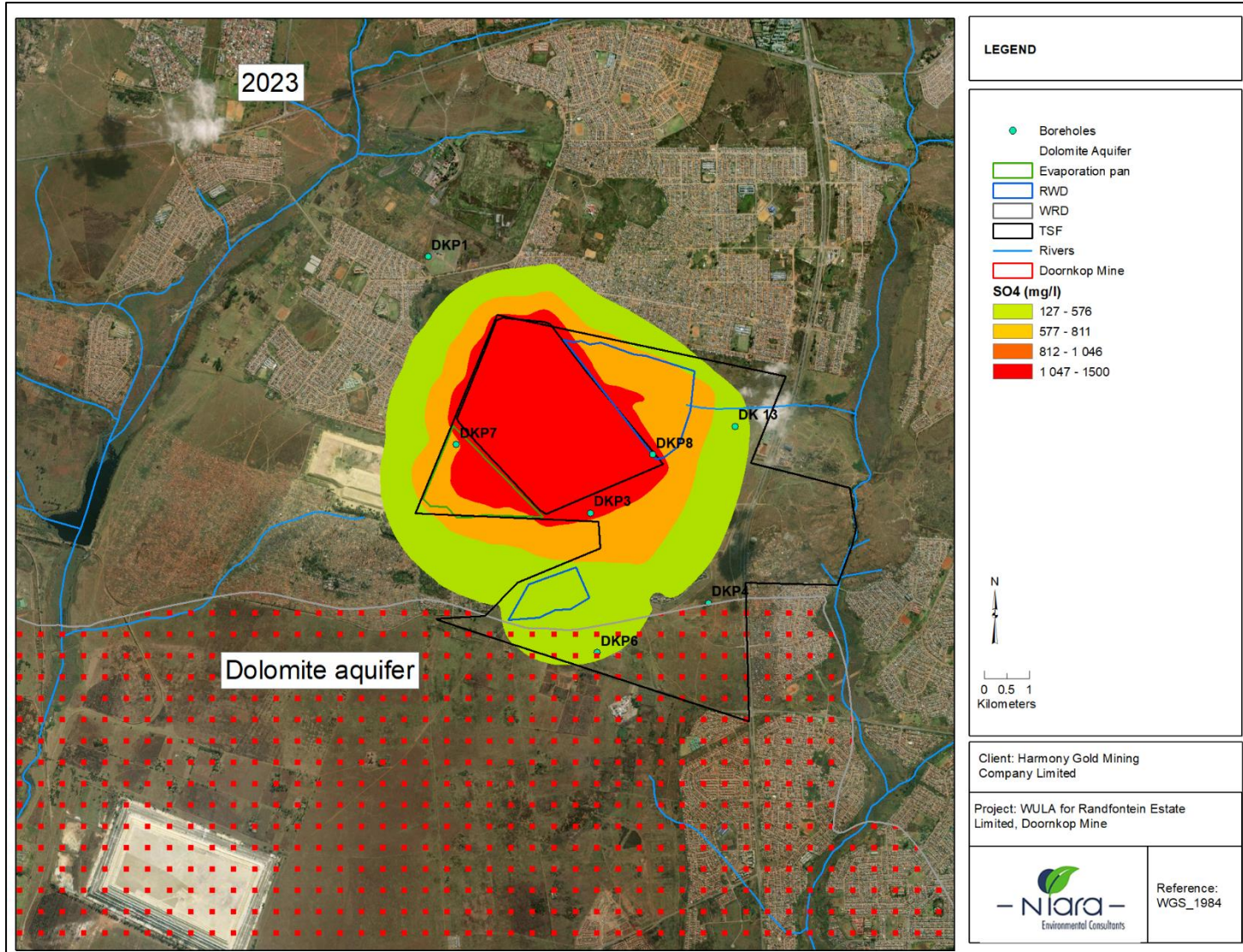


Figure 7-4: Status of contamination plume.



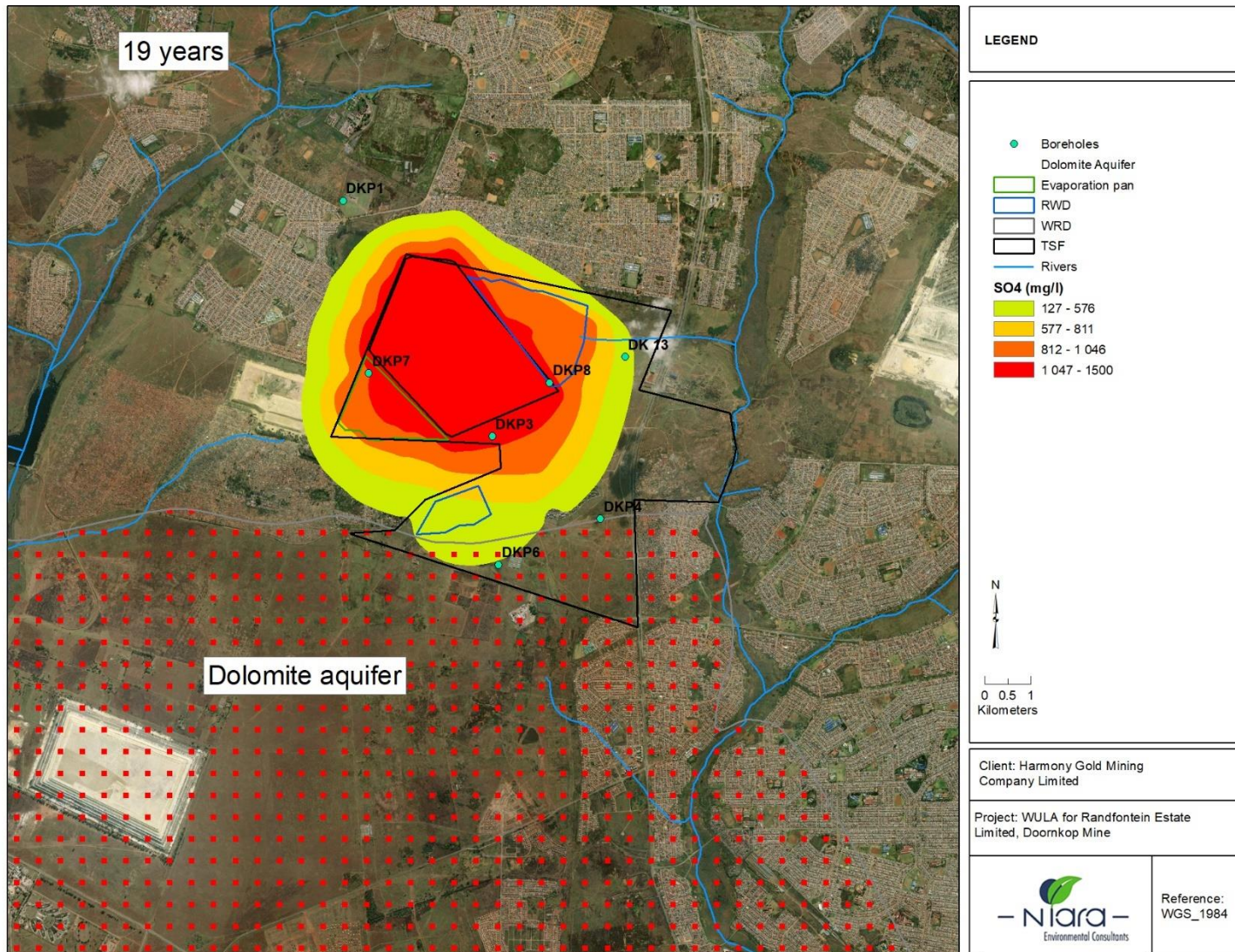


Figure 7-5: Predicted plume at closure (19 years LOM).



It is important to note that large portion of the mine is covered by Ventersdorp lava, an outcrop which also covers the TSF area and surrounding facilities. As a result, contamination within this area migrate slowly due to low hydraulic conductivity (refers to K values for Lava and quartzite). The tributary of the Klip River that emerges east of the RWD traverse with the outer edge of the plume. The stream may be influenced by surface overflow. However, contamination occurs within the regional water table with minimal interaction between the stream and the aquifer. Therefore, the plume occurring within the regional water table does not have any influence on this stream. Critical measures related to RWD and TSF impact on this stream will further be discussed under geohydrological impacts and measures.

Predictions made related to impacts which may occurs during operation until closure. The predicted plume is depicted in Figure 7-5. The driving force behind plume migration remain the same. These are hydraulic conductivity and relatively flat topography that result in low gradient around the TSF area. Although the plume continues to spread in all direction immediately surrounding the TSF, general migration of plume is towards the south and south east.

The upper edge of the stream in the east still occurs within the plume boundary. Borehole DKP 3, DKP 7 and DKP 8 is also affected by the plume. Major aquifer composed of the dolomite rock occurs to the south of the mine. This plume has not reached the Karst Aquifer or dolomite which occupies the southern boundary of the mine. The dolomite is classified as a major aquifer system in this report. The aquifer is also characterised by high aquifer vulnerability, suggesting that groundwater may easily be impacted. This is because the aquifer generally comprises of high hydraulic conductivity.

Total inflow predicted is about $0.074 \text{ m}^3/\text{s}$ (75 l/s), which translates to $6393.6 \text{ m}^3/\text{day}$ (6.4Mℓ/d). This volume is less compared to average daily dewatering of about $8435.29 \text{ m}^3/\text{day}$ recorded in May 2023. Long term dewatering volume is about $8255.27 \text{ m}^3/\text{day}$ recorded between October 2021 to May 2023. This average is also high compared to simulated inflow (Figure 7-6). Several possibilities do exist that result in low simulated volume compared to dewatering volume. This may relate to:

- Artificial recharges from surface water sources not accounted for in the model.
- Mine water interflow or seepage into Doornkop from neighbouring mines.
- Geological structures seep more water than the volume accounted for in the model

Detail assessment has been discussed under accumulated impact section. This includes historical assessment of water origin and water sources that infiltrates into mine working.



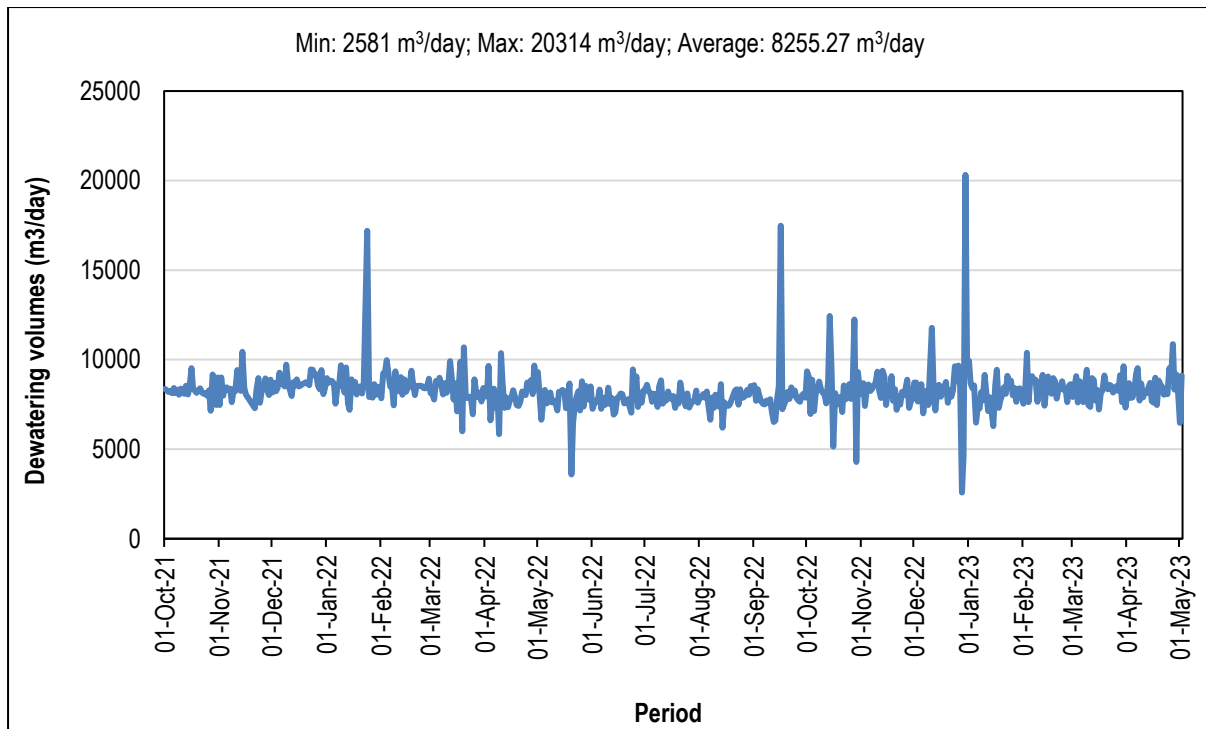


Figure 7-6: Dewatering volumes, October 2021 to May 2023.

7.8.3. Post -facility operation,

Post closure impacts were simulated using 50- and 100-years projections. These projection aims to understand plume migration after all activities have ceased. Impacts that may arise during this phase are critical. These are impacts associated with plume migration, water level recovery and whether the mine will decant or not. 50- and 100-year contamination plume will continue to spread to the south and south east. Borehole DKP 3, DKP 4, DKP 7 and DKP8 will be affected by bot 50- and 100-year plume migration.

Dolomite aquifer occurs to the south of the operation. 50- and 100-year plume migration will affect a little portion of the dolomite aquifer. This plume will migrate and affect the north east boundary of the dolomite as shown in Figure 7-7 and Figure 7-8. Critical at this stage is to ensure that management measures are in place to prevent artificial recharge of aquifer with contaminated water. This may have significant impact on the aquifer. Groundwater management measures to assist with impact prevention are discuss in detail in this report.

Decant at Doornkop is not expected. It must be noted that the mine is interconnected with other mines which may influence future predictions due to inflows associated with these mines. Current inflow predictions suggest that there may be artificial or water seepage of unknown sources which is entering the operation. Detail discussion related to the influence of other mine towards Doornkop operation is discuss under accumulated impact.



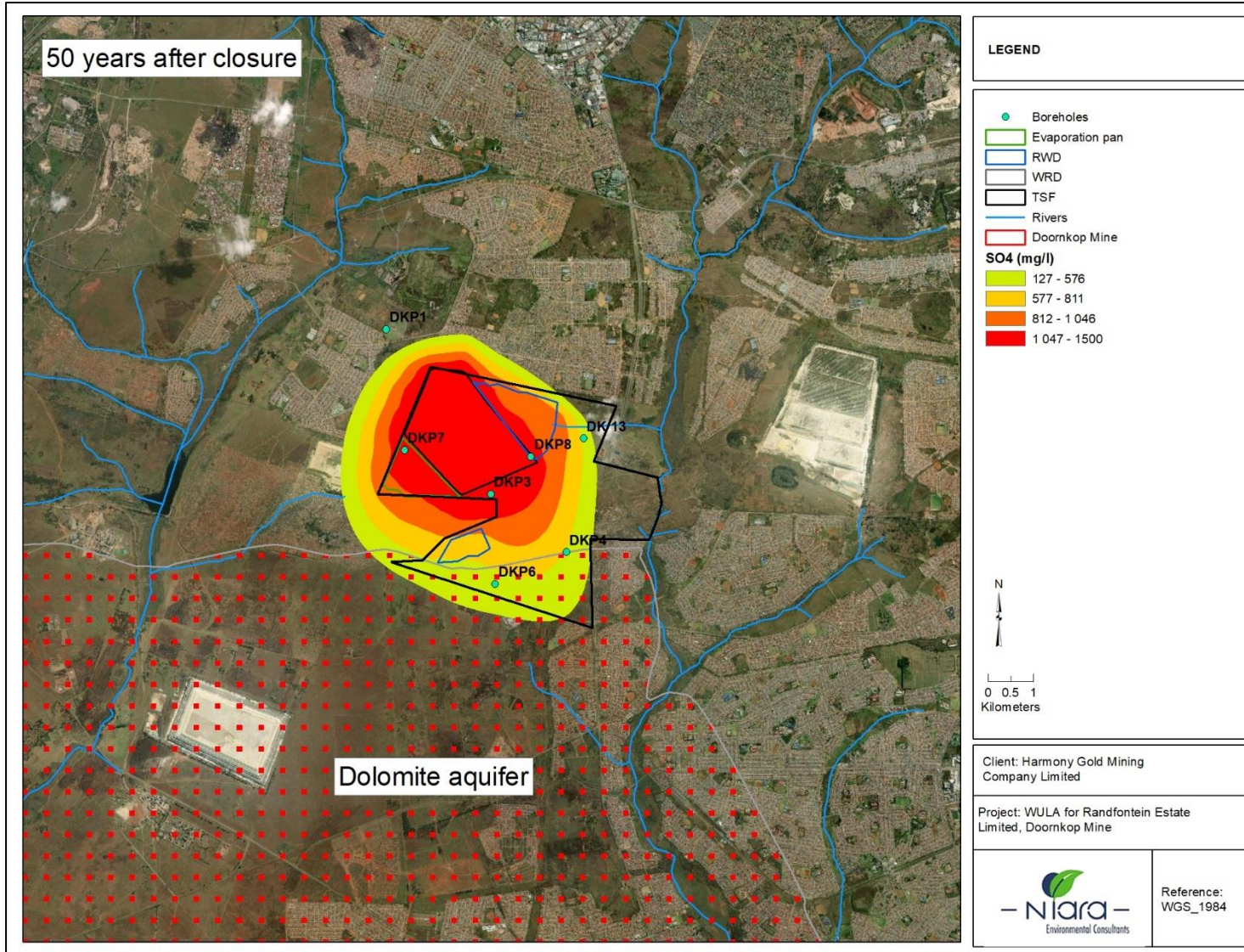


Figure 7-7: Predicted plume, 50 years after closure.



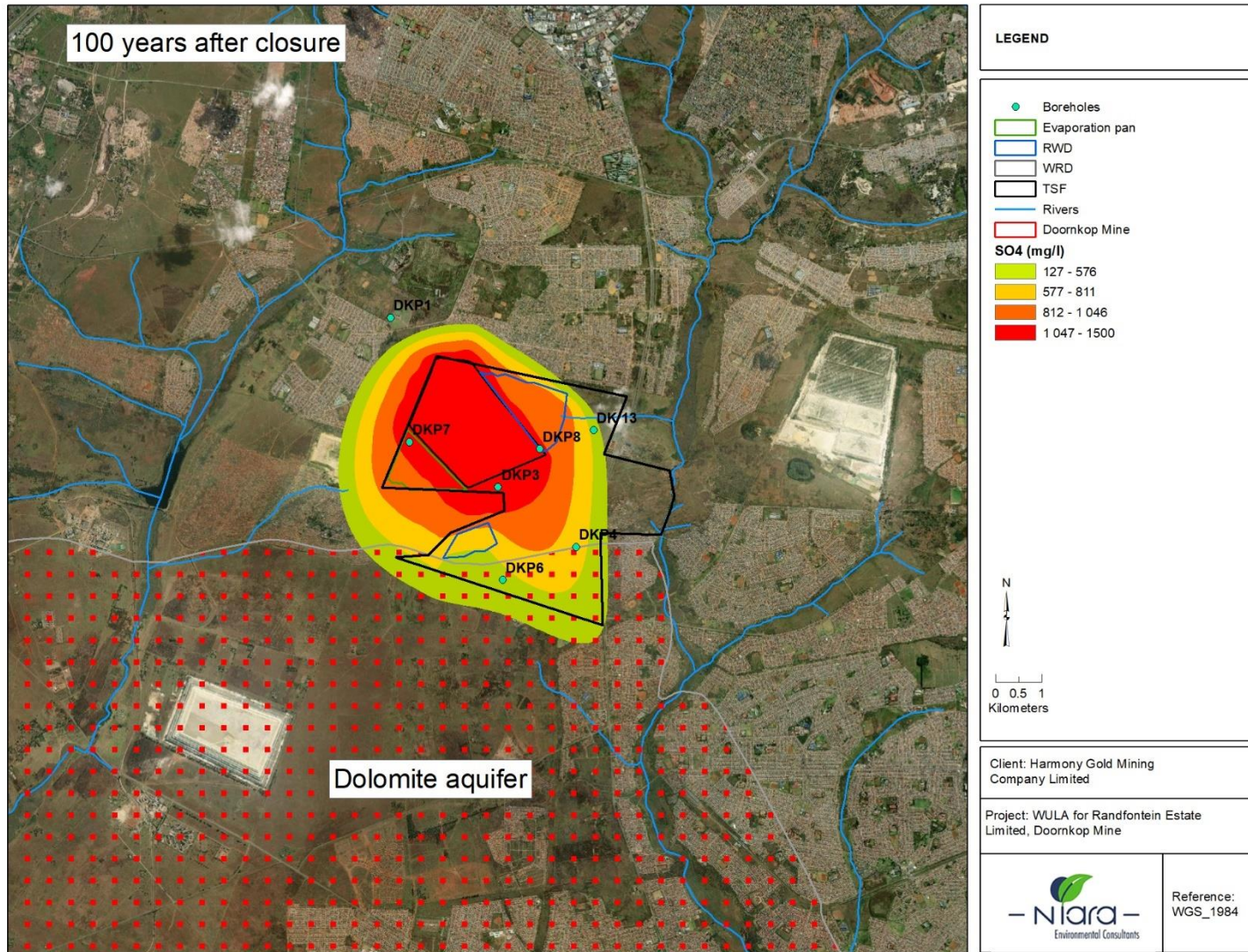


Figure 7-8: Predicted plume, 100 years after closure.



8. Geohydrological Impacts

8.1. Construction phase

Major activities associated with construction phase at Doornkop Mine has been undertaken a long time ago. This includes sinking of the shaft, construction of TSF, WRD, RWD, processing plant and sewage facility, etc. Therefore, impact associated with construction will only be applicable to new infrastructures. The construction activities would likely have minimal impact to water resources, local water quality, water flows, surface water and groundwater interactions.

8.1.1. Impacts on Groundwater Quantity

In most circumstances, construction phase does not pose major impact on groundwater level, yield, and availability. In instances where dewatering and abstraction is required to lower the water table prior to construction, such activities may pose impact on groundwater quantity.

8.1.2. Impacts on Groundwater Quality

Construction of new facilities are likely to have impact into water quality. The main groundwater contamination sources which may be expected during this construction include oil, diesel, petrol, grease, and other liquid. Due to construction activities, it is also expected that certain quantity of solid waste may be generated which may have a negative impact into water resources. These impacts would be minimal to non-existence if appropriate management practices are followed.

8.1.3. Groundwater Management

It is crucial to identify all construction activities that are likely to affect groundwater quantity and quality prior to constructions. Mitigation measures for such construction must be established to minimise, mitigate, reduce, and prevent impact associated with construction. Mitigation measures applicable to this phase includes:

- 🌱 Repairing of equipment and vehicle on designated area.
- 🌱 Storage of hydrocarbon on designated area.
- 🌱 Excavate and remove hydrocarbon spillage on soil during construction.
- 🌱 Disposed any contaminant on designated facility.
- 🌱 Prevent erosion on excavated surface.
- 🌱 Report spillage and incident for rehabilitation.



8.2. Operational phase

8.2.1. Impacts on Groundwater Quantity

Major impact associated with operation phase is the lowering of the groundwater level. Heavy pumping within the mine affect baseflow towards rivers and other ecological dependency ecosystem. Impact of dewatering at Doornkop was incorporated in groundwater model. Predicted impact associated with mining suggest minimal impact towards groundwater level. Dewatering of boreholes and underground working form part of the major activities known to affect groundwater level, yield, and availability.

Impact associated with potential increase in dewatering and abstraction volume must be simulated and predicted prior to such increase. Such increase may result in various impacts such as: reducing surface water flow rate and flow volume; lowering of groundwater level within the mine and surrounding area, and declining groundwater yield. Therefore, management measures related to these activities are critical to reduce and minimise any impacts.

8.2.2. Impacts on Groundwater Quality

Impact associated with contamination sources such as TSF, WRD and Evaporation dam remain a major concern. This is because these facilities may pose severe impact into water resources. This impact includes:

- ☛ Generation of acid mine drainage which may migrate towards fresh groundwater and surface water resources.
- ☛ Weathering of newly exposed soil which could cause leaching and oxidation resulting in water resources contamination.
- ☛ Unauthorized discharge of mine contaminated water.
- ☛ Seepage, overflow, infiltration, and runoff of mine contaminated water into the aquifer and water resources.

Contamination plume migration towards low lying areas is expected. Simulated plume will most likely affect an area surrounding the TSF area. This plume will migrate and spread towards the south and south east. Although the plume will migrate slowly towards down gradient, groundwater within the mine boundary will be affected by the plume. Therefore, measure to prevent these potential impacts are critical and described in the sections below.

8.2.3. Impacts on Surface Water

Uncontrolled discharge associated with dam overflow and seepage will most likely affect the rivers in the west and east. Mine facilities occur upstream of the facilities such as TSF, RWD and Evaporation dams, etc. Overflow of the facility will severely affect surface water resources. Deterioration of surface water quality remain one of the major impacts associated with the facilities. Dam storage and size is crucial for managing water containment facility.



Reduced flow associated with dewatering is not expected. Dewatering at Doornkop occurs within the deeper aquifer and deep underground working. No abstraction is undertaken within the shallow aquifer which may potentially be connected to surface water. Interaction between deep aquifer and surrounding rivers is not expected.

8.2.4. Groundwater Management

Through adoption of proper water management strategies, these impacts could be minimised if not avoided. Doornkop mine have water management strategy which requires the minimisation and prevention of impacts associated with Doornkop Mine activities. The following measures are critical to reduce and minimise the impact:

- ✔ Development of storm water management plan and construct formal storm water management system to prevent, divert and separate clean and dirty water. This will prevent contaminated water, including sewage, from entering the clean environment. This is critical for preventing impacts from entering the Klip River and Wonderfonteinspruit Rivers. Critical areas include the TSF, RWD and Evaporation Dam Area.
- ✔ Divert clean storm water from the facility. Intercept and collect any contaminated storm water. Seepage from the dams must be intercepted and pumped back to facilities. Collect all dirty runoff from the eastern boundary of the mine and pump it back to containment facilities.
- ✔ Cleaning and desilting of the dams must be undertaken regularly. Dry season must be targeted for cleaning of dams (Evaporation dams, RWD and ESF evaporation dam).
- ✔ Regular inspections of facilities focusing on assessing compliance related to design capacity, authorised capacity and volumes, and general compliance aspects must be undertaken.
- ✔ Chemical storage area must be lined and bunded to prevent the dilution of chemical and storm water. Chemicals within the facility must be used in accordance with relevant regulation. Ensure that fuel and oil are stored in designated area, and cars are washed and maintained in designated area or workshops. All hazardous materials inter alia oils, fuels, paints, turpentine, and thinners must be stored appropriately to prevent these contaminants from entering the aquifer.
- ✔ Groundwater deterioration due to runoff of contaminated water, overflow, seepage, infiltration must be prevented through proper maintenance of flow meter and other maintenance related to treatment infrastructure (Install flow meters in all pipeline discharging to the dams)
- ✔ Surface and groundwater monitoring plan should be implemented and conducted as discussed under monitoring section, and other related studies. Conduct groundwater quality monitoring as recommended to track the pollution plume and serves as an early warning system for contamination. Dewatering boreholes are only monitored for abstraction volume. These boreholes must also be monitored for levels and quality. They will provide crucial information related to deep water level and quality.
- ✔ Operation and treatment of the sewage should comply with relevant regulation and standards. The facility must treat the sewage in line with design capacity and volumes. Flow meters must be installed for inflow and outflow.



- ✔ Discharge of mine water must comply with discharge quality applicable to the facility. Ensures that the discharge volume is in line with discharge limit. Install flow meter to monitor the discharge. Regular monitoring of discharge quality is critical.
- ✔ Investigate and predict potential mine water interflow and inflow from other mines. Investigate potential sources of water underground.
- ✔ Investigate contamination and implement mitigation measures when contamination is identified.
- ✔ Establish a database for management of surface water quality data, groundwater quality data, mine water discharge data and other relevant data.
- ✔ Establish an incident register for environmental or water related incident that occurs within the facility. Reports or notify relevant department. Investigate and document incident. Establish mitigation measures and implement such measures. Monitor and inspect for other potential incident.
- ✔ Ensure that procedures are in place for spill prevention, clean-up, contaminant handling and treatment. Leakages on the soil and contaminated soil must be removed and disposed properly in a registered facility. Ensure that areas where spillage of contaminant occurs are excavated and rehabilitated.
- ✔ Minimise or reduce construction and operational footprint within the dolomite aquifer area in the south of the facility. Plume predictions have shown that the mine will not affect the dolomite aquifer during operation. Post closure phase will affect little portion of the dolomite in the north east of the dolomite.
- ✔ Ensures that tailing dams and solid waste rocks are deposited in an approved area, and that regular inspection is undertaken. Regular maintenance of TSF to prevent erosion and failure is required.
- ✔ Conduct groundwater level monitoring to assess trends and impacts of groundwater abstraction and dewatering. Monitor and record abstraction rates to prevent over abstraction.
- ✔ Ensure that approved volumes are abstracted from dewatering boreholes and underground working. Monitor and record dewatering volumes. Ensures that dewatering and pumping does not reduce surface water flow.

8.3. Decommissioning phase

Decommissioning phase will not be characterised by major impacts. Impact related to plume and mine water rebound is expected to influence post closure activities. Impact during decommissioning will still mimic operations phase impacts. Activities which may introduce additional impacts in spillage of hydrocarbon during site rehabilitation and removal of infrastructure. The plume spread slowly, hence impact related to plume will not immediately affect this phase. Even during post closure, the plume would have travelled little distance from the original sources due to low hydraulic conductivity. Groundwater will also recover slowly which takes a longer period.



8.4. Post- mining phase

8.4.1. Groundwater Quantity

All abstractions are expected to cease during this phase. Simulated model suggests that groundwater level within the aquifer will recover during post closure. Simulated model has indicated that groundwater level during operational phase is not significantly affected. Operational groundwater level decline to an average of 1619 m. During post closure, this groundwater level will recover to an average of 1621 m. This recovery groundwater level reflects pre mining groundwater level which was simulated.

Decant of mine water at Doornkop Mine is not expected as the shafts are expected to recover below surface elevation. Neighbouring mines (Cooke 1 shaft) to the south are located at lower elevation compared to Doornkop. If passages and tunnels between Doornkop and these mines are not sealed, Doornkop will most likely affect other operations. The tunnel between Cooke 1 shaft and Doornkop Mine is currently sealed, suggesting that the two shafts are isolated.

A site visit was conducted to the underground, particularly, level 106 which is used to link Cook 1 shaft and Doornkop Mine. Floor elevation from this level drops towards Cooke 1 shaft, with seepage water on the floor flowing towards Cooke 1 shaft. Important to note that although this seepage is flowing towards Cooke 1 shaft, Cooke shaft is under closure phase which means rewatering of Cooke shaft will result on shaft water level above Doornkop floor elevation. If seepage pathways or preferential pathways between the two mines exist, including through the sealed wall, then Doornkop Mine will be affected by Cooke shaft. This scenario will occur during the operational phase at Doornkop Mine. Post closure where mine water level at Doornkop Mine will rise, then the phase is likely to affect Cooke operation if preferential flow path exists.

8.4.2. Groundwater Quality

Groundwater quality will be affected during post closure phase. This is because contamination will continue to spread within the aquifer. Deep boreholes located towards the south east of the facility will be affected by the plume. The plume is concentrated within the mine boundary in south and south east of the mine. An area north and west of the TSF or surrounding the TSF will be affected by the plume.

No privately owned boreholes that will be affected by this plume. This is based on the current information and such information related to hydro census boreholes must be updated as advised by regulators to ensures that impacts are assessed. A small portion to the north east of the dolomite aquifer will be affected by the plume. Such impacts are predicted to occurs in 50-years after closure and in 100 years after closure



8.4.3. Cumulative Impacts

8.4.3.1. Background

For this discussion, accumulative impacts refer to impacts from one or several mining activities. In general, cumulative impacts are grouped into local impacts, regional impacts, and global impacts. This assessment will only focus on localised impacts within the immediate surrounding environment. The section is presented with the focus to highlight critical issues related to Doornkop Mine and its linkage or connection with other mines. Figure 8-3 and Figure 8-4 shows Doornkop Mine and the connection with Cooke 1 shaft (Cooke operation).

Doornkop Mine is located within the Witwatersrand Basin. Neighbouring mines includes Durban Roodepoort Deep (DRD), which borders the mining right area in the east, Cooke 1 shaft occurring to the southwest and South Roodepoort Main Reef (SRMR) which occurs to the north of the mine. Underground mining activities commenced at the depth of approximately 500 m below ground and currently at the depth of 1 969.6 m below ground.

The existence of interconnection between Doornkop Mine and Cooke 1 shaft highlight the need to understand the possible influence of these mines on each other. These mines are linked through an underground tunnel at level 106 (Figure 8-1 and 8-2). Level 90 links Cooke operation with Doornkop number 1A ventilation shaft. The following provides the summary of mine connection and elevation with additional information shown in Figure 8-1 and Figure 8-2:

- ✔ Doornkop Mine and Cooke 1 shaft: 790 mamsl.
- ✔ Cooke 1 and Cooke 2: 940 mamsl.
- ✔ Cooke 2 and Cooke 3: 670 mamsl.
- ✔ Cooke 3 and Cooke 4 (Ezulwini): 582 mamsl.

Other connections do exist between Cooke 4 and South Deep. The connection between Cooke 3 and Ezulwini was previously sealed. The connection between Doornkop Mine and Cooke 1 shaft is also sealed. These mines are located to the south of Doornkop Mine. No connection exists between Doornkop Mine and DRD, and Doornkop Mine and SRMR.



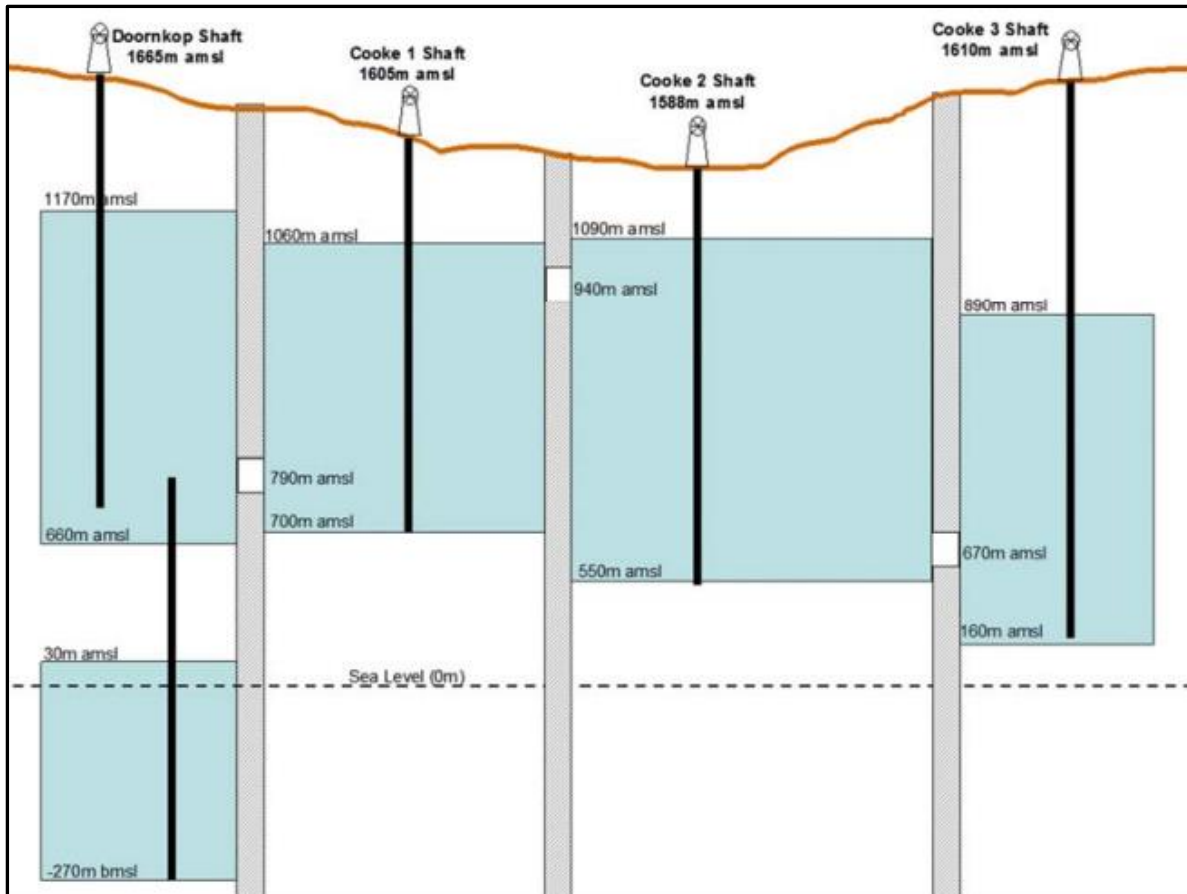


Figure 8-1: Map showing shaft elevation (Golder, 2009).

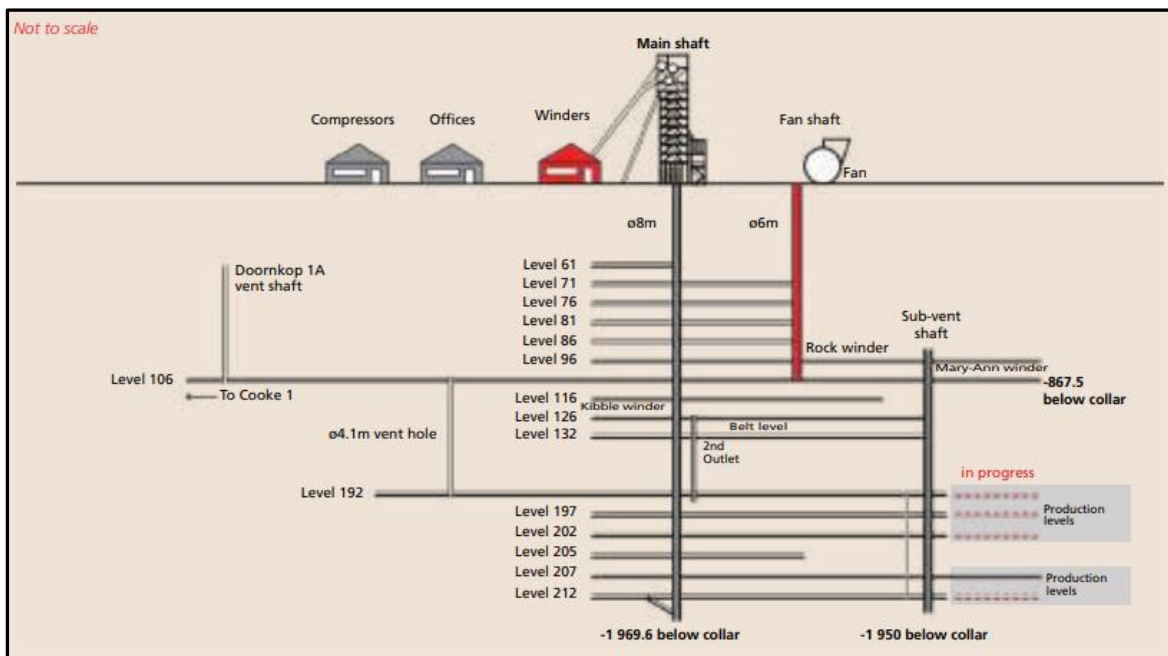


Figure 8-2: Doornkop: Schematic of shaft and mining layout.



8.4.3.2. Historical water issues and risk

Historical assessment of mine water inflow at Doornkop and surrounding mines suggest that the Cooke operations has a lot of water to pump compared to Doornkop Mine. This is because Cooke operations are mining below the dolomite aquifer which occurs to the south of Doornkop Mine. This aquifer, which is known for huge storage and occurrence of groundwater is not significantly disturbed above the Doornkop Mine. Access to underground mine is located outside the dolomite deposit. Doornkop number 1A ventilation shaft is located within the dolomite. However, this ventilation shaft relates to Cooke 1 shaft level 90. The following summarises dewatering volumes for Cooke operations and Doornkop Mine as of 2009 and 2013 (Van Biljon, 2013).

- 🌿 Doornkop: 4.5 Mℓ/d (2013).
- 🌿 Cooke 1: 16 Mℓ/d.
- 🌿 Cooke 2/3: 6 Mℓ/d.
- 🌿 Cooke 4: 65 Mℓ/d.

Mine water inflow and dewatering volumes have significantly increased at Doornkop Mine. In 2013, dewatering was calculated as 4.5 Mℓ/d as of 2013. This volume has increased to 8.44 Mℓ/d as of May 2023. Long term average dewatering suggests a dewatering volume of 8.3 Mℓ/d since October 2021. Figure 8-3 shows dewatering volume

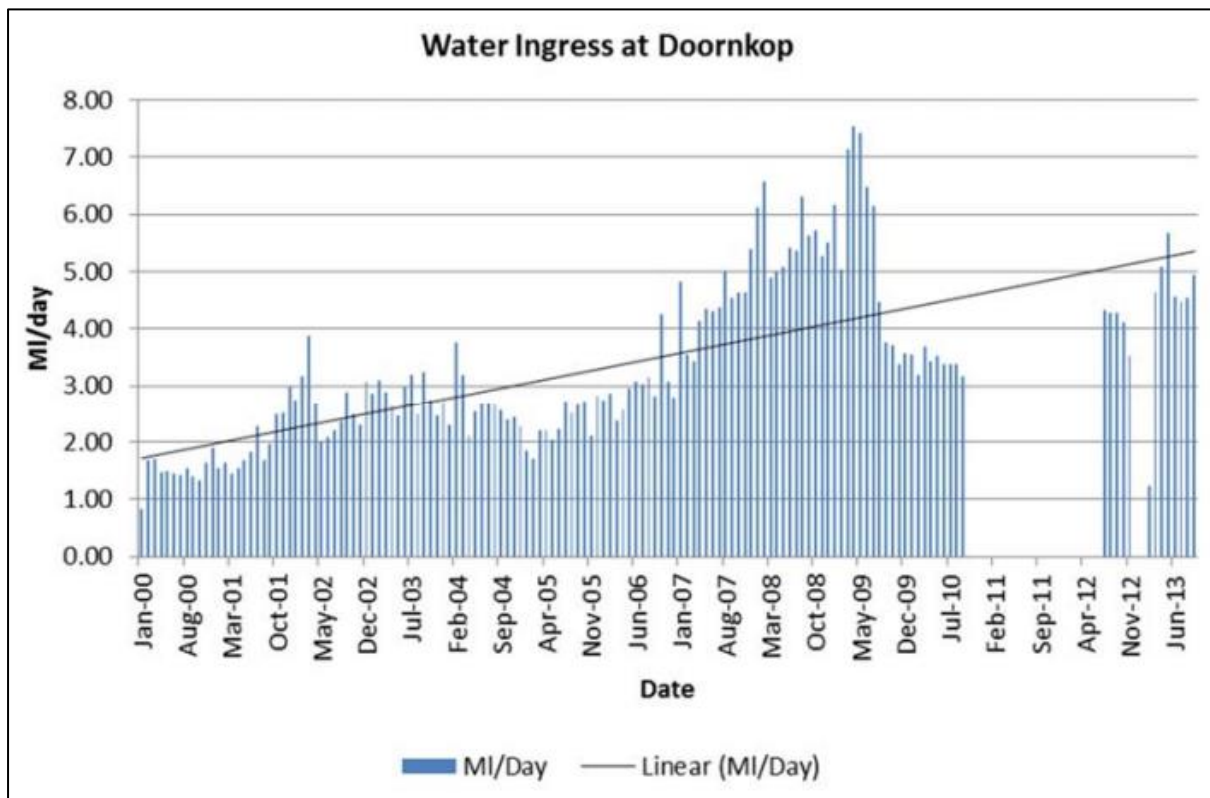


Figure 8-3: Dewatering volumes since January 1990.



From the figure above, Doornkop Mine use to pump about 2 Mℓ/d which have increased to 8.44 Mℓ/d. This timeline provides an indication regarding the increasing water ingress into underground which eventual force the mine to pump it out. With Cooke operation being under closure, this volume will increase once Cooke cease with dewatering and commerce with rewatering of the voids. This remaining one of the major risks which Doornkop must address urgently.

Huge volume of groundwater was removed at Cooke 4 shaft. This was about 66 Mℓ/d (Golder, 200; Van Biljon, 2013) which suggest that Cooke 4 shaft have intercepted high storage aquifer (Dolomite) which seep high volume of groundwater to underground operation. Cooke 1 shaft was pumping about 16 Mℓ/d (Golder, 2009). This suggests the potential risk associated with Cooke closure. With Doornkop still mining, seepage from neighbouring mine will find its way to Doornkop, which will have negative impact into the operation in terms of increased volume, storage of surplus water and increased risk on water containment infrastructures.

Historical pumping at SRMRA have ceased since the mine has closed and flooded. The mine was pumping about 3.5 Mℓ/d on average. Major concern is associated with the fault occurring around these mines. Both Doornkop and SRMRA are mining between these faults (Saxon and Roodepoort fault) which may act as preferential flow path transporting groundwater from one mine to another. Doornkop is mining slightly deeper compared to SRMRA. Historical reviewed have shown that increased inflow was noted for Doornkop soon after SRMR have closed. Current inflow into Doornkop Mine is estimated as 6.4Mℓ/d. The mine is currently pumping about 8.44 Mℓ/d which suggest that there may be unknown water sources that infiltrates into mine working.

8.4.3.3. Risk Associated with mine interflow

Water ingress, inflow and mine water interflow are a critical component towards water management strategy. This is due to the direct links and influence that the component has at Doornkop. Figure 39 and 40 shows mine water rebound within Doornkop Mine and Cooke operations. During the remaining life of mine, Doornkop Mine will be affected by the rising and flooding groundwater at Cooke operation. When Cooke operation cease dewatering, flooded mine operation is expected to affect Doornkop within five months. This suggest that current and known link or tunnels between the operations must be sealed. An estimated decant of 16 Mℓ/d from Cooke 1 to Doornkop, which will increase pumping requirement to 21 Mℓ/d. Complete flooding of Cooke operations is estimated to further increase pumping requirement to 27 Mℓ/d (Golder, 2009; Van Biljon, 2013).



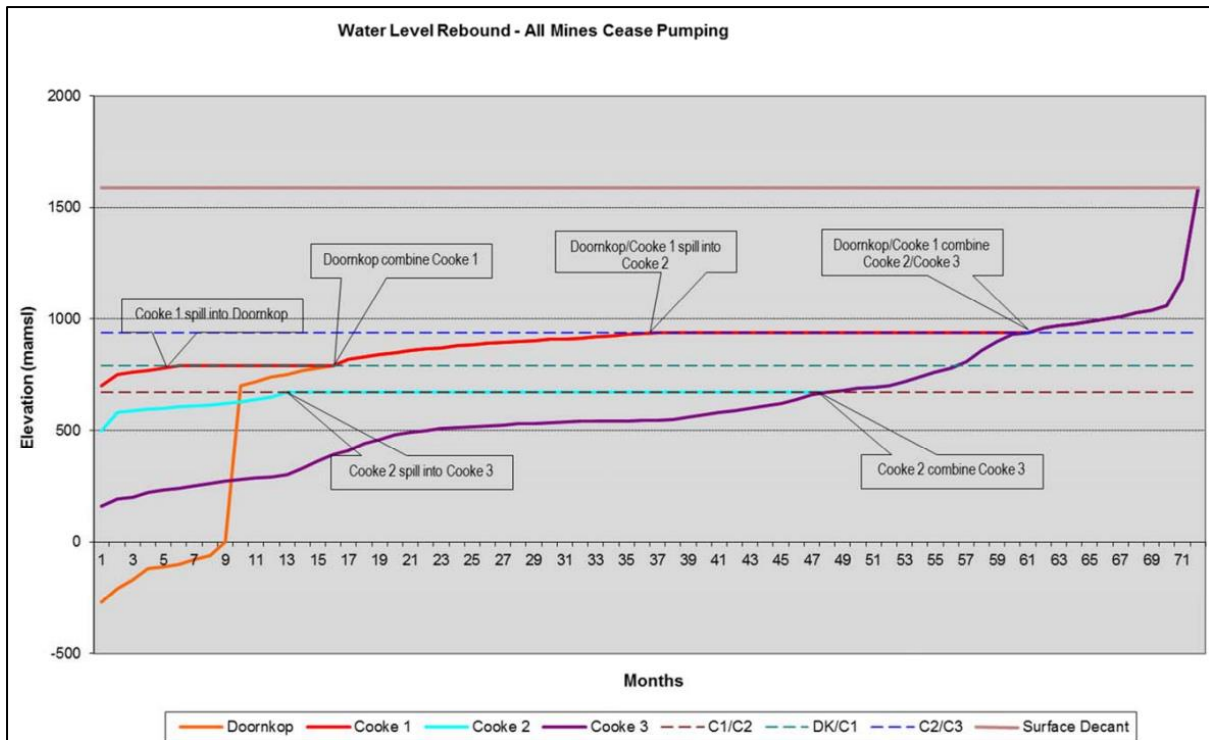


Figure 8-4: Water level rebound when all mines cease pumping including Doornkop

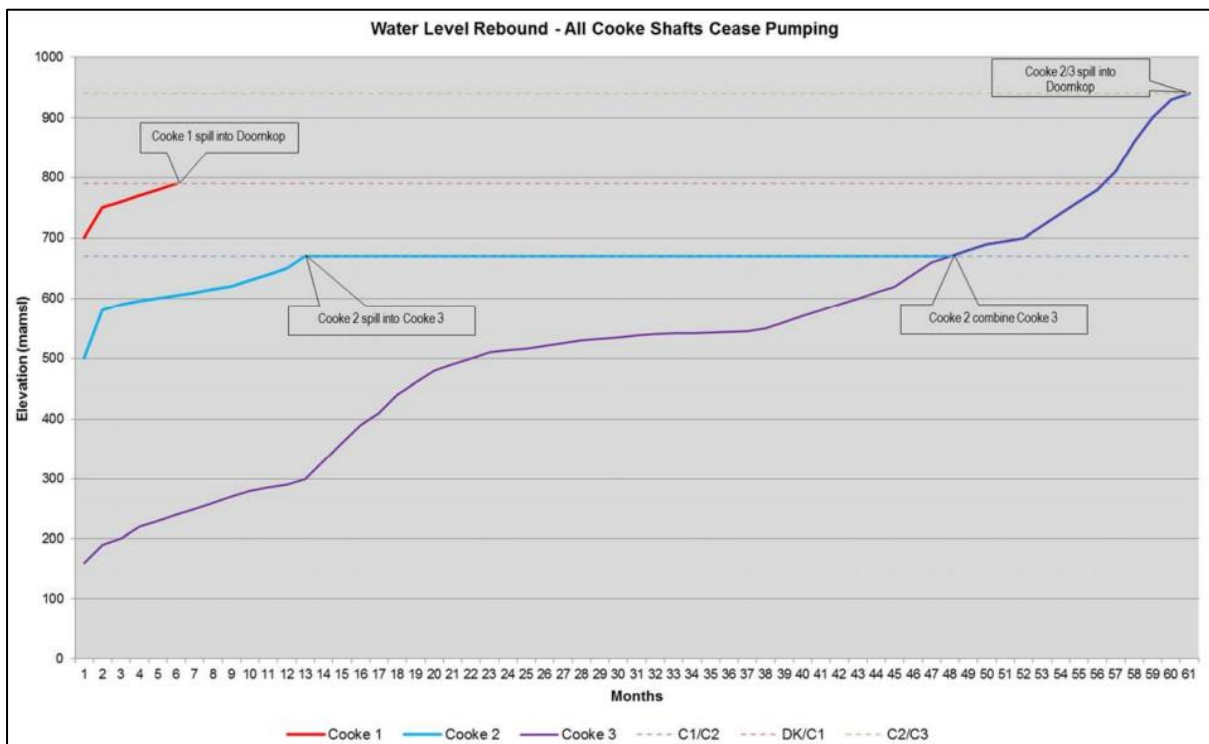


Figure 8-5: Water level rebound when all Cooke operation cease pumping.



8.4.3.4. Water origin

The origin of mine water entering Doornkop have been assessed using stable isotope of oxygen-18 (^{18}O) and Deuterium (^2H) (Van Biljon, 2014). The following sites were samples

- 🌿 Dolomite Water source located 2 km south of Doornkop Mine.
- 🌿 202-W3 collected at level 202, from “Black Duck Dyke” intersection.
- 🌿 197-HLGW collected at level 197 from a fault intersection.
- 🌿 197-S8 Tway: Collected at level 197 from a dyke intersection.
- 🌿 Mine water.

The following observation were made based on isotope samples:

- 🌿 Water collected from the fault intersection (197-HLGW) correlated with the dolomite samples. It was concluded that this has the same sources which suggest that the fault may be discharging dolomite water into mine working.
- 🌿 202-W3 and 197-S8 Tway underground water samples shows similar signature. This water is different from the dolomite sources and may be associated with the host rock water sources (Deep aquifer, fissure water)
- 🌿 Mine water sample collected from West Rand Basin (WRB) (Not from Doornkop) reflect signature of rain water recharge.

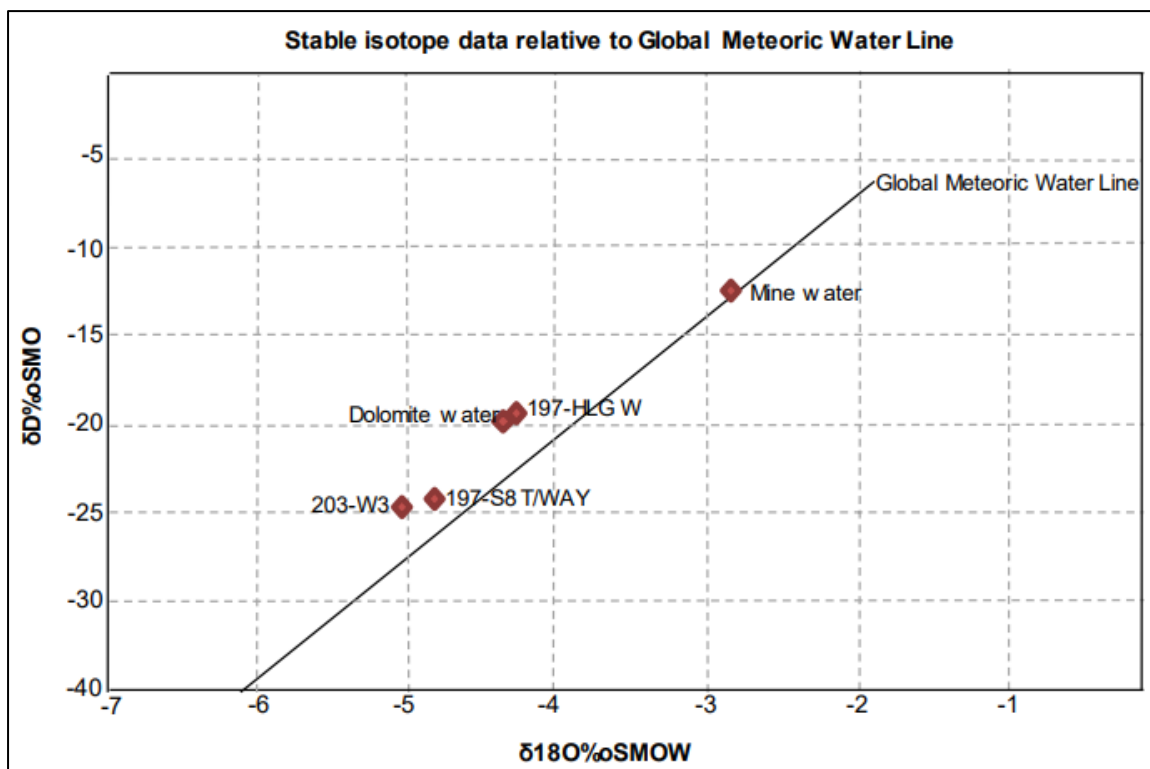


Figure 8-6: Mine water sources and origin.



8.4.4. Groundwater Management

Groundwater management during closure is discussed in detail under post closure management plan. Management of water during this phase includes rehabilitation, remediation, monitoring and inspection of rehabilitated facility. The following summarise some of the measures:

- ✔ Rehabilitation of all facilities including TSF, WRD and mine water containment facility will be undertaken.
- ✔ Regular inspection must be carried out to ensure that rehabilitation is effective.
- ✔ Groundwater monitoring must be carried out during this phase.
- ✔ Preparation of trenches and TSF drainage for long term management of seepage.
- ✔ Storm water management facility must be designed to ensures that impact related to runoff water is prevented.
- ✔ Rehabilitate all activities to ensures that all surface side reduces the infiltration of contaminated water.

8.5. Impact assessment criteria

Impact assessment was compiled in line and in accordance with applicable regulation (DEAT, 1998; DEAT, 2002; NEMA EIA Regulations, 2010; EIA Regulations, 2014). The following criteria was adopted for the study.

Table 8-1: Description of the assessment criteria

Criteria	Description
Extent	This assess whether impacts will only cover footprint extent only within activities or the scale will be site scale, regional, national, and international impacts scale with a rating of 1 to 5.
Duration	Duration assess and provide ranting in terms of the period which the impacts will last in the environment. This is done by providing a rating of 1 to 5 from short term, short to medium term, medium term, long term and permanent.
Intensity	Focus on assessing whether impacts will be destructive, destroy the impacted environment and or changes the functioning of the environment. This is rated from insignificant, low, medium, high, and very high with a rating of 2, 4, 6, 8 and 10 respectively.
Probability	Probability in this case will deal with the likelihood of impact to occur. This is rated from 1 to 5 from improbable (0 %), possible (25 %), likely (50 %), highly likely (75 %) and definite (100 %).



Table 8-2: Assessment criteria and ranking.

Extent		Duration	
Description	Score	Description	Score
Footprint	1	Short term	1
Site/local	2	Short to medium	2
Regional	3	Medium term	3
National	4	Long term	4
International	5	Permanent	5
Intensity		Probability	
Description	Score	Description	Score
Insignificant	2	Improbable	1
Low	4	Possible	2
Moderate	6	Likely	3
High	8	Highly likely	4
Very High	10	Definite	5

These are parameters that are used to quantify the impacts. The rating of probability, intensity, duration, and extent are used to compute the significance of potential impacts without mitigation measures (Table 8-3).

$$\text{Significance} = (\text{Extent} + \text{Intensity} + \text{Duration}) \times \text{Probability}$$

Table 8-3: Significance rating without mitigation.

Scale		Description
< 30	Low	Impacts are minimal, with little effects, limited importance. No mitigation required.
30 -60	Medium	Impact has an influence, can be mitigated, impact can be reduced to acceptable level, impact remain of medium significant. Requires management measures to be reduced.
>60	High	Major impacts, impact is significant, mitigation measures are required to reduce the risk, impact is high importance.



This phase is only applicable to construction of new facilities. Major infrastructures such as mine shafts, processing plant, TSF and WRD, etc, are already constructed since Doornkop is an existing mine.

Table 8-4: Impact assessment, ranking and significance rating without mitigation (Construction of new facilities).

Impacts	Extent	Duration	Intensity	Probability	Significance
Groundwater contamination due to contaminated storm water	1	1	2	2	8
Groundwater contamination due to seepage, leakage, and infiltration	1	1	2	2	8
Groundwater contamination due to contaminated soil	1	1	2	2	8
Surface water contamination due to system failure	2	1	6	2	18
Contamination of surface water due to discharge of unsuitable quality	2	1	6	2	18
Contamination of shallow aquifer/groundwater	2	4	6	3	36
Contamination of deeper aquifer/groundwater	2	4	4	2	20
Contamination of soil due to hydrocarbon spillage	2	4	8	4	56



Table 8-5: Impact assessment, ranking and significance rating without mitigation (Operational phase).

Impacts	Extent	Duration	Intensity	Probability	Significance
Lowering of water table/impact on shallow/perched aquifer	1	1	4	2	12
Lowering of water table/impact on deeper aquifer	1	1	6	2	16
Mine water decants during operation	1	1	2	1	4
Groundwater contamination due to contaminated storm water	2	2	6	3	30
Groundwater contamination due to seepage, leakage, and infiltration	2	4	6	4	48
Groundwater contamination due to contaminated soil	2	4	4	2	20
Surface water contamination due to system failure	3	1	8	2	24
Contamination of surface water due to discharge of unsuitable quality	3	1	8	2	24
Contamination of surface water due to waste facilities (TTSF, WRD)	2	4	6	3	36
Contamination of surface water due to RWD/PCD and Evaporation dams	3	4	8	4	60
Contamination of shallow/perched aquifer/ groundwater	2	4	8	4	56
Contamination of deeper aquifer/ groundwater	2	4	8	4	56
Contamination of soil due to due to TSF, WRD, RWD/PCD, Evaporation dam, etc	2	4	8	4	56



Table 8-6: Impact assessment, ranking and significance rating without mitigation (Post closure).

Impacts	Extent	Duration	Intensity	Probability	Significance
Lowering of water table/impact on shallow/perched aquifer	1	1	2	1	4
Lowering of water table/impact on deeper aquifer	1	1	2	1	4
Mine water decants during post closure	1	1	2	1	4
Groundwater contamination due to contaminated storm water	2	1	6	3	30
Groundwater contamination due to seepage, leakage, and infiltration	2	4	2	2	16
Groundwater contamination due to contaminated soil	2	4	4	2	20
Surface water contamination due to system failure	3	3	6	3	36
Contamination of surface water due to discharge of unsuitable quality	3	1	2	1	6
Contamination of surface water due to waste facilities (TTSF, WRD)	2	4	6	3	36
Contamination of surface water due to RWD/PCD and Evaporation dams	3	4	8	4	60
Contamination of shallow/perched aquifer/ groundwater	2	4	8	4	56
Contamination of deeper aquifer/groundwater	2	4	8	4	56
Contamination of soil due to due to TSF, WRD, RWD/PCD, Evaporation dam, etc	2	4	8	4	56



9. Groundwater monitoring system

9.1. Groundwater monitoring network

9.1.1. Source, plume, impact, and background monitoring

A risk based approach was considered in reviewing the current monitoring and aligning the program to regulatory requirement. Groundwater monitoring within the mine have been designed to monitor strategic or specific locations that includes the following:

- 🌿 Background monitoring: Boreholes located up gradient of activities or development, to determine the actual state of groundwater quality within the aquifer. This data is critical to determine baseline groundwater quality prior to development, and to collect baseline data for future comparison.
- 🌿 Source monitoring: Boreholes located down gradient of activities or development, down gradient of contamination sources, to monitor impact of contamination sources.
- 🌿 Plume monitoring: Boreholes located within the flow path or predicted plume direction and monitor the spread and extent of contamination.
- 🌿 Impact monitoring: Boreholes where receptors are located, restricted to areas where impact is expected and serves as early warning system.

9.1.2. System response monitoring network

All boreholes are monitored for groundwater level. Monitoring boreholes consist of shallow and deep boreholes that focus on understanding impacts of abstraction into shallow water table and regional water table. Two dewatering boreholes are approximately 200 m deep and these boreholes will provide information related to deep aquifer groundwater level, decline and recovery during dewatering of the boreholes.

9.1.3. Monitoring frequency

Monitoring at Doornkop Mine is an ongoing program for groundwater quality, levels, and dewatering volumes. Current monitoring program allow monitoring on a quarterly basis for all parameters including levels. Underground dewatering system allow daily recording of dewatering volumes. Therefore, the following monitoring frequency is recommended:

- 🌿 Groundwater quality: Must be conducted on quarterly basis
- 🌿 Groundwater level: Must be conducted monthly
- 🌿 Dewatering volumes (Underground and boreholes): Must be recorded daily



9.2. Monitoring parameters

Water is characterised by a range of dissolved inorganic constituents. These constituents can be affected by wide range of chemical, physical, and microbiological contaminants. As a result, there are extensive constituents that can be analysed during monitoring (DWAF, 1998; Hodgson and Krantz, 1998). The following parameters are currently being monitored for Doornkop Mine. These parameters are suitable for monitoring of impact within the mine.

Groundwater quantity:

- ☛ Groundwater level.
- ☛ Dewatering volumes/abstraction (Two boreholes & underground pumps).

Groundwater quality:

☛ Chemicals:

- ☛ Chloride (Cl)
- ☛ Sulphate (SO₄)
- ☛ Total Alkalinity
- ☛ Calcium (Ca)
- ☛ Magnesium (Mg)
- ☛ Sodium (Na)
- ☛ Potassium (K)
- ☛ Iron (Fe)
- ☛ Manganese (Mn)
- ☛ Aluminium (Al)
- ☛ Nitrate (NO₃) as N
- ☛ Nitrite (NO₂) as N
- ☛ Ammonium (NH₄) as N
- ☛ Manganese (Mn)
- ☛ Nickel (Ni)
- ☛ Zinc (Ni)
- ☛ Dissolved Uranium (U)
- ☛ Free Cyanide (CN)
- ☛ Cyanide WAD
- ☛ Total Cyanide (CN)

☛ Physical parameters:

- ☛ pH,
- ☛ Total Dissolved Solids (TDS)
- ☛ Electrical Conductivity (EC)
- ☛ Turbidity

☛ Microbiological parameters

- ☛ Ecoli
- ☛ Total Coliform
- ☛ Faecal Coliform



9.3. Monitoring boreholes

Groundwater monitoring up and down gradient of the facility has been established. Table 9-1 shows the list of current monitoring boreholes that includes newly drilled boreholes. All current monitoring are shallow monitoring boreholes. Deep boreholes have been drilled to understand the status of deep groundwater resources within the facilities. Newly drilled boreholes have been placed in strategic location to cover source, plume, and impacted area.

The mine has two deep dewatering boreholes. These boreholes are currently monitoring groundwater abstraction and dewatering. It is therefore recommended that these two boreholes are monitored for groundwater quality and groundwater level apart from abstraction volumes. Deep dewatering boreholes are critical in understanding impacts related to abstraction within the mine. These boreholes are included in the monitoring program for quality, levels, and abstraction volumes.

Table 9-1: Monitoring boreholes.

Borehole ID	Latitude	Longitude	Depth (m)	Monitoring Purpose
DKP1	-26.19135	27.77329	36	Background Monitoring
DKP3	-26.21286	27.78848	27	Source Monitoring
DKP4	-26.22042	27.7995	30	Impact Monitoring
DKP6	-26.22458	27.78913	18	Impact Monitoring
DKP7	-26.20712	27.77593	33	Source Monitoring
DKP8	-26.20797	27.79432	21	Source Monitoring
DK 13	-26.2056	27.802		Source Monitoring



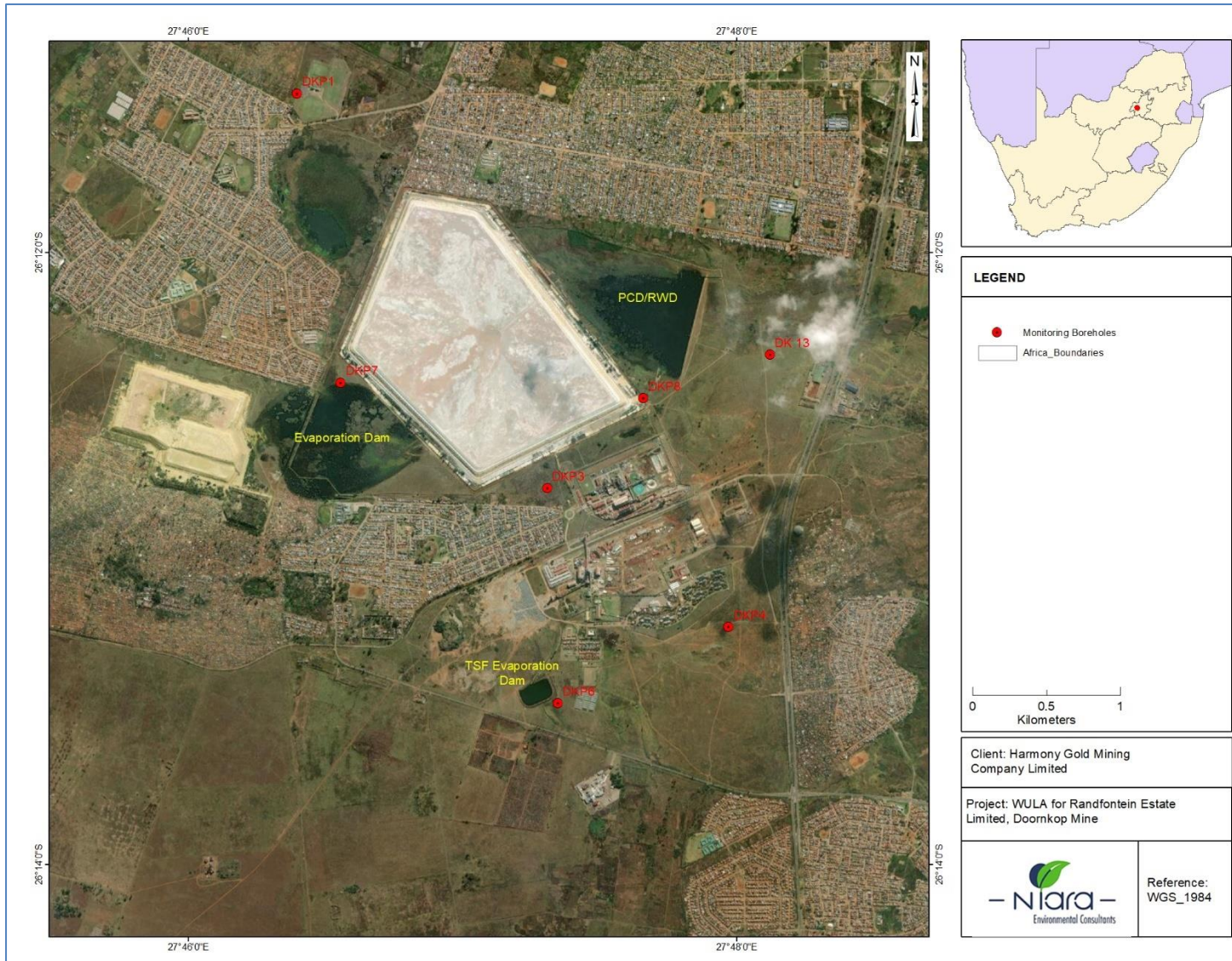


Figure 9-1: Distribution of monitoring boreholes.



10. Groundwater Environmental Management Programme

10.1. Current groundwater conditions

The current groundwater condition is characterised by groundwater quality affected by Mn which is a main concern. Contamination plume shows that current plume has only affected the immediate vicinity of the TSF. Groundwater level is not significantly affected by the operation. No privately own boreholes occur within the area with declining groundwater level. Little decline is observed in these boreholes.

10.2. Predicted impacts of facility

Predicted plume will spread towards the south and south east of the mine. The north east portion of the dolomite will be affected by the spread of plume in 50- and 100-plume predicted. Inflows is predicted as 6.4. Mℓ/d while closure of Cooke operations will most likely increase the flow to approximately 27 Mℓ/d. When this happens, Doornkop Mine will be affected in terms of the water storage which in turn will need more storage, treatment of surplus water and discharge, and ensures that dewatering volumes will still comply with predicted volumes/

10.3. Mitigation measures

10.3.1. Lowering of groundwater levels during facility operation

- ✔ Avoid over abstraction of dewatering boreholes. This will prevent significant lowering of groundwater level. Predictions have shown that groundwater level will decline from an average of 1625 mamsl to 1619 mamsl. This indicates that dewatering does not have major impacts.
- ✔ Continuous monitoring of groundwater level. This will allow collection of data required to assess any trends.
- ✔ Control and reduce demand associated with mine water. This will prevent over abstraction when more water is needed.

10.3.2. Rise of groundwater levels post- facility operation

Dewatering will continue until closure, hence rise in groundwater level will not affect the mine. However, post closure phase when pumping has ceased will result in groundwater recovery or rise. Monitoring will be needed to assess recovery level during post closure.

10.3.3. Spread of groundwater pollution post- facility operation

To reduce impacts during this phase, rehabilitation of all facilities will be crucial. Prepare and maintain water containment facility to reduce any overflow or dams. Remove all other contaminant on surface. Rehabilitate infrastructure not needed during this phase. Detail information is discussed under post closure plan.



11. Post Closure Management Plan

11.1. Remediation of physical activity

Infrastructure

- ☛ Determine which roads, buildings and structures are retained, and assign for future use options
- ☛ Plan and implement immediate demolition and dismantling of other facilities
- ☛ All infrastructure, equipment, plant, temporary or mobile offices must be removed from the prospecting site and transported offsite
- ☛ All compacted sites must be ripped or ploughed, and where necessary, topsoil must be replaced and re-establish vegetation.
- ☛ All waste material must entirely be removed and disposed at a registered landfill facility.
- ☛ Scraps and waste steel must be transported to an approved site for recycling.

Access Road

- ☛ All constructed access roads which will not be required by the farm owner must be ripped or ploughed and seeded with appropriate seeds and fertilizers.
- ☛ Road construction material that is likely to affect re-growth of vegetation must be scraped or removed and the material must be disposed in an approved manner.
- ☛ Any gate or fence erected during mining and which are not required by the farm owner must be removed.

Underground shafts

- ☛ Underground shafts must be closed to prevent any access to the underground workings.
- ☛ Entrance to the shafts must be blocked by mean of waste rock or capped with concrete to prevent public access.
- ☛ Infilling of the depression must be conducted.
- ☛ Landscaping, revegetation, and rehabilitation activities must be conducted within the surface area to conform with future land use.

Collapse or underground cave in:

- ☛ Structural reinforcement or infilling or backfilling tunnels with waste rock to prevent the underground working from collapsing

Surface subsidence

- ☛ Structural reinforcement at the surface to prevent subsidence
- ☛ All areas that are susceptible to subsidence or collapse must be surrounded by fence with a warning sign to prevent public access



11.2. Remediation of storage facilities

Tailing Storage Facility

- ☛ Landscaping, particularly of sloping surfaces; drainage system, retaining embankments, contoured furrowing to arrest erosion, regular inspections, and monitoring.
- ☛ Prevention of public access, fencing off dangerous areas, displaying clear warning signs
- ☛ Landscaping and revegetation

Waster rocks dump

- ☛ If waste rocks satisfy geotechnical criteria and found not to generate any acid or contamination, waste rock must therefore be used as backfill during mining or during rehabilitation after closure.
- ☛ Waste rock must be used to stabilize pit walls or tunnels and to backfill stopes and galleries.
- ☛ To prevent subsidence and slope failure, the following must be conducted: landscaping with slope reduction and furrowing, rock retaining walls, revegetation, and rehabilitation programs
- ☛ Prevention of public access; fencing off dangerous areas, displaying clear warning signs

Return water dams, pollution control dams, evaporation dams

- ☛ Select and prepare storage facility to contain seepage during closure.
- ☛ Remove and backfill other dams not required.
- ☛ Safe disposal of impounded contaminated water.
- ☛ Decontamination of embankment material, including riprap and spillway material.
- ☛ Removal and safe disposal of liner material.
- ☛ Assessment and possible soil clean-up underneath the liner system.
- ☛ Reinstatement of drainage patterns, including the breaching and shaping of embankments, silt/sediment traps and routing channels.
- ☛ Disposal of demolition waste and salvage of equipment.
- ☛ Final reclamation and revegetation.

11.3. Remediation of environmental impacts

- ☛ Chemical or hydrocarbon contaminated materials or soils must be removed and disposed at a recognized or registered disposal facility.
- ☛ All chemical storage tanks must be emptied and transported offsite.
- ☛ All temporary or portable sewage facility must be removed and sewage must be disposed of at a licensed Wastewater Treatment Works.
- ☛ French drains if available, must be compacted and covered with appropriate top soil and seeded with a vegetation seed mix.
- ☛ Safe disposal of impounded contaminated water.



- ☛ Contaminated surface area must be removed or excavated, and replaced with top soil and rehabilitated.
- ☛ Contaminated soil, rumbles and other foreign material must not be used for the purpose of rehabilitation.
- ☛ All contaminated material and remaining material or aggregate must be removed from the site.
- ☛ Compacted area must be ripped and ploughed.

11.4. Remediation of water resources impacts

Contaminated Aquifer, Surface, and Groundwater Resources

- ☛ Rehabilitation of all contamination sources to reduce the spread of contamination.
- ☛ Cleanup of all spillage that can results in aquifer contamination.
- ☛ Assess and identify any contaminated aquifer, surface, and groundwater.
- ☛ Restrict the use of contaminated surface and groundwater.
- ☛ Provide alternative source of water supply to affected users, where investigations confirm impacts as a result of the operation.
- ☛ Treatment of contaminated water through relevant and contaminant specific method, if deemed appropriate and feasible.

Final rehabilitation and land use

- ☛ Rehabilitation of all disturbed areas must be conducted where required. This must be done through replacing and levelling of topsoil, vegetation re-establishment, appropriate seeding and fertilized if necessary.
- ☛ The final rehabilitation of the site must, where possible and feasible, restore pre mining conditions or reflect a situation close to natural form.

Monitoring and inspection

- ☛ Monitoring of rehabilitation activities must be implemented for a period of one year. This must include:
- ☛ Rehabilitated site in general must be monitoring.
- ☛ Regular monitoring of seed growth, vegetation growth and establishment must be implemented.
- ☛ Rehabilitation activities such as sealed caps, backfilled hole and trenches will requires regular inspection and must be implemented.
- ☛ Post closure surface and groundwater sampling must be implemented



12. Conclusion and Recommendations

Introduction and Background

- ✔ Niara Environmental Consultants (Pty) Ltd has been appointed by Harmony Gold Mining Company Limited (Randfontein Estates Limited) to conduct specialist hydrogeological study for Doornkop Mine.
- ✔ The mine is located within the City of Johannesburg Metropolitan Municipality of the Gauteng Province, approximately 30 km west of Johannesburg.

Geographical setting

- ✔ The area has a surface landform of hills and gently undulating topography with elevation that varies from 1 640 m to 1 680 m above mean sea level (amsl).
- ✔ The mine is located within the western boundary of C22A quaternary catchment of the Vaal Water Management Area (WMA).
- ✔ The area is drained by two main perennial rivers, namely, the Klip River in the east and Wonderfonteinpruit Rivers in the west.
- ✔ Doornkop Mine falls in the Southern African Highveld which is classified as a warm temperate climate zone with dry winter.
- ✔ Temperature reaches a minimum of -3 °C and a maximum of 16 °C in July and a minimum of 15.5 °C and maximum of 29.9 °C in January.
- ✔ The region falls in the summer rainfall area, with average annual rainfall of 675 mm/annum. Scope of Work

Prevailing groundwater conditions - site specific

- ✔ Regional geology of the area is chronologically divided into: Witwatersrand Supergroup, Ventersdorp Supergroup. Transvaal Supergroup and Karoo Supergroup.
- ✔ Surface outcrop occurring within the area includes: Jeppetown Subgroup, Johannesburg Subgroup, Turffontein Subgroup, Klipriviersberg Group, Rietgat Formation, Black Reef Formation, Malmani Subgroup (Dolomite), Vaalian diabase and Dwyka Group
- ✔ The main rock deposit includes diamictite, shales, mudrocks, diabase, dolomite, limestones, quartzite, conglomerate, and lava.
- ✔ The underlying geology is characterised by major zones or reefs of the Witwatersrand Basin that includes: Elsburg Formations, The Kimberleys, The Black Reef, The Livingstone Reefs, The Ventersdorp Contact Reef (the "VCR") and The South Reef
- ✔ Doornkop Mine area is dominated by major structural features that includes faults and dykes. These geological structures include Roodepoort Fault, Saxon Faults, Doornkop Fault, and the Black Duck Dyke.



Hydrogeology

- Hydrogeology of the mine site is characterised by various aquifer system that controls groundwater occurrence.
- These aquifers are classified as: Intergranular and Fractured aquifer: Dwyka Group, Klipriviersberg Group and Rietgat Formation; Fractured aquifer system: Jeppes town Subgroup, Johannesburg Subgroup, Turffontein Subgroup and Black Reef Formation and Karst Aquifer: Malmani Subgroup (Malmani Dolomite).
- Target for groundwater occurrence includes weathered zones, shear zones, intrusive rock formations, contact zones between weathered lithology and intrusive sills and bedding planes, and fault and fractured zones.
- Witwatersrand Supergroup is composed of perched, unconfined, and confined aquifer system.
- General groundwater level of the study area varies from 2.11 mbgl to 13.84 mbgl.
- Water strikes recorded in some boreholes varies from 6 mbgl to 29 mbgl. The depth of the boreholes varies ranges from 18 mbgl to 36 mbgl.
- The Bayesian Correlation suggest that groundwater levels within the project area mimic surface topography.

Contamination sources

- The contamination sources that are likely to contaminate surface and groundwater resources if not properly managed are: Tailings Storage Facility (TSF), Reclaimed Waste Rock Dump (WRD), Wastewater Treatment Plant (WWTP), Sludge Settling Ponds, Return Water Dam (also called Pollution Control Dam (PCD), Underground Mine, Underground Discharge, Attenuation Dam, Evaporation Dam and Farmer's Dam.
- The main pathways that are likely to transport contaminants within the mine site will be: Runoff and infiltration through soil or vadose zone, Fault and dykes occurring within the study area, Groundwater or aquifer and Surface water or streams.
- The Klip and Wonderfonteinspruit River are the water courses which may potential be affected by contaminants emanating from the sources. Groundwater quality

Groundwater quality

- In general, groundwater quality within the mine comprises of boreholes with good water quality and boreholes that shows exceedance in some parameters
- Mn concentration at Doornkop Mine present a concern since the boreholes recorded high concentration above the SANS 2015.
- Long term water quality trends at Doornkop Mine suggest a huge improvement in groundwater quality.



- Historical assessment of groundwater quality reflects concentration of impacted groundwater within the mine.
- The piper diagram has classified groundwater into six hydrogeochemical facies, which are typically of: Shallow fresh groundwater, Mixed water sources, Deeper fresh groundwater, Evaporation water sources and Mine drainage influence.

Aquifer Characterisation

- Aquifer Vulnerability have classified the aquifer as moderate vulnerability for fractured and intergranular aquifer, and most vulnerable for dolomite.
- This aquifer is classified as minor aquifer system for fractured and intergranular aquifer, and major for dolomite aquifer and strictly no degradation for dolomite aquifer
- The aquifer is classified as medium susceptibility for fractured and intergranular aquifer and Strictly Non-Degradation for dolomite

Results of the model

- The model shows regional groundwater level deeper than the monitoring boreholes.
- Steady state groundwater flow model suggest that groundwater will flow perpendicular to the flow line, towards the south and south east of the mine.
- Steady state groundwater level varies from 1611 mamsl to 1625 mamsl across the model boundary.
- Drawdown in groundwater level is observed, with average groundwater level of 1619 mamsl.
- Simulation suggest that the two dewatering boreholes does not have major impact on groundwater level.
- Simulated plume result shows contamination within the TSF, RWD and Evaporation dam, and immediate surrounding area.
- Post closure impacts simulated for 50- and 100-years indicates that plume will continues to spread to the south and south east.
- Borehole DKP 3, DKP 4, DKP 7 and DKP8 will be affected by bot 50- and 100-year plume migration.
- Current inflow into Doornkop Mine is estimated as 6.4Mℓ/d. The mine is currently pumping about 8.44 Mℓ/d which suggest that there may be unknown water sources that infiltrates into mine working.
- Complete flooding of Cooke operations is estimated to affect Doornkop and inflows increase pumping requirement to 27 Mℓ/d has been estimated.

Post Closure Management Plan

- Determine which roads, buildings and structures are retained, and assign for future use options
- All infrastructure, equipment, plant, temporary or mobile offices must be removed from the prospecting site and transported offsite



- ✔ All constructed access roads which will not be required by the farm owner must be ripped or ploughed and seeded with appropriate seeds and fertilizers.
- ✔ Underground shafts must be closed to prevent any access to the underground workings.
- ✔ Structural reinforcement or infilling or backfilling tunnels with waste rock to prevent the underground working from collapsing
- ✔ Structural reinforcement at the surface to prevent subsidence
- ✔ Landscaping of all facilities, particularly of sloping surfaces; drainage system, retaining embankments, contoured furrowing to arrest erosion, regular inspections, and monitoring.
- ✔ Prevention of public access, fencing off dangerous areas, displaying clear warning signs
- ✔ If waste rocks satisfy geotechnical criteria and found not to generate any acid or contamination, waste rock must therefore be used as backfill during mining or during rehabilitation after closure.
- ✔ Select and prepare storage facility to contain seepage during closure
- ✔ Remove and backfill other dams not required
- ✔ Chemical or hydrocarbon contaminated materials or soils must be removed and disposed at a recognized or registered disposal facility
- ✔ All chemical storage tanks must be emptied and transported offsite
- ✔ All temporary or portable sewage facility must be removed and sewage must be disposed of at a licensed Wastewater Treatment Works.
- ✔ Rehabilitation of all contamination sources to reduce the spread of contamination.

Recommendations

- ✔ The mine must update groundwater model every three years or as recommended in the licence. This will allow the predictions and improvement in the current knowledge.
- ✔ Review water containment infrastructures with the focus to understand if the facility can manage an increased dewatering volume.
- ✔ Investigate water treatment options with the focus to treat possible increase in mine water inflow and dewatering.
- ✔ Investigates and assess cumulative impacts from neighbouring mines, closure management strategies, inflows, plumes, and interaction with Doornkop



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Appendices



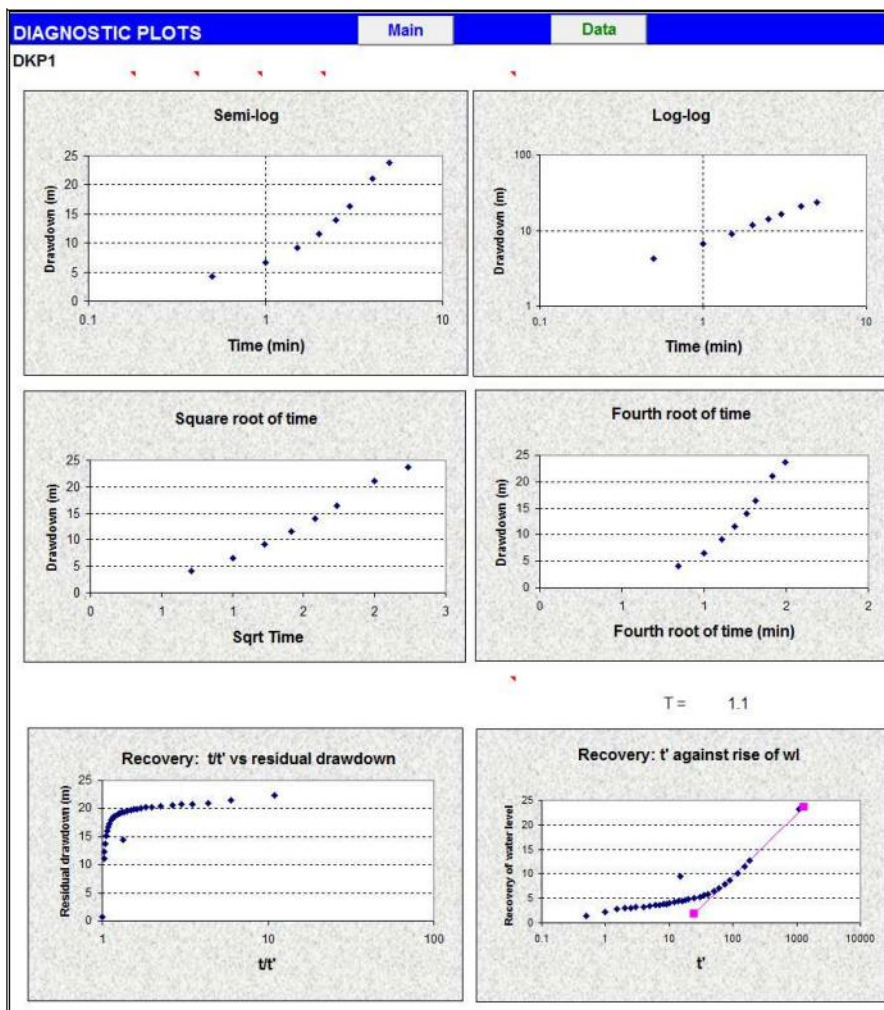
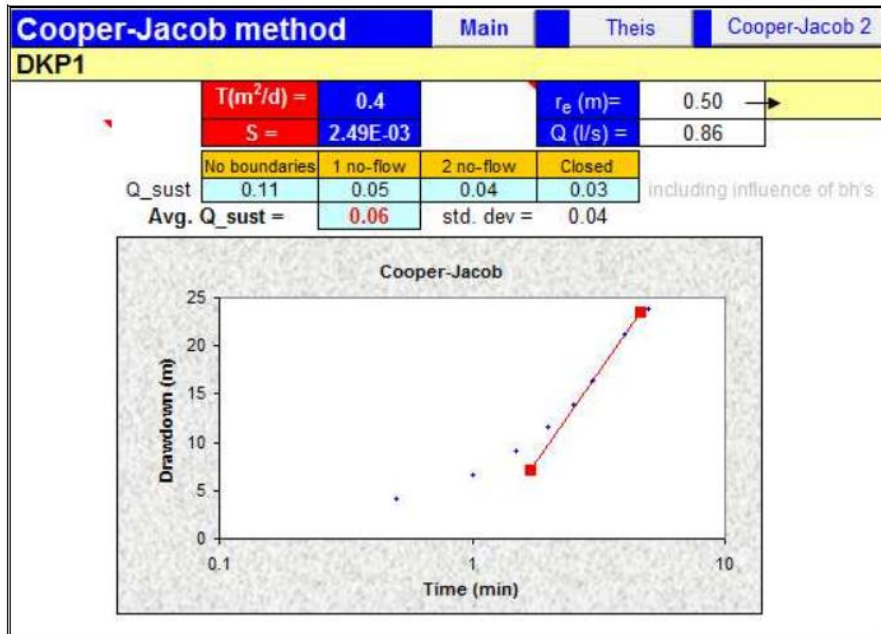
Appendix 1: Geophysical survey report

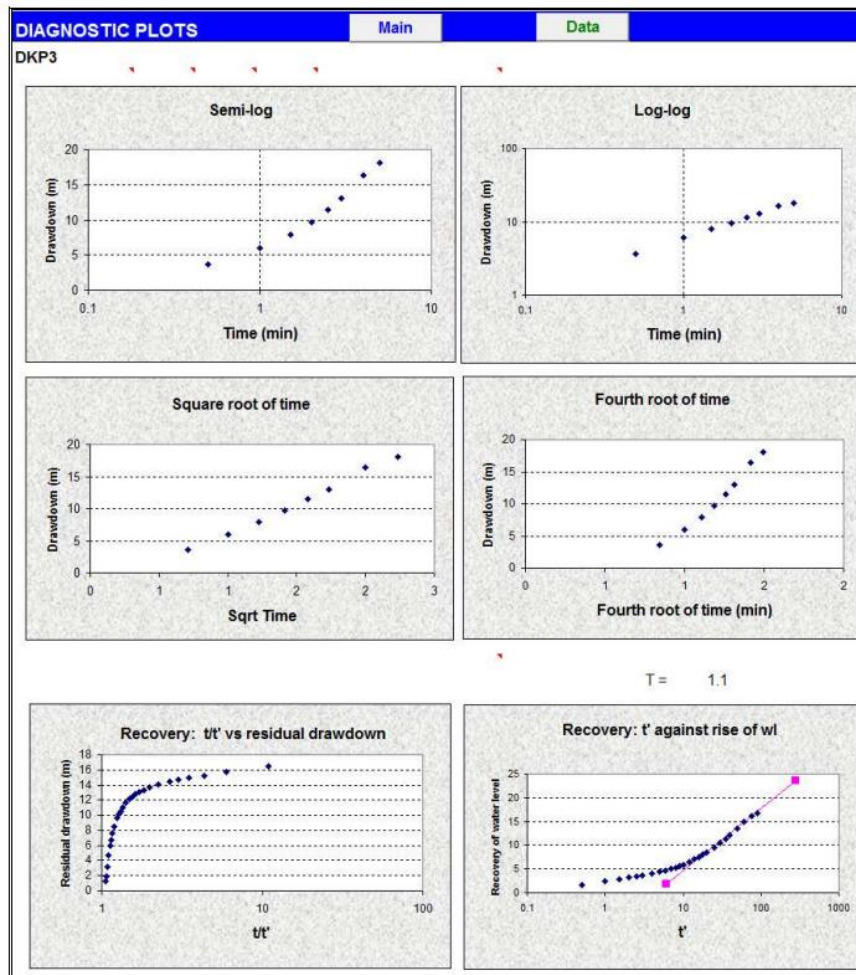
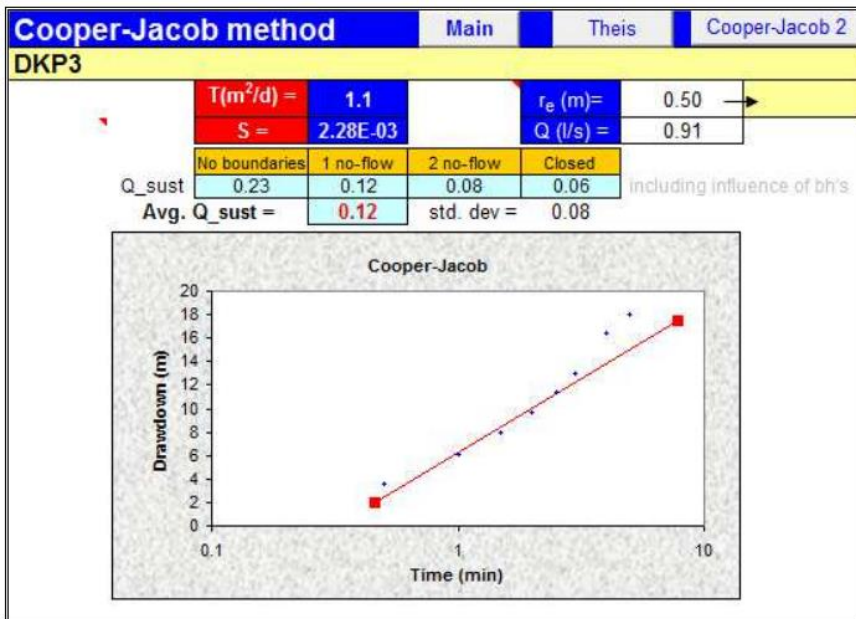


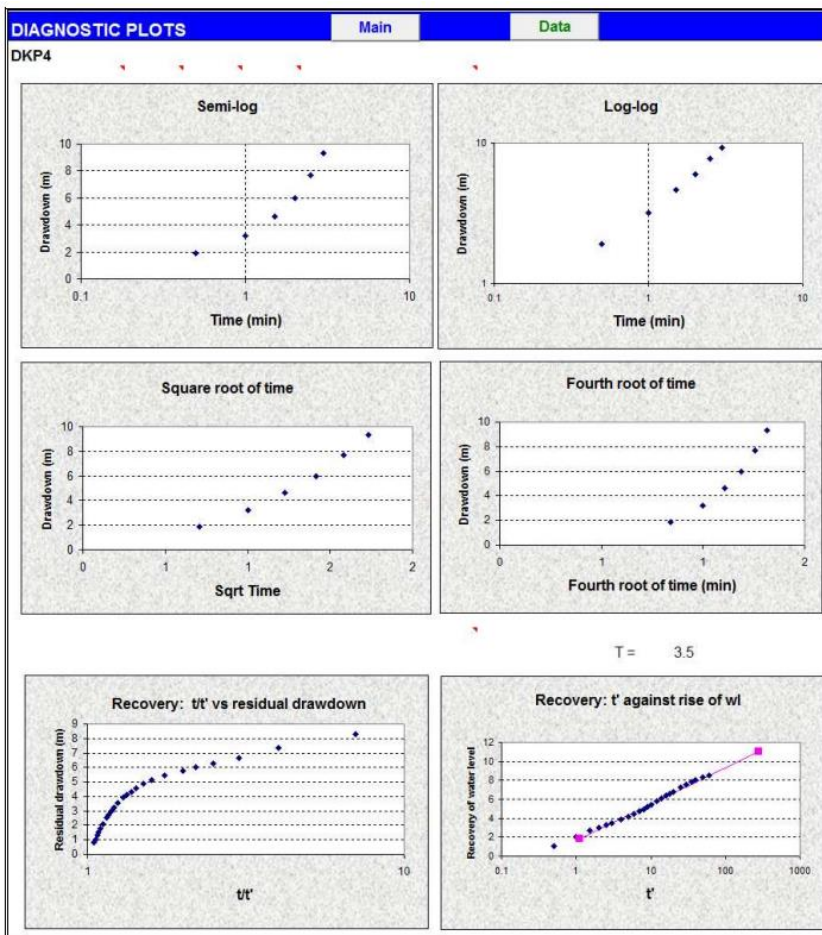
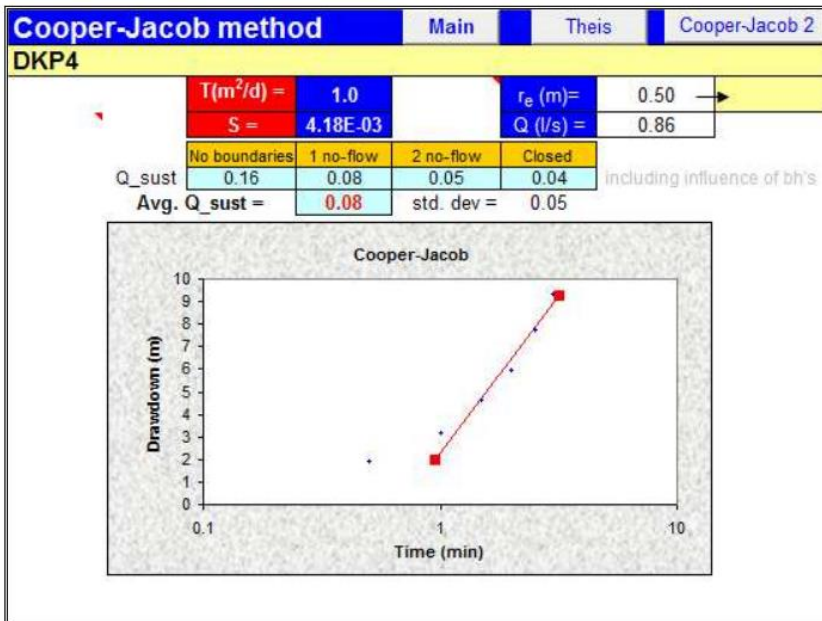
Appendix 2: Drilling report and log

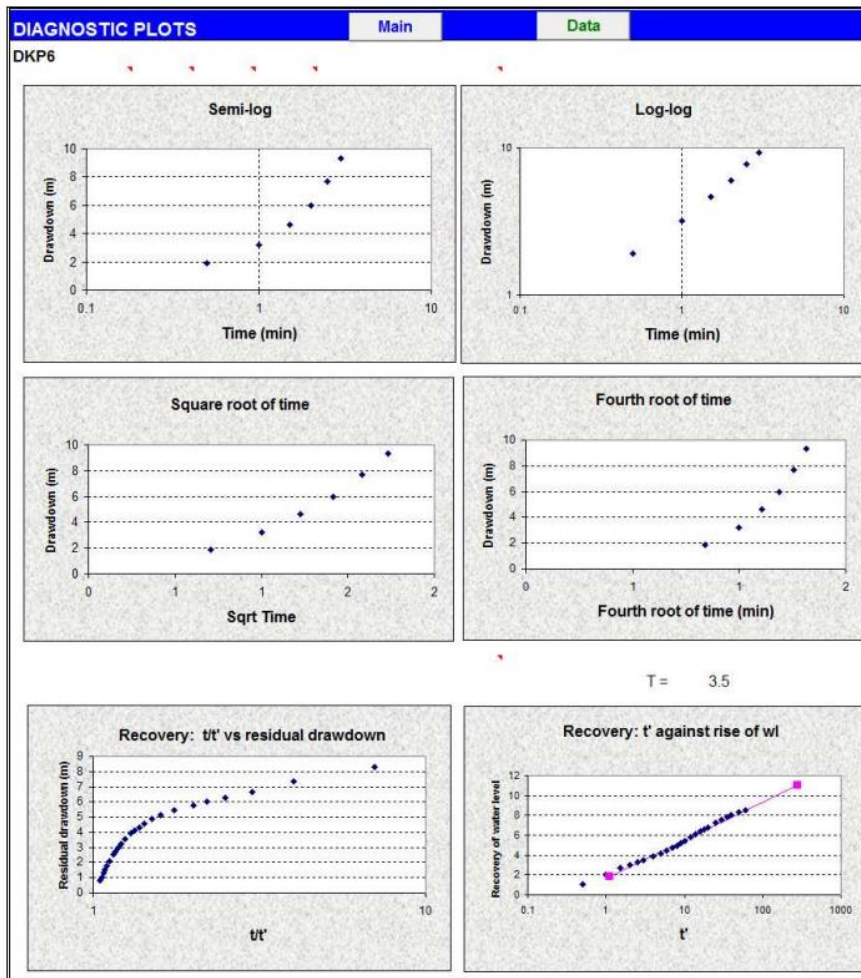
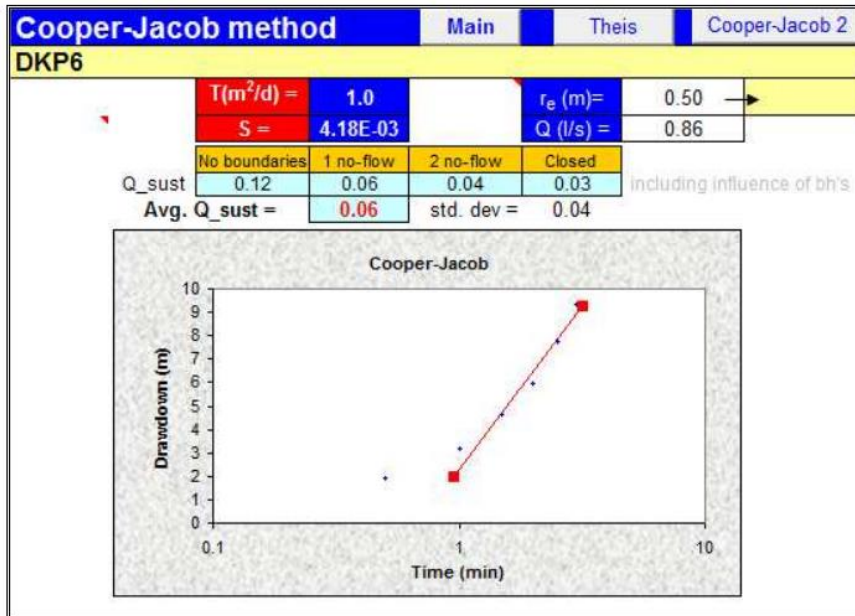


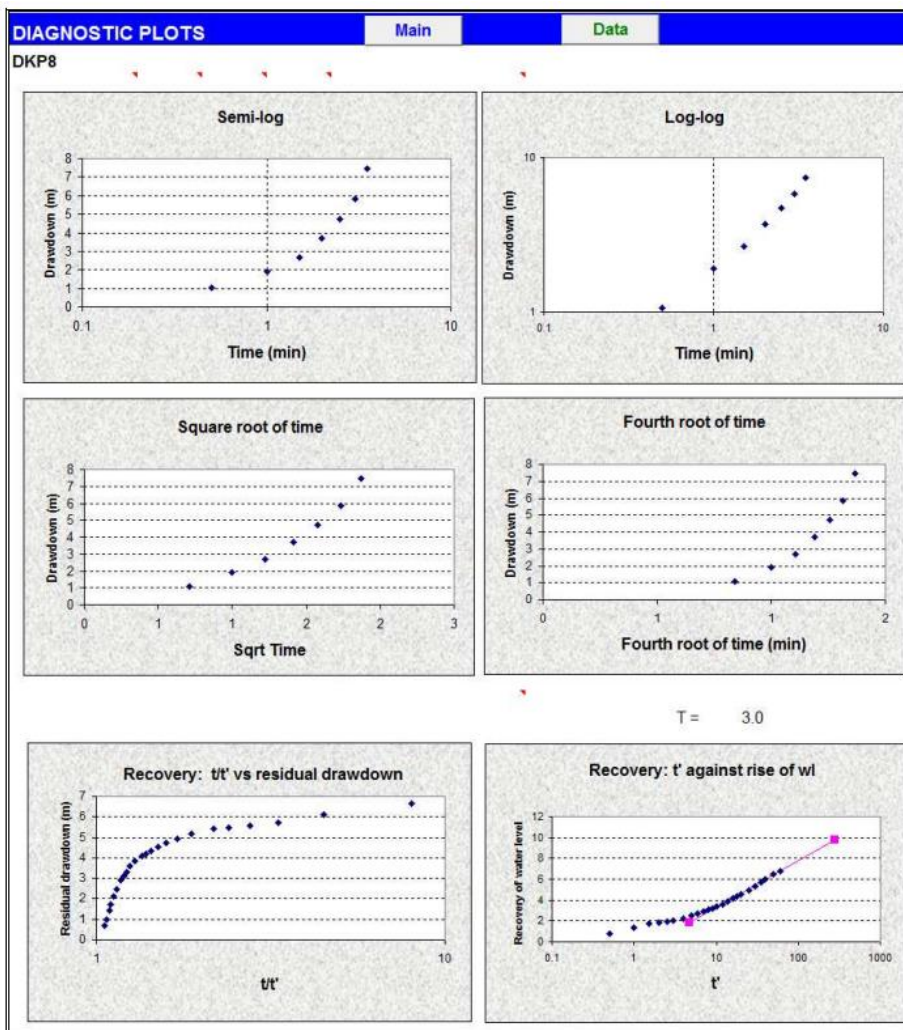
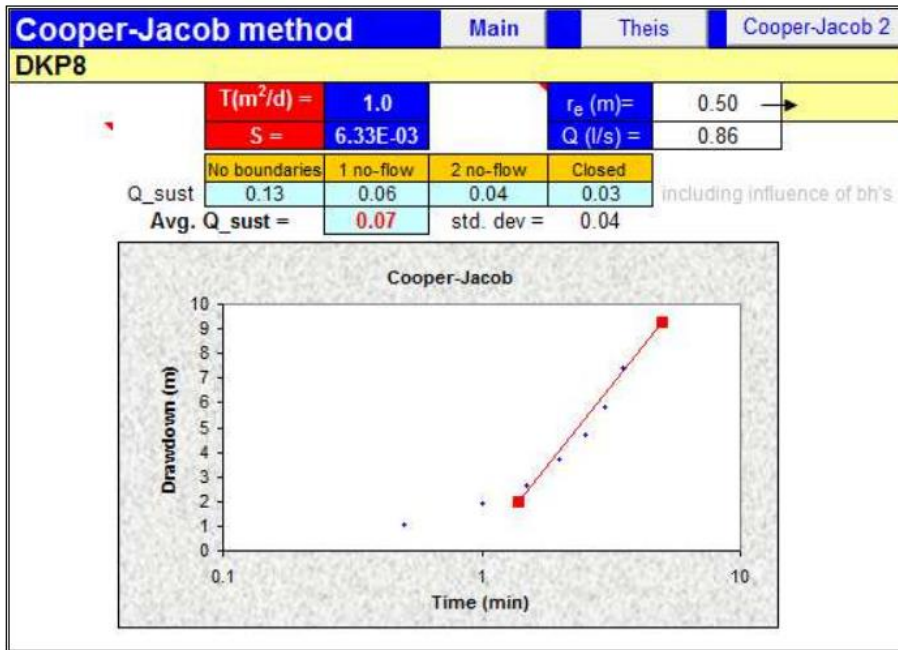
Appendix 3: Pump testing results.













Appendix 4: X-Ray Diffraction (XRD).

		WATERLAB (PTY) LTD <small>Reg. No.: 1983/009165/07 V.A.T. No.: 4130107891</small>					
		<small>23B De Havilland Crescent Perseus TechnoPark, Meiring Naudé Road, Pretoria P.O. Box 283, 0020</small>		<small>Telephone: +2712-349-1066 Facsimile: +2712-349-2064 Email: accounts@waterlab.co.za</small>			
CERTIFICATE OF ANALYSES X-RAY DIFFRACTION [o]							
Date received: 2023/06/30 Project number: 1000		Report number: 122233		Date completed: 2023/08/03 Order number:			
Client name: NRN Consulting Address: 21 Twig Street, West Acres, Mbombela, 1201 Telephone: ---				Contact person: Charles Rikhotso Email: info@nrnconsulting.co.za Cell: 083 557 3155			
Analyses		Sample Identification:					
		DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS
Sample Number		23-12645	23-12646	23-12647	23-12648	23-12649	23-12650
Mineral Amount (weight %)		Composition (%) [o]					
Quartz		82.2	83.6	86.2	77.1	84.3	86.8
Pyrophyllite		8.7	4.1	2.7	2.2	2.9	6.1
Chloritoid		5.3	10.9	10.1	10.0	11.0	5.8
Chlorite		1.5	0.6	0.5	2.7	0	0
Muscovite		2.4	1.0	0.5	8.0	0.6	1.4
Pyrite		0	0	0	0	1.2	0
[o] = Outsourced							
Note: The material was prepared for XRD analysis using a back-loading preparation method. Diffractograms were obtained using a Malvern Panalytical Aeris diffractometer with a PIXcel detector and fixed slits with Fe-filtered Co-Kα radiation. The phases were identified using X'Pert Highscore Plus software. The relative phase amounts (weight %) were estimated using the Rietveld method. Comment: <ul style="list-style-type: none"> • In case the results do not correspond to the results of other analytical techniques, please let me know for further fine-tuning of XRD results. • Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group. • Due to preferred orientation and crystallite size effects, results may not be as accurate as shown. • Smectite, lizardite (serpentine), vermiculite, chlorite, and kaolinite peaks overlap, and further tests would be necessary to distinguish them. Identification is largely based on peak shapes and positions. • Traces of additional phases may be present. Amounts below 0.5 weight % may be unreliable. • Amorphous phases, if present, were not taken into consideration during quantification. 							
Ideal Mineral compositions:							
Compound Name		Chemical Formula					
Chlorite		(Mg,Fe)5Al(AISi3O10)(OH)8					
Chloritoid		FeAl2SiO5(OH)2					
Muscovite		KA12((OH)2Al Si3 O10)					
Pyrite		FeS2					
Pyrophyllite		Al(Si2O5)(OH)					
E. Botha Geochemistry Project Manager							
The information contained in this report is relevant only to the sample/samples supplied to WATERLAB (Pty) Ltd. Any further use of the above information is not the responsibility or liability of WATERLAB (Pty) Ltd. Except for the full report, parts of this report may not be reproduced without written approval of WATERLAB (Pty) Ltd.							




Appendix 5: Acid-Base Accounting (ABA).

		WATERLAB (PTY) LTD						
		Reg. No.: 1983/009165/07		V.A.T. No.: 4130107891				
		23B De Havilland Crescent Persekor TechnoPark, Meiring Naudé Road, Pretoria P.O. Box 283, 0020			Telephone: +2712 – 349 – 1066 Facsimile: +2712 – 349 – 2064 Email: accounts@waterlab.co.za			
CERTIFICATE OF ANALYSES								
ACID – BASE ACCOUNTING								
EPA-600 MODIFIED SOBEK METHOD								
Date received:		2023/06/30			Date completed:		2023/08/03	
Project number:		1000		Report number:		122233		
Order number:								
Client name:		NRN Consulting				Contact person:		Charles Rikhotso
Address:		21 Twig Street, West Acres, Mbombela, 1201				Email:		info@nrnconsulting.co.za
Telephone:		---				Cell:		083 557 3155
Acid – Base Accounting		Sample Identification						
Modified Sobek (EPA-600)		DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Sample Number		23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
Paste pH		7.6	7.4	3.2	7.2	5.5	7.2	7.1
Total Sulphur (%) (LECO)		0.27	0.24	0.07	0.34	1.20	0.37	0.37
Acid Potential (AP) (kg/t)		8.39	7.37	2.27	11	37	12	12
Neutralization Potential (NP)		2.28	1.77	-0.755	0.255	-0.755	0.255	0.508
Nett Neutralization Potential (NNP)		-6.11	-5.60	-3.02	-10	-38	-11	-11
Neutralising Potential Ratio (NPR) (NP : AP)		0.271	0.240	0.333	0.024	0.020	0.022	0.044
Rock Type		I	II	II	I	I	I	I
<p>* Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.</p>								
<p>S. Laubscher _____ Assistant Geochemistry Project Manager</p>								




Appendix 6: Net Acid Generation (NAG)

		WATERLAB (PTY) LTD						
		23B De Havilland Crescent Perseus TechnoPark, Mering Naudé Road, Pretoria P.O. Box 263, 0020			Telephone: +2712 – 349 – 1066 Facsimile: +2712 – 349 – 2064 Email: accounts@waterlab.co.za			
CERTIFICATE OF ANALYSES								
NET ACID GENERATION								
Date received:		2023/06/30		Report number:		122233		
Project number:		1000		Date completed:		2023/08/03		
Client name:		NRN Consulting				Contact person:		Charles Rikhotso
Address:		21 Twig Street, West Acres, Mbombela, 1201				Email:		info@nrnconsulting.co.za
Telephone:		---				Cell:		083 557 3155
Sample Identification: pH 4.5								
	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS	
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D	
NAG pH: (H₂O₂)	4.0	3.2	5.1	3.1	2.5	3.1	3.1	
NAG (kg H₂SO₄ / t)	4.70	4.51	<0.01	5.49	23	6.86	6.66	
Sample Identification: pH 7.0								
Net Acid Generation	DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS	
Sample Number	23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D	
NAG pH: (H₂O₂)	4.5	4.5	5.1	4.5	4.5	4.5	4.5	
NAG (kg H₂SO₄ / t)	1.57	1.37	2.35	1.37	3.53	1.37	1.57	
S. Laubscher Assistant Geochemistry Project Manager								




Appendix 7: Sulphur speciation.

		WATERLAB (PTY) LTD						
		Reg. No.: 1983/009165/07		V.A.T. No.: 4130107891				
		23B De Havilland Crescent Persekor Techno Park, Meiring Naudé Road, Pretoria P.O. Box 283, 0020			Telephone: +2712 – 349 – 1066 Facsimile: +2712 – 349 – 2064 Email: accounts@waterlab.co.za			
<u>CERTIFICATE OF ANALYSES</u> SULPHUR SPECIATION								
Date received:	2023/06/30					Date completed:	2023/08/03	
Project number:	1000	Report number: 122233			Order number:			
Client name:	NRN Consulting				Contact person:		Charles Rikhotso	
Address:	21 Twig Street, West Acres, Mbombela, 1201				Email:		info@nrnconsulting.co.za	
Telephone:	---				Cell:		083 557 3155	
Analyses		Sample Identification						
		DTSF 1	DTSF 2	DTSF 3	DWRD 1	HW 2300m below	Footwall 2300m BS	Footwall 2300m BS
Sample Number		23-12645	23-12646	23-12647	23-12648	23-12649	23-12650	23-12650 D
Total Sulphur (%) (ELTRA)		0.27	0.24	0.07	0.34	1.20	0.37	0.37
Sulphate Sulphur as S (%)		0.08	0.04	0.02	0.06	0.06	0.07	0.05
Sulphide Sulphur (%)		0.19	0.20	0.05	0.28	1.13	0.31	0.32
Notes:								
<ul style="list-style-type: none"> Samples analysed with Pyrolysis at 550°C as per Prediction Manual For Drainage Chemistry from Sulphidic Geological Materials MEND Report 1.20.1. Multiply Sulphate Sulphur to calculate SO₄ % by 2.996. Please see the method for interferences. Organic Sulphur is not taken into account and may be included in the results. Please let me know if results do not correspond to other data. 								
E. Botha								
Geochemistry Project Manager								
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Appendix 8: Leachable TCLP.

		WATERLAB (PTY) LTD				
		Reg. No.: 1983/00916/07	V.A.T. No.: 4130107891			
		23B De Havilland Crescent Perseus Techno Park, Meiring Naudé Road, Pretoria P.O. Box 283, 0020	Telephone: +2712 – 349 – 1066 Facsimile: +2712 – 349 – 2064 Email: accounts@waterlab.co.za			
CERTIFICATE OF ANALYSES EXTRACTIONS AS 4439.3						
Date received:	2023/06/30	Report number:	122233			
Project number:	1000	Date completed:	2023/08/02			
Client name:	NRN Consulting	Order number:				
Address:	21 Twig Street, West Acres, Mbombela, 1201	Contact person:	Charles Rikhotso			
Telephone:	---	Email:	info@nrnconsulting.co.za			
		Cell:	083 557 3155			
Analyses	Sample Identification					
	DTSF 1		DTSF 2		DTSF 3	
Sample Number	23-12645		23-12646		23-12647	
Leachate	TCLP - 1		TCLP - 1		TCLP - 1	
Dry Mass Used (g)	50		50		50	
Volume Used (mℓ)	1000		1000		1000	
pH Value at 25°C	4.9		5.0		4.9	
Inorganic Anions	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Dissolved Solids at 180 °C	390	7800	112	2240	58	1160
Chloride as Cl	4	80	3	60	<2	<40
Sulphate as SO ₄	73	1460	18	360	25	500
Nitrate as N	0.5	10	0.3	6.0	<0.1	<2.0
Nitrite as N	<0.05	<1.0	<0.05	<1.0	<0.05	<1.0
Fluoride as F	<0.2	<4.0	<0.2	<4.0	<0.2	<4.0
Total Cyanide as CN [o]	<0.07	<1.40	<0.07	<1.40	<0.07	<1.40
Hexavalent Chromium as Cr ⁶⁺	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ICP Elements	See ICP TCLP tab					
[o] = Outsourced						
Analyses	Sample Identification					
	DWRD 1		HW 2300m below		Footwall 2300m BS	
Sample Number	23-12648		23-12649		23-12650	
Leachate	TCLP - 1		TCLP - 1		TCLP - 1	
Dry Mass Used (g)	50		50		50	
Volume Used (mℓ)	1000		1000		1000	
pH Value at 25°C	5.0		4.9		4.9	
Inorganic Anions	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Dissolved Solids at 180 °C	132	2640	50	1000	100	2000
Chloride as Cl	<2	<40	<2	<40	<2	<40
Sulphate as SO ₄	7	140	<2	<40	2	40
Nitrate as N	7.8	156	0.6	12	4.4	88
Nitrite as N	<0.05	<1.0	<0.05	<1.0	<0.05	<1.0
Fluoride as F	<0.2	<4.0	<0.2	<4.0	<0.2	<4.0
Total Cyanide as CN [o]	<0.07	<1.40	<0.07	<1.40	<0.07	<1.40
Hexavalent Chromium as Cr ⁶⁺	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ICP Elements	See ICP TCLP tab					
[o] = Outsourced						
NEMWA Limits						
*Please note:	<ul style="list-style-type: none"> - The samples were used as received. - The results are reported as received. The moisture content were not taken into account. 					
S. Laubscher						
Assistant Geochemistry Project Manager						
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Appendix 9: ICP TCLP.

WATERLAB (PTY) LTD CERTIFICATE OF ANALYSES ICP QUANTITATIVE ANALYSIS							
Date received:	2023/06/30				Date Completed:	2023/08/02	
Project number:	1000				Report number:	122233	
Client name:	NRN Consulting				Contact person:	Charles Rikhotso	
Address:	21 Twig Street, West Acres, Mbombela, 1201				Email:	info@nrnconsulting.co.za	
Telephone:	---				Cell:	083 557 3155	
Extract	Sample Dry Mass	Volume	Mass (g/l)	Factor			
TCLP	50	1000	50	20			
Sample Id	Sample number	As	As	B	B	Ba	Ba
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.020	<0.025	<0.500	<0.025	<0.500
DTSF 1	23-12645	0.043	0.860	<0.025	<0.500	0.037	0.740
DTSF 2	23-12646	0.033	0.660	<0.025	<0.500	<0.025	<0.500
DTSF 3	23-12647	0.001	0.020	<0.025	<0.500	<0.025	<0.500
DWRD 1	23-12648	0.006	0.120	<0.025	<0.500	0.026	0.520
HW 2300m below	23-12649	0.008	0.160	<0.025	<0.500	<0.025	<0.500
Footwall 2300m BS	23-12650	0.015	0.300	<0.025	<0.500	<0.025	<0.500
Sample Id	Sample number	Cd	Cd	Co	Co	Cr	Cr
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.020	<0.025	<0.500	<0.025	<0.500
DTSF 1	23-12645	<0.001	<0.020	0.072	1.44	<0.025	<0.500
DTSF 2	23-12646	<0.001	<0.020	0.027	0.540	<0.025	<0.500
DTSF 3	23-12647	<0.001	<0.020	<0.025	<0.500	<0.025	<0.500
DWRD 1	23-12648	<0.001	<0.020	<0.025	<0.500	0.027	0.540
HW 2300m below	23-12649	<0.001	<0.020	<0.025	<0.500	0.030	0.600
Footwall 2300m BS	23-12650	<0.001	<0.020	<0.025	<0.500	0.031	0.620
Sample Id	Sample number	Cu	Cu	Hg	Hg	Mn	Mn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.001	<0.020	<0.025	<0.500
DTSF 1	23-12645	0.085	1.70	<0.001	<0.020	1.03	21
DTSF 2	23-12646	0.023	0.460	<0.001	<0.020	0.561	11
DTSF 3	23-12647	0.020	0.400	<0.001	<0.020	0.052	1.04
DWRD 1	23-12648	0.037	0.740	<0.001	<0.020	0.644	13
HW 2300m below	23-12649	0.037	0.740	<0.001	<0.020	1.04	21
Footwall 2300m BS	23-12650	0.020	0.400	<0.001	<0.020	0.961	19
Sample Id	Sample number	Mo	Mo	Ni	Ni	Pb	Pb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.500	<0.025	<0.500	<0.001	<0.020
DTSF 1	23-12645	<0.025	<0.500	0.171	3.42	0.031	0.620
DTSF 2	23-12646	<0.025	<0.500	0.094	1.88	0.054	1.08
DTSF 3	23-12647	<0.025	<0.500	0.030	0.600	0.001	0.020
DWRD 1	23-12648	<0.025	<0.500	0.038	0.760	0.017	0.340
HW 2300m below	23-12649	<0.025	<0.500	0.061	1.22	0.026	0.520
Footwall 2300m BS	23-12650	<0.025	<0.500	0.046	0.920	0.029	0.580
Sample Id	Sample number	Sb	Sb	Se	Se	V	V
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.020	<0.001	<0.020	<0.025	<0.500
DTSF 1	23-12645	0.004	0.080	0.002	0.040	<0.025	<0.500
DTSF 2	23-12646	0.001	0.020	0.001	0.020	<0.025	<0.500
DTSF 3	23-12647	<0.001	<0.020	0.004	0.080	<0.025	<0.500
DWRD 1	23-12648	0.001	0.020	<0.001	<0.020	<0.025	<0.500
HW 2300m below	23-12649	0.001	0.020	<0.001	<0.020	<0.025	<0.500
Footwall 2300m BS	23-12650	0.001	0.020	<0.001	<0.020	<0.025	<0.500
Sample Id	Sample number	Zn	Zn				
		mg/l	mg/kg				
Det Limit		<0.025	<0.500				
DTSF 1	23-12645	0.130	2.60				
DTSF 2	23-12646	0.047	0.940				
DTSF 3	23-12647	<0.025	<0.500				
DWRD 1	23-12648	0.104	2.08				
HW 2300m below	23-12649	0.038	0.760				
Footwall 2300m BS	23-12650	0.027	0.540				
Analysed on ICP OES							
Analysed on ICP MS							
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Appendix 10: Water quality certificate



Test Report

Page 1 of 2

Client: Harmony Gold Mining Company Limited
Address: Randfontein Office park, Corner of Main Reef Road and Ward Avenue, Randfo
Report no: 156184
Project: Harmony - Doornkop Mine

Date of report: 28 June 2023
Date accepted: 21 June 2023
Date completed: 28 June 2023
Date received: 21 June 2023

Lab no:	285437	285438	285439	285440		
Date sampled:	20-Jun-23	20-Jun-23	20-Jun-23	20-Jun-23		
Aquatico sampled:	Yes	Yes	Yes	Yes		
Sample type:	Water	Water	Water	Water		
Locality description:	DKP 4	DKP 13	DKP3	DKP8		
Analyses	Unit	Method				
A AQL pH @ 25°C	pH	ALM 20	7.97	8.29	7.85	7.99
A AQL Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	32.7	67.6	20.0	65.0
A AQL Total Dissolved solids @ 180°C	mg/l	ALM 24	194	384	114	398
A AQL Total Alkalinity	mg CaCO ₃ /l	ALM 01	106	111	75.4	81.6
A AQL Chloride (Cl)	mg/l	ALM 02	19.3	78.6	12.8	20.3
A AQL Sulphate (SO ₄)	mg/l	ALM 03	38.0	105	5.26	244
A AQL Nitrate (NO ₃) as N	mg/l	ALM 06	1.95	1.78	2.11	3.48
A AQL Total oxidised nitrogen as N	mg/l	ALM 06	2.29	2.12	2.42	3.77
A AQL Nitrite (NO ₂) as N	mg/l	ALM 07	0.335	0.338	0.316	0.288
A AQL Ammonium (NH ₄) as N	mg/l	ALM 05	0.303	0.410	0.287	0.307
A AQL Fluoride (F)	mg/l	ALM 08	<0.263	<0.263	<0.263	<0.263
A AQL Calcium (Ca)	mg/l	ALM 30	44.8	40.0	14.9	63.1
A AQL Magnesium (Mg)	mg/l	ALM 30	5.66	38.3	11.0	34.5
A AQL Sodium (Na)	mg/l	ALM 30	16.4	24.7	7.35	19.6
A AQL Potassium (K)	mg/l	ALM 30	8.73	4.67	3.10	3.07
A AQL Aluminium (Al)	mg/l	ALM 31	<0.002	<0.002	<0.002	0.004
A AQL Iron (Fe)	mg/l	ALM 31	<0.004	<0.004	<0.004	<0.004
A AQL Manganese (Mn)	mg/l	ALM 31	<0.001	0.199	<0.001	0.217
A AQL Copper (Cu)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002
A AQL Nickel (Ni)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002
A AQL Zinc (Zn)	mg/l	ALM 31	<0.002	<0.002	<0.002	<0.002
A AQL Cobalt (Co)	mg/l	ALM 31	<0.003	<0.003	<0.003	<0.003
A AQL E.coli	CFU/100ml	ALM 40	<1	<1	<1	<1
N AQL Faecal coliform	CFU/100ml	ALM 42	<1	2	<1	<1
A AQL Total coliform	CFU/100ml	ALM 40	<1	14	<1	<1

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

AQL = Aquatico Laboratories ; AQK = Aquatico Laboratories based in Kathu

AQL 89 Regency Drive, R21 Corporate Park, Centurion, South Africa
AQK 28 Karee ave, Kathu, Northern Cape, South Africa

Tel: +27 12 450 3800
Tel: +27 53 880 0208

www.aquatico.co.za
www.aquatico.co.za





Test Report

Page 2 of 2

Client: Harmony Gold Mining Company Limited	Date of report: 28 June 2023
Address: Randfontein Office park, Corner of Main Reef Road and Ward Avenue, Randfo	Date accepted: 21 June 2023
Report no: 156184	Date completed: 28 June 2023
Project: Harmony - Doornkop Mine	Date received: 21 June 2023

Lab no:	285437	285438	285439	285440
Date sampled:	20-Jun-23	20-Jun-23	20-Jun-23	20-Jun-23
Aquatico sampled:	Yes	Yes	Yes	Yes
Sample type:	Water	Water	Water	Water
Locality description:	DKP 4	DKP 13	DKP3	DKP8
Analyses	Unit	Method		
A AQL Turbidity	NTU	ALM 21	6.69	78.5
A AQL Total Cyanide (CN)	mg/l	ALM 16	<0.005	<0.005
A AQL Cyanide WAD	mg/l	ALM 15	<0.003	<0.003
A AQL Free Cyanide (CN)	mg/l	ALM 14	<0.008	<0.008
A AQL Dissolved Uranium (U)	mg/l	ALM 37	<0.015	<0.015

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

Authenticated signature on first page

AQL = Aquatico Laboratories ; AQK = Aquatico Laboratories based in Kathu

AQL 89 Regency Drive, R21 Corporate Park, Centurion, South Africa
AQK 28 Karee ave, Kathu, Northern Cape, South Africa

Tel: +27 12 450 3800
Tel: +27 53 880 0208

www.aquatico.co.za
www.aquatico.co.za



Curriculum vitae: Charles Rikhotso

1. **Surname:** Rikhotso
2. **First names:** Charles
3. **Date of birth:** 18-10-1984
4. **Gender:** Male
5. **Nationality:** RSA

6. Qualifications

Institution	Completion date	Degree /Diploma
University of the Witwatersrand	June, 2023	MSc: Hydrogeology
University of Free State	2016	Masters: Environmental Management
University of Free State	2012	Bsc Honours: Geohydrology
Tshwane University of Technology	2011	B Tech: Geology
Tshwane University of Technology	2010	National Diploma: Geology

7. Membership of professional bodies

Name of institution	Membership number
South African council for natural scientific profession	Pr.Sci.Nat : 400068/16

8. Employment history

Date and duration	Name of employer	Position held
06/02/2023-31/08/2023	Sibanye Stillwater	Superintendent Environmental Water Engineer
01/01/2017-31/01/2023	Department of Water and Sanitation	Scientist Production: Hydrogeology
01/03/2011-31/12/2016	Council for Geoscience	Hydrogeologist

9. Relevant work Experience

- Surface and groundwater monitoring within mining, agricultural, chemical, sewage and other industries,
- Water use licence application, external audit and waste licence audit and inspection
- Geotechnical investigation, engineering geological investigation, soil sampling and assessment, soil profiling.
- Assessment of water quality and quantity and related impacts
- Assessment of sustainable groundwater abstraction, usage, dewatering, decant, seepage and overflow
- Perform water balance assessment, surface and groundwater interaction, recharge and discharge processes
- Hydrogeological investigation which involve aquifer characterisation and groundwater exploration
- Perform geohydrological investigations or research that involve mapping, gathering of data, compilation of maps and reports, laboratory and field parameter measurement and analysis.
- Assessment, identification and characterization of contaminated area, environmental related impacts, contamination sources, contamination flow path, receiving environment and associated risk
- Aquifer pump testing and analysis
- Aquifer or groundwater vulnerability studies
- Determination of groundwater recharge processes

- Surface and groundwater pollution assessment
- Development of conceptual and groundwater model
- Delineation and characterization of impacted areas
- Geochemical assessment and waste classification, assessment of potential acid mine drainage generation material
- Characterisation of acid mine drainage water, neutral mine drainage and saline mine drainage water
- Water sampling for domestic and irrigation assessment, pollution assessment and pollution trend identification
- Water sampling for stable and radioisotope analysis
- Assessment of groundwater origin, recharge processes and age dating
- Isotope and hydrochemical analysis and interpretation
- Groundwater exploration for borehole water supply

SACNASP

South African Council for Natural Scientific Professions

herewith certifies that

Charles Rikhotso

Registration Number: 400068/16

is a registered scientist

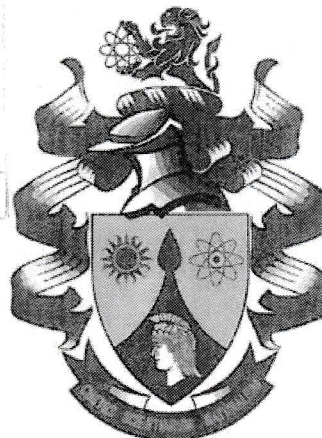
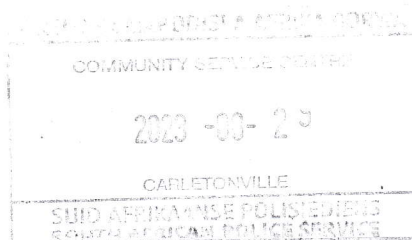
in terms of section 20(3) of the Natural Scientific Professions Act, 2003
(Act 27 of 2003)

in the following field(s) of practice (Schedule 1 of the Act)

Earth Science (Professional Natural Scientist)

Effective 9 March 2016

Expires 31 March 2024



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I certify that this document is a true reproduction/copy of the original which has been personally inspected by me and that from my observations the document has not been altered in any manner.
Charles Rikhotso

Date/Date: _____

[Signature]

Chairperson

[Signature]

Chief Executive Officer



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