China African Precious Metals: Orkney Gold Mine

Geohydrological Investigation as input to the EMPR

March 2015

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PROJECT DETAILS

Project Title: **China African Precious Metals: Orkney Gold Mine Geohydrological Investigation as input to the EMPR**

Project Number: **CAP-ORK-14-10-30**

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Date: **March 2015**

Location: **Orkney, North-West**

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- Recommendations represented in this technical report apply to the site conditions and features as they existed at the time of Shangoni's investigations, and those reasonably foreseeable. The recommendations do not necessarily apply to conditions and features that may arise after the date of this technical report, of which Shangoni had no prior knowledge nor had the opportunity to evaluate.

EXECUTIVE SUMMARY

Shangoni AquiScience, a division of Shangoni Management Services Pty Ltd, was appointed by China African Precious Metals: Orkney Gold Mine to review the potential hydrogeological impacts associated with the operation of CAPM 6 & 7 Shaft in the town of Orkney. The aim of the report was to document the findings of a groundwater survey in terms of i) baseline geohydrological conditions; ii) probable groundwater related impacts; and iii) management plans and monitoring protocols. The report was written in such a way that it can be incorporated into the updated EMP document structure.

CAPM Orkney Mine is situated within the C24H and C24B quaternary catchments of the Olifants Water Management Area and in the South-eastern Highveld groundwater region of South Africa.

The study area is generally flat but undulating with the slimes dams and waste rock dumps forming the only significant topographical highs. The CAPM shafts are situated at approximately 1305 mamsl to 1335 mamsl). Shafts 6 and 7 are situated on the western slope of a water divide, most probably a dolerite dyke controlling the flow, with surface flow following the contours perpendicular towards the Skoonspruit on gradients ranging between 0.01 and 0.02. Flow from shafts 1, 2 and 3 will be mostly towards the Vaal River to the south on gradients ranging between 0.005 and 0.02. Shaft 4 is situated on the eastern slope of the water divide mentioned above and flow will mostly be directed towards the south-southeast.

Shaft 7 will be operated and extraction of ore will be from the Ventersdorp Contact Reef (VCR) and Elsburg Reef. The VCR, an auriferous, urnaniferous, pyritic, oligiomictic conglomerate, is unconformable with the underlying quartzites and it ranges in thickness from 40 cm to 400 cm. The VCR unconformity is recognised as being the last regional unconformity occurring within the Witwatersrand Basin and basically signifies the conclusion of the sedimentary processes within the basin. The approximately 2800 Ma old VCR is a unique Witwatersrand orebody, from which about 6% of the world's gold production is derived. A major portion of this production is mined at depths exceeding 2500 m and deepest levels of mining are at about 3600 m. The orebody's hangingwall consists of volcanic rocks. This differs from the older Witwatersrand orebodies, which have quartzitic hangingwalls. The thickness of the Ventersdorp Contact Reef is generally about 1.20 m, but is highly variable, at an average dip of about 18°.

The geohydrology of the overlying strata in the area is still governed by the *in-situ*, pre-mining geological constraints. Flow in the upper weathered aquifer follows the topography and drainage occurs towards the major river systems, the Vaal River towards the south and the Skoonspruit towards the west.

Two major aquifer systems (regional scale) are present within the study area. These systems are the i) lava aquifer of the Rietgat Formation and the ii) dolomitic (possibly karstic in places) aquifer of the Malmani Subgroup.

The groundwater occurrence in the Rietgat Formation is associated with zones of weathering, brecciation and jointing as well as lithological and dyke contact zones. The classification as a M*inor Aquifer* is based on the groundwater yield potential of 45% of boreholes on record producing more than 2 l/s. Groundwater rest levels occur between 10- and 30 mbs.

The Chuniespoort Group of rocks with approximate thickness of between 1 and 3 km is mostly composed of chemically derived carbonate sediments. These sediments alternate between chert-rich and chert-poor dolomite. The dolomites of the Chuniespoort Group represent the most important aquifer in South Africa. This is due to the generally high to very high storativity and often highly permeable characteristics of this rock type, caused by chemical weathering which resulted in karstification in some places. The continuity of the dolomitic aquifer is interrupted by geological structures in the form of vertical and sub-vertical intrusive dykes. These low permeability or impermeable rocks serve as barriers to the movement of groundwater through the dolomite, resulting in the formation of compartments. The groundwater yield potential is classed as excellent on the basis that 50% of the boreholes on record produce more than 5 l/s with a maximum of 126 l/s and is as a result classified as a *Major Aquifer*.

Recharge (% of MAP) of the Ventersdorp Supergroup varies between 3% and 5% with an average recharge of 4.1% according to the various methods used as in the RECHARGE software programme. Recharge of the Chuniespoort dolomites range between 5.3% and 8% with a harmonic mean of 7.1%. In general, recharge of the dolomite formations is relatively high due to highly transmissive soils and areas of karstification. Sinkholes can exert a significant influence on the rate of recharge in the dolomites to the subsurface since they provide preferential pathways along which water can rapidly infiltrate from surface to the underlying aquifer.

A hydrocensus of boreholes on and surrounding the various CAPM Orkney mines was conducted during January/February 2015. The survey located 55 privately owned and Anglo Gold Vaal River Operations monitoring boreholes. The majority of the boreholes are located within close proximity of Shaft 6 and Shaft 7 while some were surveyed scattered throughout the study area. The majority of boreholes function as monitoring boreholes while the remainder are privately owned mainly used for small scale irrigation/gardening purposes. A good Bayesian correlation of $r^2 = 0.93$ (n = 21) exists between the surface topography and the static hydraulic heads. Based thereupon an assumption can be made that groundwater flow paths mimic surface topography.

In general the groundwater quality from the hydrocensus boreholes indicate relatively good water quality with most samples recording within the SANS 241:2011 drinking water standards. The water is typical of unpolluted groundwater either being of a Ca-HCO_3^- type typical of dolomitic areas or groundwater with no dominating cations or anions.

Groundwater sampled downstream or in close proximity of slimes dams in the study area (not CAPM owned or operated) recorded *Poor* (*class 3*) to *Unacceptable* (*class 4*) water quality. Very high salinities (EC and TDS) were recorded (SO_4 as the largest contributor) with EC ranging between 382 mS/m and 612 mS/m and SO_4 between 1916 mg/l and 2720 mg/l. Elevated inorganic N and soluble Pb, Mn and Co were also recorded typical of seepage effects from tailings dams.

A simplified conceptual model was developed using a risk based approach, whereby impact source areas were identified, pathways characterised and potential receptors identified. Initially only shafts 6 and 7 will be operational and will require dewatering. Gold ore will be extracted from the Ventersdorp Contact Reef (VCR) and Elsburg Reefs.

CAPM Orkney Mine will not make use any mine residue deposits or containment dams as ore will not be processed by CAPM; the risk towards groundwater pollution is therefore minimal. However, water accumulating in gold mine shafts are known to contribute to acid mine/rock drainage (AMD). Pyrite, a mineral closely associated the VCR, is by far the greatest contributor to acid mine/rock drainage. It logically follows that there will be long term water contamination risks within the shaft when it is allowed to re-fill with water. This type of water will have a low pH and a high acidity and may contain toxic and radioactive heavy metals. Production of AMD within the shaft may continue for many years after mines are closed. Aquifers within the vicinity will only be affected when the water within the shaft rises towards pre-mining conditions and towards the environmental critical level (ECL). The rate at which, and up to which point the water will rise is highly complex and an unknown factor given the multitude of parameters involved and the fact that mines within in the KOSH region are hydrologically interconnected. However previous studies with the KOSH area indicate a likely probability of decant and rise to the ECL at 17-50 Ml/d when all pumping ceases. The quality of the decant water is expected to be contaminated but will improve over time as existing areas of exposed sulphide mineralisation are flooded or oxidised. Subsequent decant from 4 Shaft is probable and will require close and continuous monitoring.

It is anticipated that groundwater drawdown will constitute the greatest groundwater risk from an environmental perspective during the operational phase, the significance of which will depend on the extent of the cone of depression and the positions of privately owned boreholes. However, given the mining depth the drawdown, effect on receptors is anticipated to be small.

Steady and transient state numerical groundwater flow models were constructed to simulate current aquifer conditions and future drawdown impacts to provide a tool for evaluating different management options for the future. A three-dimensional (3-D) numerical groundwater flow model was developed using the modelling software Feflow (Finite Element Subsurface Flow) version 6.1.

The steady state flow patterns indicate that groundwater flow patterns follow the surface topography with recharge occurring at the higher elevations and discharging at lowest points, in this case being the

Skoonspruit and Vaal River drainage lines. A surface and groundwater divide, most probably a dolerite dyke trend north-south to the east of 7 Shaft.

Mine dewatering will have an impact on the groundwater volumes available in the aquifers surrounding the proposed 7 Shaft but the zone of influence will be limited in extent. As the dewatering initiates, the cone of depression will migrate and expand as the groundwater system attempts to retain a state of equilibrium. Although the aquifers are believed to be interconnected, the zone of influence will be limited in extent. The radius of influence indicates that the shaft dewatering will influence significantly on groundwater levels in close proximity to 6 & 7 Shaft but will not extend towards any receptors.

During the closure phases when all pumping within the region has ceased, the water in the shaft/s may rise towards the Environmentally Critical Level (ECL) where, if contaminated and affected by AMD reactions, may pollute aquifers or surface drainages. The rate at which, and up to which point the water will rise is highly complex and unknown given the multitude of parameters and dewatering schemes within the KOSH area. However previous studies in the KOSH area indicate a likely probability of decant and rise to pre-mining conditions and the ECL. However, at the CAPM 7 Shaft the groundwater table is not expected to return to pre - mining conditions. The reason being that decant will occur at 40 Level, creating a permanent dewatering cone towards 4 Shaft. The quality of the decant water is expected to be contaminated but will improve over time as existing areas of exposed sulphide mineralisation are flooded or oxidised. The gold mines are generally grouped together very tightly, resulting in hydrological interconnections between adjacent mines. This makes it difficult, if not impossible, to consider the water-related closure risks in isolation.

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DEFINITIONS

Acid rock drainage/ Acid mine drainage

Acid rock drainage (ARD), also known as acid mine drainage (AMD), is the generation of sulphate and acidity as a result of the oxidation of pyrite when exposed to water and oxygen, producing sulphuric acid (H_2SO_4). ARD is a major cause of the contamination of groundwater in areas where coal and gold mining takes place.

Aquifer vulnerability

The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Sedimentary rocks composed of or derived from sand or sand-like particles.

Baseflow

Stormflow and baseflow are non-process related terms to signify high amplitude low frequency flow in a river during and immediately after a precipitation event and low amplitude high frequency flow in a river during dry or fair weather periods. Baseflow is not a measure of the volume of groundwater discharged into a river or wetland, but it is recognised that groundwater makes a contribution to the baseflow component of river flow. The term groundwater contribution to baseflow should be used.

Boundary Condition: Hydraulic Head/ Dirichlet/ 1st Kind

The Dirichlet boundary condition is the first type of boundary condition that defines the values on the border of the problem domain. A hydraulic-head boundary condition applies a pre-defined hydraulic head to a node. Instead of calculating hydraulic head as a simulation result, at these nodes the head is given by the boundary condition value. This can lead to an inflow into the model when neighbouring nodes have a lower potential, or to an outflow from the model when there is a gradient from the neighbouring nodes towards the boundary condition. Head boundary conditions are applied in cases where the hydraulic potential is known in advance. This can be the case for example for surface water bodies with a perfect connection to groundwater (surface water level equals groundwater level), for pump sumps where a constant level is kept for dewatering purposes, or for seepage faces (in combination with a constraint condition).

Boundary Condition: Cauchy/ Fluid Transfer

A transfer boundary condition applies a pre-defined reference head combined with a conductance parameter (transfer rate). Transfer boundary conditions are applied in cases where a reference potential is linked to the aquifer via a separating medium. This can be the case for example for rivers or lakes with a limited connection to groundwater (surface water level equals groundwater level) or for partly clogged drains.

Boundary Condition: Fluid Flow

By default, all model boundaries in FEFLOW are assumed to be impermeable, i.e., no water can flow into the model or out of the model. At boundaries where this is not true, boundary conditions have to be set specifically. Boundary conditions can be placed both at outer model borders and inside the model.

Boundary Condition: Neumann Type/ Fluid-Flux

A flux boundary condition applies a pre-defined flux (Darcy flux) to nodes along a line (2D model) or to nodes enclosing faces of elements (3D). For the calculation of hydraulic head as a simulation result, at these nodes an additional inflow/outflow is considered. Flux boundary conditions are applied in cases where the gradient or inflow/outflow velocity is known in advance. This can be the case for example for inflows into the aquifer in a valley from steep slopes or for the connection to a neighbouring aquifer where the flux can be assumed as constant.

Darcy Flux

The Darcy flux (or velocity) is the hydraulic conductivity (K) times the gradient of the water/piezometric level (i.e. q=Ki). Velocity an indication of the rate at which groundwater and groundwater contamination are moving.

FeFlow

FEFLOW is a professional software package for modelling fluid flow and transport of dissolved constituents and/or heat transport processes in the subsurface. FEFLOW is developed by DHI-WASY GmbH, the German branch of the DHI Group. DHI-WASY's areas of expertise encompass groundwater hydrology, surface water hydrology and geographic information systems. In these fields, DHI-WASY provides software, training and consulting services.

Hydraulic conductivity

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

Hydraulic head

Hydraulic head is the height above a datum plane such as sea level of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system. Hydraulic heads provide an indication of the direction of groundwater flow and are used to determine hydraulic gradients.

Kriging interpolation

Kriging is a method of interpolation named after a South African mining engineer named D. G. Krige who developed the technique in an attempt to more accurately predict ore reserves. Over the past several decades kriging has become a fundamental tool in the field of geostatistics.

Piezometric head

An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.

Seepage velocity

The seepage velocity is defined as the Darcy flux divided by the effective porosity. This is also referred to as the average linear velocity.

Stiff diagram

A Stiff diagram is an elongate polygon, the precise shape of which is determined by "joining the dots" corresponding to the milli-equivalents per litre (meq/l) concentrations of each major ion on a template.

Storativity

It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. It measures the volume of water stored and released in an aquifer and is used to quantify the safe yield of an aquifer system.

Transmissivity

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity (K) and thickness (b) of the saturated portion of an aquifer ($T = Kb$).

Zone of influence / cone of depression

The cone-shaped area around a borehole that results from the lowering of the water table or piezometric surface by abstraction.

ABBREVIATIONS

a – Annum
A_r – Aquifer media rating
ARD – Acid rock drainage
A_w – Aquifer media weight
ca – Approximately
CAPM – China Africa Precious Metals
C_r – Hydraulic conductivity rating
C_w – Hydraulic conductivity weight
Cl_P – Chloride concentration in precipitation
Cl_{GW} – Chloride concentration in groundwater
CMB – Chloride mass balance method
D_r – Depth to water table rating
D_w – Depth to water table weight
D_oH – Department of Health
DTM – Digital terrain model
DWA – Department of Water Affairs
DWAF – Department of Water Affairs and Forestry
EC – Electrical conductivity
EMP – Environmental Management Programme
EMPR – Environmental Management Programme Report
FeFlow – Finite Element Subsurface Flow & Transport Simulation System
Ga –Billion years
GRDM – Groundwater Resource Directed Measures
HH – Hydraulic head
I_r – Impact of vadose zone rating
I_w – Impact of vadose zone weight
l/s – Litres per second
K_{xy} – Horizontal hydraulic conductivity (m/d)
K_z – Vertical hydraulic conductivity (m/d)
LOM – Life of Mine
mamsl – Meters above mean sea level
MAP – Mean annual precipitation
Ma – Million years
mbcl – Meters below collar level

mbgl – Meters below ground level
mbwl – Meters below (initial) water level
mbs – Meters below surface
meq/l – Milli-equivalent per litre
mg/l – Milligrams per litre
mm/a – Milli-litres per annum
mmol/l –milli-molar per litre
NGA – National Groundwater Archive
NWA – National Water Act
REV – Representative Elemental Volume
RMSE – Root mean square error
ROI – Radius of influence
R_r – Recharge rating
R_w – Recharge weight
S_r – Soil type rating
S_w – Soil type weight
SaClLm –Sandy-clay-loam
T –Transmissivity (m^2/d)
T_r – Topography aspect rating
T_w – Topography aspect weight
USGS –United States Geological Survey
VCR –Ventersdorp Contact Reef
Z_m – Topography in meters
3-D –Three dimensional

1. INTRODUCTION

Shangoni AquiScience, a division of Shangoni Management Services Pty Ltd, was appointed by China African Precious Metals: Orkney Gold Mine to review the potential hydrogeological impacts associated with the operation CAPM 6 & 7 Shaft in the town of Orkney. This report provides methodology, findings and recommendations based on the specialist geohydrological study which will subsequently be combined with the other relevant environmental impact assessments in the updated Environmental Management Programme (EMP). Shangoni Management Services (Pty) Ltd. was commissioned by China African Precious Metals (Pty) Ltd. (CAPM) to update the Environmental Management Programme (EMP) of Orkney Gold Mine. The draft EMP (dated October 2013) was updated as part of a Section 11 sale in terms of the Minerals and Petroleum Resources Development Act No. 28 of 2002 (MPRDA). The EMP update was done to change the name of the owner of the EMP and to compile the EMP according to the new Department of Mineral Resources (DMR) EMP template.

The aim of the geohydrological report is to document the findings of a groundwater survey in terms of i) baseline geohydrological conditions; ii) probable groundwater related impacts; and iii) management plans and monitoring protocols. The report was written in such a way that it can be incorporated into the final EMP document structure. The main focus areas required to assess the geohydrological conditions include:

- Description of geohydrological conditions.
- Prediction of the geohydrological impact resulting from the proposed mining activities. This includes the description of possible negative groundwater related impacts during operation.
- Design of a groundwater management framework and monitoring programme to pro-actively manage current and foreseeable impacts.
- Recommendations in terms of regional closure strategy was focussed on, which due to the complexity involved, was outside the scope of this investigation.

2. TERMS OF REFERENCE AND SCOPE OF WORK

2.1 Objectives of the Investigation

This report provides methodology and findings of the geohydrological baseline study that will be used as reference for the groundwater impact assessment and management plan for the proposed mining operation.

The objectives of this project are to:

1. Provide specialist geohydrological inputs to the EMP process.
2. Identify potential geohydrological impacts and make recommendations on management or mitigation measures.

2.2 Scope

In order to reach the stated objectives, the following actions were conducted as part of this investigation:

Phase 1 – Field work

An initial hydrocensus was carried out within the study area. The census included surveying and identifying all surface and groundwater (boreholes and springs) related features. This was done to i) identify possible interested and affected parties (IAPs) that may be affected by the mining operations; ii) to gather baseline information (borehole water levels and groundwater quality) prior to initiation of the mining activities; and to iii) gather information such as groundwater levels for use in the numerical groundwater impact model.

Phase 2 - Reporting

- Combine and interpret available topographical, hydrogeological and related information.
- Baseline description of the geohydrology in vicinity of the study area.
- Calculate groundwater flow velocities to be used in the numerical and conceptual models.
- Classify the status of the aquifer/s and estimate the vulnerability of aquifer/s to pollution (DRASTIC).
- Estimate groundwater recharge for the area using available information.
- Determine the area of influence during operational phases with aid from numerical flow models.
- Identify impacts and rate them in a risk assessment.
- Identify gaps in the current monitoring network and recommend a suitable monitoring programme with focus on the operational areas and IAPs.

3. BACKGROUND INFORMATION

3.1 Background and location

In March 1998, the Anglo American, Vaal Reefs No.'s 1 to 7 Shafts changed over to ARMgold 1 (which comprised No.'s 1, 2 and 5 Shafts) and ARMgold 2 (which comprised, No.'s 3, 4, 6, & 7 Shafts). During October 2003, ARMgold merged with Harmony Gold and the shaft names changed to Harmony Orkney Operations – No. 1 to 7 Shafts. During March 2008, Pamodzi gold bought over the operations from Harmony Gold. Aurora Empowerment Systems took over management of the Orkney Operations from Pamodzi late in 2009. Pamodzi was provisionally liquidated in March 2009 and a final liquidation order was granted against Pamodzi on the 6th of October 2009. The Orkney Operations have remained dormant until recently, when Pamodzi entered into a sale agreement with CAPM (on 1 August 2011), in terms of which CAPM agreed to acquire all the assets of Orkney Gold Mine. CAPM is currently in the process of rehabilitating the shafts and is commencing with opening-up procedures.

Orkney Gold Mine is located in the Matlosana local municipality that falls under the Dr Kenneth Kaunda district municipality in the North West Province. The mine consists of 7 shafts (Figure 1), of which none are currently operational. From discussions, it became evident that the mine plans to commence with the dewatering of 6 & 7 Shaft at the end of December 2013, where after mining will commence. Shaft 3 and Shaft 5 will be decommissioned with no future mining activities envisaged. It was indicated that, although no commencement dates are known, mining of Shaft 1, Shaft 2 and Shaft 4 are planned in the due future. The mining area is bound to the east and north by the Buffelsfontein Gold Mine owned by Village Main Reef and to the west and south by the Tau Lekoa Mine, Kopanang and Great Noligwa of AngloGold Ashanti Limited ("AngloGold").

4. METHODOLOGY

4.1 Geohydrological desktop study

The desktop study entailed a collection of all existing relevant data and mining plans from the client and published data in the public domain. Aerial photos and geological maps were studied to identify possible structural features. This data was used to get familiarised with the site conditions and project objectives. The following information was sourced as part of the desktop study:

- Topographical map: sheet 22626DC Klerksdorp and 2626DD Stilfontein at a scale of 1: 50 000.
- Geological map: sheet 2626 West Rand at a scale of 1: 250 000.
- Digital Terrain Model (DTM).
- Hydrogeological map: sheet 2526 Johannesburg at a scale of 1: 500 000.
- Mean monthly rainfall data from the South African Rain Atlas, Index No. 292/288999.
- Quaternary catchment water management attributes (GRDM).

4.2 Hydrocensus and groundwater quality

A hydrocensus was performed around the shaft areas to identify groundwater users and the groundwater potential. During the survey, all available details of boreholes and borehole-owners were collected and recorded. Where possible, information was collected on water use, water levels and yields of boreholes, etc. This information was used to assess the potential risk posed by the mining activities on the groundwater regime and users thereof. The data collected was also used in the numerical flow model calibration. The following parameters were captured during the hydrocensus (where possible):

- XYZ Coordinates
- Existing equipment
- Current use
- Yield
- Static/dynamic water level
- Water quality

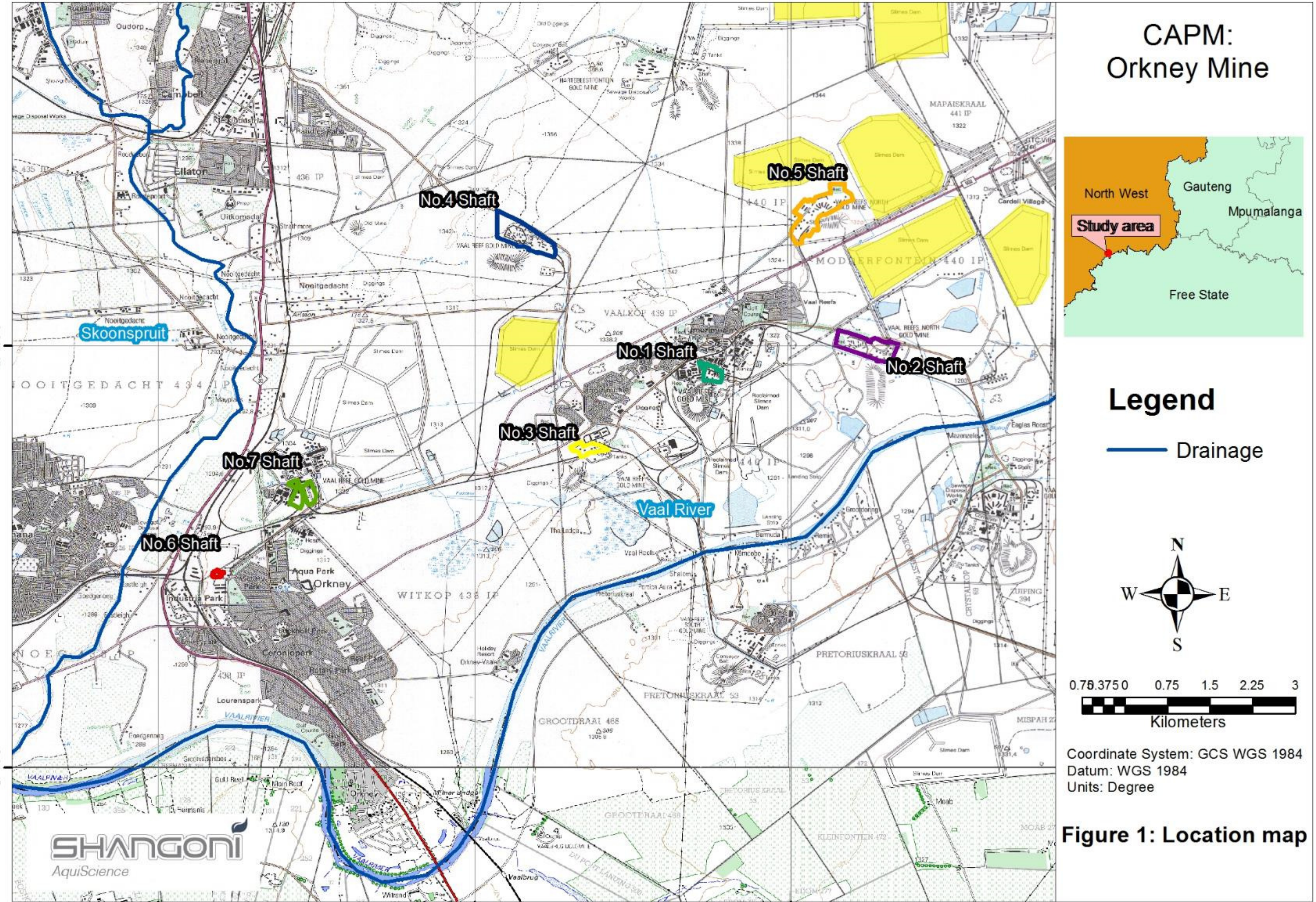


Figure 1: Location map

Water quality was interpreted based on the colour coded domestic classification system as summarised in Table 1 (WRC, 1998), including interpretation based on the South African National Standard for drinking water (SANS 241: 2011) as displayed in Table 2.

Table 1: Colour coded classification system (WRC, 1998)

Classification	Risk
Class 0	Ideal drinking water suitable for lifetime use
Class 01	Good drinking water suitable for lifetime use
Class 02	Marginal drinking water which may be used without health effects by the majority of individuals in all age groups but may cause some effects in sensitive individuals.
Class 03	Poor drinking water which poses a risk of chronic health effects, especially in babies, children and the elderly.
Class 04	Unacceptable water quality posing severe acute health effects even with short term use.

Table 2: SANS 241: 2011 physical aesthetic, operational and chemical parameters

Parameter	Risk	Unit	Standard limits [a]
Physical and aesthetic determinands			
Electrical conductivity	Aesthetic	mS/m	≤170
Total dissolved solids	Aesthetic	mg/l	≤1200
Turbidity [b]	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH [c]	Operational	pH units	≥5 to ≤9.7
Chemical determinands – macro			
Nitrate as N [d]	Acute health	mg/l	≤11
Sulphate as SO_4^{-2}	Acute health	mg/l	≤500
	Aesthetic	mg/l	≤250
Fluoride as F	Chronic health	mg/l	≤1.5
Ammonia as N	Aesthetic	mg/l	≤1.5
Chloride as Cl^-	Aesthetic	mg/l	≤300
Sodium as Na	Aesthetic	mg/l	≤200
Zinc as Zn	Aesthetic	mg/l	≤5
Chemical determinands – micro			
Antimony as Sb	Chronic health	mg/l	≤0.020
Arsenic as As	Chronic health	mg/l	≤0.010
Cadmium as Cd	Chronic health	mg/l	≤0.003
Total chromium as Cr	Chronic health	mg/l	≤0.050
Copper as Cu	Chronic health	mg/l	≤2.0

Iron as Fe	Chronic health	mg/l	≤2.0
	Aesthetic	mg/l	≤0.30
Lead as Pb	Chronic health	mg/l	≤0.010
Manganese as Mn	Chronic health	mg/l	≤0.50
	Aesthetic	mg/l	≤0.10
Mercury as Hg	Chronic health	mg/l	≤0.006
Nickel as Ni	Chronic health	mg/l	≤0.07
Selenium as Se	Chronic health	mg/l	≤0.010
Uranium as U	Chronic health	mg/l	≤0.015
Vanadium as V	Chronic health	mg/l	≤0.2
Aluminium as Al	Operational	mg/l	≤0.3

[a] The health-related standards are based on the consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years.

[b] Values in excess of those given in column 4 may negatively impact disinfection.

[c] Low pH values can result in structural problems in the distribution system.

[d] This is equivalent to nitrate at 50 mg/l NO_3^-.

4.3 Hydrochemistry

Knowledge of processes that control natural water composition is required for rational management of water quality. Hydrogeochemistry seeks to determine the origin of the chemical composition of groundwater and the relationship between water and rock chemistry, particularly as they relate to water movement. A basic tool in hydrochemical studies used to summarize and present water quality data is graphical interpretation. A considerable number of methods and procedures exist but the most widely used are diagrams known as **Stiff** and **Piper** diagrams.

A **Stiff** diagram is an elongate polygon, the precise shape of which is determined by "joining the dots", corresponding to the milli-equivalents per litre (meq/l) concentrations of each major ion on a template. This conversion is applicable to charged species only, i.e. ions, as it is essentially a measure of the number of "moles of charge" available for participation in a range of electrochemical reactions. Conversion to meq/l is achieved by multiplying the mmol/l concentrations (mmol/l = mg/l divide by relative atomic mass) by the valence (i.e. the charge) of the ion. For instance, if we convert directly from mg/l, the concentration is multiplied by the valence and divided by the molecular atomic mass. Fortunately most major cations and anions do not vary in valence so that constant conversion factors can be established for many dissolved species.

To plot an analysis on a **Piper** diagram, the cations and anions are first plotted separately in the triangles at bottom left and right respectively, and then lines are drawn upwards from the plotting positions within both triangles parallel to the outer edges of the upper diamond (Figure 2). Evolution of groundwater and facies can as a result be established.

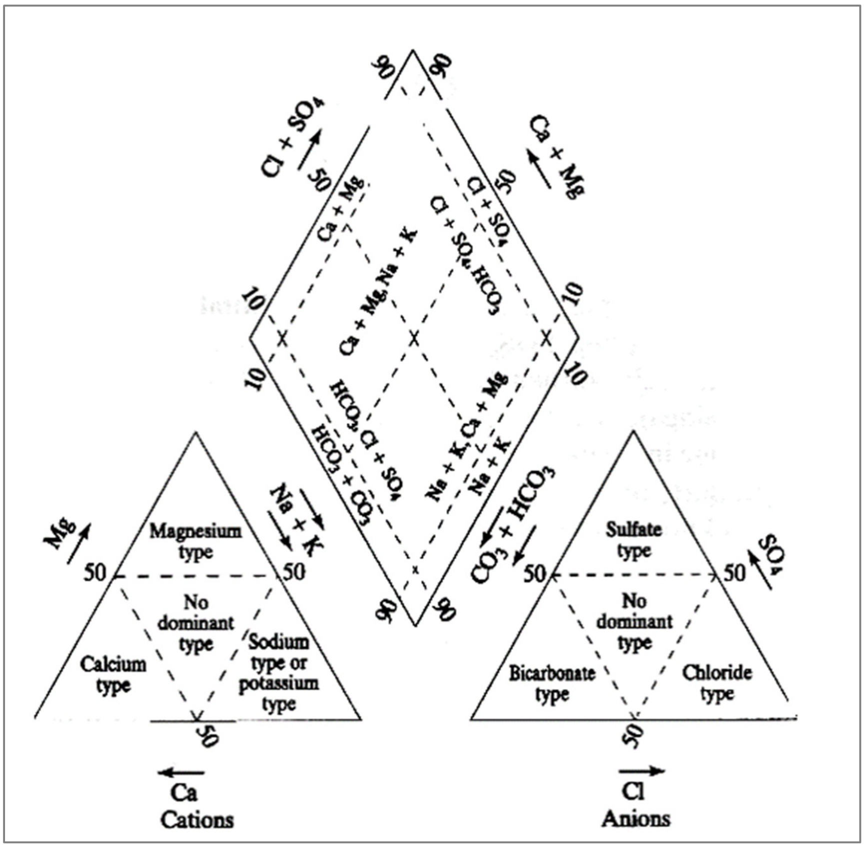


Figure 2: Classification of hydrochemical facies using the Piper plot

4.4 Groundwater recharge estimation

Groundwater recharge was estimated using the *RECHARGE* software program (van Tonder and Xu, 2000). The following methods/sources were used to estimate recharge:

i. Geology
ii. Groundwater Recharge Map (Vegter)
iii. Acru Recharge Map (Schulze)
iv. Cl method
v. Literature

4.5 Aquifer classification

The aquifer classification system used to classify South African aquifers is the National Aquifer Classification System developed by Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification. Parsons suggested that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues.

The South African Aquifer System Management Classification is presented by five major classes listed below and defined in Table 3:

- Sole Source Aquifer System
- Major Aquifer System
- Minor Aquifer System
- Non-Aquifer System
- Special Aquifer System

Table 3: Aquifer classification scheme (Parsons, 1995)

Aquifer system	Defined by Parsons (1995)	Defined by DWA minimum requirements (DWAF, 1998)
Sole source aquifer	An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there are no reasonable alternative sources should the aquifer become depleted or impacted upon. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major aquifer	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.	High yielding aquifer (5-20 l/s) of acceptable water quality.
Minor aquifer	These can be fractured or potentially fractured rocks that do not have a high primary hydraulic conductivity, or other formations of variable hydraulic conductivity. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are both important for local supplies and in supplying base flow for rivers.	Moderately yielding aquifer (1-5 l/s) of acceptable quality or high yielding aquifer (5-20 l/s) of poor quality water.
Non-aquifer	These are formations with negligible hydraulic conductivity that are generally 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 does occur, although imperceptible, and needs to be considered when assessing risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 l/s) of good quality water or moderately yielding aquifer (1-5 l/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	

4.6 Aquifer vulnerability

Groundwater plays an important role in supplying water to many regions of Southern Africa due to its low annual average precipitation of 460 mm, which is well below the world average of 860 mm. The quality of groundwater resources in South Africa has therefore received considerable focus and attention on the need for a proactive approach to protect these sources from contamination (Lynch *et. al.*, 1994). Groundwater protection needs to be prioritised based upon the susceptibility of an aquifer towards pollution. This can be done in two ways, namely i) pollution risk assessments and ii) aquifer vulnerability. Pollution risk assessments consider the characteristics of a specific pollutant, including source and loading while aquifer vulnerability considers the characteristics of the aquifer itself or parts of the aquifer in terms of its sensitivity to being adversely affected by a contaminant should it be released.

The DRASTIC model concept developed for the USA (Aller *et. al.*, 1987) is well suited for producing a groundwater vulnerability evaluation for South African aquifers. The DRASTIC evaluates the intrinsic vulnerability (*IV*) of an aquifer by considering factors such as **D**epth to water table, natural **R**echarge rates, **A**quifer media, **S**oil media, **T**opographic aspect, **I**mpact of vadose zone media, and hydraulic **C**onductivity. Different ratings are assigned to each factor and then summed together with respective constant weights to obtain a numerical value to quantify the vulnerability:

$$\text{DRASTIC Index } (IV) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

Where *D*, *R*, *A*, *S*, *T*, *I*, and *C* are the parameters, *r* is the rating value, and *w* the constant weight assigned to each parameter (Lynch *et al*, 1994). The scores associated with the vulnerability of South African aquifers are shown in Table 4.

Table 4: South African National Groundwater Vulnerability Index to Pollution (Lynch *et al*, 1994)

Score	Vulnerability
50-87	Least susceptible
87 - 109	Moderate susceptible
109 - 226	Most susceptible

The concept of DRASTIC in vulnerability assessments is based on:

- A contaminant is introduced at the surface of the earth or just below it.
- A contaminant is flushed into the groundwater by precipitation.
- A contaminant has the mobility of water.
- The area evaluated is 0.4 km^2 or larger.

The weighting for each parameter is constant. The minimum value for the DRASTIC index that one can calculate (assuming all seven factors were used in the calculation) is therefore 24 with the maximum value being 226. The higher the DRASTIC index the greater the vulnerability and possibility of the aquifer to become polluted if a pollutant is introduced at the surface or just below it.

4.7 Formulation of conceptual model

The first step in any modelling exercise is the development of a conceptual model. This is an idealisation of the real world that summarises the current understanding of site conditions and how the groundwater flow system works. It includes all of the important features of the flow system, while incorporating simplifying assumptions.

4.8 Numerical groundwater model

Numerical groundwater flow models were constructed to simulate current aquifer conditions and impacts and to provide an evaluation tool for different future management options. The three dimensional (3-D) modelling package *FeFlow® 6.1* (Finite Element Subsurface Flow & Transport Simulation System) was used for the simulation. The model was run in steady state conditions until representative hydraulic conductivity and recharge distributions were obtained with simulated hydraulic head distributions closely mimicking the measured levels.

Subsequently to the model being run, the steady state solution was used to construct a transient groundwater flow model. Calibration of the flow model was largely aided by recharge inferred and water level information gathered during the hydrocensus.

A numerical groundwater model is a representation of the real system. It should be viewed as an approximation of which the accuracy depends on the data quality and confidence assigned to the model. There will thus always be errors associated with a numerical model due to uncertainties in the real world situation and incapability of the model to describe all physical variables. Numerical models nevertheless are and remain the best evaluation and decision making tool available to quantify groundwater and mass balances and to determine the behaviour of the system on a macro-scale.

4.9 Environmental Impact Assessment

An impact rating process is designed to provide a numerical rating of the various environmental impacts identified for the various project activities. The significance or quantification of the risk process follows the established impact/risk assessment facets:

Probability = Likelihood of an impact occurring	**Magnitude** = Duration + Extent + Environment/3

The weight assigned to the various parameters for positive and negative impacts is presented in Table 5. The significance or severity of the impact is then determined and categorised into one of four categories, listed in Table 6 and described in Table 7.

Table 5: Impact rating

Rating	Probability	Duration	Extent	Environment
1	Rare	Lasting days to a month	Effect limited to the site. (metres)	Limited damage to minimal area of low significance, (e.g. ad hoc spills within plant area). Will have no impact on the environment.
2	Unlikely	Lasting 1 month to 1 year	Effect limited to the activity and its immediate surroundings. (tens of metres)	Minor effects on biological or physical environment. Environmental damage can be rehabilitated internally with / without help of external consultants.
3	Possible	Lasting 1 – 5 years	Impacts on extended area beyond site boundary (hundreds of metres)	Moderate, short-term effects but not affecting ecosystem functioning. Rehabilitation requires intervention of external specialists and can be done in less than a month.
4	Likely	Lasting 5 years to Life of Organisation	Impact on local scale / adjacent sites (km's)	Serious medium term environmental effects. Environmental damage can be reversed in less than a year
5	Almost certain	Beyond life of Organization / Permanent impacts	Extends widely (nationally or globally)	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate

Table 6: Severity of the impact

Environmental Impact Rating					
Probability	**Magnitude**				
	1 Minor	**2 Low**	**3 Medium**	**4 High**	**5 Major**
5 Almost Certain	Medium (11)	High (16)	High (20)	Very High (23)	Very High (25)
4 Likely	Low (7)	Medium (12)	High (17)	Very High (21)	Very High (24)
3 Possible	Low (4)	Medium (8)	High (13)	High (18)	Very High (22)
2 Unlikely	Low (2)	Low (5)	Medium (9)	High (14)	High (19)
1 Rare	Low (1)	Low (3)	Medium (6)	Medium (10)	High (15)

Table 7: Description of the impact or severity rating

Score	**Description**	**Rating**
1 - 7	An acceptable impact for which mitigation is desirable but not essential. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in either positive or negative short term effects on the social and/or natural environment.	Low / Negligible
8 - 12	An important impact which requires mitigation. The impact is insufficiently itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in either a positive or negative medium to long term effect on the social and/or natural environment.	Medium / Minor
13 - 18	A serious impact, if not mitigated, may prevent the implementation of the project (if it is a negative impact). These impacts would be considered by society as constituting a major and usually long-term change to the (natural and/or social) environment and result in severe effects or beneficial effects.	High / Moderate
19 - 25	A serious impact, which if negative, may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are immitigable and usually result in very severe effects or very beneficial effects.	High / Major

5. DESKTOP STUDY

5.1 Quaternary catchment and location

CAPM Orkney Mine is situated within the C24H and C24B quaternary catchments (Figure 3) of the Olifants Water Management Area and in the south-eastern Highveld groundwater region of South Africa. The shaft earmarked for operation is 7 Shaft which is situated within the C24H catchment. Relevant information pertaining to water management for both the C24H and C24B quaternary catchments can be viewed in Table 8 (GRDM).

Table 8: Quaternary catchment information (GRDM)

Attribute	C24H	C24B
Area	839.7 km^2	592.6 km^2
Mean annual rainfall	~600 mm/a	~600 mm/a
Mean annual runoff	7 mm/a	32 mm/a
Baseflow	0 mm/a	3 mm/a
Population	~300 000 Count	~30 000 Count
Mean annual evaporation	1700 - 1800 mm/a	1700 - 1800 mm/a
Total groundwater use	1.4 Mm^3/a	5.12 Mm^3/a
Present Eco Status Category	C Category	C Category
Recharge	~30 mm/a	~30 mm/a
	~5%	~5%
Exploitation potential	7 Mm^3/a	5 Mm^3/a
Vegetation type	Dry sandy Highveld Grassland	Rocky Highveld Grasses
Ecoregion	Highveld	Highveld
Groundwater General Authorization	45 $m^3/ha/a$	75 $m^3/ha/a$
Groundwater regions	Western & Central Highveld	Central Highveld & North-eastern Pan Belt

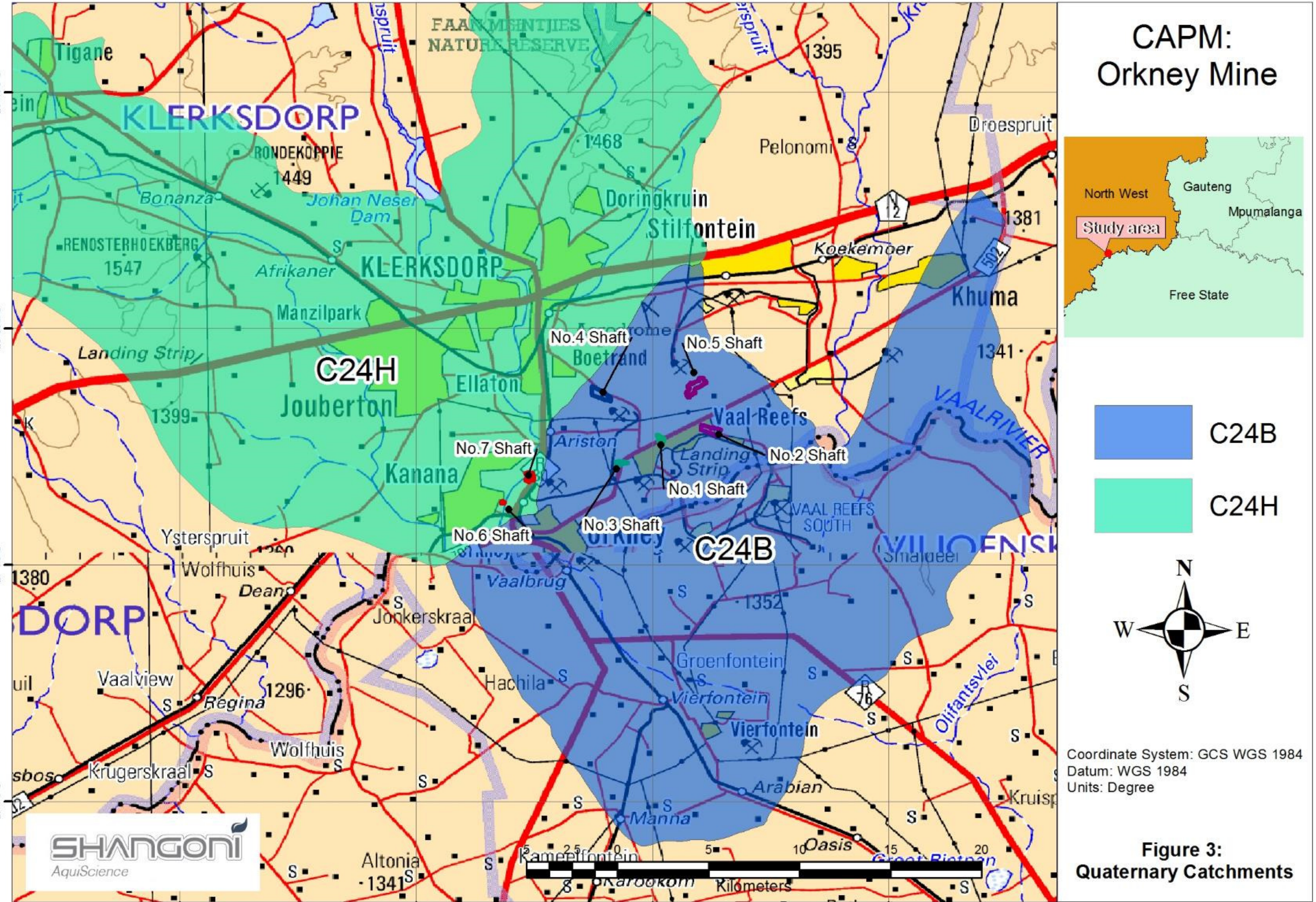


Figure 3: Quaternary Catchments

The total groundwater usage is significantly greater in the C24B catchment compared to the C24H which is estimated to be 5.12 Mm^3/a and 1.4 Mm^3/a, respectively (Table 9). This is attributed to the extensive mining activities in the C24B catchment.

Table 9: Total groundwater use in the C24H and C24B quaternary catchment (GRDM)

Type of use	Volume (Mm^3/a)	Volume (Mm^3/a)
	C24H	C24B
Total use	1.4	5.1207
Rural use	0.003	0
Municipal use	0.3294	0
Irrigational use	0.628	0
Livestock use	0.1789	0.2217
Mining use	0.1875	4.843
Industry use	0.072	0.056
Aquatic ecosystem use	0	0

5.2 Climate, drainage and topography

The regional climate is the typical Highveld climate with moderately wet, warm summers and cold dry winters. Rainfall is almost exclusively due to showers and thunderstorms and occurs mainly in the summer from October to April with maximum falls recorded during January (Figure 4). The average annual rainfall is in the region of 600 mm/a.

CAPM Orkney Mine is situated within the Middle Vaal Water Management Area and Vaal River catchment. The Vaal River drains west towards the south-southwest of the shaft areas with Shaft 2 being the closest (approximately 1.4 km). The Skoonspruit with origin being the John Neserdam 16 km north, drains south towards the Vaal River where it confluence 5.4 km south-west from Shaft 6. Shaft 6 and 7 are situated within this mini-catchment of the Skoonspruit.

The study area is generally flat but undulating with the slimes dams and waste rock dumps forming the significant topographical high points. The CAPM shafts are situated at approximately 1305 mamsl (shaft 6) to 1335 mamsl (shaft 5). Shafts 6 and 7 are situated on the western slope of a water divide, most probably a dolerite dyke or faulting zone controlling the flow, with surface flow following the contours perpendicular towards the Skoonspruit on gradients ranging between 0.01 and 0.02. Flow from shafts 1, 2 and 3 will be mostly towards the Vaal River to the south on gradients ranging between 0.005 and 0.02. Shaft 4 is situated on the eastern slope of the water divide mentioned above and flow will mostly be directed towards the south-southeast.

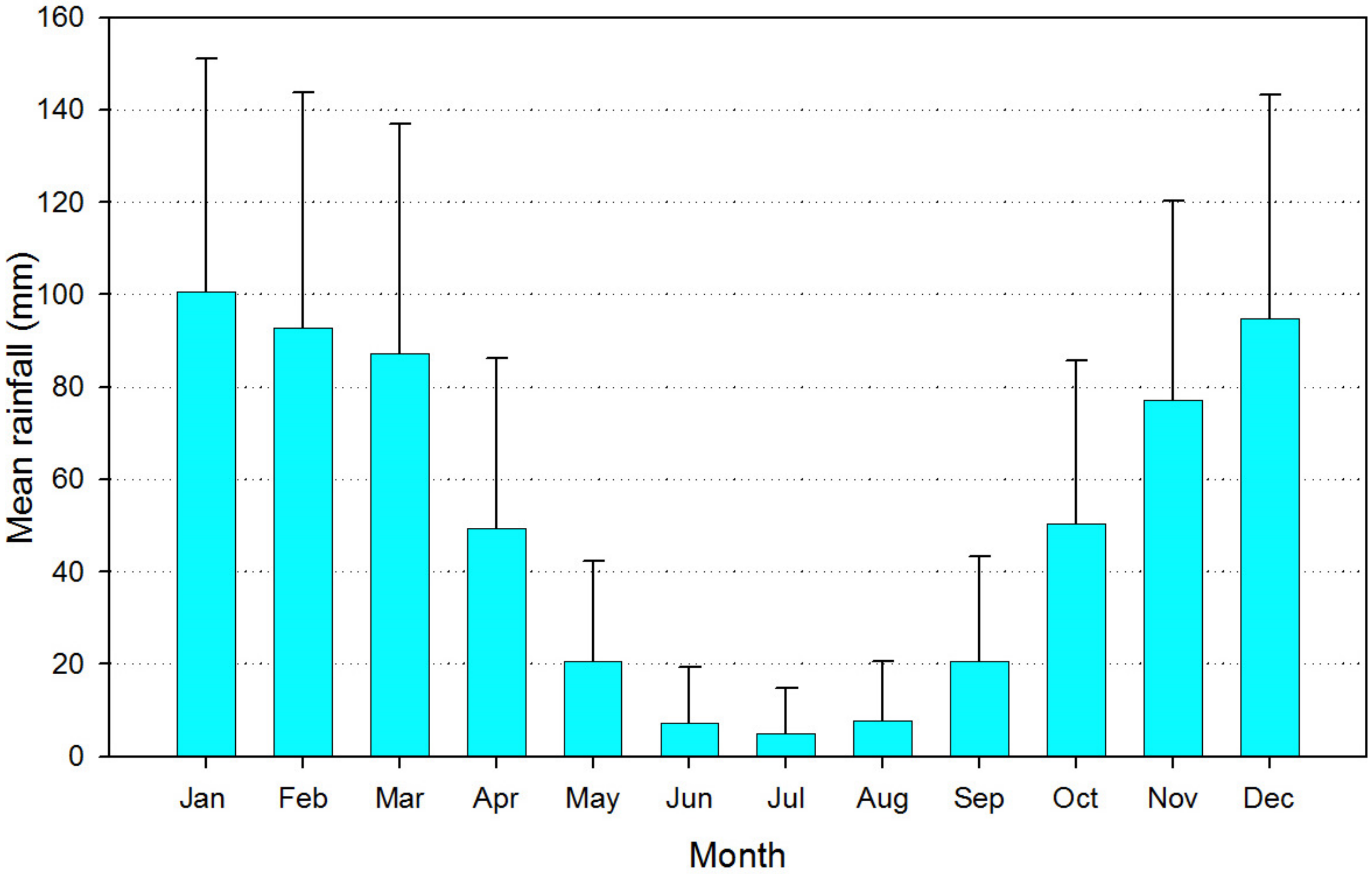


Figure 4: Monthly rainfall (South African Rain Atlas, Index No. 172/170303)

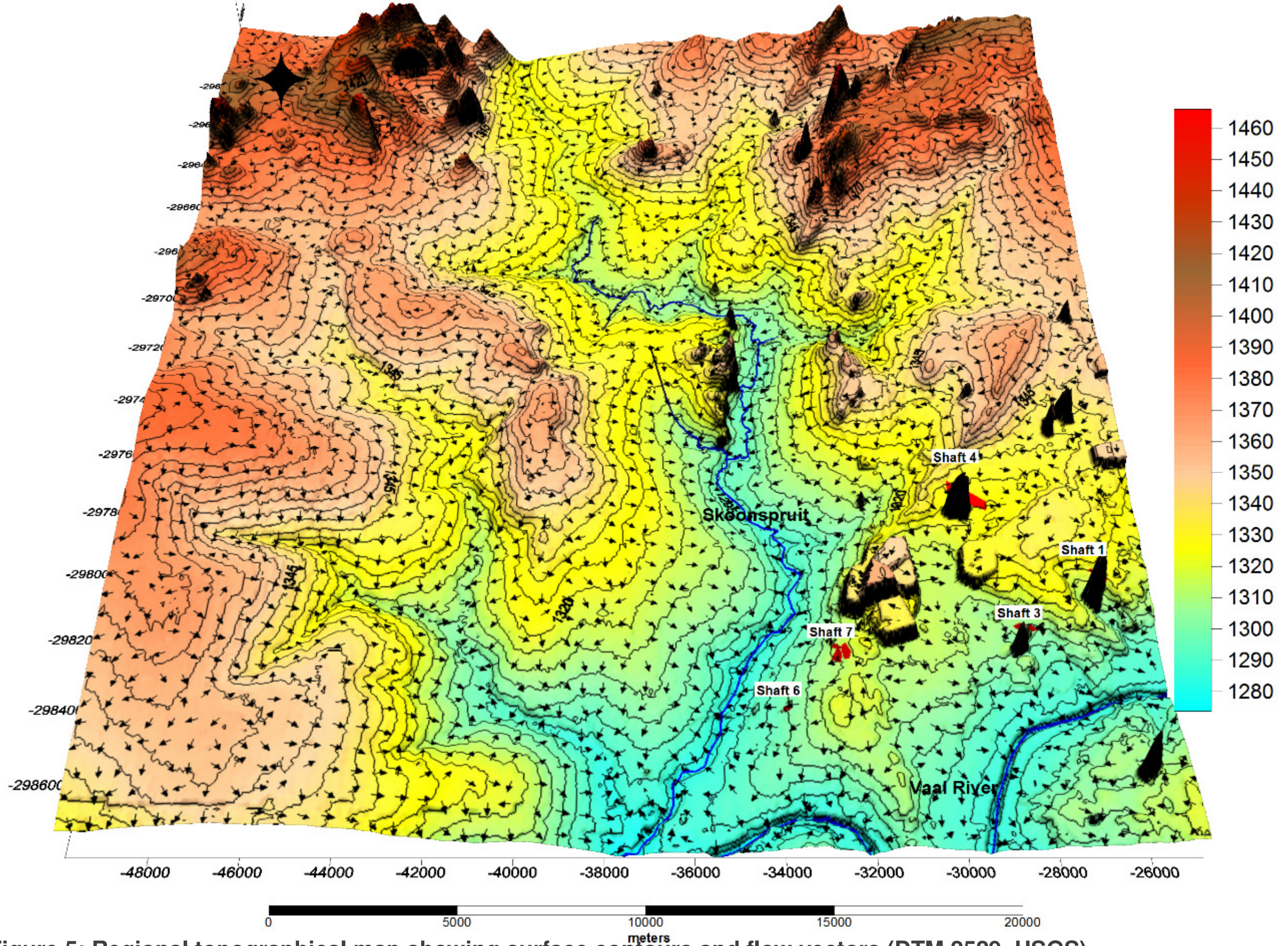


Figure 5: Regional topographical map showing surface contours and flow vectors (DTM 2529, USGS)

5.3 Geology

5.3.1 Geological setting

The Mesoarchaean Witwatersrand Basin, one of the world's premier gold regions and the greatest known source of gold on Earth, was deposited between ca. 2985 and 2849 Ma on the Kaapvaal Craton (ca. 3.6–3.2 Ga). The Witwatersrand Supergroup overlies the Dominion Group (ca. 3074±6 Ma), and is made up of coarse clastic rocks and bimodal volcanic rocks. The Witwatersrand Supergroup consists of the West Rand and Central Rand groups. The West Rand Group unconformably overlies the Dominion Group with clastic and largely marine sedimentary rocks. This sequence was deposited in a tectonically stable environment of the volcano-sedimentary succession of the Dominion Group. Unconformably overlying the West Rand Group are sandstone, conglomerate and shale units of the Central Rand Group. The upper part of the Central Rand Group is unconformably overlain by the Ventersdorp Contact Reef (VCR) of the Venterspost Formation and the Elsburg Reefs, which has the maximum age of 2729±19 Ma.

Unconformably overlying the VCR is the Neoarchaean Ventersdorp Supergroup (ca. 2.72–2.63 Ga), which comprises ultramafic and mafic metavolcanic rocks of the Klipriviersberg Group, and metasedimentary rocks and bimodal metavolcanic rocks of the Platberg Group (R-Vr; Rm). Bimodal metavolcanic and clastic metasedimentary rocks of the Platberg Group overlie the Klipriviersberg Group (ca. 2709±8 Ma). The group attains a maximum thickness of approximately 330 m and consists of boulders, cobbles, and fragments of (mainly) amygdaloidal metavolcanic rocks, with subordinate amounts of quartzite, chert and shale. . Normal fault activity and extension arguably accompanied emplacement of the Klipriviersberg Group, and culminated in graben formation and deposition of the Platberg Group.

Unconformably overlying the Ventersdorp Supergroup is the relatively thin Black Reef Formation (Vbr), which has been interpreted as the basal lithostratigraphic unit of the Palaeoproterozoic Transvaal Supergroup. The formation consists of a lower quartzite unit, with a sporadically developed conglomerate at the base, overlain by interbedded, black carbonaceous shale and dolomite beds in the upper portion. The Black Reef Formation represents a highly reflective interface due to a major laterally extensive acoustic impedance contrast between high-velocity, high density dolomite of the Chuniespoort Group of the Transvaal Supergroup and the underlying low-velocity, less dense Ventersdorp metabasalts. Above the Black Reef Formation, the Transvaal Supergroup is divided into the Chuniespoort Group and the Pretoria Group. The Chuniespoort Group consists of dolomite, banded iron formation and lacustrine deposits.

The 1: 250 000 2626 West Rand geological map is shown in Figure 6 and a generalised cross section and seismic 3D model of the regional stratigraphy are illustrated in Figure 7 (from Manzi *et. al.* 2013).

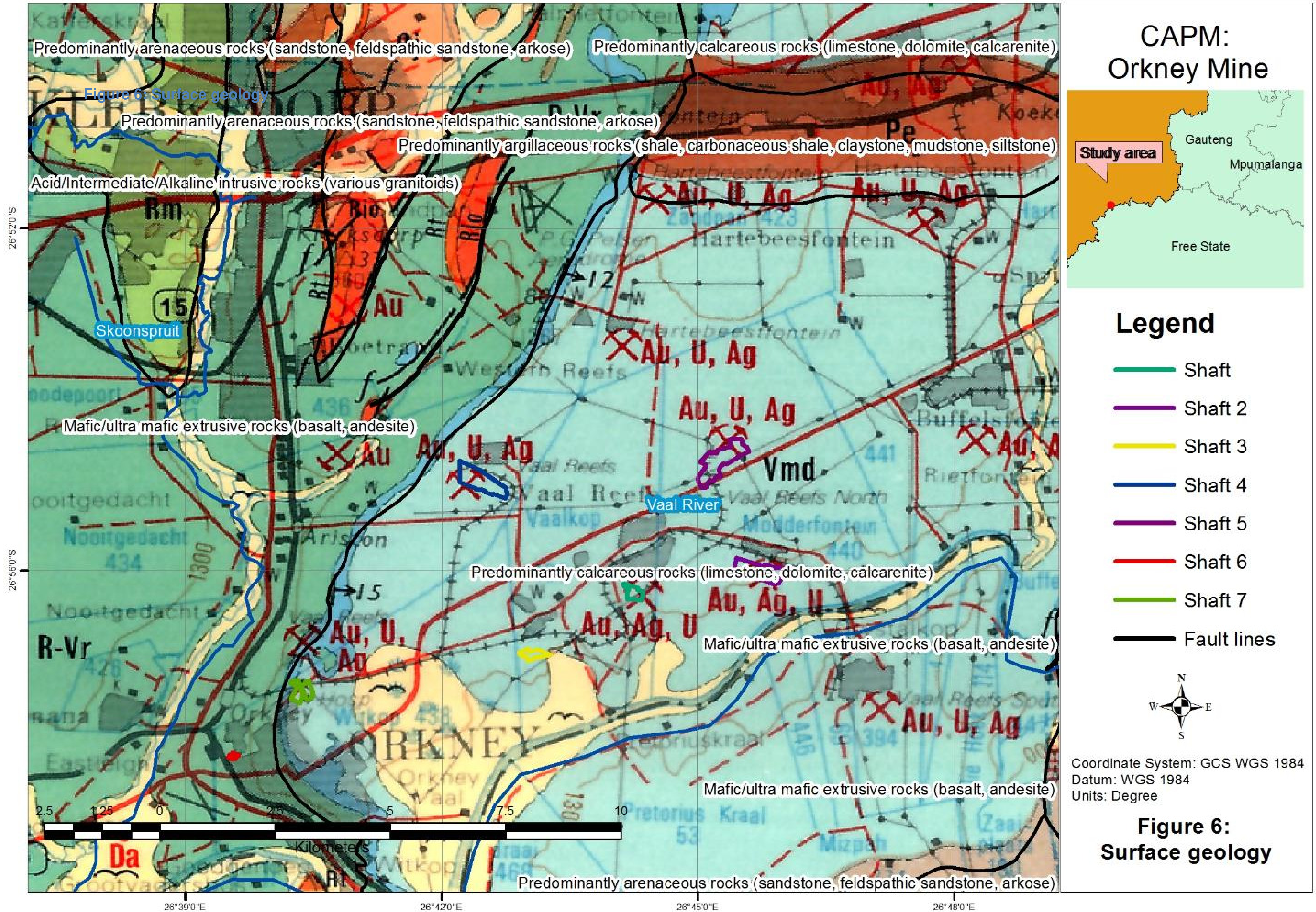
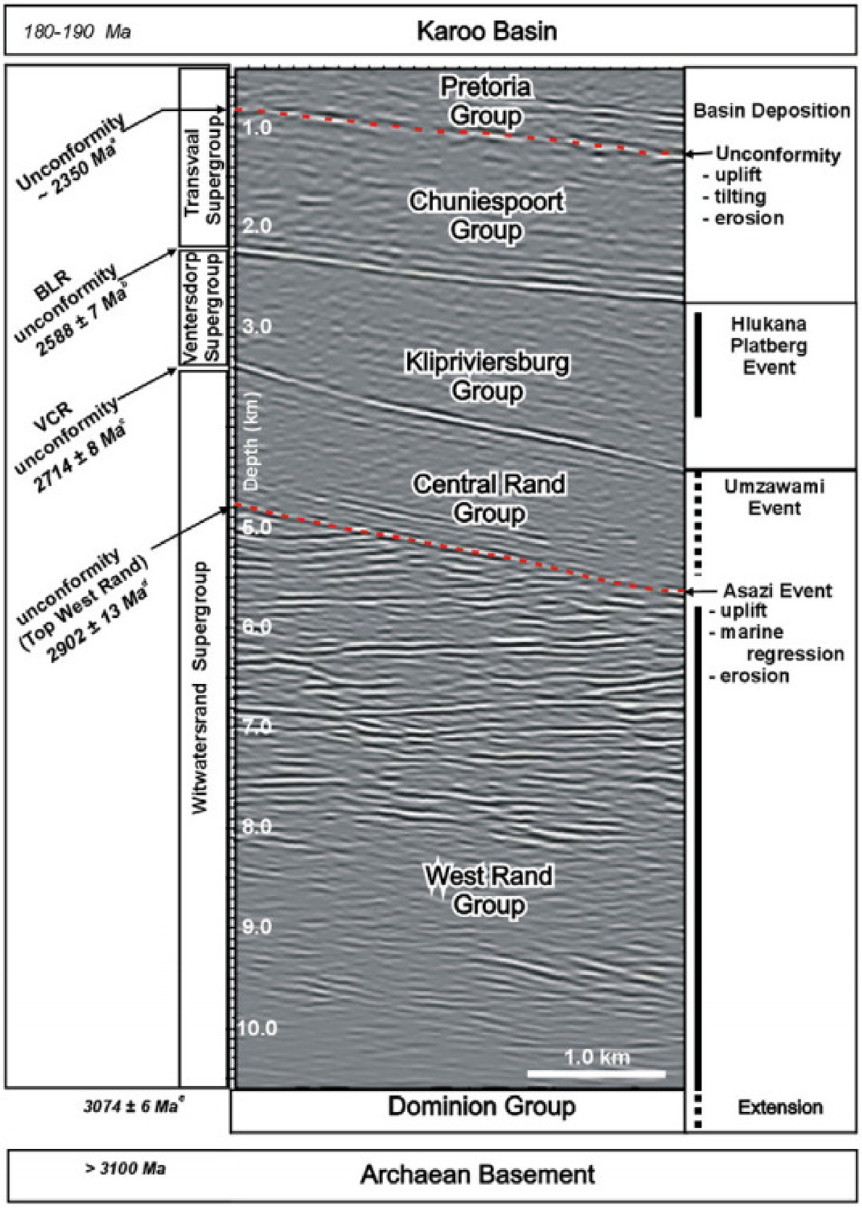


Figure 6: Surface geology



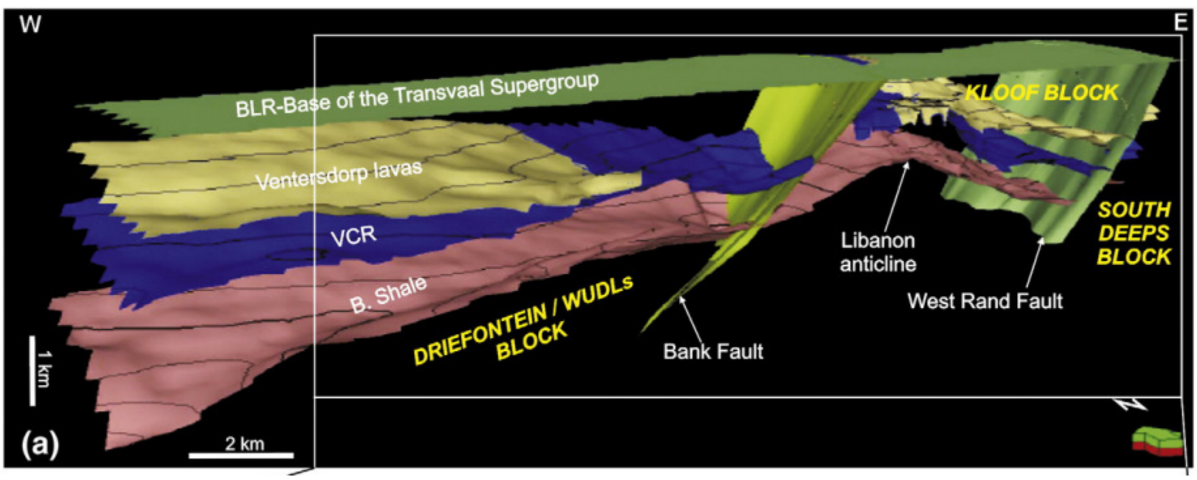


Figure 7: Generalised cross section and seismic model across the Witwatersrand goldfields (from Manzi *et. al.* 2013).

5.3.2 Local geology

The Witwatersrand Basin is late Archaean in age and is considered to be around 2.7 to 2.8 Ga old. Gold occurs in laterally extensive quartz pebble conglomerate horizons or reefs, or near to unconformities, which are generally less than 2 m in thickness. The most fundamental control to the gold distribution in the basin remains the sedimentary features, such as facies variations, erosive surfaces and channel directions. Gold generally occurs in native form and is often associated with pyrite and carbon.

The Klerksdorp Goldfield is located on the Northwest margin of the Witwatersrand Basin and lies some 150 km south-southwest of Johannesburg. Exploration, development, and production history in the area dates from 1886 and following dormant periods, large-scale production commenced during the 1940s. The Witwatersrand Basin sedimentary rocks are overlain by up to 2,000 m of cover rocks and the reefs themselves occur at depths of between 80 m and 4,000 m below surface. Three primary conglomerate reefs are exploited within the Klerksdorp Goldfield, namely the Vaal Reef, the Ventersdorp Contact Reef (VCR) and the Elsburg Reefs. The Vaal Reef and VCR reef horizons occur at depths of between 80 m and 4,000 m below surface. The VCR dips moderately west-north-west, while the Vaal Reef generally dips gently to the southeast. The Elsburg Reefs have historically been exploited at Orkney 6 Mine and Orkney 7 Mine, usually in conjunction with the overlying VCR. The geology of the project area and stratigraphic column and sedimentology of the Witwatersrand sequence in the area of the Klerksdorp goldfield is illustrated in figures 8 and 9, respectively.

5.3.2.1 Vaal Reef (Shafts 1-5)

The Vaal Reef is by far the most significant reef mined at the Orkney Operations and is the major contributor to gold production. The reef strikes northeast and is heavily faulted to form a series of graben structures. The Vaal Reef, which occurs in the Central Rand group of the Klerksdorp Goldfield, has mining grades of between 15 g/t and 20 g/t and comprises a series of oligomictic conglomerates and quartzite packages developed on successive non-conformities. Several distinct facies have been identified, each with its own unique gold distribution and grade characteristics. The Vaal Reef is usually no more than 80 cm thick and is well-mineralised, with nodular and crystalline pyrite, gold, uraninite and carbonaceous matter concentrated along the base of the conglomerate layer. It is believed to have been transported largely from a source area to the north and northwest of the basin and lies on an erosional surface, or unconformity, that was covered by fluvial drainage during a transgressive stage of basin development. The reef dip is generally less than 30° but can vary locally in direction and magnitude and may in some places exceed 45° in dip. Gold is present throughout the reef horizon, however it tends to be concentrated close to the basal contact where carbon commonly occurs as thin seams close to the regional unconformity. Well-mineralised carbon seams occur most commonly in three stacked sequences (Manzi *et. al.* 2013).

Pyrite is present within the Vaal Reef with a prevalence of between 10%-30%.

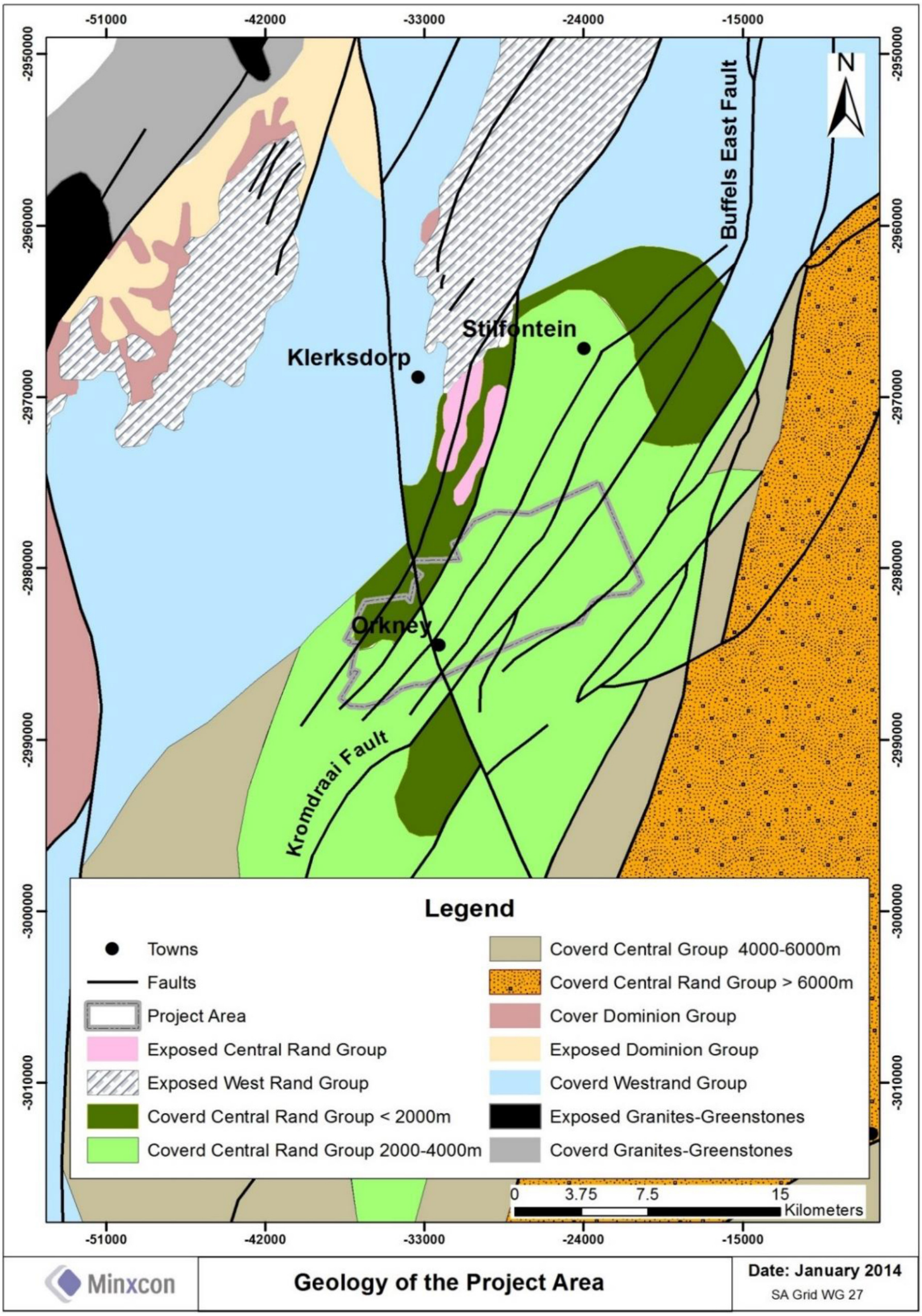


Figure 8: Geology of the mining areas (Minxcon, 2014)

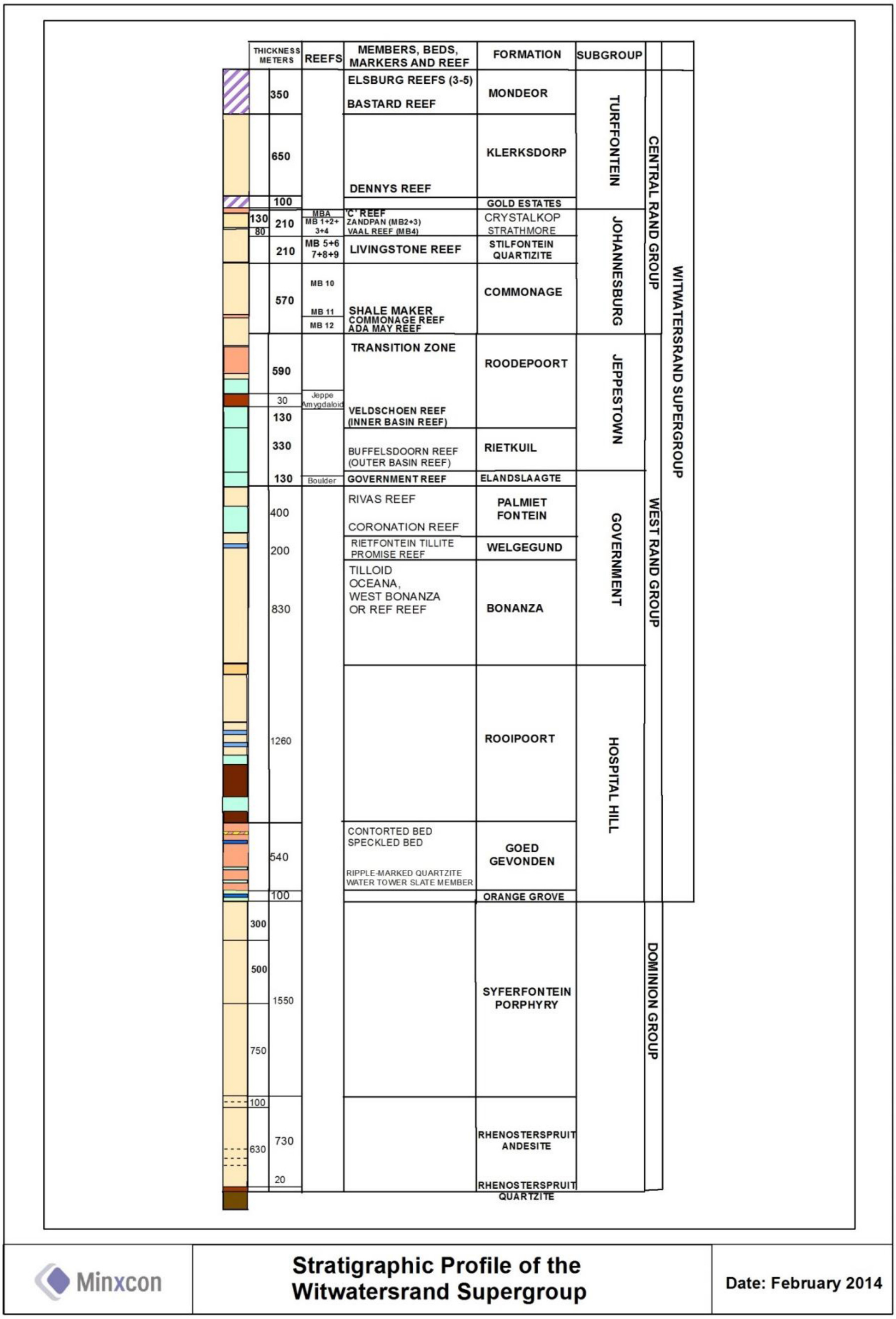


Figure 9: Stratigraphic profile of the Witwatersrand Supergroup (Minxcon, 2014)

5.3.2.2 Ventersdorp Contact Reef (VCR) (Shafts 3, 6 & 7)

At the base of the Klipriviersberg Group, and conformable with the overlying lavas, is a succession of conglomerates and quartzites known as the VCR. The VCR, an auriferous, urnaniferous, pyritic, oligiomictic conglomerate, is unconformable with the underlying quartzites and it ranges in thickness from 40 cm to 400 cm. The VCR unconformity is recognised as being the last regional unconformity occurring within the Witwatersrand Basin and basically signifies the conclusion of the sedimentary processes within the basin (Minxcon, 2014).

The approximately 2800 Ma old VCR is a unique Witwatersrand orebody, from which about 6% of the world's gold production is derived. A major portion of this production is mined at depths exceeding 2500 m and deepest levels of mining are at about 3600 m. The orebody's hangingwall consists of volcanic rocks. This differs from the older Witwatersrand orebodies, which have quartzitic hangingwalls. The thickness of the VCR is generally about 1.20 m, but is highly variable, at an average dip of about 18°. A pronounced unconformity beneath this orebody is also expressed by varying footwall rock type characteristics and frequent rolling of the reef plane. These rolls follow topographic variations of the palaeosurface (Roberts and Schweitzer, 1999).

The VCR has been exploited historically at Orkney 3 Shaft, Orkney 6 Shaft and Orkney 7 Shaft. The VCR, as with the Vaal Reef, can occur as a composite reef consisting of several distinct sedimentary packages. A terrace and slope-based geological model was developed by AngloGold for the VCR and has been retained by the geologists of all subsequent geology teams employed by all the subsequent owners, including Harmony, Pamodzi and Aurora. The model divides the mineralized zones into a main channel; lower, middle, and upper terraces; and also involves delineation of certain higher-grade, reworked channels. The reef is clearly identifiable and its location at the contact between the overlying Klipriviersberg lavas and the underlying Witwatersrand Supergroup rocks renders the footwall and hangingwall rocks distinct from the reef, except in areas where Elsburg conglomerates sub-outcrop against the VCR. The contrasting lithologies aid fault negotiation and have often facilitated the use of three-dimensional seismic survey techniques to image the gross reef topography in the past. Mining of the VCR stopped during 2004 and currently the reef is not being exploited by any of the Orkney Shafts (Minxcon, 2014).

Pyrite (FeS_2) is present within the VCR with a prevalence of between 10%-30% (Minxcon, 2014).

5.3.2.3 Elsburg Reef (Shafts 6 & 7)

The Elsburg Reefs rest on the Gold Estates Quartzites. Each reef was deposited disconcordantly over and on top of its predecessor. The reefs are oligiomictic to polymictic, matrix to pebble supported, small to medium pebble conglomerates. The dip of the reefs ranges from 5° to 15° and the strike is subject to pronounced changes, which are considered to be mainly controlled by faulting. The Elsburg Reefs have historically been exploited at Orkney 6 Mine and Orkney 7 Mine, usually in conjunction with the overlying VCR, against which they sub-outcrop along a northeast trending band, south of and sub-parallel to the Buffelsdoorn Fault. The sedimentological characteristics of the Elsburg Reefs in the region of the sub-outcrop are similar to those exhibited by the VCR (Minxcon, 2014).

5.3.3 Geological intrusives

The major faults within the lease area include the (Minxcon, 2014):

- Nooitgedacht and Buffelsdoorn faults occurring in the Orkney 6 Shaft and Orkney 7 Shaft areas;
- Witkop fault between Orkney 6 Shaft and Orkney 7 Shaft;
- WK22 and Orkney 3 Shaft faults between Orkney 7 Shaft and Orkney 3 Shaft;
- Orkney 5 Shaft Fault; and
- Orkney 2 Shaft South Fault.

These faults typically have throws of tens of metres and further divide the reef into blocks of up to 100 m in width. The horsts and grabens are further disturbed by faults sympathetic to the major faults and typically have throws of tens of meters and further divide the reef into blocks of up to 100 m in width. Drilling from access development can identify these brittle faults, as the dip of the stratigraphy is reasonably constant (15º to 20º).

Dykes and sills of various ages are common in the mining area, the older ones often being related to faults, with varying amounts of throw, whereas the younger ones are accepted as not being related to faulting. The most common intrusives in the mining area are the olivine lamprophyres and ilmenite-diabases. These intrusives usually strike north-south, dip vertically, are thin, transect all other structures and have movements on the contacts, which are often weight-bearing (Minxcon, 2014).

A generalised and schematic cross section of faulting zones and dykes present within the study region is displayed in Figure 10 (source: Mining Mirror, October 2011).

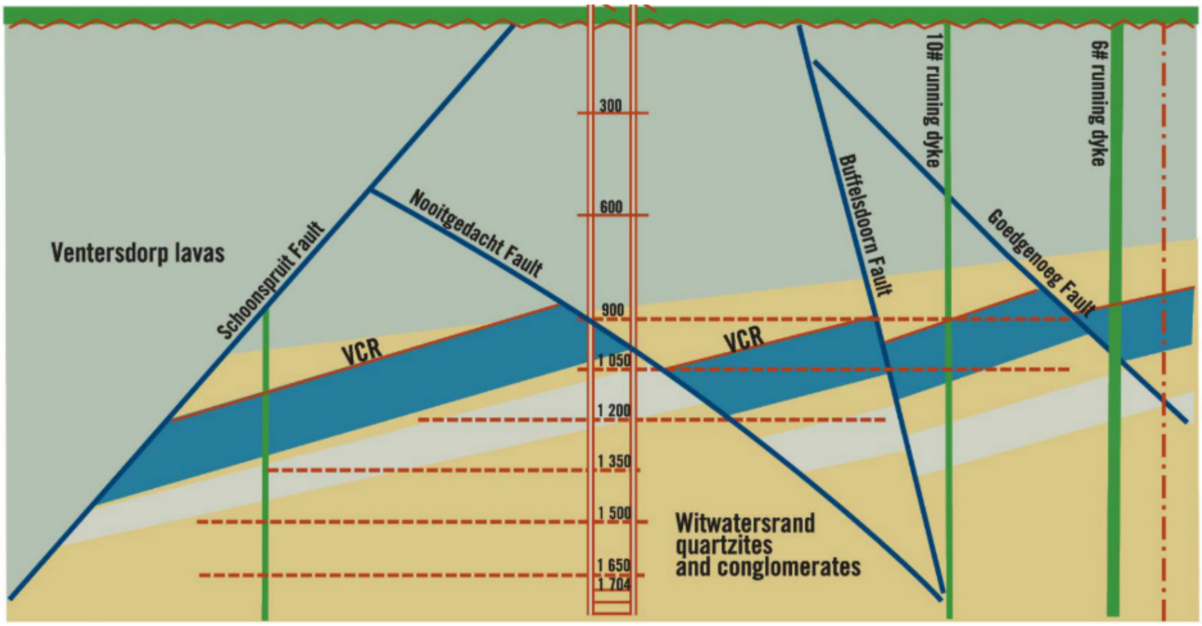


Figure 10: Generalised cross section of fault zones and dykes within the study region

5.4 Regional Hydrogeology

The DWS have characterised South African aquifers based on the rock formations in which it occur together with its capacity to transmit water to boreholes drilled into specific formations. The water bearing properties of rock formations in South Africa can be classified into four classes defined as:

1. **Class A - Intergranular**
   - Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.
2. **Class B - Fractured**
   - Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.
3. **Class C - Karst**
   - Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.
4. **Intergranular and fractured**
   - Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water is stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into the fractured aquifer.

Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields (Figure 11).

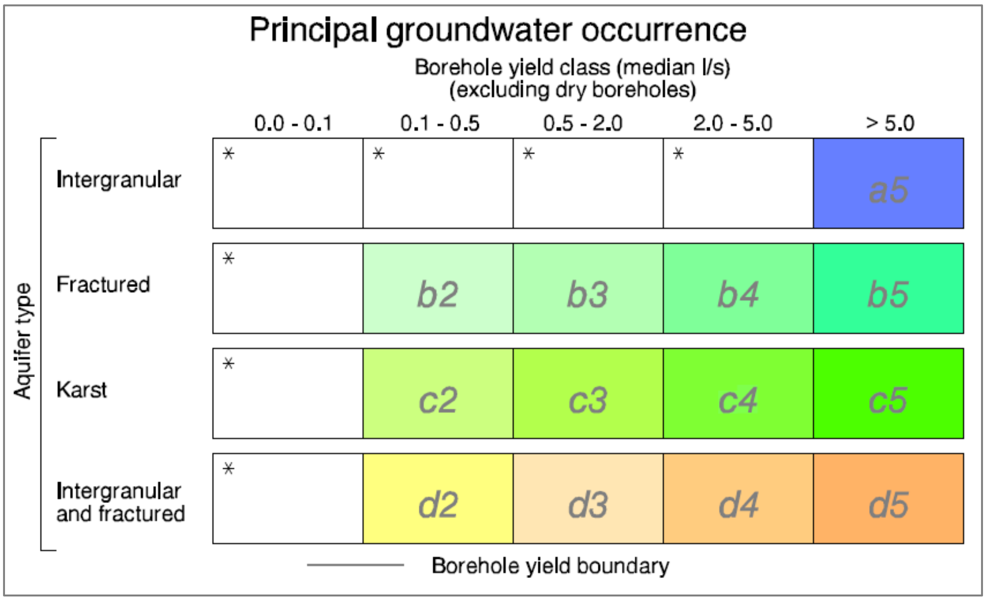


Figure 11: Borehole yield classes

A simplified hydrogeological map illustrating the typical groundwater occurrences for the study region, adapted from Geohydrological Sheet 2526 Johannesburg, is shown in Figure 12. The map shows that shafts 1-5 are situated on the Chuniespoort dolomites (Malmani Subgroup). Shaft 6 is directly underlain by the Platberg Group and specifically the Rietgat Formation belonging the Ventersdorp Supergroup which is comprised mostly of andesitic lava with interbedded shale, conglomerate and limestone while Shaft 7 is on the Chuniespoort dolomites and the Rietgat lava contact. Due to the fact that the GIS image was developed from the 1: 250 000 geological map, it may be possible that the dolomite lava contact may extend further east and 7 Shaft may also be located on the Ventersdorp lavas. This should be confirmed as no geological logs could be obtained for the study area.

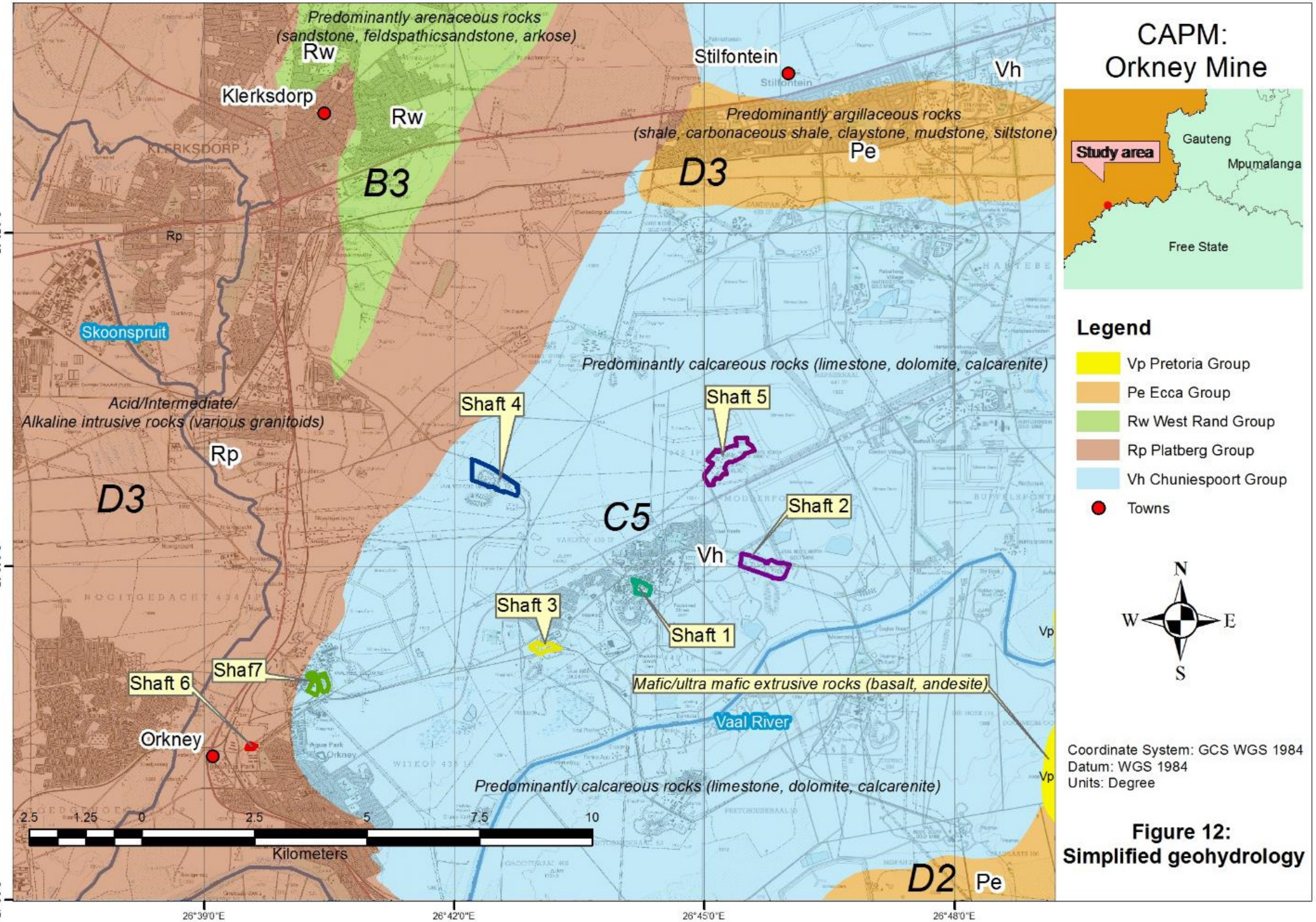


Figure 12: Simplified geohydrology

5.4.1 Chuniespoort Group (Karst aquifer)

The Chuniespoort Group of rocks with approximate thickness of between 1 and 3 km directly underlies shafts 1-5 and is mostly composed of chemically derived carbonate sediments. These sediments alternate between chert-rich and chert-poor dolomite.

The dolomites of the Chuniespoort Group represent the most important aquifer in South Africa. This is due to the generally high to very high storativity and often highly permeable characteristics of this rock type. As infiltrating rainwater containing weak carbonic acid percolates through dolomite along planes of weakness such as faults, fractures and joints associated with intense deformation, it dissolves the dolomite. The soluble bicarbonates produced by the dissolution process are transported away in solution resulting in the development of open cavities and caves in extreme instances. The chemical weathering described by this process is referred to as karstification. Perhaps the most significant result of karstification, is its association with the development of sinkholes. The rate and extent of water level drawdown is one of the critical factors in the development of ground subsidence and sinkholes. The risk is greatest in areas where the groundwater level occurs closer to surface (<30 m) and where it fluctuates more than 6 m in response to pumping (Barnard, 2000).

Studies by Enslin and Kriel (1967) in the Carletonville area indicated that that the storativity of dolomite in this vicinity decreases in increasing depth below surface. A decline from an estimated 9.1% at a depth of 61 mbs to 1.3% at a depth of 146 mbs is reported. According to Bredenkamp *et. al.* (1995), however the storativity of dolomitic aquifers generally varies between 15% and 5%.

The continuity of the dolomitic aquifer is interrupted by geological structures in the form of vertical and sub-vertical intrusive dykes. These low permeability or impermeable rocks serve as barriers to the movement of groundwater through the dolomite, resulting in the formation of compartments (Barnard, 2000). The groundwater yield potential is classed as excellent on the basis that 50% of the boreholes on record produce more than 5 l/s with a maximum of 126 l/s.

5.4.2 Rietgat Formation (Platberg Group)

The Rietgat Formation (Platberg Group) of the Ventersdorp Supergroup is composed mainly of andesitic lava with interbedded shale, conglomerate and impure limestone. The Platberg Group overlies the Klipriviersberg Group which is composed of mainly andesitic lava and tuff. The Platberg Group and the Klipriviersberg Group together with the Allanridge (andesite) and Bothaville Formations (conglomerate & sandstone), the latter two formations conformably overlying the Platberg Group, forms the Ventersdorp Supergroup. The Platbeg Group and the Klipriviersberg Group, overlying the VCR and the Vaal Reef of the Central Rand Group, attains a maximum thickness of approximately 2 km.

The groundwater occurrence in the Rietgat Formation is associated with zones of weathering, brecciation and jointing as well as lithological and dyke contact zones. Nel *et. al.* (1939) considered the water-bearing properties of the lava to be controlled largely by their mode of extrusion, hypothesizing that all intermittent outpouring of lava resulted in the superimposition of several sheet flows, each sheet being compact in its centre and amygdaloidal toward its upper and lower margins. These differences resulted in variations in the degree, mode and depth of weathering. Water circulating along unconformable surfaces or joints caused contiguous rocks to decompose, the amygdaloidal phases being affected most in giving rise to spongy material with a high storage capacity. The classification of the groundwater yield potential as moderate is based on that 45% of boreholes on record produce more than 2 l/s with the groundwater rest level occurring between 10- and 30 mbs.

5.5 Aquifer recharge

The groundwater recharge was estimated using the RECHARGE program, which include using qualified guesses as guided by various schematic maps. The following recharge values as in Table 10 were inferred from the RECHARGE software programme (van Tonder and Xu, 2000).

Table 10: Recharge percentages of MAP inferred for the study area

Method/reference	Ventersdorp Supergroup	Chuniespoort
Geology	4.0	8.0
Vegter	5.5	8.0
Acru	4.55	-
Harvest Potential Map	3.03	5.31
Cl method	3.33	-
Literature	1-3	8.0
Harmonic mean	**4.1**	**7.1**
Recharge mm/a	**27.675**	**47.925**

Notes: *Recharge per annum were calculated using a MAP figure of 675 mm.*

Recharge is defined as the addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers. Recharge of the Ventersdorp Supergroup varies between 3% and 5% with an average recharge of 4.1% of MAP according to the various methods used as in the RECHARGE software programme. Recharge of the Chuniespoort dolomites range between 5.3% and 8% with a harmonic mean of 7.1%. In general, recharge of the dolomite formations is relatively high due to transmissive soils, the presence of dykes and/ or faults and karstification. Sinkholes and the presence of intrusive bodies or faulting zones can exert a significant influence on the rate of recharge in the dolomites to the subsurface since they provide preferential pathways along which water can rapidly infiltrate from surface to the underlying aquifer.

5.6 Aquifer classification

CAPM 6 Shaft and possibly 7 Shaft are directly underlain by rocks of the Rietgat Formation forming part of the Platberg Group of the Ventersdorp Supergroup Complex. The Rietgat Formation is composed mainly of andesitic lava with interbedded shale, conglomerate and impure limestone. The remaining CAPM shafts are underlain by rocks of the Malmani Subgroup belonging to the Chuniespoort Group of rocks of the Transvaal Supergroup. The Malmani Subgroup is mainly composed of dolomite with interbedded layers of chert.

According to the regional aquifer classification map of South Africa based on the Borehole Prospects map provided by JR Vegter, Hydrogeological Consultant and AJ Seymour, Department of Water and Sanitation (previously Department of Water Affairs), the surrounding rocks belonging to the Ventersdorp Supergroup and the Chuniespoort Group have been identified as minor and major aquifer types, respectively. Based on the underlying hydrogeology of the project area the aquifers can be classified according to Parsons Classification System as follows:

- Ventersdorp Supergroup – Rietgat Formation
    - Minor aquifer
- Chuniespoort Group – Malmani Subgroup
    - Major aquifer

Note that the above classification is based on the useable/potable aquifer of which aquifer depth would most probably not exceed 150 – 250 m.

5.7 Aquifer vulnerability

Tables 11 -15 summarizes the aquifer classification vulnerability scores for the aquifer/s in vicinity of the project area.

Table 11: DRASTIC vulnerability scores

Factor	Range/Type		Weight	Rating		Total	
	Rietgat Formation	Malmani subgroup		Rietgat Formation	Malmani subgroup	Rietgat Formation	Malmani subgroup
D	0 - 15 m	15 - 30 m	5	7	3	35	15
R	10 - 50 mm	50 - 100 mm	4	6	8	24	32
A	Fractured	Dolomite	3	6	10	18	30
S	Sandy-clay-loam	Sandy-clay-loam	2	4	4	8	8
T	0-2%	0-2%	1	10	10	10	10
I	Ventersdorp	Dolomite	5	4	9	20	45
C	-	-	3	-		-	

The final DRASTIC scores for the aquifers present in the study region are shown in Table 12.

Table 12: Aquifer DRASTIC vulnerability scores

Aquifer	DRASTIC Score	Susceptibility
Rietgat Formation	115	Medium to high
Malmani Subgroup	140	High

In order to achieve the Groundwater Quality Management Index a points scoring system as presented in Table 13 and Table 14 were used.

Table 13: Ratings for the Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification			
Class	**Points**	**Rietgat**	**Malmani**
Sole Source Aquifer System	6		
Major Aquifer System	4		4
Minor Aquifer System	2	2	
Non-Aquifer System	0		
Special Aquifer System	0-6		
Second Variable Classification (weathered/fractured)			
High	3		3
Medium	2		
Low	1	1	

Table 14: Ratings for the Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification			
Class	**Points**	**Rietgat**	**Malmani**
Sole Source Aquifer System	6		
Major Aquifer System	4		4
Minor Aquifer System	2	2	
Non-Aquifer System	0		
Special Aquifer System	0-6		
Aquifer Vulnerability Classification			
High	3	3	3
Medium	2		
Low	1		

The occurring aquifers in terms of the above definitions, are classified as minor and major aquifer systems. The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as medium and high.

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index$_{Rietgat}$ = Aquifer System Management x Aquifer Vulnerability:

2 X 3 = 6

GQM Index$_{Malmani}$ = Aquifer System Management x Aquifer Vulnerability:

4 X 3 = 12

Table 15: GQM index for the study area

GQM Index	Level of Protection	Rietgat	Malmani
<1	Limited		
1-3	Low level		
3-6	Medium level	6	
6-10	High level		
>10	Strictly non-degradation		12

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Groundwater Quality Management Index of a maximum of 12 for the study area, indicating that **very high level of groundwater protection** is required.

Due to the very high GQM index calculated for this area a strictly non-degrading level of protection is needed to adhere to DWS's water quality objectives. Reasonable and sound groundwater protection measures are therefore required to ensure that no cumulative pollution affects the aquifer.

In terms of DWS's overarching water quality management objectives which is i) protection of human health and ii) the protection of the environment, the significance of this aquifer classification is that if any potential risk exist, measures must be triggered to limit the risk to the environment, which in this case is the i) protection of the secondary underlying aquifers and ii) the streams/rivers within the project area.

5.8 Hydrocensus

5.8.1 Hydrocensus of privately owned boreholes

Hydrocensus surveys of boreholes on and surrounding the various CAPM Orkney mines were conducted during January/February 2015. *Note that because active mining will commence at No. 6 & 7 shafts, surveying preference was given to the area in vicinity of these shafts.*

During the hydrocensus, all available details of boreholes and borehole-owners were collected. This information was used to identify the Interested and Affected Parties which may be impacted upon by the shaft development activities, specifically relating to impacts on water quantity. The hydrocensus boreholes were subjected to water level measurements including chemical analysis to evaluate the chemical characteristics of the groundwater and to establish baseline data prior to commencement with mining activities. These details are also essential for the flow model calibration.

The survey located 55 privately owned and Anglo Gold Vaal River Operations monitoring boreholes (Table 16). The majority of the boreholes are located within close proximity of Shaft 6 and Shaft 7 while some scattered boreholes were surveyed in vicinity of the remaining shaft areas (Figure 13). The majority of boreholes function as monitoring boreholes while the remainder are privately owned boreholes mainly used for small scale irrigation/gardening purposes.

Note that a variety of monitoring boreholes were inaccessible during the survey and water levels could not be obtained from all boreholes.

Seven (7) surface water localities, which included the Skoonspruit, the Vaal River and two return water dams (not CAPM owned) were surveyed and sampled during the hydrocensus. Two fissure water samples (sampled by and received from CAPM) were also analysed for water quality.

5.8.2 Depth to water table

The recorded water levels for the surveyed boreholes measured between 2.98 mbcl and 30.26 mbcl with an average of 10.19 mbcl. No springs were located within the surveyed area. All borehole water levels were deemed to be static water levels.

Table 16: Hydrocensus boreholes

SITE ID	Coordinates		Elevation	WATER LEVEL (mbs)	STATUS	OWNER	APPLICATION	SAMPLED
Privately owned								
H/BH 01	-26.97502	26.66445	1313	7.19	In use	Mr Bylefeld	Garden use	Yes
H/BH 02	-26.97499	26.66387	1313	NAWL	In use	Mr.Els	Garden use	Yes
H/BH 03	-26.97326	26.67033	1323	10.5	In use	Mr Swart	Garden use	Yes
H/BH 04	-26.97339	26.67132	1324	11.15	In use	Mr Smit	Garden use	Yes
H/BH 05	-26.97289	26.67321	1321	9.41	Not in Use	Mr Tretheweg	-	Yes
H/BH 06	-26.96847	26.66502	1316	10.5	In use	Mr Magakwe	Garden use	Yes
H/BH 07	-26.97922	26.66500	1310	6.61	In use	Mr Brits	Garden use	Yes
H/BH 08	-26.98153	26.66282	1308	10.97	In use	Mr Pringle	Domestic & Garden Use	Yes
H/BH 15	-26.98283	26.64301	1294	7.59	In use	World Wide Group (Bertus)	Domestic & Garden Use	Yes
H/BH 16	-26.92833	26.66501	1297		Not in Use	Mr Martin Brits	-	No
H/BH 17	-26.92682	26.66509	1298		Not in Use	Mr Martin Brits	-	No
H/BH 18	-26.93049	26.66319	1293	2.98	Not in Use	Mr Martin Brits	-	Yes
H/BH 19	-26.92731	26.67139	1303	5.24	In use	Mr A.S Smit	Garden use	Yes
WELL 01	-26.93285	26.67002	1304		Not in Use	Mr Tobie	-	N
Mine owned boreholes								
H/BH 09	-26.96416	26.66893	1315	9.42	Not in Use	Mine Property	-	Yes
H/BH 10	-26.89889	26.69661	1329	15.64	Not in Use	Mine Property	-	No
H/BH 11	-26.90403	26.71267	1344	21.87	In use	Mine Property	Monitoring	Yes
H/BH 12	-26.92724	26.68169	1321	11.88	Not in Use	Unknown	-	Yes
H/BH 13	-26.95879	26.71311	1307	8.67	In use	Mine Property	Monitoring	Yes
H/BH 14	-26.97295	26.66224	1310	7.8	Not in Use	Municipality	-	No
H/BH 20	-26.96352	26.73587	1297	7.22	Not in Use	Mine Property	Old Production BH	Yes
H/BH 21	-26.96348	26.73587	1297	7.34	Not in Use	Mine Property	Old Production BH	Yes

SITE ID	Coordinates		Elevation	WATER LEVEL (mbs)	STATUS	OWNER	APPLICATION	SAMPLED
VRM 49	-26.93113	26.74297	1328	30.26	In use	Mine Property	Monitoring BH	No
VRM 54	-26.91085	26.77090	1324	9.33	In use	Mine Property	Monitoring BH	Yes
VR 46	-26.97853	26.70277	1297	3.79	In use	Mine Property	Monitoring BH	Yes
FS 002	-26.96836	26.72253	1294	9.91	In use	Water Affairs - Mid Vaal	Monitoring BH	Yes
VR 03	-26.92828	26.68524	1327.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 75	-26.94659	26.66390	1296.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 45 S	-26.95381	26.69915	1314.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 45 D	-26.95378	26.69914	1314.00	Locked	In use	Mine Property	Monitoring BH	No
VR 28	-26.95291	26.71474	1307.00	Locked	In use	Mine Property	Monitoring BH	No
VR 30	-26.95612	26.72046	1301.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 56	-26.91433	26.74997	1330.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 66	-26.94369	26.74738	1314.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 67	-26.94730	26.74866	1308.00	Locked	In use	Mine Property	Monitoring BH	No
VR 42	-26.95811	26.75138	1296.00	Locked	In use	Mine Property	Monitoring BH	No
VRM 64	-26.94117	26.75163	1311.00	Locked	In use	Mine Property	Monitoring BH	No
VR 24	-26.94360	26.75704	1299.00	Locked	In use	Mine Property	Monitoring BH	No
VR 41	-26.94522	26.76407	1295.00	Locked	In use	Mine Property	Monitoring BH	No
VR 06A	-26.94071	26.77981	1297.00	Locked	In use	Mine Property	Monitoring BH	No
BUF 03	-26.92701	26.78926	1311.00	Locked	In use	Mine Property	Monitoring BH	No
VR	-26.93939	26.78525	1299.00	Locked	In use	Mine Property	Monitoring BH	No
VR 45	-26.98091	26.69542	1302.00	Locked	In use	Mine Property	Monitoring BH	No
VRR 26	-26.96889	26.72115	1295.00	Locked	In use	Mine Property	Monitoring BH	No
VRR 25	-26.96820	26.72268	1294.00	Locked	In use	Mine Property	Monitoring BH	No
VRR 27	-26.96832	26.72250	1294.00	Locked	In use	Mine Property	Monitoring BH	No
VRR 24	-26.96772	26.72441	1293.00	Locked	In use	Mine Property	Monitoring BH	No

SITE ID	Coordinates		Elevation	WATER LEVEL (mbs)	STATUS	OWNER	APPLICATION	SAMPLED
VR 47	-26.96716	26.72634	1294.00	Locked	In use	Mine Property	Monitoring BH	No
VR 08	-26.96674	26.72210	1297.00	Locked	In use	Mine Property	Monitoring BH	No
Surface Water								
SW 01	-26.98473	26.63229	1287	-	Skoonspruit d/s 6 & 7 Shaft	DWA	Various	Yes
SW 02	-26.93459	26.66422	1291		Skoonspruit u/s 6 & 7 shaft	DWA	Various	Yes
SW 03	-27.01612	26.69443	1289	-	Vaal River – d/s but u/s 6&7 shafts	DWA	Various	Yes
SW 04	-26.96552	26.73627	1292	-	Vaal River - Centre	DWA	Various	Yes
SW 05	-26.94627	26.78079	1293	-	Vaal River- u/s	Unknown	Various	Yes
SW 06	-26.94749	26.76051	1293	-	Return water dam	Unknown	Various	Yes
SW 07	-26.95814	26.70347	1311	-	Water from tailings - Return Water pond	Unknown	Various	Yes

NAWL – No access to water level

d/s – downstream

u/s - upstream

All water levels recorded were static levels

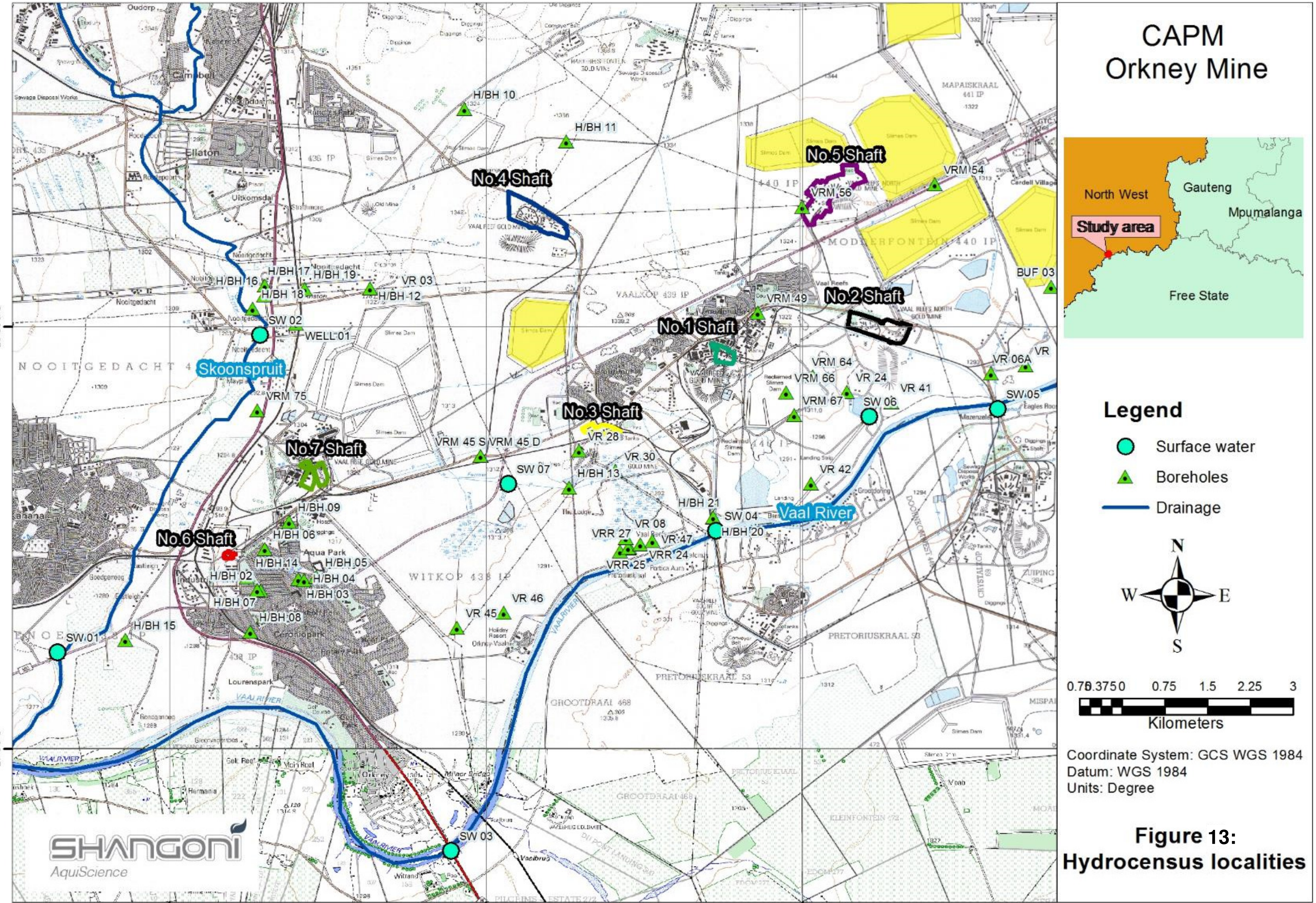


Figure 13: Hydrocensus localities

5.8.3 Groundwater quality

In general, pH, salinity (TDS/EC), sulphate (SO_4) and soluble metal levels are good indicators to evaluate the quality of groundwater within a gold mining environment. These indicator parameters can be used as reference data to assess temporal groundwater trends during operation. Short summaries on the significance of these indicator parameters are given in Table 17 (S*ince CAPM will not be processing the ore on-site no significant water quality effects are anticipated during mining)*.

Table 17: Significance of indicator parameters in a gold mining environment

Parameter	Significance
pH	pH is the negative logarithm of the hydrogen ion concentration in solution. At pH less than 7 water is acidic, while at pH greater than 7 water is alkaline. Alternatively, conditions which favour neutralisation of hydrogen ions result in an increase in pH, referred to as an alkalinization process. Acid mine drainage (AMD) is typically encountered at gold mines due to the presence and oxidation of sulphide minerals (most notably pyrite) resulting in the formation of sulphuric acid and acidity. Although the pH of water does not have direct health consequences except at extremes of the spectrum, it could have indirect consequences on the environment. Typically groundwater is slower to react to AMD than surface water given the greater levels of neutralising minerals in groundwater (buffer capacity). An acidic environment results in greater solubility of heavy metals in solution with some being highly toxic even in very low concentrations. The pH of pristine groundwater water sources lies within the range of 6.0 - 8.5 and depends on the geology and concentrations of base or acid compounds in solution.
TDS/EC	The total dissolved solid (TDS) content of groundwater, measured in mass per volume (typically mg/l) measures the quantity of dissolved materials in a sample of water and is related to electrical conductivity (EC). EC is a measure of how well a material accommodates the transport of electric charge. The more salts dissolved in the water, the higher the EC and TDS values. Both EC and TDS are used to estimate the amount of total dissolved salts, or the total amount of dissolved ions in the water. Sulphate is the main contributor to elevated salinity in a mining environment.
Sulphate (SO_4)	Sulphate is an anion found in ground- and surface water and can be a good indicator of contamination resulting from mining activities (e.g. AMD from coal and gold mines). Sulphate concentrations of 600 mg/l and more cause diarrhoea in most individuals and adaptation may not occur.
Soluble heavy metals	The generation of low pH drainage enhances the dissolution of heavy metals in water especially nickel (Ni) and copper (Cu) with lower levels of a range of trace and semi-metal ions such as lead (Pb), arsenic (As), aluminium (Al) and manganese (Mn). Iron (Fe) is also a good initial indicator of AMD reactions as the dissolution sequence of pyrite (FeS_2) results in the solubility of ferrous iron (Fe^{2+}) and the precipitation of ferric iron (Fe^{3+}) and ferric hydroxide (FeOH) also known as 'yellow-boy'.

The groundwater quality results, interpreted based on the i) SANS 241: 2011, the ii) South African Water Quality Guidelines (WRC, 1998), iii) according to the indicator parameters as in Table 17, are tabulated and discussed in the following tables and sections. The data shown in Table 18 is groundwater hydrochemistry obtained from boreholes located in relative close proximity to shafts 6 and 7.

Table 18: Hydrochemistry for groundwater sampled from boreholes in close proximity to shafts 6 and 7

SITE ID	SANS 241: 2011	HBH 01	HBH 02	HBH 03	HBH 04	HBH 05	HBH 06	HBH 07	HBH 08	HBH 09	HBH 15
pH	5 – 9.7	8.15	7.81	7.83	8.06	7.56	7.64	7.66	7.42	7.87	7.52
EC mS/m	≤170	82.7	82.2	87.1	84.5	118	101	81	111	72.1	**162**
TDS mg/l	≤1200	537.55	534.3	566.15	549.25	767	656.5	526.5	721.5	468.65	**1053**
Ca mg/l	-	94.8	88.2	80.8	77.4	113	108	69.9	133	74	**154**
Mg mg/l	-	38.1	49	38.5	38.4	64.3	56.3	48.4	52.3	44.8	97.2
Na mg/l	≤200	23.9	22.1	54.8	56.6	72.8	27.2	34.3	27.5	25.7	65.3
K mg/l	-	1.22	1.37	4.73	6.26	2.66	1	1.4	1.46	0.796	1.51
MALK mg/l	-	164	194	225	219	364	208	180	300	179	413
Cl mg/l	≤300	80.2	81.9	69.8	78.2	81.5	87.7	86.4	51.6	66.4	**222**
SO_4 mg/l	≤500	123	126	117	115	175	165	103	162	111	122
NO_3 mg N/l	≤11	1.32	2.36	2.03	<0.017	<0.017	3.46	5.6	7.09	1.48	**11**
NH_4 mg N/l	≤1.5	0.038	0.042	0.045	0.172	0.302	0.094	0.055	0.048	0.066	0.163
Inorganic N mg/l	-	1.358	2.402	2.075	0.172	0.302	3.554	5.655	7.138	1.546	11.16
PO_4 mg P/l	-	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
F mg/l	≤1.5	0.249	0.21	0.24	0.281	0.225	0.206	0.197	0.222	0.191	0.274
Al mg/l	≤0.3	<0.003	<0.003	0.174	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Fe mg/l	≤2.0	<0.003	<0.003	<0.003	<0.003	0.163	<0.003	<0.003	<0.003	<0.003	<0.003
Mn mg/l	≤0.5	<0.001	<0.001	<0.001	0.055	0.116	<0.001	<0.001	<0.001	<0.001	<0.001
Cr mg/l	≤0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu mg/l	≤2.0	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006
Ni mg/l	≤0.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zn mg/l	≤5.0	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.013	0.119
Co mg/l	≤0.50	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd mg/l	≤0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pb mg/l	≤0.010	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Classification		Class 1 Good									Class 2 Marginal
Worst parameter		EC, Ca						EC	EC, Ca, NO_3	EC	EC/TDS, Ca, Cl,

The hydrochemistry shown in Table 18 are for boreholes sampled and located in close proximity to CAPM shafts 6 and 7. In general the data indicates relatively good water quality with all samples recording within the SANS 241:2011 drinking water standards. In addition neither of the indicator parameters as in Table 17 recorded in high concentrations. The water is typical of unpolluted groundwater with either being of a Ca-HCO_3^- type typical of dolomitic areas or groundwater with no dominating cations or anions as illustrated by the Piper diagram and Stiff diagrams in Figures 14 and 15, respectively.

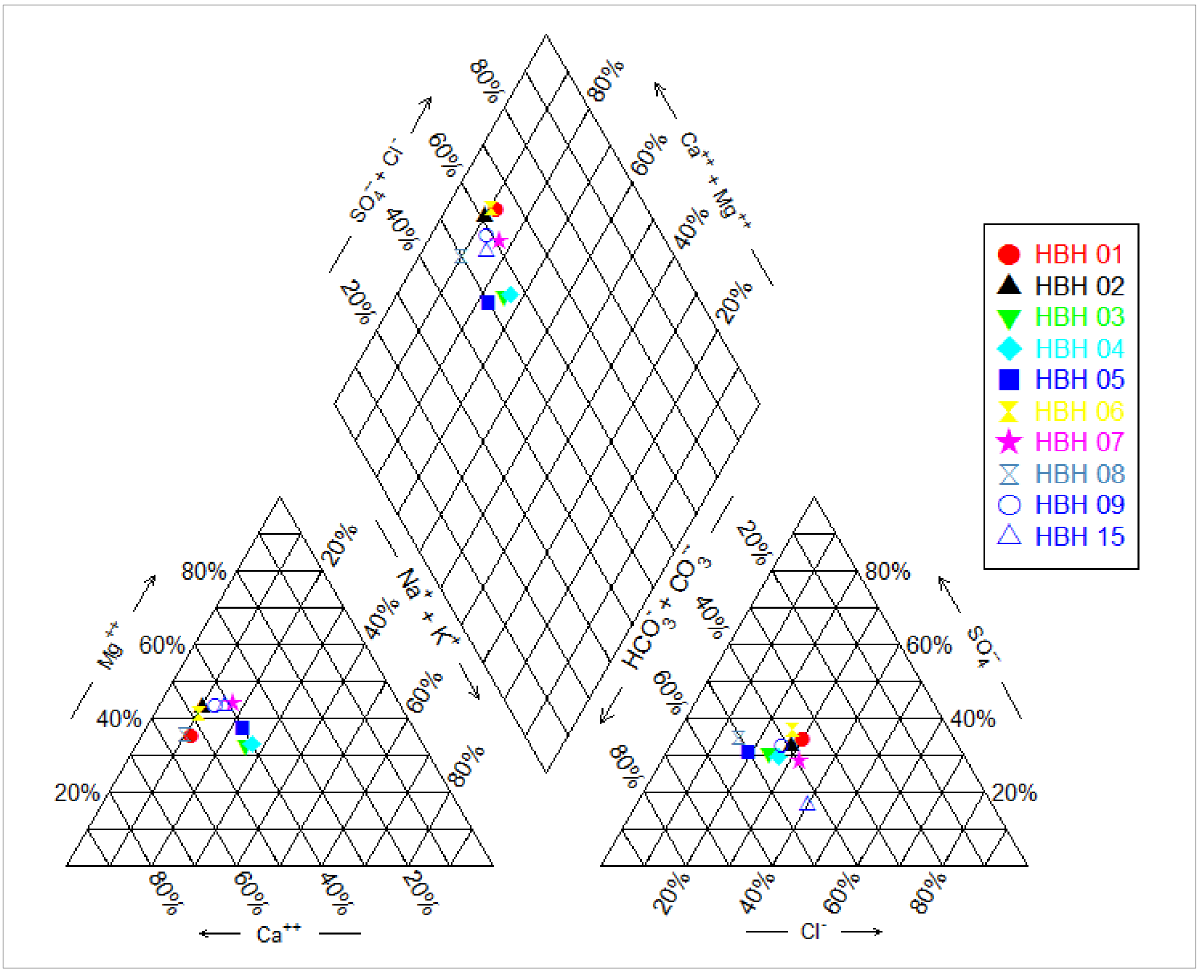


Figure 14: Piper diagram for boreholes in close proximity to 6 and 7 Shaft

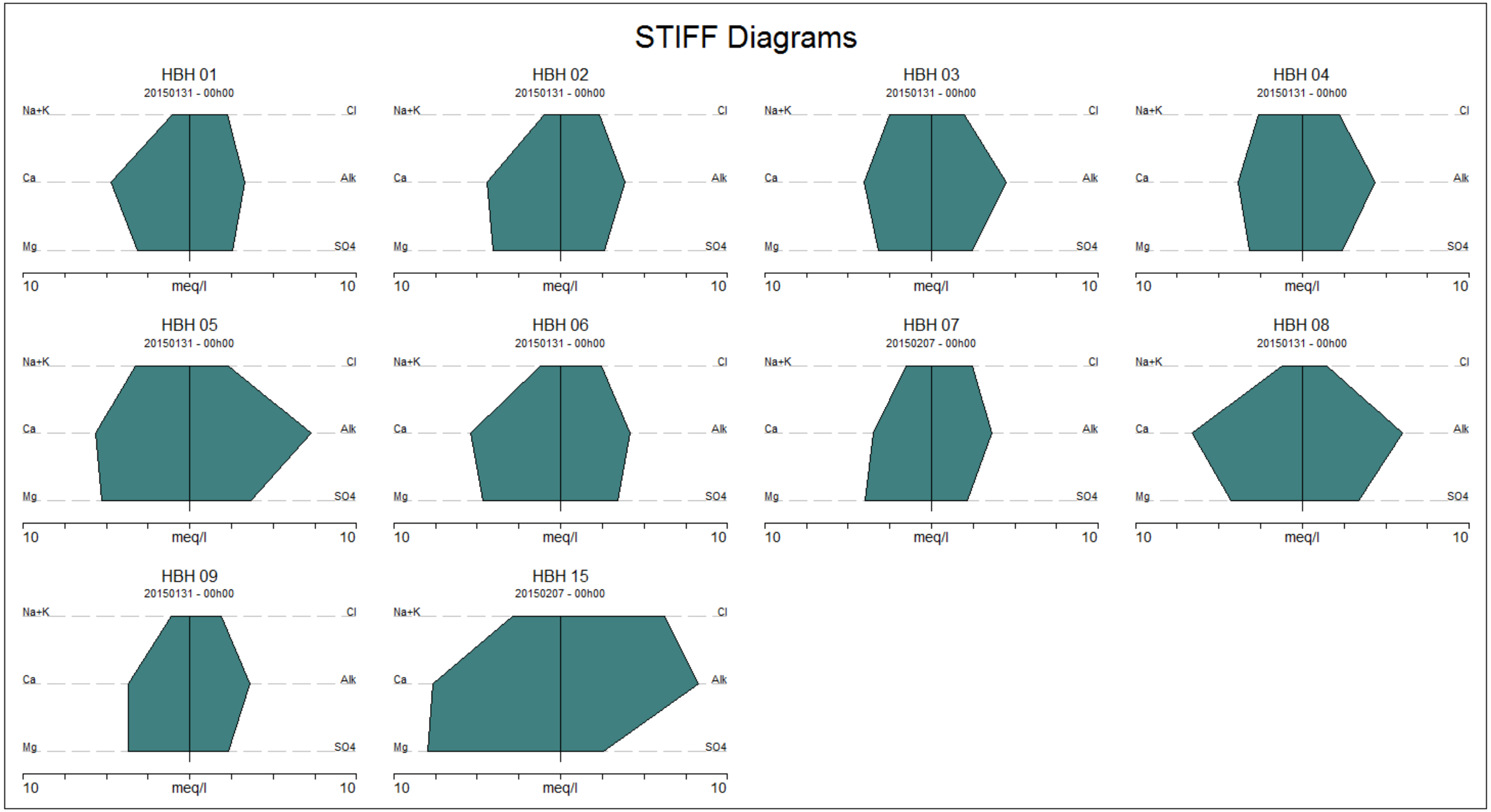


Figure 15: Stiff diagrams for boreholes in close proximity to 6 and 7 Shaft

No boreholes could be located in close proximity of 4 Shaft. The nearest boreholes, nine (9) in total (refer to Figure 13) are located approximately 1.5 km north and 3.5 km south-west towards the Skoonspruit. Only four (4) of these were sampled for hydrochemical quality due to either blocked or inaccessible boreholes. The data is shown in Table 19.

Table 19: Hydrochemistry for groundwater sampled from boreholes in relative close proximity to 4 Shaft

SITE ID	SANS 241: 2011	HBH 11	HBH 12	HBH 18	HBH 19
pH	5 – 9.7	7.82	7.13	7.65	7.47
EC mS/m	≤170	68.7	55.8	52.2	**257**
TDS mg/l	≤1200	446.55	362.7	339.3	**1670.5**
Ca mg/l	-	83.3	37.7	51	**378**
Mg mg/l	-	47.7	21.4	20	**128**
Na mg/l	≤200	5.35	29.9	28.1	91.1
K mg/l	-	2.73	9.11	6.08	0.6
MALK mg/l	-	312	22.5	219	257
Cl mg/l	≤300	24.2	51.2	20.4	93.8
SO_4 mg/l	≤500	44.9	167	16.9	**1084**
NO_3 mg N/l	≤11	0.25	0.509	0.47	1.89
NH_4 mg N/l	≤1.5	0.089	1.03	**3.78**	0.054
Inorganic N mg/l	-	0.339	1.539	4.25	1.94
PO_4 mg P/l	-	<0.008	<0.008	<0.008	<0.008
F mg/l	≤1.5	0.203	0.126	0.215	0.122
Al mg/l	≤0.3	<0.003	<0.003	<0.003	<0.003
Fe mg/l	≤2.0	<0.003	<0.003	<0.003	<0.003
Mn mg/l	≤0.5	<0.001	<0.001	<0.001	<0.001
Cr mg/l	≤0.05	<0.001	<0.001	<0.001	<0.001
Cu mg/l	≤2.0	<0.001	<0.001	<0.001	<0.001
Ni mg/l	≤0.07	<0.001	<0.001	<0.001	<0.001
Zn mg/l	≤5.0	<0.002	<0.002	0.177	<0.002
Co mg/l	≤0.50	<0.001	<0.001	<0.001	0.067
Cd mg/l	≤0.003	<0.001	<0.001	<0.001	<0.001
Pb mg/l	≤0.010	<0.004	<0.004	<0.004	<0.004
Classification		Class 1 Good	Class 0 Ideal	Class 3 Poor	Class 4 Unacceptable
Worst parameter		Ca	-	NH_4	EC/TDS, SO_4

The groundwater quality for the boreholes located near 4 Shaft range from *Ideal (class 0)* to *Unacceptable (class 4)* according to the colour coded classification system proposed by the DWS for drinking water. Two boreholes, *HBH 18* and *HBH 19* recorded parameters exceeding the SANS 241: 2011 guidelines; total ammonia at *HBH 18* (3.78 mg N/l); and EC (257 mS/m), TDS (1671 mg/l), and SO_4 (1084 mg/l) at *HBH 19. HBH 18* and *HBH 19* are classified as *Poor (class 3)* and *Unacceptable* *(class 4)*, respectively. Good water quality in terms of drinking water standards was recorded for boreholes *HBH 11* and *HBH 12* with *Good* (*class 1*) and *Ideal* (*class 0*) classifications, respectively.

The Piper diagram (Figure 16) and Stiff diagrams (Figure 17) indicate that boreholes *HBH 11* and *HBH 18* display no mining related influence with Ca/Mg-HCO_3^- type waters while boreholes *HBH 12* and *HBH 19* have SO_4/Cl-HCO_3^- type characters indicating a probable mining related influence, which can most probably be sourced from a slimes dam situated upstream thereof. Very poor quality was recorded for *HBH 19* (mostly SO_4) situated directly downstream from the slimes dam. This slimes dam belongs to another mining company and not to CAPM.

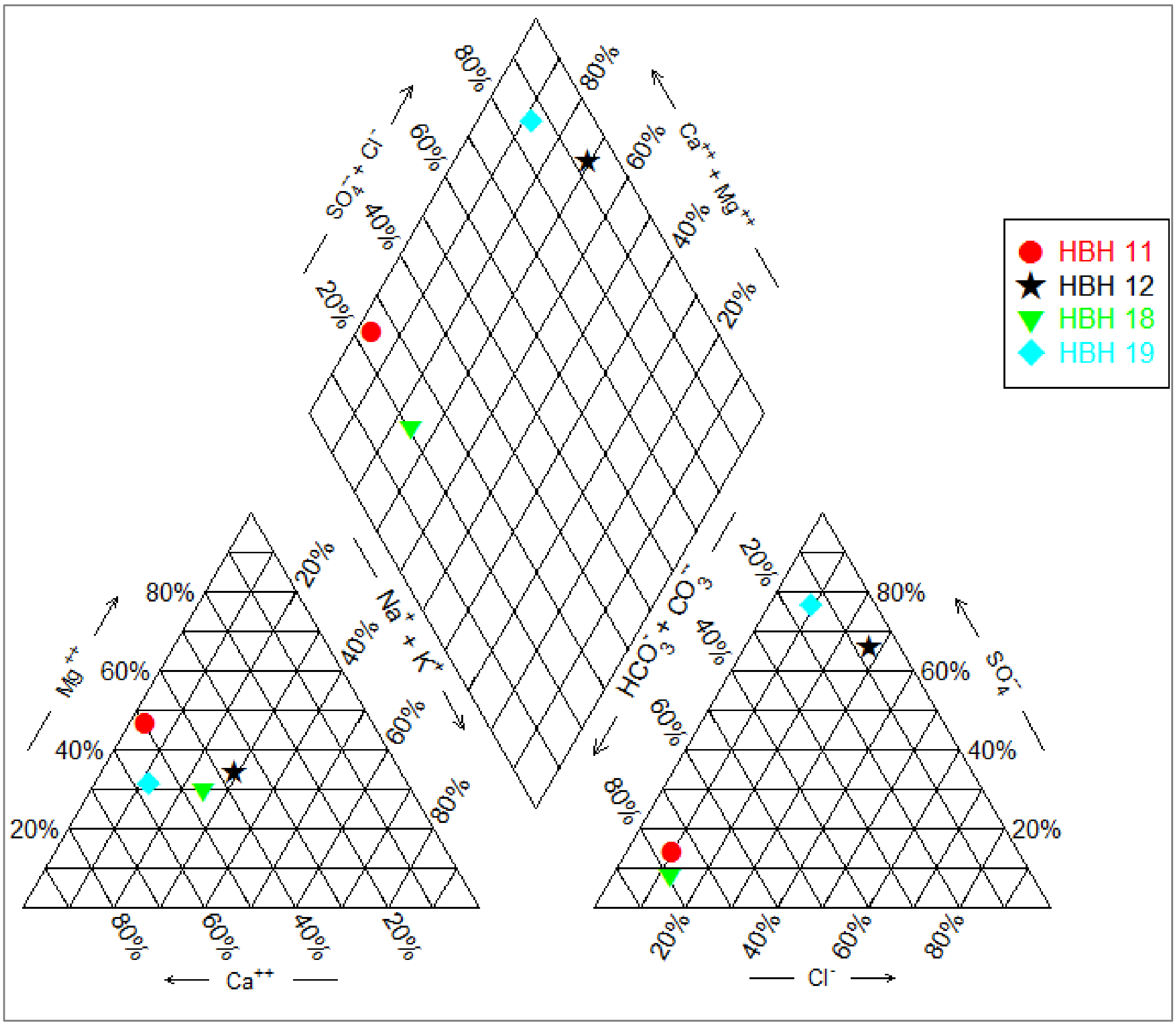


Figure 16: Piper diagram for boreholes in close proximity to 4 Shaft

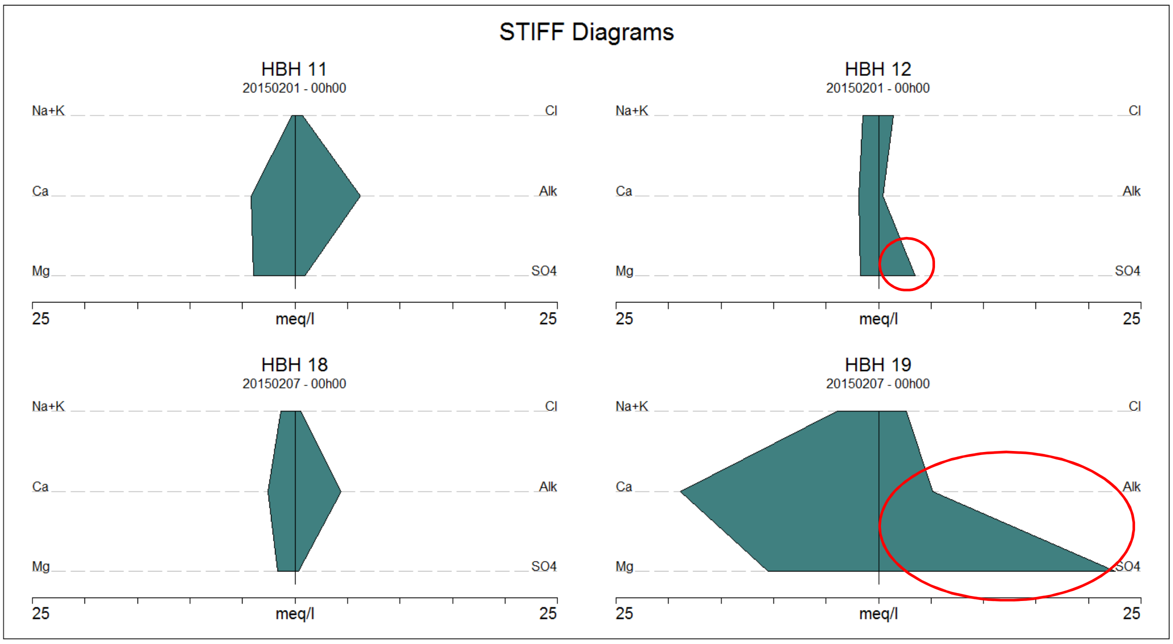


Figure 17: Stiff diagrams for boreholes in close proximity to 4 Shaft

Four (4) other boreholes were sampled within the study area. These were *HBH 13* (downstream and to the south of 3 Shaft); *HBH 20* (3 km south from 1 Shaft on the Vaal River banks); *VR 46* (3.5 km southwest from 3 Shaft towards the Vaal River); and *VRM 54* (1.5 km east from 5 Shaft). The groundwater qualities from these boreholes are shown in Table 20.

Only one (1) borehole recorded water quality parameters to be within acceptable drinking water standards. The remaining three (3) water qualities' recorded *Unacceptable* quality with a subsequent class 4 classification. Very high salinities (EC and TDS) were recorded (SO_4 as the largest contributor) with EC ranging between 382 mS/m and 612 mS/m and SO_4 between 1916 mg/l and 2720 mg/l. Elevated inorganic N were also recorded for boreholes *HBH 13* and *VRM 54* with values of 24.51 mg N/l and 35.6 mg N/l, respectively while high to very high soluble Pb, Mn and Co were recorded for *HBH 13*, *VR 46* and *VRM 46*, respectively.

The Piper diagram and Stiff diagrams in figures 18 and 19, respectively indicate sodium enrichment and Na type water with no dominant anion activity for *HBH 20*. This may be due to groundwater that had been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Groundwater quality from boreholes *HBH 13*, *VR 46* and *VRM 54* suggest mining related pollution and sulphate enrichment as indicated by their plot positions in the Piper diagram (Figure 18) and the extended SO_4 tail on the anion side of the Stiff diagrams (Figure 19). The high SO_4 may indicate acid mine drainage reactions. These three boreholes are all located downstream or in close vicinity of slimes dams (not CAPM operated or owned).

Table 20: Hydrochemistry for groundwater sampled from the study area

SITE ID	SANS 241: 2011	HBH13	HBH20	VR46	VRM54
pH	5 – 9.7	6.92	8.69	7.43	7.37
EC mS/m	≤170	**402**	59.6	**382**	**612**
TDS mg/l	≤1200	**2613**	387.4	**2483**	**3978**
Ca mg/l	-	**533**	4.08	**255**	**445**
Mg mg/l	-	**124**	8.71	**288**	**315**
Na mg/l	≤200	**316**	106	**305**	**715**
K mg/l	-	40.8	9.58	8.43	29.7
MALK mg/l	-	196	113	84.4	207
Cl mg/l	≤300	202	64.2	258	**414**
SO_4 mg/l	≤500	**1916**	88.4	**2077**	**2720**
NO_3 mg N/l	≤11	**23.7**	<0.017	<0.017	**17.1**
NH_4 mg N/l	≤1.5	0.812	0.65	0.779	**18.8**
Inorganic N mg/l	-	**24.51**	0.65	0.779	**35.9**
PO_4 mg P/l	-	<0.008	<0.008	<0.008	<0.008
F mg/l	≤1.5	<0.055	0.17	0.06	<0.055
Al mg/l	≤0.3	<0.003	<0.003	<0.003	<0.003
Fe mg/l	≤2.0	0.144	<0.003	0.466	<0.003
Mn mg/l	≤0.5	0.451	<0.001	**2.81**	0.172
Cr mg/l	≤0.05	<0.001	<0.001	<0.001	<0.001
Cu mg/l	≤2.0	<0.001	<0.001	<0.001	<0.001
Ni mg/l	≤0.07	<0.001	<0.001	<0.001	<0.001
Zn mg/l	≤5.0	0.017	<0.002	<0.002	0.059
Co mg/l	≤0.50	0.171	<0.001	0.05	**1.24**
Cd mg/l	≤0.003	<0.001	<0.001	<0.001	<0.001
Pb mg/l	≤0.010	**0.016**	<0.004	<0.004	0.004
Classification		Class 4 Unacceptable	Class 0 Ideal	Class 4 Unacceptable	Class 4 Unacceptable
Worst parameter		SO_4	-	SO_4	SO_4, N

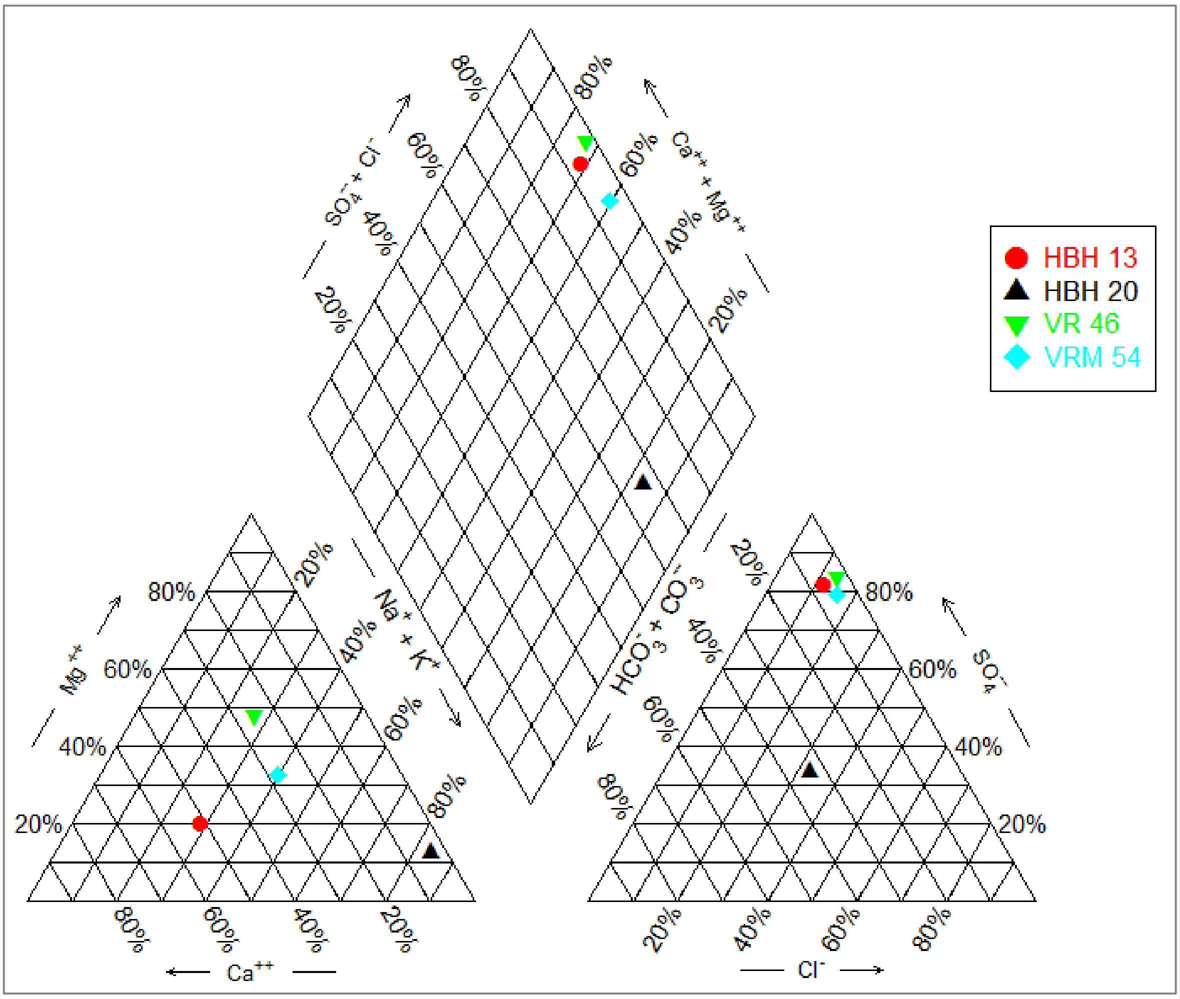


Figure 18: Piper diagram for boreholes sampled within the study area

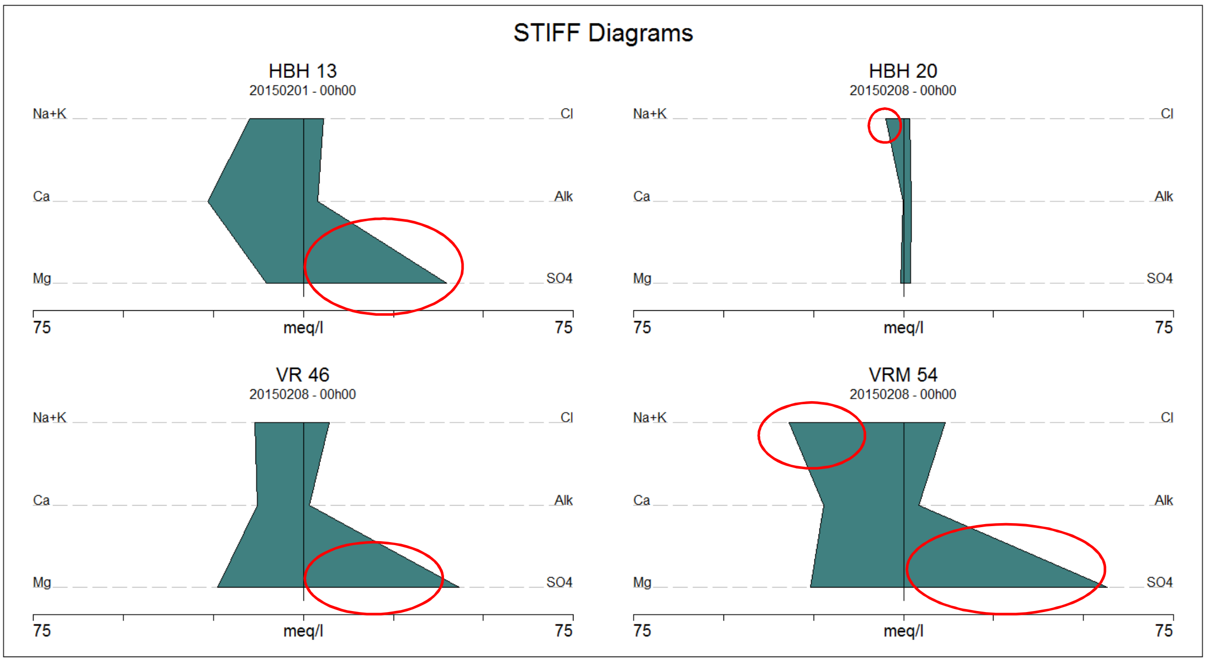


Figure 19: Stiff diagram for boreholes sampled within the study area

5.8.4 Fissure water quality

Samples from fissure water draining into the 6 and 7 shafts were taken for hydrochemical analysis to get an idea of the water quality within the shaft areas. *Note that the water which has accumulated within the shafts could not be sampled due to depth of the water levels and flooding of mining areas.* The quality was evaluated according to the SANS 241: 2011 standards for drinking water and according to the General Limit applicable to discharge of wastewater into a water resource (Government Notice No. 399; Government Gazette 26187; DWAF, 2004). The hydrochemical data is shown in Table 21 and illustrated in terms of a Piper and Stiff diagrams in figures 20 and 21.

Table 21: Hydrochemical data for 6 and 7 Shaft fissure water

SITE ID	SANS 241: 2011	General Limit*	Shaft 6 (fissure)	Shaft 7 (fissure)
pH	5 – 9.7		7.8	8.22
EC mS/m	≤170	≤150	90.4	125
TDS mg/l	≤1200	-	587.6	812.5
Ca mg/l	-	-	84.4	111
Mg mg/l	-	-	54.8	68.8
Na mg/l	≤200	-	21.8	77.5
K mg/l	-	-	2.11	3.91
MALK mg/l	-	-	176	137
Cl mg/l	≤300	-	72.1	66.7
SO_4 mg/l	≤500	-	**171**	**442**
NO_3 mg N/l			**6.99**	**9.64**
NO_3 + NO_2 mg N/l	≤11	≤15	7.05	9.70
NH_4 mg N/l	≤1.5	≤6	0.045	0.042
PO_4 mg P/l	-	≤10	0.023	0.023
F mg/l	≤1.5	≤1	0.275	0.255
Fe mg/l	≤2.0	-	<0.003	<0.003
Mn mg/l	≤0.5	-	<0.001	<0.001
Cr mg/l	≤0.05	-	<0.001	<0.001
Cu mg/l	≤2.0	≤0.01	<0.001	<0.001
Zn mg/l	≤5.0	≤0.1	<0.002	<0.002
Cd mg/l	≤0.003	≤0.005	<0.001	<0.001
Pb mg/l	≤0.010	≤0.01	<0.004	<0.004
As mg/l	≤0.010	≤0.02	<0.007	<0.007
Se mg/l	≤0.010	≤0.02	<0.007	<0.007
Hg mg/l	≤0.006	≤0.005	<0.007	<0.007
B mg/l	-	≤1	0.033	0.088
CN. mg/l	≤0.070	≤0.02	<0.01	<0.01
Susp solids mg/l	-	≤25	2	7
COD mg/l	-	≤75	11.9	**94**
Faecal coliforms cfu/100 ml	0	≤1000	<1	**2**
Classification			Class 1 Good	Class 2 Marginal
Worst parameter			EC, NO_3	SO_4, F. coliforms

* Wastewater limit values applicable to discharge of wastewater into a water resource

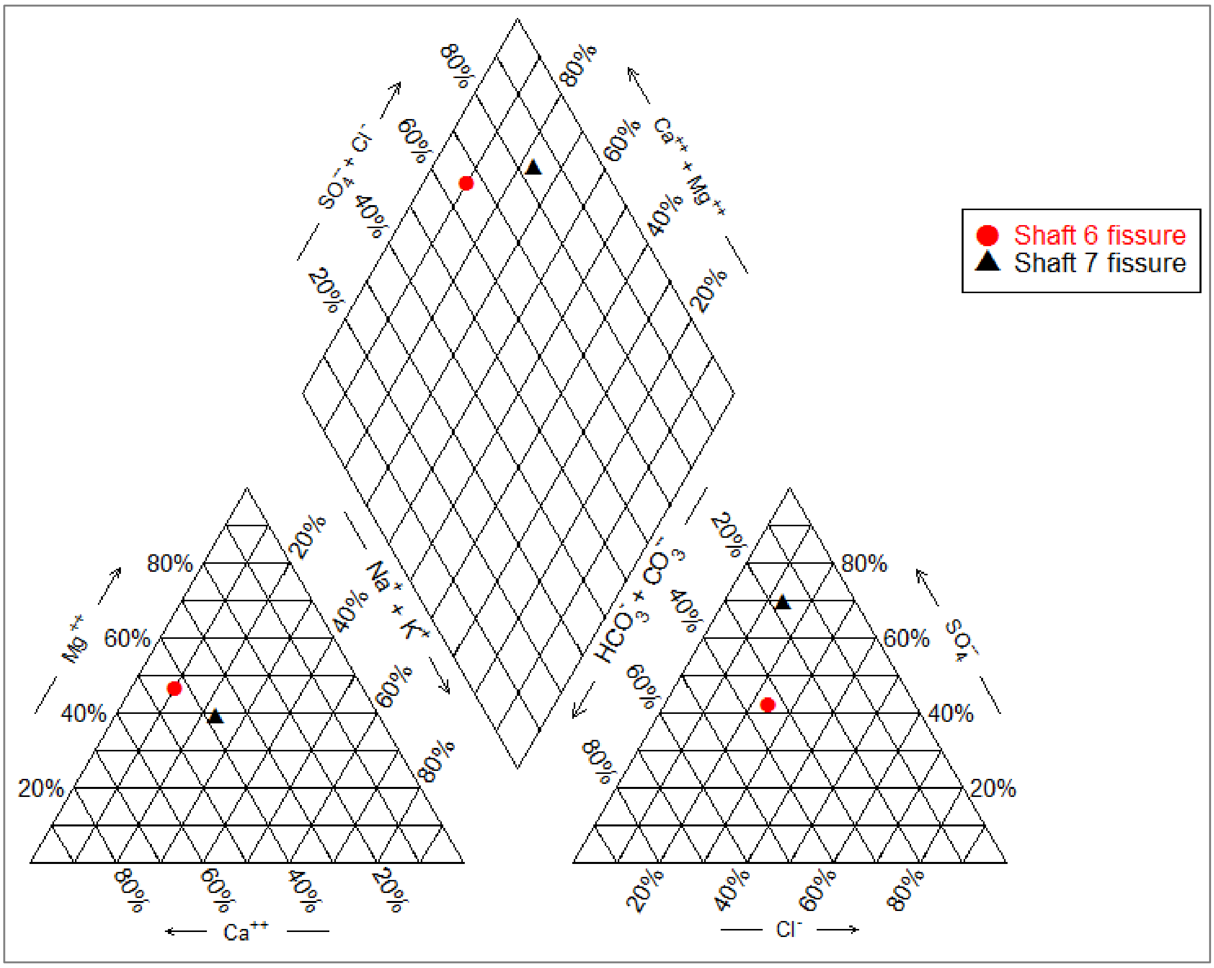


Figure 20: Piper diagram illustrating the ratios of major cation and anion activity for fissure water

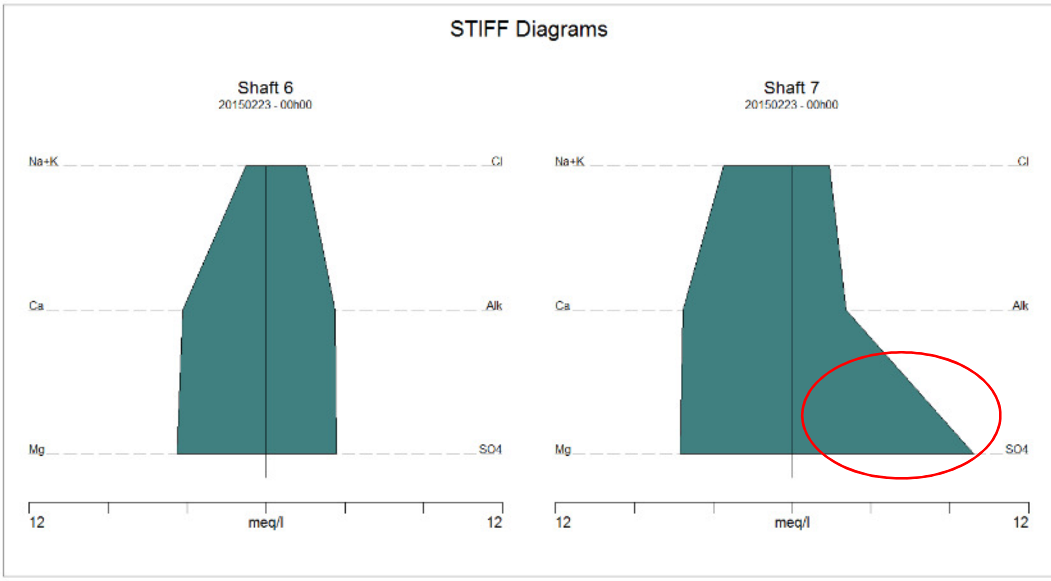


Figure 21: Stiff diagrams illustrating ratios of major cation and anion activity (in meq/l) for fissure water

The hydrochemical data in Table 21 indicates that the *6 Shaft* fissure water recorded well within SANS 241: 2011 drinking water guidelines. The EC and NO_3 values recorded slightly above the *Ideal (class 0)* guidelines as proposed by the DWA (DWAF, 1998) and can be classified as *Good* (*class 1*). All parameters recorded well within the General Limit relating to wastewater discharge.

Fissure water quality for *7 Shaft* recorded slightly elevated EC, SO_4 and NO_3 but all parameters nevertheless remain well within the SANS 241: 2011 guidelines. The only parameter that recorded above the SANS guidelines is faecal coliforms with a value of 2 cfu/100 ml (SANS guideline = 0 cfu/100 ml). As a result of the slightly elevated SO_4 and faecal coliforms the water can be classified as *Marginal* (*class 2*). With respect to the General Limit, all parameters except for chemical oxygen demand (COD), with a concentration of 90 mg/l, recorded above the discharge limits.

Note that the fissure water quality may give an indication of the water quality expected within the shafts. However, given that the shafts extend to the mineable gold seams containing high pyrite content (FeS_2), the shafts' water may be of lesser quality as given in this report. It is recommended that the shaft water qualities be analysed frequently during mining and even more so if discharge into the environment remains an option.

5.8.5 Surface water quality

Seven (7) surface water samples were taken during the hydrocensus and subjected to chemical analyses. The samples included:

- Two (2) samples on the Skoonspruit up- and downstream from Orkney town and from 6 and 7 Shaft.
- Three (3) samples on the Vaal River.
- Two (2) samples from return water dams (not CAPM owned or operated) located within the study area.

Hydrochemical data for the surface water samples is shown in Table 22 and their sampling positions in Figure 22. Although it is not expected that CAPM would contribute to any surface water quality deterioration given that the ore will not be processed on site and distance from drainage features, the data in Table 22 should nevertheless serve as baseline data for the operational phases of mining.

SW1 and *SW2* were sampled on the Skoonspruit up- and downstream relative to 6 and 7 Shaft and Orkney town. The data indicates significantly deteriorating water quality from the upstream locality *SW2* compared to its downstream counterpart *SW1*. The already poor quality at *SW2* deteriorated from a *Poor (class 3)* classification to an *Unacceptable (class 4)* at *SW1*, largely due to the increase in the total ammonia (NH_3 + NH_4) concentration. A similar increase is observed with respect to the Na, Cl, total alkalinity, PO_4 and Mn concentrations which could imply sewage and organic waste pollution; most probably a sewage influx from the vicinity of Orkney.

Table 22: Hydrochemistry for surface water samples taken during the hydrocensus (Jan/Feb-15)

		Skoonspruit		Vaal River			Other	
SITE ID	SANS 241: 2011	SW2 (u/s)	SW1 (d/s)	SW5	SW4	SW3	SW6	SW7
pH	5 – 9.7	7.09	7.94	9.34	9.42	9.1	8.18	8.45
EC mS/m	≤170	52.1	76.2	62.6	63.4	62.2	**309**	**205**
TDS mg/l	≤1200	338.65	495.3	406.9	412.1	404.3	**2008.5**	**1332.5**
Ca mg/l	-	41.7	49.2	53.7	56	54.4	316	197
Mg mg/l	-	16.8	19.6	20.3	21.1	20	117	47.7
Na mg/l	≤200	33.8	58.1	48.1	49.4	49.2	**288**	179
K mg/l	-	6.95	11.6	9.03	9.07	8.45	23.1	33.2
MALK mg/l	-	107	202	131	133	128	146	121
Cl mg/l	≤300	43.4	74	48.3	49.2	52.2	210	88.1
SO_4 mg/l	≤500	75.5	83.6	105	109	106	**1383**	**767**
NO_3 mg N/l	≤11	1.13	<0.017	<0.017	<0.017	<0.017	0.521	1.67
NH_4 mg N/l	≤1.5	**2.38**	**11.1**	0.028	0.065	0.04	**4.31**	**5.23**
Inorganic N mg/l	-	3.51	11.1	0.028	0.065	0.04	4.831	6.9
PO_4 mg P/l	-	0.333	1.66	0.151	0.135	0.148	<0.008	0.021
F mg/l	≤1.5	0.287	0.365	0.315	0.306	0.279	<0.055	0.253
Al mg/l	≤0.3	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Fe mg/l	≤2.0	<0.003	0.208	<0.003	<0.003	<0.003	<0.003	<0.003
Mn mg/l	≤0.5	<0.001	0.471	<0.001	<0.001	<0.001	0.007	**5.85**
Cr mg/l	≤0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu mg/l	≤2.0	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.459
Ni mg/l	≤0.07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.113
Zn mg/l	≤5.0	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co mg/l	≤0.50	<0.001	<0.001	0.001	0.003	0.002	0.441	0.167
Cd mg/l	≤0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pb mg/l	≤0.010	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.059
Classification		*Poor class 3*	*Unacceptable class 4*	*Ideal class 0*			*Unacceptable class 4*	Poor class 3
Worst parameter		NH4	NH4	-			SO4	SO_4, Mn

* Shaded values exceed SANS 241: 2011 guidelines and red font indicate parameters of concern for which no human health based guideline exist

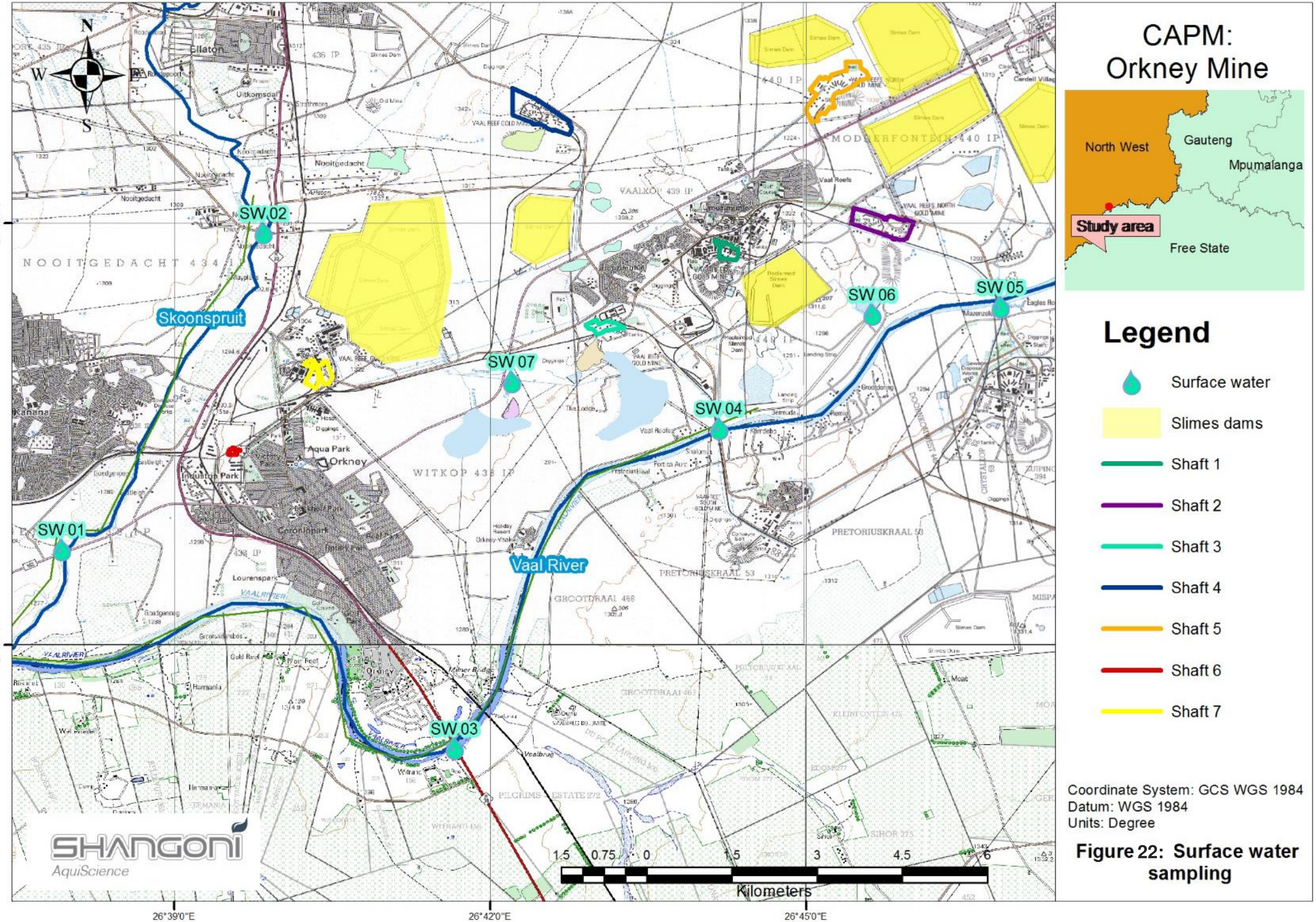


Figure 22: Surface water sampling

Samples *SW3-SW5* were taken on the Vaal River south from the study area. The quality from the Vaal River recorded *Ideal (class 0)* water quality and remain stable between the 3 localities. A concern may be the NH_4 (and absence of NO_3) and PO_4 levels which may also be an indication of sewage pollution. *Note that the classification is solely based upon parameters analysed and is not a suggestion of use.*

Samples *SW6* and *SW7* were sampled from return water dams (not CAPM owned or operated) identified and located during the hydrocensus. These dams show typical profiles from mining environments with very high salinities (mostly contributed by SO_4 but also Na and Cl to lesser extents), high inorganic nitrogen, and low to high soluble metal levels.

5.9 Hydraulic gradients and velocity

The direction and rate of groundwater flow is determined by the groundwater gradients and aquifer transmissivity. Under natural/steady state conditions groundwater will flow from higher to lower hydraulic gradients. Steep hydraulic gradients and high aquifer transmissivity will allow for greater groundwater seepage velocities. The groundwater gradients are important for use in geohydrological studies as it is used in estimations of the Darcy Flux and seepage velocity used in contaminant transport modelling, i.e. in determining the rate at which groundwater and pollutants move through a matrix (although not part of this investigation). First estimations of groundwater flow directions can be made by correlating the topography elevations with the hydraulic head of static water levels. A good correlation may be an indication of groundwater flow mimicking the surface topography.

Static hydraulic head elevations were plotted against surface elevation/topography and are shown in Figure 23. A good Bayesian correlation of $r^2 = 0.93$ (n = 21) exists between the surface topography and the static hydraulic heads. Based thereupon an assumption can be made that groundwater flow paths mimic surface topography.

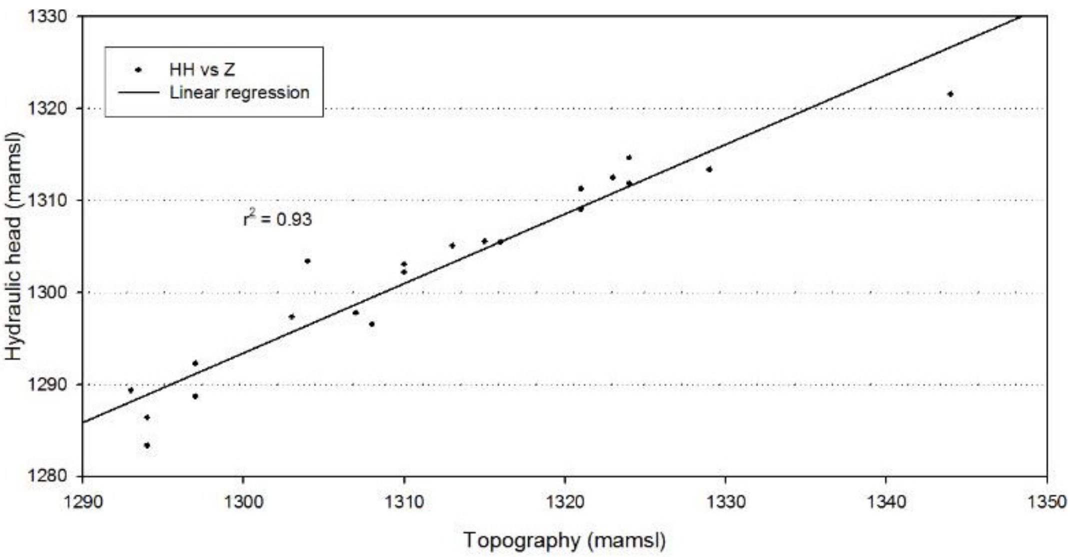


Figure 23: Bayesian correlation of groundwater levels

Interpolated (Kriging) topography and hydraulic head contour maps for the study area are shown in Figure 24. Note that the topographical map excludes artificial surface features such as the slimes dams. The figures below show that groundwater flow in vicinity of the CAPM Orkney Mine shaft areas are similar to the surface water drainage. Flow is predominantly towards the surface drainage features being west towards the Skoonspruit (shafts 6 & 7) and south towards the Vaal River (shafts 1-5). A topographical high, functioning as a flow boundary is evident from the topography map which also functions as a groundwater flow boundary. This feature may be an indication of an igneous intrusion, possibly a dolerite dyke or could be a faulting zone.

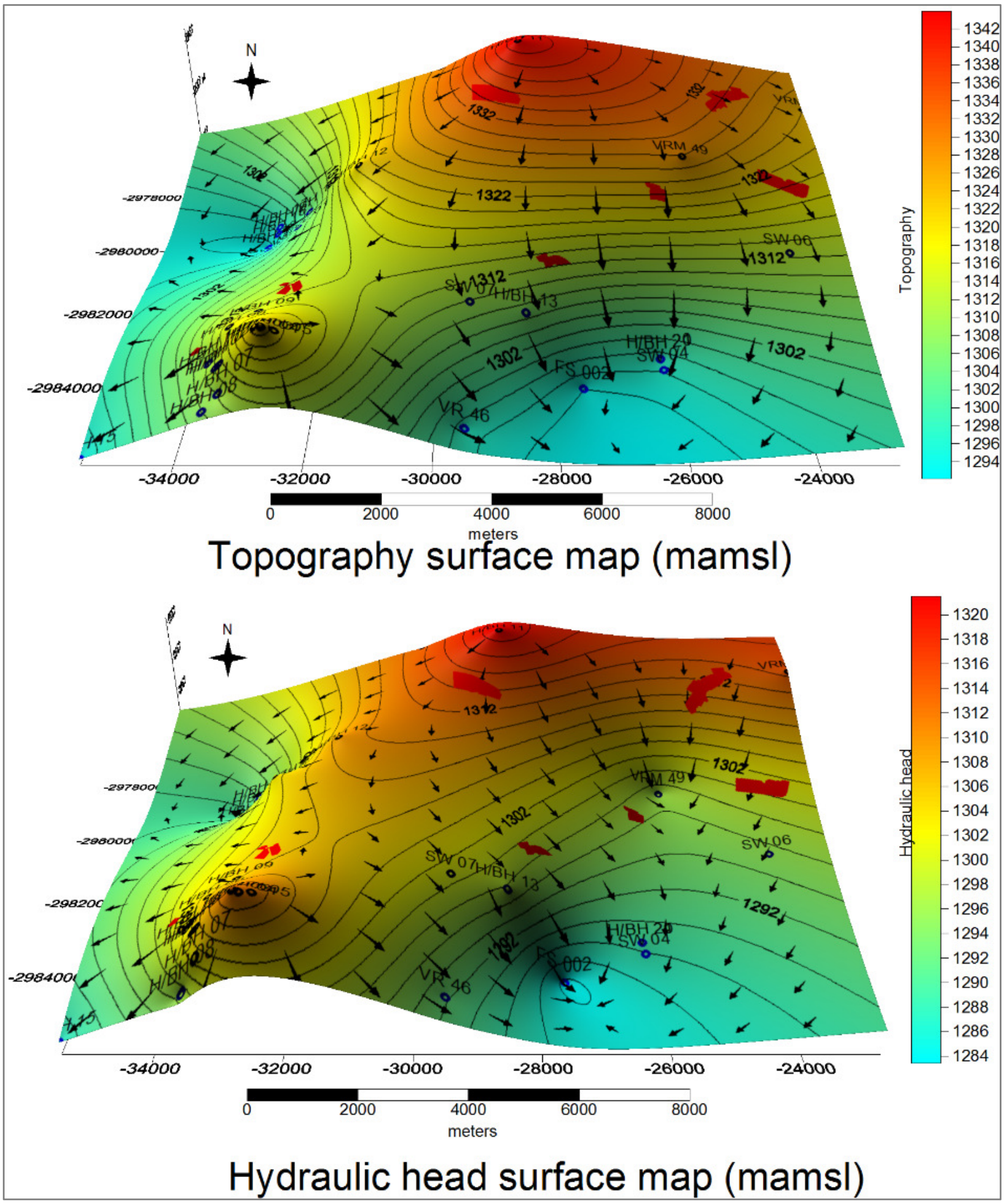


Figure 24: Interpolated topographical and hydraulic head contours (in mamsl)

The gradient map shown in Figure 25 was numerically calculated using the direction and magnitude of the interpolated hydraulic heads. The figure shows that the regional hydraulic gradients vary between 0.001 and 0.02 but on average is gentler being between 0.001 and 0.01.

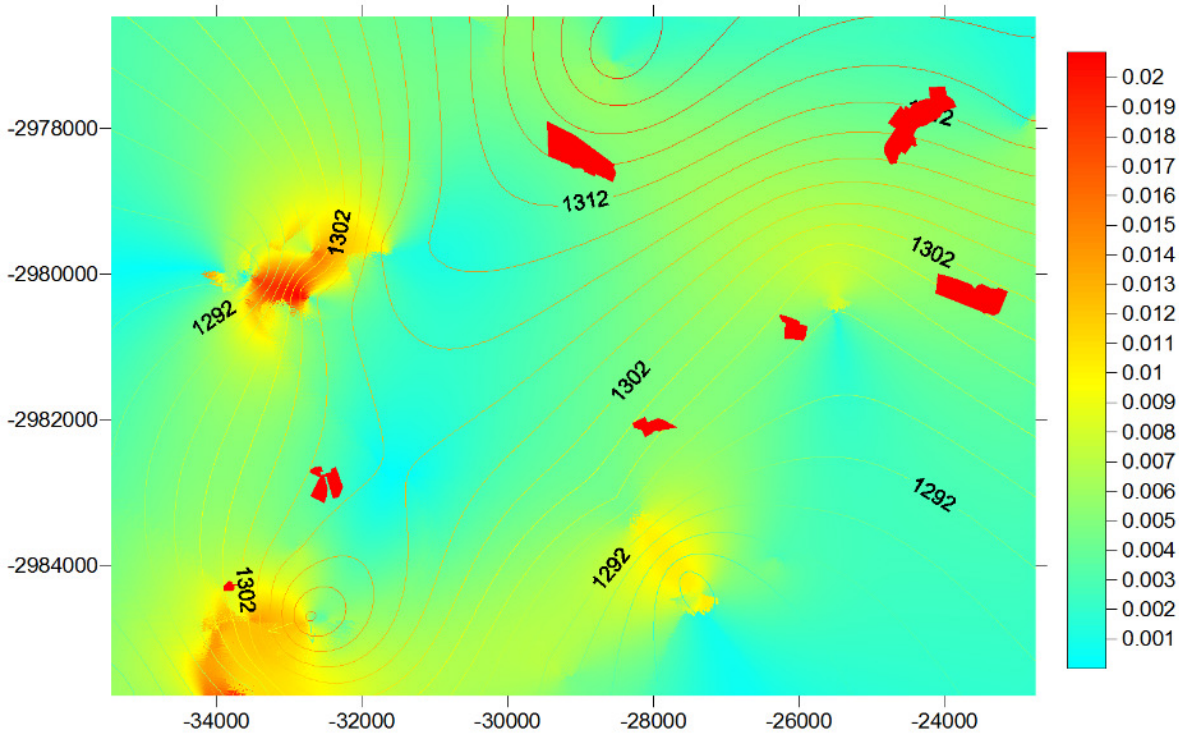


Figure 25: Hydraulic head gradients and contours in vicinity of study area

The rate of movement of ground water is important in many problems, particularly those related to pollution. For example, if a harmful substance is introduced into an aquifer upgradient from a supply borehole, it becomes a matter of great urgency to estimate when the substance will reach the borehole. The velocity at which groundwater (and pollutants) move can be calculated using a combination of i) Darcy's Law, ii) the velocity equation and iii) effective porosity (water can only move through the openings of rocks). Combining the above, an equation for the seepage velocity can be obtained:

$$\mathrm{v} = \frac{Ki}{\emptyset}$$

where: v = seepage velocity

K = hydraulic conductivity

i = hydraulic gradient

ø = effective porosity (probable)

Expected groundwater seepage rates for the various geological zones within the study area are shown in Table 23.

Table 23: Groundwater gradients and seepage rates

Aquifer	Hydraulic conductivity (m/d)	Hydraulic gradient	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
Fractured Ventersdorp	0.01	0.01	0.05	0.002	0.72
Fractured/weathered Chuniespoort	0.1	0.01	0.1	0.01	3.6

***Note**: Hydraulic parameters assigned is typically encountered for the lithology and sourced from literature*

It should be noted that because of the heterogeneity of fractured rock environments resulting from preferential flow paths formed by intrusive dykes and other igneous intrusions, the transport velocities could be orders of magnitude greater than the average velocities shown above. However, the above is based upon conservative values and could therefore imply worse case scenarios.

5.10 Aquifer types and yields

An aquifer is comprised of a geological formation, or group of geological formations, or part of a formation that contains sufficient saturated permeable material to store and transmit water and to yield economical quantities of water to boreholes or springs. It is the storage medium from which groundwater is abstracted. *It should be managed properly and at all times, be protected from over-exploitation and contamination.* The thickness and extent of an aquifer is influenced by fracture extent, orientation, aperture, as well as the thickness of the geological layers.

Four (4) possible aquifers of note can be distinguished underlying the study area (inferred from 1: 250 000 2626 West Rand Geological Map):

i) Shallow perched unconfined or semi-confined unconsolidated aquifer.
ii) Fractured and weathered confined or semi-confined lava aquifer in the Rietgat Formation of the Ventersdorp Supergroup.
iii) A shallow weathered dolomite aquifer, associated with shallow fractures and weathering on top of the solid bedrock.
iv) Alluvial aquifer related to the Vaal River and Skoonspruit.

Note that the term aquifer in this regards only refers to the usable exploitable aquifers. This usually occurs in the top 250 mbs.

5.10.1 Shallow weathered/perched aquifer

The first system is a shallow aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. This layer is sometimes also referred to as a perched aquifer. Usually this layer is poorly developed and is generally not considered as an aquifer given its inability to sustain reasonable or useful quantities of groundwater. Rainfall that infiltrates into the weathered rock soon reaches an impermeable layer of shale or clay underneath the weathered zone. The movement of groundwater on top of this shale is lateral and in the direction of the surface slope. The water discharges at surface in the forms of fountains and springs where the flow paths are obstructed by a barrier, such as a dolerite dyke, paleo-topographic highs in the bedrock, or where the surface topography cuts below the groundwater table at streams.

This aquifer generally has low yields, typically in the range of 0.1 l/s with phreatic water levels sometimes occurring on un-weathered bedrock or clayey layers. Where consideration of the shallow aquifer system becomes important is during seepage estimations into voids and mass transport simulations from mine-induced contamination sources, because a lateral seepage component in the shallow water table zone in the weathered zone often occurs. Because of its shallow position and direct interaction with the surface, this aquifer has most characteristics of a primary type aquifer.

This shallow unconfined system has very low hydraulic conductivities and transmissivities and will therefore yield very little groundwater and can as a result not be regarded as an aquifer or be exploited as such. Yields of less than 0.1 l/s are expected.

5.10.2 Fractured confined/ semi-confined lava aquifer

The second aquifer system is the double porosity lava aquifer of the Ventersdorp Supergroup where groundwater yields, although more heterogeneous, can be significantly higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often being significantly higher than the water-bearing fracture position. The aquifer forms in transmissive fractures in the consolidated and mostly impervious bedrock, and also on contact between diabase sills or dykes and the lava. Aquifer hydraulic parameters largely depend on the degree of fracturing within the host rock but hydraulic conductivity is mostly between 0.01 m/d and 0.0001 m/d. Rest water levels as recorded during the hydrocensus were between 3.98 mbs and 15.64 mbs with an average of 8.64 mbs.

5.10.3 Fractured dolomite aquifer

A fractured rock aquifer most probably exist within the dolomitic formations of the Chuniespoort. Aquifer yields largely depend on the degree of fracturing which can be significant in dolomite. Although no yield information could be obtained during the hydrocensus, boreholes drilled intersecting a good yielding fracture typically yield in excess of 5 l/s. The aquifer is however highly heterogeneous and hydraulic parameters and yields can differ substantially within the aquifer. Hydraulic conductivities typically range between 0.001 m/d and 1 m/d. Water levels recorded during the hydrocensus for the dolomitic aquifer were between 7.22 mbs and 30.26 mbs with an average of 13.0 mbs.

5.10.4 Alluvial aquifer

A Tertiary alluvial aquifer related to the Vaal River, and possibly the Skoonspruit are also probably present. An alluvial aquifer comprises of unconsolidated material deposited by water, typically occurring adjacent to rivers and in buried paleo-channels. The aquifers are generally composed of clay, silt, sand, gravel or similar unconsolidated material deposited by running water. The depth of this aquifer is unknown but is usually not greater than 30 m-50 m. Two boreholes were surveyed within this aquifer with water levels of between 3.79 mbs and 7.34 mbs. Yields were not available during the time of the survey. Alluvial aquifers are generally shallower than sedimentary and fractured rock aquifers and water levels often fluctuate due to varying recharge and pumping rates. Due to their shallow and unconfined nature, alluvial aquifers are susceptible to contamination and pollution. These types of aquifers are of primary nature and mostly homogeneous. Hydraulic conductivity of this aquifer is generally between 0.01 m/d and 10 m/d.

6. SITE CONCEPTUAL MODEL

The first step in a numerical modelling exercise is the construction of a conceptual model of the problem and the relevant aquifer domain. The conceptual model consists of a set of assumptions that reduce the real problem and the real domain to simplified versions that are acceptable in view of the objectives of the modelling and of the associated management problem.

6.1 Representative elementary volume

As discussed earlier the geohydrology and aquifers that could be affected by 7 Shaft’s dewatering is located within the Platberg/Klipriviersberg Group consisting mostly of lava, shale and conglomerate. In general, lavas have very low effective porosity and hydraulic conductivity rendering groundwater yields and movement low and slow respectively. However, the study area are widely intruded by other igneous types of rocks such as dolerite and has been subjected to intense faulting. These intrusions and fault zones have resulted in large scale fracturing of the host lava and the development of preferential groundwater flow paths for the movement of groundwater. Some fractures are laterally extensive and form important local zones of groundwater flow within rocks of generally low permeability. The model would therefore constitute a series of interconnected vertical conduits where zones of higher hydraulic conductivity exist adjacent to zones of lesser conductivity, i.e. the host rock. The hydraulic parameters of these different zones could frequently be orders of magnitude different.

From the description of the geohydrology it is highly possible that the aquifer is highly heterogeneous in that the aquifer parameters could vary sharply over short distances. It is therefore clear that on a very small scale (microscopic scale or pore scale) a porous media approach of modelling will lead to an inadequate description of the modelling problem with resulting inaccuracies. The realistic alternative therefore is to move to a coarser scale of aquifer description by introducing measurable phenomenological coefficients such as hydraulic gradients. In the continuum approach, the concept of the representative elementary volume (REV) is evoked. The REV is a theoretical approach in which representative values for flow (and transport) parameters are averaged over an appropriate volume. On a larger scale (macroscopic scale) therefore, parameters are averaged and for a sufficiently large modelling cell size (representative elementary volume) a porous media approach can be adopted by specifying regional representative aquifer parameters.

6.2 Groundwater impacts and receptors

The site conceptual model was developed using a risk based approach, whereby impact source areas were identified, pathways characterised and potential receptors identified. Initially only 7 Shaft will be operational and dewatered. Raw materials will be transported by road to Buffels Low Grade Plant in close proximity to the Hartebeesfontein No 2 shaft; which is the property of Village Main Reef Mine. CAPM Orkney Mine will therefore not have any mine residue deposits or containment dams, which within a gold mining operation probably constitutes the greatest groundwater quality risk towards shallow usable aquifer systems. Groundwater pollution is therefore not foreseen as a major geohydrological risk with regards to the operational phases. However, gold seams are known to contribute to acid mine/rock drainage (AMD). Pyrite, a mineral closely associated with gold-bearing strata and constituting between 10% and 30% of the VCR, is by far the greatest contributor to acid mine/rock drainage.

Mining gold inevitably involves exposing these pyritic materials to oxygen and water. In the deep gold mines, these materials are exposed in the voids created by the mining process. It logically follows that there will be long term water contamination risks within the shaft when it is allowed to fill with water. Aquifers within the vicinity will only be affected when the water within the shaft rises towards the environmental critical level (ECL), if or when this might occur is unknown. This type of water will have a low pH and a high acidity and contains toxic and radioactive heavy metals.

6.2.1 Deep gold mines and acid rock drainage potential

Gold and many mine wastes contain sulphidic material which may oxidise to produce acid rock drainage (ARD). A number of factors control the generation of ARD, but of primary importance are the relative abundance of acid producing minerals (generally the sulphides) and acid consuming minerals (generally carbonates and silicates), availability of water (moisture) and an oxidising environment (exposure to air).

As previously discussed, the VCR is associated with the iron sulphide mineral pyrite (FeS_2). Mining activity will expose the pyrite to oxidising agents such as oxygen and ferric iron (Fe^{3+}). A variety of mining wastes, most notably tailings, overburden and slimes contain sulphidic material (mostly pyrite) which may oxidise to produce acid rock drainage (ARD). The result is sulphuric acid generation which acidifies water it comes in contact with. This has a number of negative consequences and most notably includes the solubilisation of a variety of trace metals, radionuclides and metalloids. A number of factors control the generation of ARD, but the most important are the relative abundance of acid producing minerals (generally the sulphides) and acid consuming minerals (generally carbonates), moisture content/ingress and exposure to air.

ARD is produced when sulphidic minerals are oxidised and hydrated (exposed to oxygen and water) resulting in increased salinity, acidity and metal solubility. Precipitated secondary minerals are common to ARD environments. However, the precipitated salts can re-dissolve following oxidation resulting in mineral dissolution. Secondary salts can be classified as acid producing, non-acid producing and acid buffering. The formation of the soluble salts Al^{3+}, Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+} and Mn^{2+} sulphate salts influence the pH of a solution because of their capacity to generate or consume protons (Lottermoser, 2003). ARD typically has pH values below 2.3 and ionic concentrations exceeding 10 000 mg/l (Caruccio et. al., 1981). Pyrite (FeS_2) is recognized as the major source of ARD. Acidic water has been found associated with many mine wastes including underground flows, mine decant, wastes and ore stockpiles. During the oxidation process of sulphide ores, the sulphidic component (S_2^-) in pyrite is oxidised to sulphate (SO_4^{2-}); acidity (H^+) is generated and ferrous iron (Fe^{2+}) ions are released (Stumm and Morgan, 1996). The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

1 Acidity (H^+), Fe^{2+} and SO_4 are released into the water when the mineral FeS_2 is exposed to water and oxygen:

$$FeS_2(s)+3.5O_2+H_2O \rightarrow Fe^{2+} + 2SO_4^{-2} + 2H^+$$

2 The highly soluble Fe^{2+} species oxidise to relatively insoluble Fe^{3+} in the presence of oxygen – the reaction is slow but is increased by microbial activity:

$$Fe^{2+}+0.25O_2+H^+ \rightarrow Fe^{3+} + 0.5H_2O$$

3 Fe^{3+} is then hydrolysed by water (at pH >3) to form the insoluble precipitate ferrihydrate $Fe(OH)_3(s)$ (also known as yellow-boy) and more acidity:

$$Fe^{3+}+3H_2O \rightarrow FeOH_3(s) + 3H^+$$

4. In addition to reacting directly with oxygen, FeS_2 may also be oxidised by dissolved Fe^{3+} to produce additional Fe^{2+} and acidity:

$$FeS_2(s)+14Fe^{3+} \rightarrow 15Fe^{2+} + 2SO_4^{2-} +16H^+$$

Reaction 4 uses up all available Fe^{3+} and the reaction may cease unless more Fe^{3+} is made available (Appelo and Postma, 1999). Reaction 2, the reoxidation of Fe^{2+}, can sustain the pyrite oxidation cycle (Nordstrom and Alpers, 1999). The rate determining step is the oxidation of Fe^{2+} to Fe^{3+} (reaction 2), usually catalysed by autotrophic bacteria.

5. The overall reaction as given by Nordstrom and Alpers (1999) is:

$$FeS_2(s)+3.75O2 + 3.5H2O \rightarrow Fe(OH)_2(s) + 2SO_4^{2-} +4H^+$$

Acidity (H^+), Fe and SO_4^{2-} are the end products of the above reactions. Reaction (1) is an abiotic process occurring at a pH >4.5 due to spontaneous oxidation of the pyrite. Process (2) is the transformation of Fe^{2+} to Fe^{3+}. This is an abiotic process when pH >4.5, but slows down and becomes biotic at pH <4.5. At a pH below 2.5 the biotic process is most prominent. Reaction (3) produces ferric hydroxide (yellow boy), and further lowers the acidity by releasing protons (H^+). The Fe^{3+} oxidises the pyrite in reaction 4 even when oxygen in absent.

Process (2) is the rate limiting process in this mechanism. This process requires oxygen, therefore, the prevention of oxygen ingress and the creation of reducing conditions within the workings is crucial to slow down the oxidation of pyrite and the resulting low pH conditions. However, if the reaction has proceeded past reaction 2 to where Fe^{3+} is produced oxygen is no longer required for the reaction to continue. Fe^{3+} will continue to oxidise the pyrite releasing Fe, SO_4 and acidity until all the pyrite, or other sulphidic mineral, has been oxidised. Ultimately, pyrite in the rocks in these mining areas will be fully oxidised and AMD will cease. There is no indication as to how long this will take, but the problem is likely to persist for centuries rather than decades.

Many sulphide ores have a mixture of sulphide minerals such as pyrrhotite (FeS), arsenopyrite (FeAsS), chalcopyrite ($CuFeS_2$), galena (PbS), cobaltite (CoAsS), gersdorffite (NiAsS) and millerite (NiS). If pyrite is dominant it initiates acid formation resulting in leaching of metal sulphides and oxides. The end result of ARD is therefore a mixture of very acidic pH, high SO_4 and soluble and precipitated Fe including toxic heavy or trace metals, metalloids and/or radionuclides in solution (Nordstrom and Alpers, 1999).

Production of AMD within the shaft may continue for many years after mines are closed. The mechanism through which mine voids fill with water after closure or when pumping stops, is conceptually illustrated in Figure 26 and Figure 27.

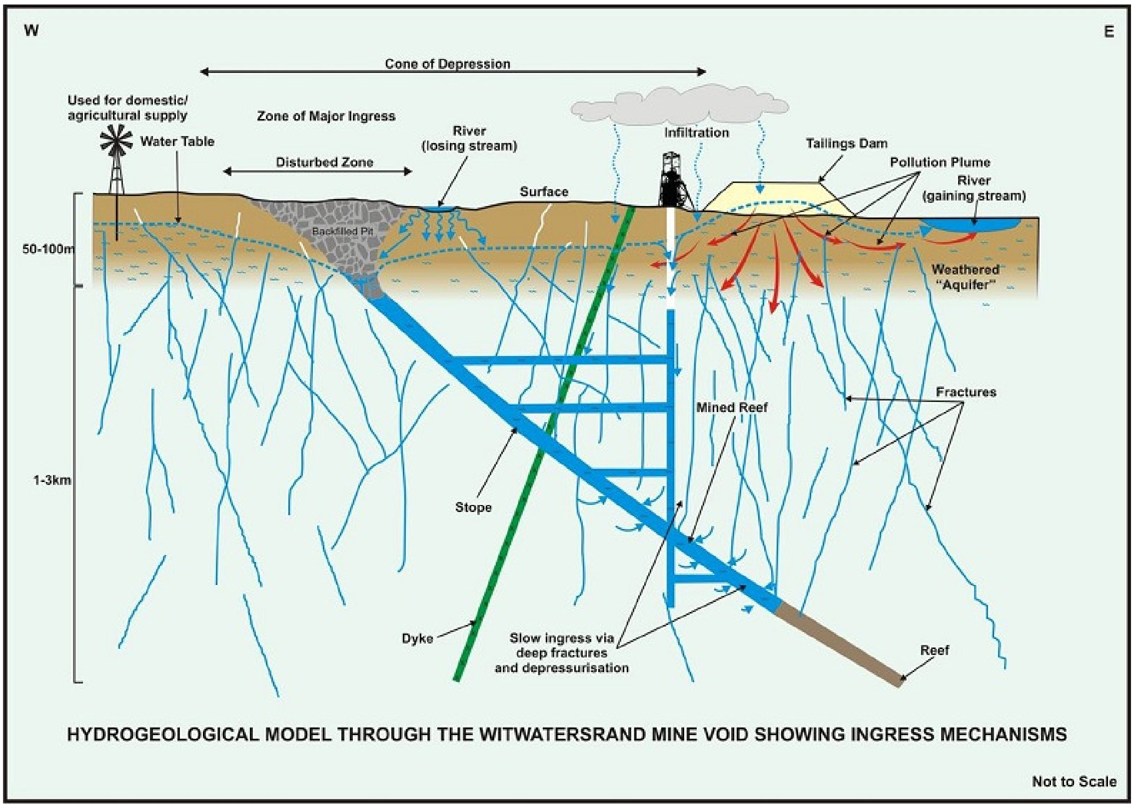


Figure 26: Conceptual model illustrating the recharge mechanisms for deep gold shafts in the Witwatersrand Goldfields (https://www.dwa.gov.za/Projects/AMDFSLTS)

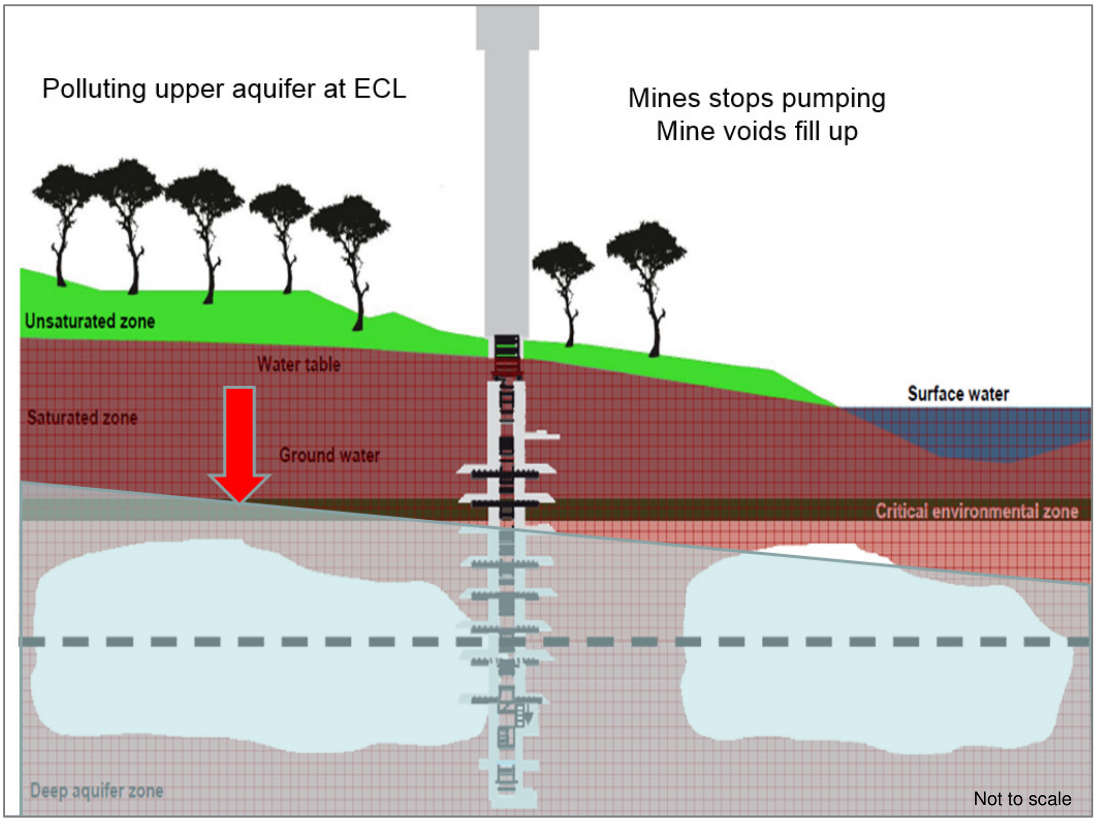


Figure 27: Conceptual illustration of the Environmental Critical Level (ECL)

6.2.2 Aquifer depletion

Initially during the operational phase, shaft dewatering could pose a groundwater depletion risk on the adjacent/overlying aquifers. Shaft dewatering will result in cone of depression, the extent of which would largely depend on the aquifer hydraulic parameters and interconnectedness of the upper aquifers and lower groundwater. If these are interconnected the cone of depression will result in a systematic drawdown of aquifer/s and may pose aquifer depletion of privately owned boreholes. It is anticipated that groundwater drawdown will constitute the greatest groundwater risk during the operational phase from an environmental perspective, the significance of which will depend on the extent of the cone of depression and the positions of privately owned boreholes. However, given the mining depth the drawdown effect on receptors is anticipated to be small.

The water abstracted will be transported to the adjacent Anglo Gold Vaal River Operations to be used in their process. No borehole abstractions other than shaft dewatering is envisaged for the mine.

The site conceptual model can be viewed in Figure 28.

6.2.2.1 Aquifer depletion

The potential impact source areas were identified as:

- *Operational phase*
    - Dewatering and potential aquifer depletion

6.2.2.2 Pathways and receptors

Any user of a groundwater or surface water resource that is affected by drawdown of the groundwater level can be defined as a receptor. Groundwater is the principle pathway. The following receptors may be found:

- Private groundwater users.
- Water courses: water users, fauna flora.

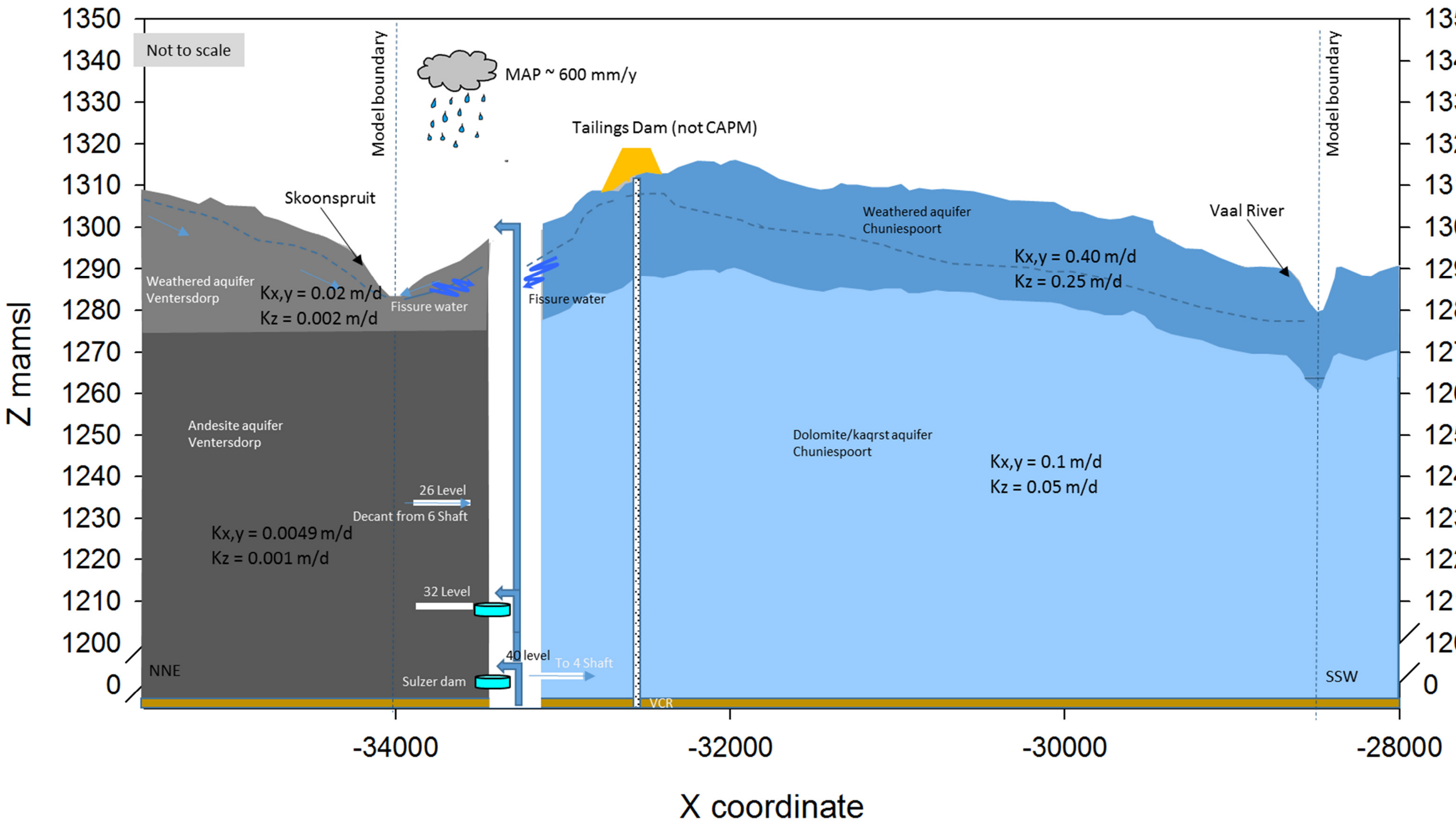


Figure 28: Operational hydrogeological conceptual model

7. NUMERICAL GROUNDWATER MODEL

7.1 Modelling software

A finite element (FE) numerical groundwater flow model was developed using the FEFLOW software code and interface. The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. FEM encompasses methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain.

7.2 Aquifer delineation

Initially, an aquifer delineation will indicate the lateral extent of the aquifer(s) in the area. An aquifer can be delineated by means of the following:

i. Mapping structures such as intrusive dykes, progressive sills or displacement faults that act as groundwater flow barriers to form aquifer compartments, and
ii. Using high or low topographical areas over which flow is not possible.

Method (i) is probably the most accurate for delineating aquifer boundaries but intricate detail are needed to map the structures of an area and these are seldom available. Therefore the modelling area was selected based on method (ii) – the use of natural groundwater barriers and flow boundaries, such as topographical highs and drainage features. The model domain delineated for the area is shown in Figure 29. The southern and western boundaries were chosen to be the Vaal River and the Skoonspruit, respectively which were assigned as hydraulic head boundaries. The north-western and north-eastern boundaries were selected based on topographical highs.

7.3 Model mesh size and setup

The model mesh was developed using 50 449 elements and 25 506 nodes with the model domain covering an area of 89.71 km^2, and differentiated using the 'Triangle' finite element method. The groundwater generated mesh is displayed in Figure 30. '*Triangle'* is an extremely fast meshing tool for complex supermeshes including lines and points. It has been developed by Jonathan Richard Shewchuk at the University of California in Berkeley. It is important to note a few aspects of the numerical modelling exercise:

- The numerical model is a very simplified representation or simulation of the actual situation.
- Measured aquifer parameters are used to calibrate the numerical model and the level of confidence of model calculations is only as good as the information (accuracy, distribution, frequency etc.) on which it is based and the conceptual understanding of the groundwater regime.
- Model calibration is done in the steady-state.

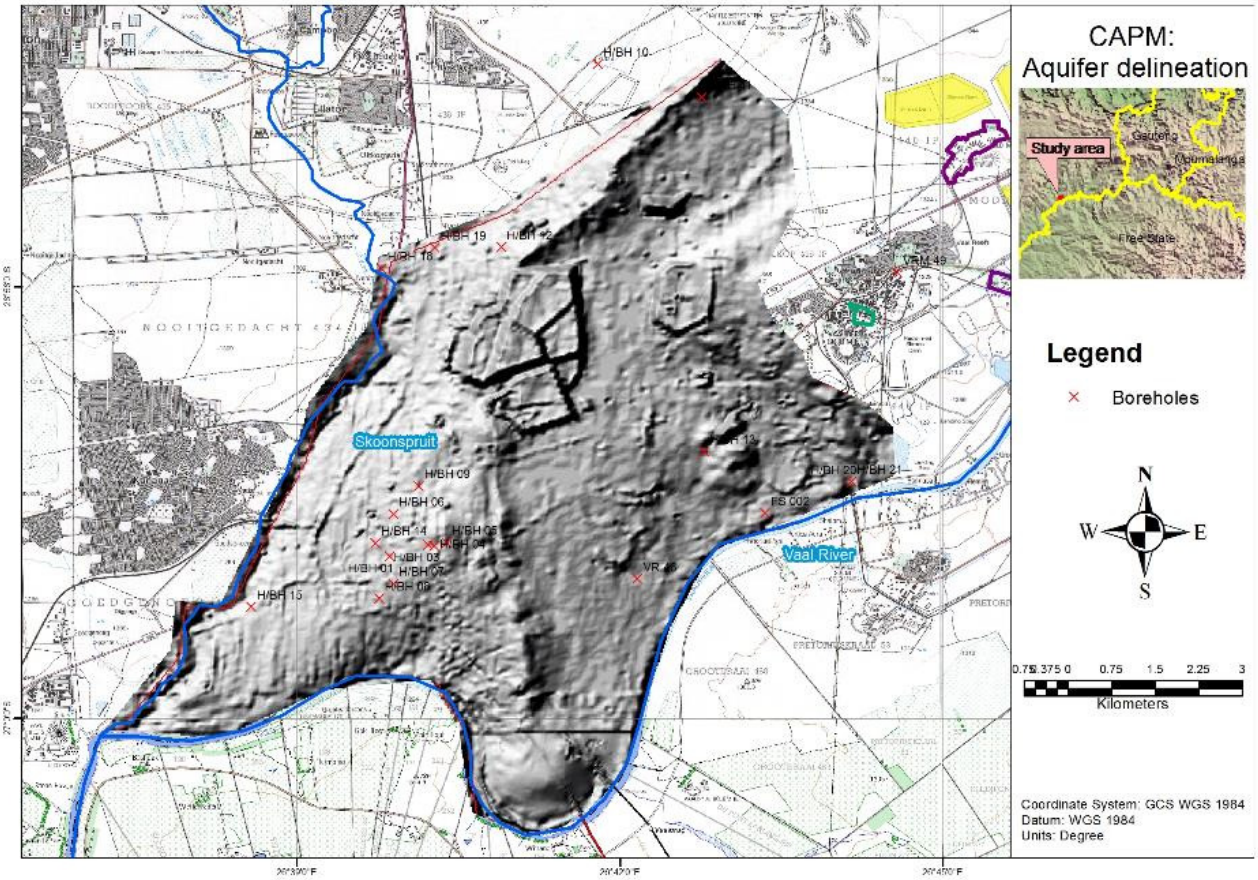


Figure 29: Model delineation

The input parameters and sources for the model setup can be viewed in Table 24.

Table 24: Model context, data, boundary conditions and assumptions

Input parameter	Scale	Source, parameter or assumption description
Topography (DTM)	1: 50 000	The topographic elevations were interpolated from the 1:50 000 scale 20 m contour intervals.
Rivers, streams, drainages	1:50 000	Digitised from topographical maps.
Geology	1:250 000	West Rand 2626 Geology map.
Boreholes and pumping rates		Data sourced from hydrocensus surveys. Water level data was available for 22 boreholes, of which 18 boreholes were situated within the model domain and were used to calibrate the model to a 91% correlation. All water levels were deemed to be of static nature during the survey.
Rainfall recharge		Rainfall data was obtained from the GRDM database.
Steady state modelling parameters		
Boundary conditions		Model boundaries consisted of hydraulic head boundaries (Skoonspruit and Vaal River to the west and south) with constraints on drainages. Topographical highs as flow boundaries were used towards the east and north.
Recharge		Recharge values are lithology specific and are expressed as percentage of the MAP.
Hydraulic Conductivity		Ranges of hydraulic values were obtained and sensitivity scenarios simulated to obtain the best possible fit. The model calibration process was used to refine the hydraulic parameters.
Transient state modelling		
Dewatering		A dewatering scenario was modelled by inserting an abstraction borehole with pumping rate at 11.59 l/s (1,330,560 l/d) with a continuous 10Y pumping time.

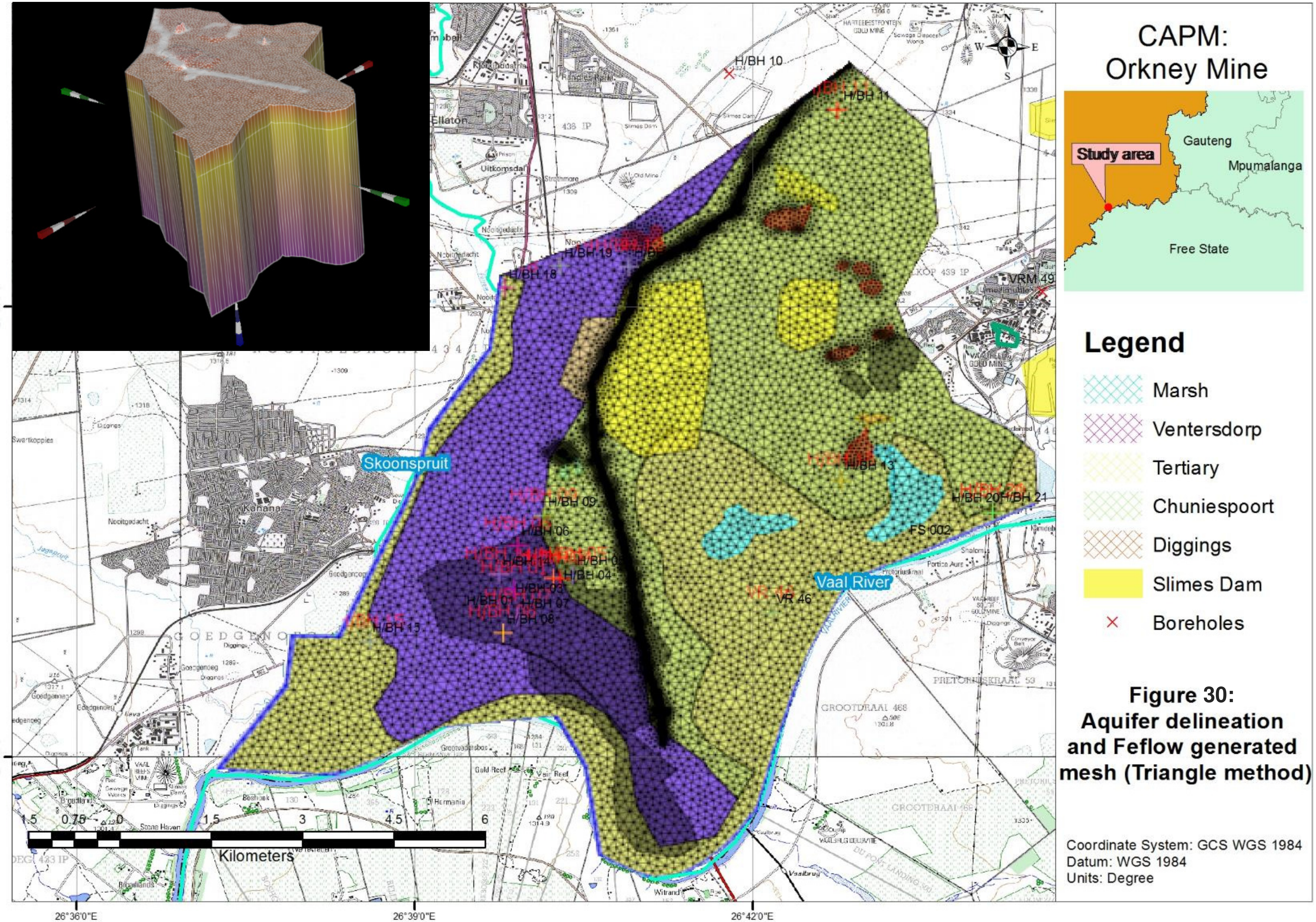


Figure 30: Aquifer delineation and Feflow generated mesh (Triangle method)

7.4 Simulation scenarios

A steady state and transient scenario were modelled in the 3-D FeFlow software. The flow model was developed and calibrated in steady-state which was used to simulate the transient flow scenarios up until the end of the operational mine phase at 7 Shaft (approximately 10 years). In the steady state, groundwater levels of gathered observation boreholes were simulated by varying aquifer parameters (hydraulic conductivity and recharge) until an acceptable fit between the measured and simulated hydraulic heads were obtained. The transient simulation was run for a period of 10 years from the onset of operation up until the end. Note that the Life of Mine of 10 years is an approximation.

The following scenarios were applied to the model:

- Scenario 1: Steady state pre-mining conditions. This scenario was used to calibrate the steady state groundwater flow model (day 0).
- Scenario 2: Transient flow model to simulate the drawdown effects on the upper aquifer resulting from shaft dewatering, simulated for a period of 10 years.

Note that because it is not expected that CAPM will contribute to groundwater pollution of the upper usable aquifer during the operational phase, given the lack of surface sources, no contaminant transport was modelled.

7.5 Limitations and assumptions of the Modelling Exercise

It must be emphasised that this modelling study concentrated on the mining development, current and foreseen, as currently occurring within the model boundary and for CAPM only. The model is based upon gathered data and scientific assumptions, especially with regards to the assumption of a homogenous porous medium, albeit not the real world situation. However, within the larger viewpoint and perspective, the Representative Elemental Volume (REV) should suffice well enough.

Other assumptions and limitations include:

- The investigation relied on existing data that were collected as a snapshot of field surveys conducted.
- A limited amount of boreholes were tested within the model domain and did not include for all the geological or hydrogeological zones. Where data was insufficient, other hydrogeological zones within the modelling catchment were assigned conservative hydraulic parameter values based on literature reviews (Freeze and Cherry, 1979; Younger, 2007).
- Aquifer parameters assigned were sourced from historical data, however it should be noted that data variability is high and the model is a simplified representation of a complex aquifer system.
- The groundwater model was calibrated in steady state.

- The groundwater model was based on a three dimensional approximation of horizontal groundwater flow.
- To simulate dewatering, pumping well was included in the model at rates obtained from the mine.
- Conservative approaches were followed with regards to assigning hydraulic and physical parameters to the steady state calibration and the transient flow model.
- Where field data was lacking for assigning of parameters, relevant data from literature was sourced.
- Except for the alluvial aquifers, stratigraphical units, delineated from surface geology within the model domain, are assumed to occur throughout the entire thickness of the model and were incorporated as such.
- Wetlands/marshes identified and delineated were assumed to be groundwater driven and flux boundaries (Neumann Type) were therefore assigned thereupon.
- Wetlands/marshes were delineated based on a desktop study and 1: 50 000 topographical maps.
- Drainages were assigned specified head (Dirichlet Type) boundary conditions allowing the system to be drained.

7.6 Steady state model calibration and flow

Aquifer parameters and recharge coefficients estimated for each zone as input to the steady state calibration model are summarised in Table 25 and Table 26, respectively. The head elevation data from 18 observation boreholes (Table 27) located within the model domain were used to calibrate the steady-state flow model. Calculated head distribution versus observed heads can be viewed in figures 31 and 32.

Table 25: Steady state calibration model hydraulic zones and parameters

Model layer	Hydrogeological unit	Hydraulic conductivity	
		Kx,y (m/d)	Kz (m/d)
Layer 1	Dolomite	0.40	0.25
	Platberg lava	0.020	0.002
	Tertiary sand	0.850	0.75
	Dykes (20m width)	0.005	
	Dykes 20m intrusion buffer zone	0.25	0.1
Layer 2	Dolomite	0.1000	0.05
	Platberg lava	0.0049	0.001
	Dykes (20m width)	0.005	0.001
	Dykes 20m intrusion buffer zone	0.250	0.075
Layer 3	VCR	0.005	0.0005

Table 26: Recharge values assigned to hydraulic zones

Hydraulic Zone	Source	Area (km²)	Recharge		
			% of MAP	Recharge (m/d)	Recharge (mm/a)
Dolomite	1:250 000 Geology (2528)	75.8	8.0	1.25E-04	45.6
Platberg lava		16.02	4.10	6.40E-05	23.37
Tertiary sand		20.35	10.00	1.56E-04	57
Dykes (20m width)		22.92	1.50	2.34E-05	8.55
Dykes 20m intrusion buffer zone	Inferred 1: 50 000 topo map	0.50	6.00	9.37E-05	34.2
Slimes		5.558	8.00	1.25E-04	45.6
Diggings		0.514	7.0	1.09E-04	39.9
Development		8.948	2.0	3.10E-05	11.315
Average			**5.92**	9.24E-05	33.19
Minimum			**1.5**	2.34E-05	8.55
Maximum			**10**	1.56E-04	57

Table 27: Observation boreholes used in model calibration

No	Site ID	X	Y	Z (mamsl)	Water Level (mbgl)	Measured Head (mamsl)
1	H/BH 01	-2984906.68	-33312.45	1313.00	7.19	1305.09
2	H/BH 03	-2984710.12	-32729.20	1323.00	10.50	1312.50
3	H/BH 04	-2984724.27	-32630.88	1324.00	11.15	1311.89
4	H/BH 05	-2984668.38	-32443.38	1321.00	9.41	1311.27
5	H/BH 06	-2984180.76	-33257.78	1316.00	10.50	1305.50
6	H/BH 07	-2985371.91	-33256.61	1310.00	6.61	1303.07
7	H/BH 08	-2985628.44	-33472.34	1308.00	10.97	1296.55
8	H/BH 09	-2983702.17	-32870.84	1315.00	9.42	1305.58
9	H/BH 11	-2977028.94	-28543.15	1344.00	21.34	1321.60
10	H/BH 12	-2979608.04	-31614.23	1321.00	11.88	1309.12
11	H/BH 13	-2983096.43	-28485.68	1307.00	8.13	1297.79
12	H/BH 14	-2984677.90	-33532.46	1310.00	7.80	1302.20
13	H/BH 15	-2985777.89	-35438.52	1294.00	7.59	1286.41
14	H/BH 18	-2979972.91	-33450.68	1293.00	2.98	1289.38
15	H/BH 19	-2979618.41	-32637.20	1303.00	5.24	1297.34
16	H/BH 20	-2983615.60	-26224.70	1297.00	7.22	1288.72
17	H/BH 21	-2983611.17	-26224.71	1297.00	7.34	1288.66
18	VR 46	-2985286.07	-29507.21	1297.00	3.79	1292.27
Average				**1298.71**	**8.84**	**1301.39**
Minimum				**1293.00**	**2.98**	**1286.41**
Maximum				**1310.00**	**21.34**	**1321.60**

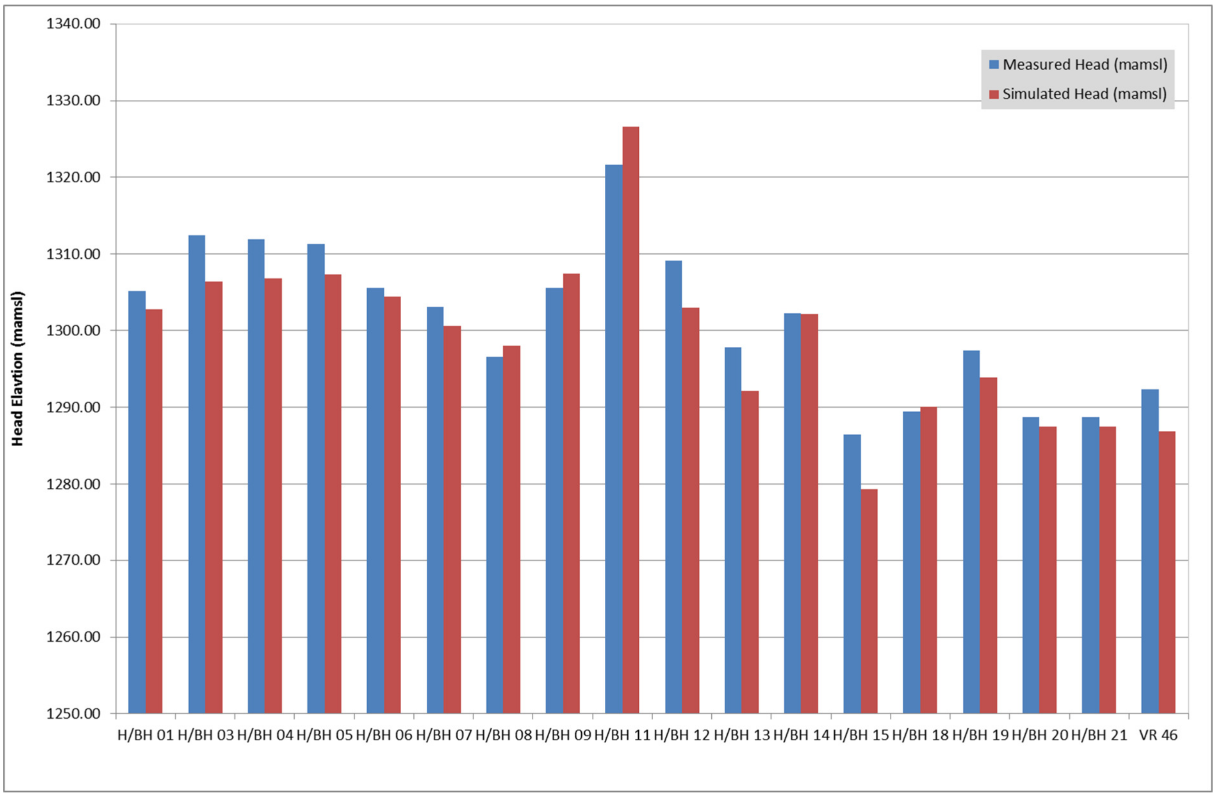


Figure 31: Simulated vs measured heads

Observed groundwater levels were plotted against measured water levels and a correlation of 0.91 was achieved (Figure 32). The correlation indicates that the developed groundwater model will accurately represent on-site conditions. The residual calibration error is expressed through the; i) mean error (ME), ii) mean absolute error (MAE) as well as the root mean squared error (RMSE) of the observed versus simulated heads. The RMSE was evaluated as a ratio of the total saturated thickness across the model domain and calculated errors are summarised below:

- Mean Error (ME): 2.38 m.
- Mean Absolute Error (MAE): 3.37 m.
- Root Mean Square Error (RMSE): 9.88 %, implicating a 9.88% deviation between observed and calibration water levels across the model domain (an error of less than 10% of the model thickness is acceptable).

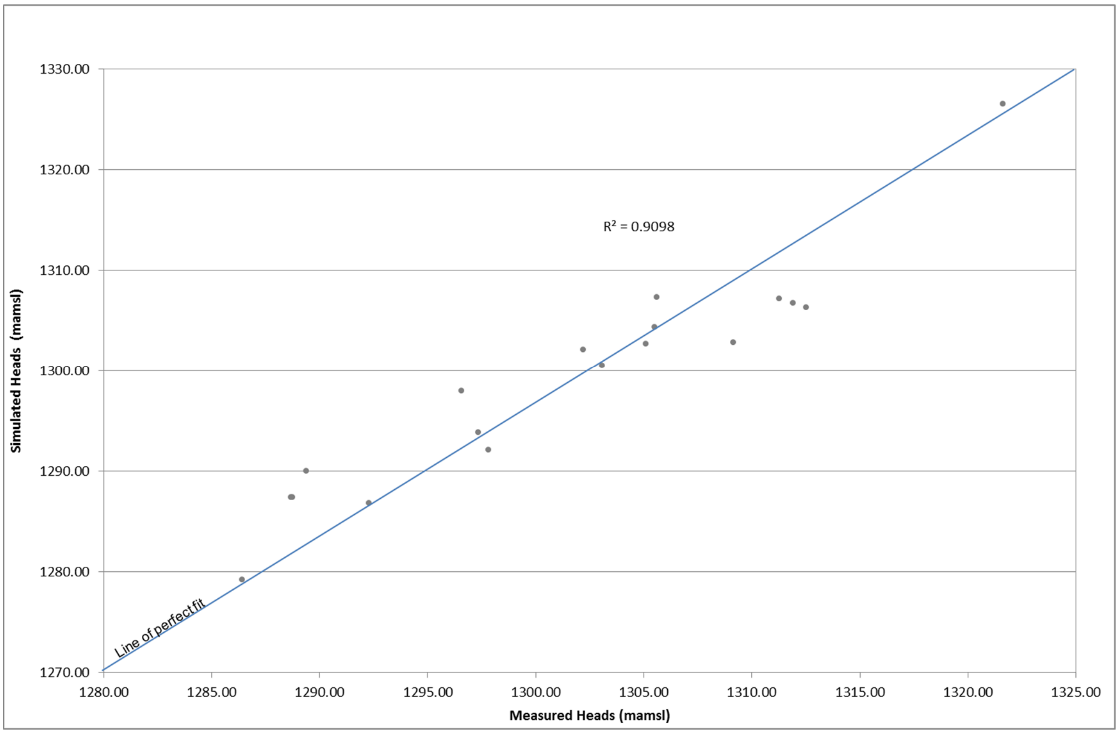


Figure 32: Correlation between calculated and observed hydraulic heads

The steady state flow patterns depicted in Figure 33 indicate that groundwater flow patterns follow the surface topography (refer to Figure 23 for Bayesian correlation) with recharge occurring at the higher elevations and discharging at lowest points, in this case being the Skoonspruit and Vaal River drainage lines, and with the dyke or faulting zone acting as a groundwater shed.

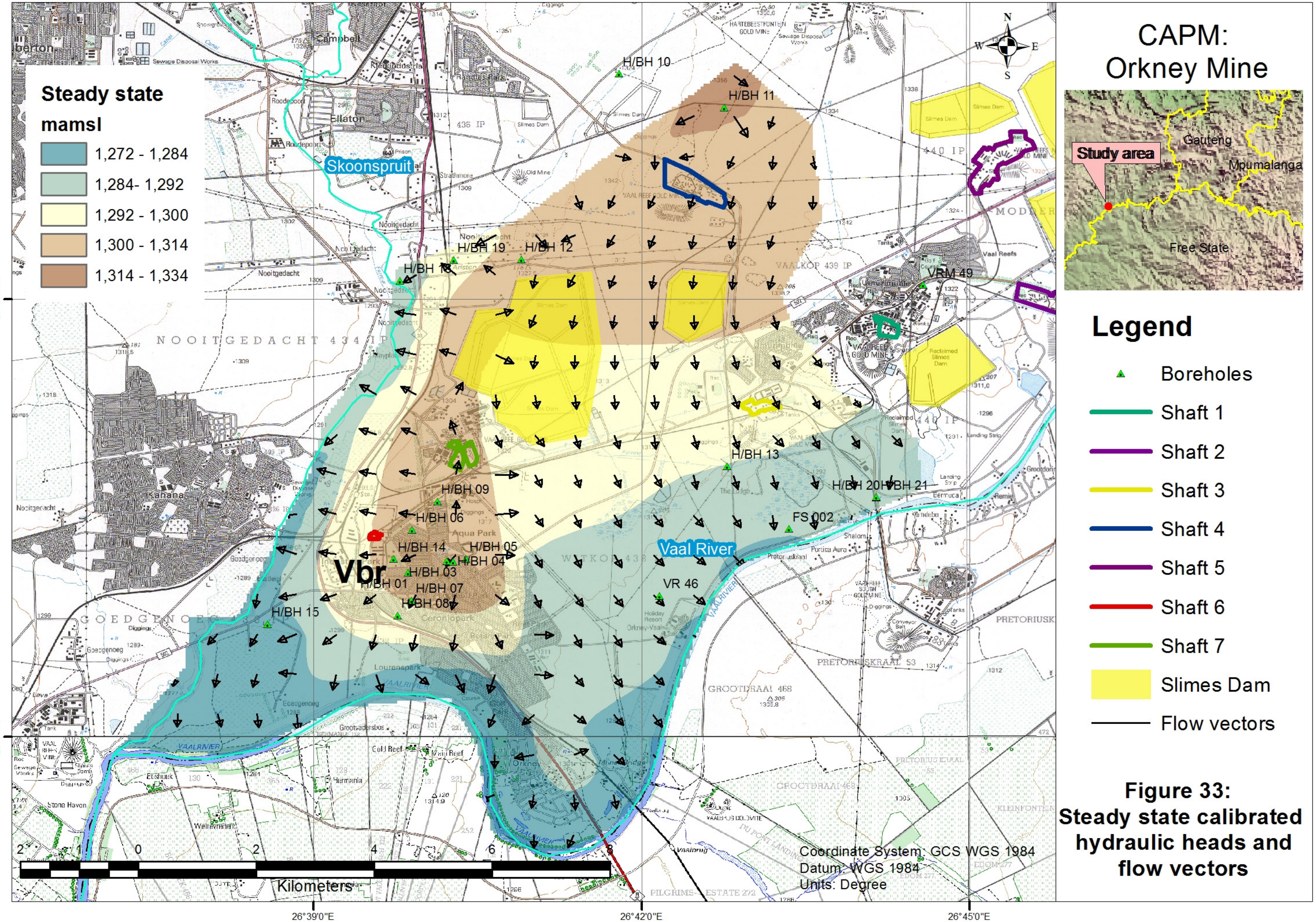


Figure 33: Steady state calibrated hydraulic heads and flow vectors

7.7 Transient flow model

The operational phase (Life of Mine) is planned to be approximately 9 years. Currently the mine is flooded and these flooded levels will have to be dewatered to allow for mining to continue, which will continue for the Life of Mine.

To simulate drawdown and the effect it will have on the groundwater table and receptor boreholes, an abstraction well was inserted into 7 Shaft. Abstraction rates (as received from CAPM) simulated for a period of 9 years are shown in the table below (Table 28):

Table 28: Dewatering rates for 7 Shaft inserted into the transient model

Well	Dewatering rate	
	l/s	l/d
Simulated dewatering well	11.59	1,330,560

7.7.1 Drawdown cone of depression

Mine dewatering will have an impact on the groundwater volumes available in the aquifers surrounding the proposed 7 Shaft but will be limited in extent. As the dewatering initiates, the zone of influence of the groundwater level drawdown will migrate and expand as the groundwater system attempts to retain a state of equilibrium. The zone of influence will however be limited given the depth of mining. The radius of influence as shown in Figure 34 indicates that the shaft dewatering will influence significantly on groundwater levels in close proximity to 7 Shaft but will not extend towards any receptors.

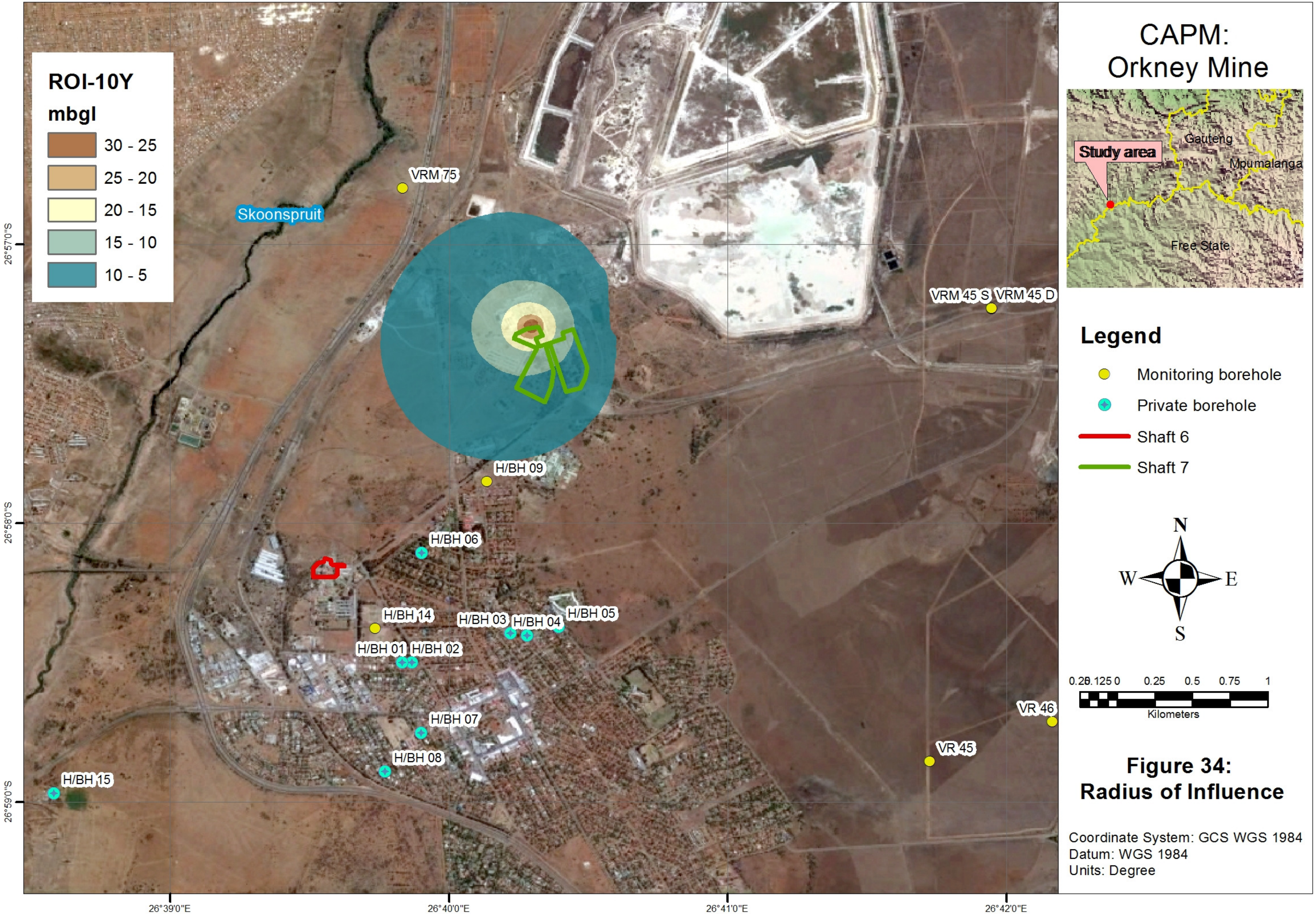


Figure 34: Radius of Influence

8. GROUNDWATER IMPACT ASSESSMENT

This part of the geohydrological input to the EMP amendment report describes and evaluates the potential impact of the 6 & 7 Shaft operational activities on the groundwater environment. It should be noted that the residual and expected future impacts of the adjacent gold residue disposal facilities on the groundwater environment was not within the scope of this investigation and was therefore not addressed in this investigation. Existing impacts and management plans are dealt with in dedicated and approved EMPR documents and closure plans for each of the applicable areas.

Activities related to the re-mining of the CAPM 6 & 7 Shaft that may potentially impact on the groundwater regime are discussed in the following subsections. An impact description of each activity is given and rated based on the results of the groundwater investigation. The most significant impacts are associated with shaft dewatering. Since no ore will be process on site, no discard, tailings dumps or pollution control dams (recognised as the largest contributors to groundwater pollution) will be generated, which was the principal reason for a groundwater transport model being excluded.

A distinction should be made between surface impacts and underground impacts. Surface impacts are mostly from tailings and rock dumps and adversely affect the groundwater and surface water quality. This occurs during the operational phase as well as after closure. Underground impacts are generally characterised by the inflow of water into the underground workings and the subsequent dewatering of the aquifer.

Groundwater quality deterioration may occur or may well have occurred in the shaft given the association of pyrite with gold ore and the prolonged residence time following the care and maintenance period. The flooded mine areas exposed to oxygen and pyrite within the mineable reef/s could undergo acid mine drainage reactions resulting in acidic pH and solubility of a range of heavy metals. Currently the quality of the flooded areas are unknown but it is probable that AMD could have occurred within the Vaal Contact Reef (VCR). Initially, pumped water will be stored within a Sulzer dam on 40 level from where it will be pumped in stages to the surface and towards the A.G.A. plant. Therefore, no groundwater quality impacts are expected to occur relating to water accumulated in 7 Shaft during the operational phase given the absence of a pathway for migration. If however, the water is to be discharged into the environment or within a receiving stream, the water quality which has accumulated should be known and compliance measured according to the General Limit.

In general, during the decommissioning phases when all dewatering activities within the KOSH area have ceased, water in the shafts may rise towards the pre-mining water levels and the Environmentally Critical Level (ECL) where, if contaminated may pollute aquifers and surface water. If the mines are allowed to flood completely there will be some interaction of mine and weathered and perched aquifers and contaminated water may seep to the Vaal River. P*revious studies with the gold mining region of* *the KOSH (Klerksdorp, Orkney, Stilfontein, Hartebeesfontein) areas indicate a likely probability of decant (17 – 50 Ml/d) and rise towards the ECL when all pumping within this region stops (WRC, 2005). However the potential impact can at this stage not be fully quantified since the Life of Mine for all the mines within the region is not known and neither are the quality nor quantity of decant water. (Due to the fact that most mines are hydrologically interconnected with the adjacent mines, the closure of one mine within the region will often have impacts on the remaining mines.)*

At the CAPM 6 & 7 Shaft the groundwater table is not expected to return to pre - mining conditions. The reason being that decant will occur at 40 Level, creating a permanent dewatering cone towards 4 Shaft. The quality of the decant water is expected to be contaminated but will improve over time as existing areas of exposed sulphide mineralisation are flooded or oxidised. It is possible that decant will occur from 4 Shaft (and others) when all mining and pumping have ceased but due to the interconnectivity of the underground mines in the region, this is currently not quantifiable.

Small groundwater quality impacts may be related to accidental spills of diesel and/ or oil on surface. Because macro-scale loading and moving equipment will be used in the proposed mining operation, millions of litres of diesel fuel and other hydrocarbons will be used each year. Fuel depots always have the risk of leakage and spillage incidents and the highest standards in design, monitoring and management at these sites will be used from construction to decommissioning. The same applies to storage, handling and disposal of all other hazardous substances like organic cleaning agents and solvents that will be extensively used at workshops and service stations.

8.1 Removal of groundwater (dewatering)

During the operational phase groundwater will be dewatered to the bottom of the No. 7 Shaft which will result in dewatering of the surrounding aquifer. However, the transient modelling exercise showed that the cone of depression is limited in extent with no boreholes included within its influence zone.

8.1.1 Management measures

- No management action is available to prevent aquifer dewatering.
- Separate clean and dirty water - divert surface flow as to not allow clean stormwater to enter the shaft areas.

8.1.2 Action plans

- Intercept drainage around the shaft.
- The dewatering of the aquifer system cannot be prevented. If the monitoring program indicates that nearby groundwater users are affected by the dewatering, the users need to be compensated for the loss.

8.1.3 Risk assessment

Impact Assessment: Dewatering

Parameter	Description	Rating
Probability	Possible	3
Duration	Lasting 1 – 5 years	3
Extent	Impacts on extended area beyond site boundary (hundreds of metres)	3
Environment	Limited damage to minimal area of low significance	1
Significance	**Medium**	**8**

8.2 Impact on groundwater quality (operational phase)

The impacts on groundwater quality are primarily related to the management of materials, wastes and spills from drilling operations and unauthorised disposal of contaminated substances. Contamination of groundwater may also arise due to incorrect handling and disposal of waste materials, the physical drilling process (sludge contains oils and greases) and oil leaks from drill rigs. This risk is considered low. Groundwater quality impacts may also arise from seepage from the recycle dam underground, although this is considered a low impact since the dam will be lined. The general risk towards groundwater quality deterioration is considered low.

8.2.1 Management measures

- During the operational phase appropriate temporary stormwater infrastructure must be developed and implemented, in accordance to Regulation 704.
- Prevent or contain contamination from spilling and oil leaks from vehicles, equipment and drill rigs.
- Construction activity management should ensure that any materials handling does not pose a material risk to soil, surface water and groundwater pollution.

8.2.2 Action plans

- Conduct regular inspections on the stormwater control measures and dam liners.
- Monthly inspections of the surface concrete work should be undertaken during the operational phase to ensure any ingress of rainwater into the shaft is prevented.

8.2.3 Risk assessment

Impact Assessment: Impact on groundwater quality (operational phase)

Parameter	Description	Rating
Probability	Possible	3
Duration	Lasting 1 – 5 years	3
Extent	Effect limited to the activity and its immediate surroundings. (tens of metres)	2
Environment	Limited damage to minimal area of low significance, (e.g. ad hoc spills). Will have no impact on the environment.	1
Significance	**Medium**	**8**

8.3 Impact on groundwater quality (decommissioning/closure phase)

During the closure phases when all pumping within the region has ceased, the water in the shaft/s may rise towards the Environmentally Critical Level (ECL) where, if contaminated and affected by AMD reactions, may pollute aquifers or surface drainages. The rate at which, and up to which point the water will rise is highly complex and unknown given the multitude of parameters and dewatering schemes within the KOSH area. However previous studies in the KOSH area indicate a likely probability of decant and rise to pre-mining conditions and the ECL. However, at the CAPM 7 Shaft the groundwater table is not expected to return to pre - mining conditions. The reason being that decant will occur at 40 Level, creating a permanent dewatering cone towards 4 Shaft. The quality of the decant water is expected to be contaminated but will improve over time as existing areas of exposed sulphide mineralisation are flooded or oxidised. The gold mines are generally grouped together very tightly, resulting in hydrological interconnections between adjacent mines. This makes it difficult, if not impossible, to consider the water-related closure risks in isolation.

Recommended long-term mine water management in terms of regional mine closure is to allow for mining basins to flood in a post-operational stage and to pump using relatively inexpensive low-lift pumping stations or well-fields to large capacity waste water treatment facilities on surface. The level to which flooding would be allowed in a regional closure area would correspond to the ECL - the level of water in the subsurface that would result in no outflow of contaminated water to the surrounding environment, nor any contamination of overlying and perched aquifers. A saleable industrial grade water product would be the end-product of treatment at surface, and would thus provide a sustainable management funding mechanism (Department of Minerals and Energy, 2008).

Currently proposed solutions to certain of the water management issues identified centre around the abstraction of contaminated water from the mine void, treatment to a quality acceptable for some water uses and sale of the water to one or other end-user. In the case of the West Rand Goldfield, this process is well advanced, with end-users having been identified for industrial quality water in the platinum mining areas surrounding the town of Rustenburg. Pilot treatment plants have been established and operated. What remains to be seen is whether these solutions truly are sustainable into the long term or whether the contaminated water in the mine voids of the Witwatersrand will remain a liability for mine owners and ultimately for society far into the future (van Tonder, *et. al.* 2008). Although the partial treatment of mine water to neutralise acidity and remove metals will be accepted in the short-term, it is important that in the medium- to long-term, mine water needs to be treated to a quality suitable for direct or indirect use.

Pumping and treating water into the future will be a costly exercise. It is therefore necessary to reduce the volume of water which is to be pumped and treated as far as possible. The water flooding the mine void comes from a number of sources, including direct recharge by rainfall, groundwater seeping into the workings, surface streams which lose water to mine openings shallow workings, open surface workings, seepage from mine residue deposits and losses from water, sewage and storm water reticulation systems. Where feasible, engineering interventions will need to be implemented to reduce the flow of water into the underground workings.

8.3.1 Management measures

- A long-term goal may entail the establishment of a joint water management strategy with mines in the region and possible treatment capacity.
- Reduce water inflow into shafts through efficient stormwater management.
- Water levels within the basins should be held at or below the relevant environmental critical levels (ECLs) through pumping of water.
- Improved monitoring of mine water, groundwater, surface water, subsidence and other geotechnical impacts of mine flooding and seismicity is required.

8.3.2 Action plans

- Implement ongoing post-closure monitoring, maintenance and operation of water treatment systems (if required).
- Develop a regional mine closure strategy with all mines in the KOSH region.
- Close or plug openings providing direct connections to surface water.
- Allow for joint flooding to the ECL at mine closure to reduce the oxidation of pyrite and pump to waste water treatment facilities.
- Short term actions could include partial treatment with neutralising minerals, but pump and treat should be a long-term goal for all mines in the KOSH region.

8.3.3 Risk assessment before mitigation

Impact Assessment: Impact on groundwater quality at closure

Parameter	Description	Rating
Probability	Possible	3
Duration	Beyond life of Organization / Permanent impacts	5
Extent	Impact on local scale / adjacent sites (km's)	4
Environment	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate	5
Significance	**Very high**	**22**

8.3.4 Risk assessment after mitigation

Impact Assessment: Impact on groundwater quality at closure

Parameter	Description	Rating
Probability	Possible	3
Duration	Lasting 1 month to 1 year	2
Extent	Effect limited to the activity and its immediate surroundings. (tens of metres)	2
Environment	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate	3
Significance	**Medium**	**8**

9. IDENTIFICATION OF WATER RELATED CLOSURE RISKS AT UNDERGROUND GOLD MINES

Due to the fact that most mines are hydrologically interconnected with adjacent mines, the closure of one mine within a region will often have impacts on the remaining mines. There is also a risk that the cumulative impact from all the mines in a region could be imposed upon the last mine in the region to cease operations. This poses a secondary risk that this last mine could be held responsible and liable for the cumulative impact of all the mines or, as a minimum, that it would be difficult, if not impossible, to apportion liability to the contributing mines within a region. It must also be recognised that different mines within a region will cease operations at different times and some framework must be established within which these mines can plan for mine closure. It is, therefore, recommended that a number of regional mine closure strategies be developed for different regions. (WRC, 2005).

In areas where mining has progressed over a period of many years, mine closure planning cannot be conceived in the initial stages of mine planning, but should become an integral part of ongoing planning and review as a matter of urgency. Poorly planned closure strategies or lack of closure strategies have the potential to cause long lasting negative economic impacts on the community. While the immediate impact is the loss of jobs and income used to support the growth of a community, there is also a direct and indirect impact on local employment, businesses, and the sale of goods and services. The negative impact on the economy can give rise to negative social impact, such as a rise in unemployment, increased crime levels and decreasing standards of delivery in social services (van Tonder *et. al.*, 2008).

Mine closure in areas of cumulative and integrated environmental impacts, without regional closure strategy planning, not only results in negative social and national economic impacts, but may also be severely detrimental to the immediate and surrounding physical environment (van Tonder *et. al.*, 2008). In assessing the closure issues relating to water, the following important points need to be considered (WRC, 2005):

1. The source of water-related impacts on a gold mine can be divided into two primary components, i.e. aboveground features and underground features.
2. All South African gold mines are extracting ore and waste material that are associated with sulphide minerals (and a greater or lesser amount of neutralizing minerals) and other contaminants and there is, therefore, an inherent water quality risk associated with gold mines. Additionally, gold mine ore bodies are associated with radionuclides.
3. The gold mines are generally grouped together very tightly, resulting in hydrological interconnections between adjacent mines. This makes it difficult, if not impossible, to consider the water-related closure risks in isolation and consequently, a number of distinct hydrological

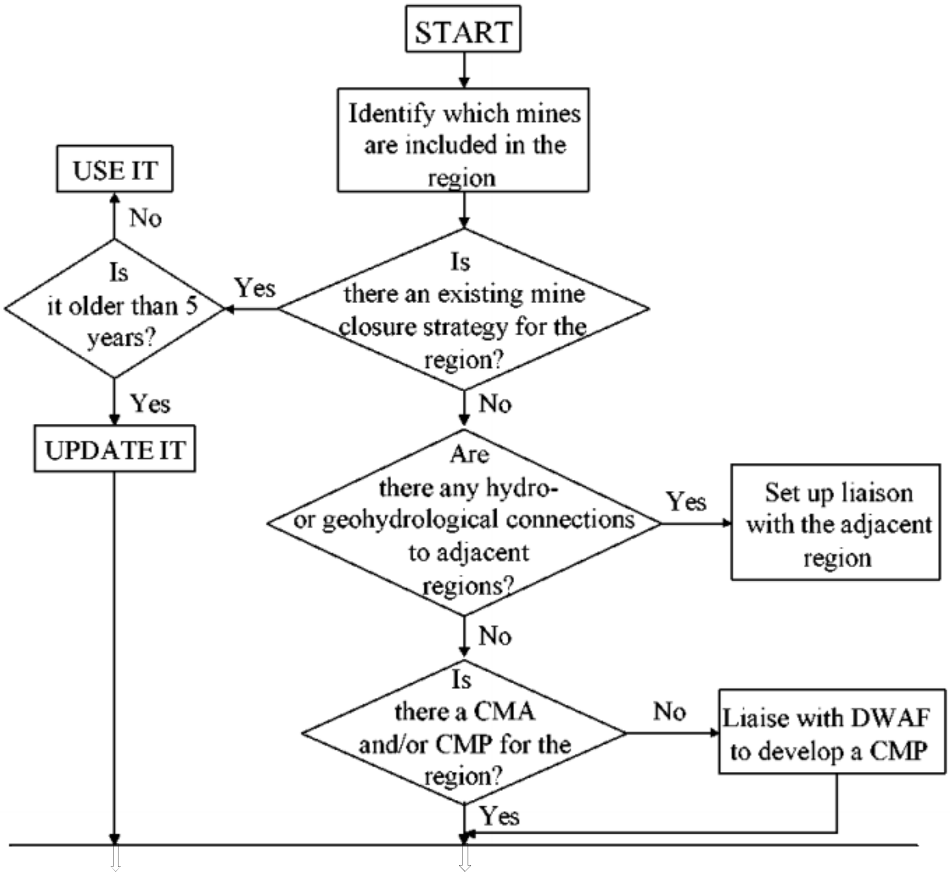
groupings of mines has been defined, each of which should develop a regional mine closure strategy within which individual mine closure plans can be assessed.

4. The surface residue deposits (tailings dams and waste rock dumps) that remain after mine closure can never be maintained in a completely reducing environment and must be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geochemical assessment (*not applicable for CAPM 7 Shaft mining although it will contribute the cumulative impact and should be considered*).
5. Underground mine workings will fill up with water over time (slow or fast depending on geohydrological setting) and this water will be contaminated (either for a limited time or in perpetuity). A key element influencing the risk that these processes pose to the water resource is whether or not this contaminated water will decant into the underground aquifers or into the surface water resource and to what extent the natural water resource can assimilate this contamination. The underground workings must, therefore, be considered to pose a potential water related risk until shown otherwise by way of a suitable regional semi-quantitative or fully quantitative geohydrological and geochemical assessments.
6. In certain mining regions, underground dewatering activities and placement of surface residue deposits pose a long-term risk with regard to formation of sinkholes which in turn pose safety, water resource and land use risks that need to be assessed.

9.1 Preparation of a regional mine closure strategy

The concept of regional mine closure is a pioneering initiative attempting to set a new system in place to protect the South African environment and communities against the impact of mining and mine closure and to ensure sustainability after mine closure. The situation of interconnected mines of the Witwatersrand Goldfields pose a unique challenge to the industry, regulators and communities impacted by more than a century of mining (van Tonder *et. al., 2008*).

In the development of a regional mine closure strategy the first step is to establish which mines are included within each region. It would clearly be reasonable that either all the mines within a given region jointly manage and fund the development of this strategy. A proposed procedure for the development of such a regional mine closure strategy is shown in Figure 35 (WRC, 2005).



DEVELOP A REGIONAL MINE CLOSURE STRATEGY

1. Construct a 3-dimensional model of all the underground workings for all the mines in the region.
2. Define all confirmed and potential hydraulic interconnections between mines.
3. Define anticipated remaining life of mine for each mine and shaft.
4. Develop a regional-scale groundwater model capable of quantifying major water ingress points, rates flooding and inter-mine flow rates.
5. Undertake a regional-scale geotechnical assessment to define regional inter-mine pollution loads.
6. Establish the probability of decant of contaminated underground water into the aquifer or surface water systems and the location, volumes and contaminant loads associated with such decants.
7. Establish surface and groundwater impacts associated with surface features (e.g. tailings dams, waste rock dumps, evaporation pans, metallurgical plant footprints, etc.).
8. With reference to the applicable WMP, establish the acceptable volumes and contaminant loads and negotiate and agree with authorities.
9. Apportion acceptable load to each mine within region and reach agreement between mines and authorities.
10. Develop and implement regional monitoring programmes to provide data to validate the basis of the regional mine closure strategy.
11. Where some of the mines are expected to impact on adjacent regions, ensure that appropriate communications are maintained with such regions.

Issue the approved regional mine closure strategy to mines and authorities in the region

Figure 35: Development of a regional mine closure strategy

10. GROUNDWATER MONITORING

The NWA introduced the concept of Integrated Water Resource Management (IWRM), comprising all aspects of the water resource, including water quality, water quantity and the aquatic ecosystem quality (quality of the aquatic biota and in-stream and riparian habitat). The IWRM approach provides for both resource directed and source directed measures. Resource directed measures aim to protect and manage the receiving environment. Examples of resource directed actions are the formulation of resource quality objectives (RQOs), the development of associated strategies to ensure ongoing attainment of these objectives, catchment management strategies and the establishment of catchment management agencies (CMAs) to implement these strategies (DWAF, 2006).

Source directed measures aim to control the impacts at the source through the identification and implementation of pollution prevention, water reuse and water treatment mechanisms. The integration of resource and source directed measures forms the basis of the hierarchy of decision-making aimed at protecting the resource from waste impacts. This hierarchy is based on a precautionary approach and the following order of priority for mine water and waste management decisions and/or actions is applicable (DWAF, 2006):

RESOURCE PROTECTION AND WASTE MANAGEMENT HIERARCHY

Step 1: Pollution Prevention

↓

Step 2: Minimisation of impacts

Water Use and reclamation

Water treatment

↓

Step 3: Discharge or disposal of waste and / or waste water

Site specific risk based approach

Polluter Pays Principle

10.1 Monitoring Principles and the risk based approach

Monitoring in general should follow the risk based approach to define or characterise the risk/s that the mining operation and its infrastructure poses on the receiving environment. This risk based approach is described in detail in the Best Practice Guideline, BPG 4: - Impact Prediction (DWAF, 2008).

Risk assessment entails the understanding of the generation of a hazard, the probability that the hazard will occur and the consequences if it should, i.e. understanding of the complete cause and effect cycle. The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is aimed at describing and defining the relationship between cause and effect.

10.1.1 Defining the source term

In the context of predictions of impact on the water resource, the main source are considered to be dewatering of the aquifer.

10.1.2 Defining the pathway

In the current context and with respect to aquifer depletion as the most significant impact during operation and groundwater quality impacts during decommissioning/closure, groundwater is also considered as the pathway.

10.1.3 Defining the receptor

The receptors in the context of the water resource would be users of the water resource itself and typical examples could be the following:

- Aquifer depletion of privately owned boreholes dependant on groundwater for domestic, livestock watering or irrigation use (operational).
- Depletion of the perched aquifer in vicinity impacting on the wetlands and its functionalities (operational).
- Reducing baseflow towards rivers/streams affecting natural flow and aquatic fauna and flora (operational).
- Deteriorating water quality of groundwater and surface water with severe consequences on users (decommissioning/closure).

10.2 Monitoring Programme

10.2.1 Monitoring points

Since no groundwater quality impacts are expected during operation of CAPM 7 Shaft no additional groundwater quality monitoring are proposed to be implemented. However, a risk of groundwater depletion was recognised during the groundwater study. Because the shaft will be dewatered, an alteration of normal groundwater flow patterns will occur in that groundwater located within the cone of depression will be flowing radially inwards towards the shaft creating a drawdown effect. Although the numerical model indicated that no impact is expected on receptor boreholes it is nevertheless proposed that monitoring of water levels take place to verify this (also needed for model updating).

A risk of groundwater deterioration does however remain within the shaft given the contact with pyrite and oxidation thereof. However, due to the short residence time during the operational phases of mining this effect may be negligible. In addition, due to the lack of a pathway for pollutant migration no risk towards receptors remain during the operational phase. However, during the decommissioning phase, groundwater will accumulate and residence times will be increased when pumping ceases. A risk of water levels rise to the *Environmentally Critical Level* and/ or decant remain when all pumping in the region ceases.

Nine (9) boreholes were identified to be included in the monitoring programme as listed in Table 29. These boreholes should be included in the monitoring programme prior to and during the operational phases of mining on a quarterly frequency. It is recommended that monitoring be initiated at least three months prior to commencement of the project to allow for seasonal fluctuations and to establish baseline conditions.

Table 29: Boreholes to be included for water level monitoring

Borehole	South	East	Owner	Use	Frequency	Expected impact
HBH 01	-26.97502	26.66445	Mr Bylefeld	Garden use	Monthly	Low
HBH 02	-26.97499	26.66387	Mr Els	Garden use		
HBH 03	-26.97326	26.67033	Mr Swart	Garden use		
HBH 04	-26.97339	26.67132	Mr Smit	Garden use		
HBH 05	-26.97289	26.67321	Mr Tretheweg	No use		
HBH 06	-26.96847	26.66502	Mr Magakwe	Garden use		
HBH09	-26.96416	26.66893	Mine property	Monitoring		
HBH14	-26.97295	26.66224	Municipality	Unknown		
VRM75	-26.94659	26.66390	Mine property	Monitoring		

Water pumped from operational CAPM shafts should be included for groundwater quality monitoring on a monthly basis for the parameters in Table 30.

Table 30: Groundwater constituents for analysis

Locality	Analyses	Frequency
7 Shaft dewatering	pH, EC, Ca, Mg, Na, K, Cl, SO_4, total alkalinity, NO_3, NO_2, PO_4, F, NH_4, As, Cd, Cr_6^+, Cu, CN^-, Fe, Pb, Mn, Hg, Se, U, Zn, B, COD, suspended solids, SOG, F. coliforms	Monthly

This monitoring schedule will must re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. Should the sampling program be changed, it would be done in consultation with the Department of Water Affairs (DWA).

Because no groundwater (or surface water) impacts are expected to occur during the operational phases of mining at 7 Shaft, no groundwater quality monitoring is proposed. However, during the decommissioning/closure phases when all pumping has ceased within the region, groundwater quality (and surface water quality) remains at risk. A regional mine closure strategy should specify water quality monitoring requirements which should be jointly managed and funded by all mines in the region.

APPENDIX A

WATER QUALITY CERTIFICATES