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MOOIPLAATS COLLIERY HYDROGEOLOGICAL SPECIALIST INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

February 2020

Conducted on behalf of:
Environmental Impact Management Services (Pty) Ltd

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List of Abbreviations

ABA	**Acid Base Accounting**
AP	**Acid Potential**
ARD	**Acid Rock Drainage (also referred to as acid mine drainage (AMD))**
ASTM	**American Society for Testing Materials**
Avg	**Average**
AUC	**Average Upper Crust**
BH	**Borehole**
CMB	**Chloride Mass Balance**
D	**Saturated Thickness**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs and Sanitation (formerly DWA or DWAF)**
EC	**Electrical Conductivity (mS/m)**
EIA	**Environmental Impact Assessment**
EIMS	**Environmental Impact Management Services**
E.N.	**Electro Neutrality**
EPA	**United States Environmental Protection Agency**
F	**Spring**
FEFLOW	**Finite Element Flow**
FEM	**Finite Element Mesh**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN 704	**Government Notice 704**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
ISP	**Internal Strategic Perspective**
IWULA	**Integrated Water Use License Application**
K	**Hydraulic Conductivity (m/d)**
l/s	**Litre per second**
LC	**Leachable Concentration**
LCT	**Leachable Concentration Threshold**
LOI	**Loss on Ignition**
LoM	**Life of Mine**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute Error**
mamsl	**Metres Above Mean Sea Level**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
mbsl	**Metres Below Static Level**
mcm	**Million Cubic Metres**
ME	**Mean Error**
meq/L	**Mili-equivalents per litre**

mg/l	**Milligrams per litre**
mm/a	**Millimetre per annum**
mS/m	**Mili Siemens per meter**
MPRDA	**Minerals and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
NAG	**Net-Acid Generation**
NGA	**National Groundwater Archive**
NNP	**Net Neutralisation Potential**
NP	**Neutralisation Potential**
NPR	**Neutralisation Potential Ratio**
NGDB	**National Groundwater Database**
NRMSD	**Normalised Root Mean Square Deviation**
NWA	**National Water Act (Act 36 of 1998)**
REV	**Representative Elementary Value**
RMSE	**Root Mean Square Error**
RQO	**Resource Quality Objectives**
S	**Storage coefficient**
Sc	**Specific Storage**
SoW	**Scope of Work**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
T	**Transmissivity (m^2/d)**
TCLP	**Toxicity Characteristic Leachate Procedure**
TC	**Total Concentration**
TCT	**Total Concentration Threshold**
TDS	**Total Dissolved Solids**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
USGS	**United States Geological Survey**
WGS	**World Geodetic System**
WM	**With Mitigation**
WOM	**Without Mitigation**
WUL	**Water Use Licence**
XRD	**X-Ray Diffraction**
XRF	**X-Ray Fluorescence**

Executive summary

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological specialist investigation and long-term water liability assessment for Coal of Africa Limited. The investigation will be performed in support of an Integrated Water Use Licence Application (IWULA) to be lodged in terms of Section 40 of the National Water Act, Act 36 of 1998 (NWA) for the extension of the existing underground mining operation of Mooiplaats Colliery.

The topography of the greater study area is strongly undulating with surrounding hills and plains. The highest topographical elevation on-site is 1724.0 mamsl to the northern boundary of the mine lease area while the lowest is at 1587.0 mamsl forming part of the lower laying drainage system towards the southwestern part of the mine lease area. On-site gradients are relatively gentle to moderate with the average slope calculated at 3.0% and –3.10% respectively

The project area falls under the Upper Vaal WMA is situated within quaternary catchment C11B. The Witpuntspruit convergence with the Vaal River before entering the mine lease area and the Wolwespruit joins the Vaal River just before it exists the mine lease boundary.

Patched rainfall data indicate that mean annual precipitation (MAP) for this rainfall zone is 700.16 mm/a, with the 5th percentile 521.72 mm/a and the 95th percentile 866.03 mm/a.

The study area is underlain by the Ecca Group of the Karoo Supergroup and fall within the Vryheid Formation, consisting mainly of arenaceous and argillaceous strata. A geological lineament and inferred dyke structure transect the northern footprint of the proposed underground workings striking in a general southwest-northeast direction.

Three main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones.

iii. Shallow quaternary and recent types of sediments (perched, unconfined) are characteristically a primary porosity aquifer.

Hydraulic conductivity values for the weathered, shallow aquifer is expected to be higher than the fractured aquifer host, however isolated discrete fractures may also provide high conductivity.

An approximation of recharge for the study area is estimated at ~6.0 % of MAP i.e. ~42.0 mm/a.

Off the boreholes visited during the hydrocensus user survey, the majority is in use (>90.0%)) with the groundwater application mostly for domestic and livestock purposes ~90.0%.

The unsaturated zone within the study area is in the order of 0.0 mbgl to 29.56 mbgl with a mean thickness of approximately 8.0 m.

Analysed data indicates that most surveyed boreholes correlate very well to topographical elevation with the regional groundwater flow direction dictated by topography.

The minimum water level recorded is artesian, 0.0 mbgl, various spring localities were also recorded within the greater study area, with the deepest static water level measured at borehole locality MPG-B16, 29.56 mbgl.

The inferred groundwater flow direction will be towards the lower laying drainage system of the Vaal River transecting the project area and will flow in a general southern to south-eastern direction

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas is moderately flat and calculated at approximately 0.008.

The expected seepage rate from contamination originating at the mine discard dump is estimated at an average of 8.6 m/a and will be dependent on local groundwater gradients.

It is noted that the overall water quality of groundwater and surface water sample analysed is good with most macro and micro determinants below the SANS 241:2015 limits. Isolated samples indicate elevated concentrations of fluoride, nitrate as well as heavy metals i.e. manganese and iron.

It is evident that monitoring localities MPG-B2 and MPG-B7 is impacted on due to their close proximity to the existing discard dump. It should be note that the majority of other monitoring localities samples analysed is good and suggest an unimpacted aquifer system.

Two distinct water categories can be distinguished i.e. Category A (Calsium-Bi-carbonate dominance, indicative of recently recharged groundwater) and Category B (Sodium/Potassium- Bi-carbonate dominance suggestive of a dynamic and coordinated environment).

It is evident that sampling locality HBH09 indicate a different hydrochemical signature compared to the other sampling localities. The hydrochemical signature of the spring localities sampled correlate well with the shallow aquifer signature and it can be inferred that spring water discharges from the shallow, weathered aquifer.

Geochemical testing was performed on mine waste facilities i.e. coal discard material as well as coal product gathered from existing stockpiles. It is evident that both composite samples analysed have a likely acid generation capacity, and due to the relatively high sulphide concentrations observed, there is enough oxidisable sulphides to sustain long term acid generation. The waste assessment conducted resulted in all the material analysed being classed as Type 3 wastes with a low risk capacity for leachate.

A GQM Index = 4 was estimated for the aquifer system and according to this estimate, a "**Medium**" level groundwater protection is required for this aquifer system. According to the DRASTIC index methodology applied, this mining activities and associated infrastructure's risk to groundwater pollution is rated as "**High**", Di = 121 due to the relatively shallow groundwater table/ piezometric head as well as flat topographical slopes.

Groundwater flow model simulations suggest the average groundwater ingress and underground dewatering volume for the LOM will be approximately $5.10E^{+02}$ m^3/d. It is expected that the groundwater drawdown will range from 2.0 m to ~ 7.0 m below the static water level (mbsl) i.e. pre-mining water levels covering an estimated area of approximately 13.0 km^2, propagating towards a western as well as north-eastern direction, reaching a maximum distance of ~750 m to the west and 1050 m to the northeast. It is noted that there is not a significant influence on water levels of neighbouring boreholes for the duration of the proposed mining operation. This can be attributed to the proposed underground void depth and hence dewatering levels and proximity of the boreholes to the pit footprints.

Baseflow discharges to the Vaal Rivers and Witpuntspruit accounts to approximately 1 326.0 m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1 117.0 m^3/d. This accounts for an average loss of ~16.0%.

It is estimated that under average rainfall conditions (MAP) the underground void will be flooded in approximately 34 years after ceasing of mining activities. The proposed depth and geometry of the underground operations allows for the entire footprint to be flooded without any decant expected.

The simulated sulphate pollution plume extend emanating from the discard dump as well as coal stockpile dumps covers an area of approximately 0.72 km^2, reaching a maximum distance of 180.0 m in a general eastern to north-eastern direction and suggest that no neighbouring boreholes as identified during the hydrocensus user survey are impacted on during the operational life of mine. Monitoring locality MPG-BH01 exceeds the SANS 241:2015 threshold for sulphate after a period of approximately eight years, reaching a maximum concentration of 560.0 mg/l.

The expected pollution plume migration potentially emanating from the underground mined out faces does not migrate more than ~100.0 m – 150.0 m from the mining footprint for the operational life of mine.

The preferred mitigation scenario i.e. implementation of a cut-off trench down-gradient of waste facilities reduces the plume extend to 0.57 km^2, with an effective footprint reduction of >20.0 %.

Post-closure the pollution plume migration stretches beyond the mine lease area to the north. The plume still does not reach any neighbouring boreholes, however two drainages and tributaries of the Witpunt-spruit towards the northern and eastern border can potentially be affected post-closure.

The model results were incorporated into a risk rating matrix to determine the significance of potential groundwater related impacts as discussed below:

During the operational phase the environmental significance rating of groundwater yield (dewatering) impacts on down-gradient receptors are rated as medium negative whereas the groundwater quality related impacts are rated as low negative. Groundwater quality impacts from the discard dump and coal stockpile areas are rated as medium negative without implementation of remedial measures and low negative with implementation of mitigation measures.

Post closure phase impacts resulting from seepage and leachate from mine waste facilities on down-gradient receptors are rated as medium negative without the implementation of remedial measures and low negative with implementation of mitigation measures.

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1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological specialist investigation and long-term water liability assessment for Coal of Africa Limited. The investigation will be performed in support of an Integrated Water Use Licence Application (IWULA) to be lodged in terms of Section 40 of the National Water Act, Act 36 of 1998 (NWA) for the extension of the existing underground mining operation of Mooiplaats Colliery. Mooiplaats Colliery (Pty) Ltd operates an existing underground mine and has an approved Mining Right MP 30/5/1/2/2/68 MP, 2007 (MR) and Integrated Water Use Licence No. 08/C11B/AGJ/2141, 02 May 2013.

This investigation will focus on the status quo of the regional groundwater system and quantify/ qualify potential impacts of the proposed activities on sensitive environmental receptors.

1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors.
ii. Determine the current status quo of the regional groundwater system including aquifer classification, aquifer unit delineation and vulnerability.
iii. Geochemical assessment and source term determination.
iv. Development of a numerical groundwater flow and mass transport model.
v. Hydrogeological impact assessment and risk matrix.
vi. Recommendations on best practise mitigation and management measures to be implemented.
vii. Compilation of an integrated groundwater monitoring network and protocol.

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-18-029-V4, submitted in January 2019. This project plan and scope of work (SoW) was compiled based on Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications as published by the Department of Water Affairs and Sanitation (DWS, 2017) as well as Government Notice NO. R. 982: Environmental Impact Assessment (EIA) Regulations controlling environmental authorization applications (NEMA, 2014). The scope of work is listed below.

1.3.1. Phase A: Desktop review and data evaluation

Phase A will entail the following activities:

i. Information gathering and data acquisition.
ii. Desk study and review of historical groundwater baseline information and existing specialist reports.

iii. Fatal flaw and gap-analysis

1.3.2. Phase B: Hydrogeological baseline assessment - hydrocensus user survey, hydrochemical analysis and aquifer classification

Phase B will entail the following activities:

i. Evaluation and review of existing monitoring data to determine trend analysis as well current background conditions and status quo.

ii. Hydrocensus user survey to evaluate and verify existing surface and groundwater uses, local and neighbouring borehole locations and depths, spring localities and seepage zones, regional water levels, abstraction volumes, groundwater application as well as environmental receptors in the vicinity of the existing underground mining footprints.

iii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of ten (10) water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

iv. Assess the structural geology and geometry of the aquifer systems with respect to hydraulic interactions and compartmentalisation.

v. Data interpretation aiding in aquifer classification, delineation and vulnerability ratings. Development of a scientifically defendable hydrogeological baseline.

vi. Compilation of geological, hydrogeological and hydrochemical thematic maps summarising the aquifer system(s), indicating aquifer delineation, groundwater piezometric map, depth to groundwater, groundwater flow directions as well as regional geology.

1.3.3. Phase C: Geochemical assessment and source term determination

Phase C will entail the following activities:

i. Laboratory analysis for geochemical assessment of 4 composite samples (Leach testing (TCLP), AMD generation, NAG Potential and sulphide speciation).

ii. Development of the conceptual geochemical model.

iii. Geochemical interpretation of laboratory results and source term determination.

iv. Drafting of a geochemical specialist report.

1.3.4. Phase D: Development of a numerical groundwater flow and mass transport model

Phase D will entail the following activities:

i. Development of a conceptual hydrogeological model in conjunction with interpreted geology data and gathered site characterisation information.

ii. Development of a regional numerical groundwater flow model by applying the Finite Element Flow

(FEFLOW) modelling software. Model domain to include existing underground footprints as well as associated infrastructure.

iii. Calibration of groundwater flow model using site specific data including hydrocensus geosites as well as existing time-series monitoring data.

iv. Development of a numerical mass transport model utilizing the calibrated groundwater flow model as basis.

v. The calibrated model will be used to simulate management scenario's as follows:

    a. Steady state groundwater flow directions, hydraulic gradient and flow velocities.

    b. Potential groundwater inflow volumes and mine dewatering rates.

    c. Seepage potential from wastewater facilities and mass transport plume migration with time.

    d. Mine post-closure decant positions and volumes with time.

    e. Water management alternatives and best practice mitigation measures.

1.3.5. Phase E: Hydrogeological impact assessment and reporting

Phase E will entail the following activities:

i. Compilation of a detailed hydrogeological specialist investigation report with conclusions and recommendations on the following aspects:

    a. Fatal flaw and gap analyses.

    b. Site baseline characterisation.

    c. Field work summary and interpretation.

    d. Aquifer classification and vulnerability.

    e. Geochemical source term determination.

    f. Numerical groundwater flow and mass transport model development, calibration and simulations.

    g. Formulation of an impact assessment and risk matrix of proposed activities.

    h. Recommendation on best practise mitigation and management measures to be implemented.

ii. Development of a surface water and groundwater monitoring program for implementation.

1.4. Project assumptions and limitations

Data limitations were addressed by following a conservative approach and assumptions include the following:

i. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic and spatial data, a lower resolution of 1:250 000 scale for geological data and a 1: 500 000 scale resolution for hydrogeological information.

ii. The Digital Elevation Model (DEM) data was interpolated with a USGS grid spacing of 25 m intervals.

iii. Rainfall data and other climatic information was sourced from the WR2012 database.

iv. Water management and catchment-based information was sourced from the GRDM and Aquiworx databases.

v. The concept of representative elementary volumes (REV) have been applied i.e. a scale has been assumed so that heterogeneity within a system becomes negligible and thus can then be treated as a homogeneous system. The accuracy and scale of the assessment will result in deviations at point e.g. individual boreholes.

vi. No site characterisation boreholes were drilled as part of this investigation and aquifer parameters as well as hydrostratigraphic units were assumed based on historical investigation and similar studies conducted.

vii. The investigation relied on data collected as a snapshot of field surveys and existing monitoring data. Further trends should be verified by continued monitoring as set out in the monitoring program.

viii. Groundwater divides have been assumed to align with surface water divides and it is assumed that groundwater cannot flow across this type of boundaries.

ix. Model calibration was achieved by assigning a ratio of 1:1 for Hydraulic Conductivity (K) in x and y directions, with a ratio of 1:10 in the z direction i.e. anisotropic aquifer.

x. Perennial rivers within the model domain have been treated as gaining type streams. As such groundwater is lost from the system via baseflow to local drainages.

xi. The numerical groundwater flow model was developed considering site specific information. It should be stated that influences from neighbouring mining developments were not taken into consideration as part of this investigation.

xii. Prior to development of the groundwater model, the system is in equilibrium and therefore in steady state i.e. quasi steady state.

xiii. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly[1].

2. METHODOLOGY

The groundwater impact assessment was undertaken by applying the methodologies as summarised below.

2.1. Desk study and review

This task entails the review of available geological and hydrogeological information including DWS supported groundwater databases (NGA/ Aquiworx), existing specialist reports, mine plans as well as climatic and other relevant groundwater data. Data collected was used to delineate various aquifer and hydrostratigraphic units, establish the vulnerability of local aquifers, aquifer classification as well as aquifer susceptibility.

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[1] Where model assumptions were made or reference values used, a conservative approach was followed. Data gaps identified should be addressed as part of the model update.

2.2. Hydrocensus user survey

A hydrocensus user survey was undertaken in August 2019 (representing dry-season contribution) in order to confirm the presence of potential sensitive environmental receptors in the vicinity of the project area, determine the surrounding groundwater application and piezometric water levels and collect water samples for analysis. Furthermore, a site visit and terrain walk-over were conducted in order to formulate and define the hydrogeological conceptual model.

2.3. Hydrochemical analysis

Water samples collected were submitted at a SANAS accredited laboratory to determine the macro and micro inorganic chemistry and potential hydraulic connections present. SANS 241:2015 Drinking Water Standards was applied and used a guideline for all water quality analysis. Inorganic chemistry was used to develop hydrochemical diagnostic plots for evaluation of hydrochemical signatures.

2.4. Geochemical assessment and waste classification

The potential risk of mine waste to generate acid i.e. acid rock drainage (ARD) was evaluated by acid base accounting testing. The latter involves a combined measurement of sulphur contents (total sulphur, sulphuric acid, sulphur, and organic sulphur), neutralisation capacity (NP), paste pH and the calculation of acid potential (AP), net neutralisation potential (NNP) and NP/AP ratio (NPR). Furthermore, waste classification of waste was undertaken in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010) [2]. The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations (LC) of samples taken.

2.5. Numerical groundwater flow and mass transport model

A numerical groundwater flow and mass transport model was developed based on site characterisation data gathered as well as the defined groundwater conceptual model. The latter will serve as a tool to evaluate various water management options and different scenarios will be applied to quantify and qualify potential groundwater impacts.

2.6. Groundwater impact assessment

Identification of preliminary and potential impacts and ratings related to new developments and/or listed activities are defined based on outcomes of the investigation. An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human and/or other related activities. The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/likelihood (P) of the impact

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[2] It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable for mine residue, the Total Concentration (TC) and Leachable Concentration (LC) thresholds as stipulated in GNR635 standards are still applied as part of the waste assessment risk based approach.

occurring. This determines the environmental risk. In addition, other factors including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S). Mitigation measures were recommended in order to render the significance of impacts identified.

3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS

The following water management legislation should be adhered to:

3.1. The National Water Act (Act 36 of 1998)

The purpose of the National Water Act, 36 of 1998 (“NWA”) as set out in Section 2, is to ensure that the country’s water resources are protected, used, developed, conserved, managed and controlled, in a way which inter alia considers the reduction, prevention and degradation of water resources. The NWA states in Section 3 that the National Government is the public trustee of the Nation’s water resources. The National Government must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons and in accordance with its constitutional mandate. Section 22 of the NWA states that a person may only use water without a license if such water use is: permissible under Schedule 1, if that water use constitutes as a continuation of an existing lawful water use, or if that water use is permissible in terms of a general authorization issued under Section 39. Permissible water use furthermore includes water use authorised by a license issued in terms of the NWA or alternatively without a license if the responsible authority dispensed with a license requirement under subsection 3.

3.1.1. Section 21 water use activities

Section 21 of the National Water Act indicates that water use includes the following:

a. taking water from a water resource (section 21(a));
b. storing water (section 21(b));
c. impeding or diverting the flow of water in a water course (section 21(c));
d. engaging in a stream flow reduction activity contemplated in section 3649 (section 21(d));
e. engaging in a controlled activity which has either been declared as such or is identified in section 37(1)50 (section 21(e));
f. discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit (section 21(f));
g. disposing of waste in a manner which may detrimentally impact on a water resource (section 21(g);
h. disposing in any manner of water which contains waste from, or which has heated in, any industrial or power generation process (section 21 (h));
i. altering the bed, banks, course or characteristics of a water course (section 21(i));

j. removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people (section 21(j)); and

k. using water for recreational purposes (section 21(k)).

3.1.2. GN 704 Regulations on the use of water for mining and related activities aimed at the protection of water resources (1999)

It is important that integrated water management should be conducted in accordance with Government Notice (GN) 704. The following regulations were referenced from the GN 704 document published.

Section 4: Restriction of Locality

"No person in control of a mine or activity may-

i. Locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on waterlogged ground, or on the ground likely to become waterlogged, undermined, unstable or cracked;
ii. Except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest;
iii. Place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or open cast mine excavation, prospecting diggings, pit or any other excavation; or
iv. Use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year flood-line of any watercourse or estuary."

Section 6: Capacity requirements of clean and dirty water systems

"Every person in control of a mine or activity must-

i. Confine any unpolluted water to a clean water system, away from any dirty area;
ii. Design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;
iii. Collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity, into a dirty water system;
iv. Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and
v. Design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act.

vi. Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years."

Section 7: Protection of water resources

"Every person in control of a mine or activity must take reasonable measures-

i. Prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act;
ii. Design, modify, locate, construct and maintain all water systems, including residue deposits, in any area so as to prevent the pollution of any water resource through the operation or use thereof and to restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or the disturbance of vegetation, or the alteration of flow characteristics;
iii. Cause effective measures to be taken to minimise the flow of any surface water or floodwater into mine workings, opencast workings, other workings or subterranean caverns, through cracked or fissured formations, subsided ground, sinkholes, outcrop excavations, adits, entrances or any other openings;
iv. Design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;
v. Prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources;
vi. ensure that water used in any process at a mine or activity is recycled as far as practicable, and any facility, sump, pumping installation, catchment dam or other impoundment used for recycling water, is of adequate design and capacity to prevent the spillage, seepage or release of water containing waste at any time;
vii. At all times keep any water system free from any matter or obstruction which may affect the efficiency thereof; and
viii. Cause all domestic waste, including wash-water, which cannot be disposed of in a municipal sewage system, to be disposed of in terms of an authorisation under the Act.

3.2. Mineral and Petroleum Resources Development Act (Act 28 of 2002)

The establishment, reclamation, expansion or decommissioning of residue stockpiles or residue deposits must be authorised in terms of the Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002). Section 42 of the MPRDA states that:

i. Residue stockpiles and residue deposits must be managed in the prescribed manner on any site demarcated for that purpose in the environmental management plan or environmental management programme in question.
ii. No person may temporarily or permanently deposit any residue stockpile or residue deposit on any site other than on a site contemplated in subsection.

3.3. National Environmental Management Act (Act 56 of 2002)

The establishment, reclamation, expansion or decommissioning of residue stockpiles or residue deposits must be authorised in terms of the Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002). Section 42 of the MPRDA states that:

3.4. National Environmental Management: Waste Act (Act 59 of 2008)

Furthermore, the establishment, reclamation, expansion or decommissioning of residue stockpiles or residue deposits must also be authorised through a waste management licence issued in terms of the National Environmental Management Waste Act 59 of 2008.

The classification and definitions herein considered the following documents[3]:

i. Government Notice 635, National Environmental Management: Waste Act 59 of 2008: National Norms and Standards for the Assessment of Waste for Landfill Disposal (hereafter referred to as GNR 635).
ii. Government Notice 636, National Environmental Management: Waste Act 59 of 2008: National Norms and Standards for Disposal of Waste to Landfill (hereafter referred to as GNR 636).

It should be noted that Government Notice GN 990 published in September 2018 serve to amend the regulations regarding the planning and management of residue stockpiles and residue deposits (2015). The main aim is to allow for the pollution control measures required for residue stockpiles and residue deposits, to be determined on a case by case basis, based on a risk analysis conducted by a competent person. Accordingly, a risk analysis must be conducted to determine the pollution control measures suitable for a specific residue stockpile or residue deposit as part of an application for a waste management licence.

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[3] It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable, the Total Concentration (TC) and Leachable Concentration (LC) thresholds as stipulated in GNR635 standards are still applied as part of the waste assessment because guidelines and limits are based on Environmental Protection Agency (EPA) of the Australian State of Victoria and still bears reference.

4. STUDY AREA AND INFRASTRUCTURE

4.1. Regional setting and site locality

The project extent and greater mine lease area is located on portions 1,2, 8 and 9 of the Farm Mooiplaats 290IT, portions 0, 1 and 2 of the farm Adrianople 296 IT as well as portions 0,2 and 3 of the Farm Klipbank 295 IT and is situated approximately 17.0 km southeast of the town of Ermelo, Mpumalanga Province, South Africa. The site is accessibly from the N2 national route and is situated approximately 1.7 km from the Camden Power Station. General site coordinates are listed in Table 4-1 with the site locality and project boundary depicted in Figure 4-1. Refer to Figure 4-2 for an aerial extend of the project area.

Table 4-1 General site coordinates (Coordinate System: Geographic, Datum: WGS84).

Latitude	-26.668
Longitude	30.012

4.2. Mining infrastructure and schedule

Mooiplaats Colliery operates an existing underground mine with an approximate footprint of 184.1 ha. The Mooiplaats Colliery mining right area (MRA) can be sub-divided into the Mooiplaats North area as well as the Mooiplaats South area covering a total footprint of approximately 4 815.5 ha. Associated infrastructure consists of a wash plant, return water dams, co-disposal/ discard dump, coal stockpiles as well as overburden stockpiles. The newly proposed life of mine (LOM) is a further 10 years until 2029 with an approximate footprint of 866.08 ha (Figure 4-3).

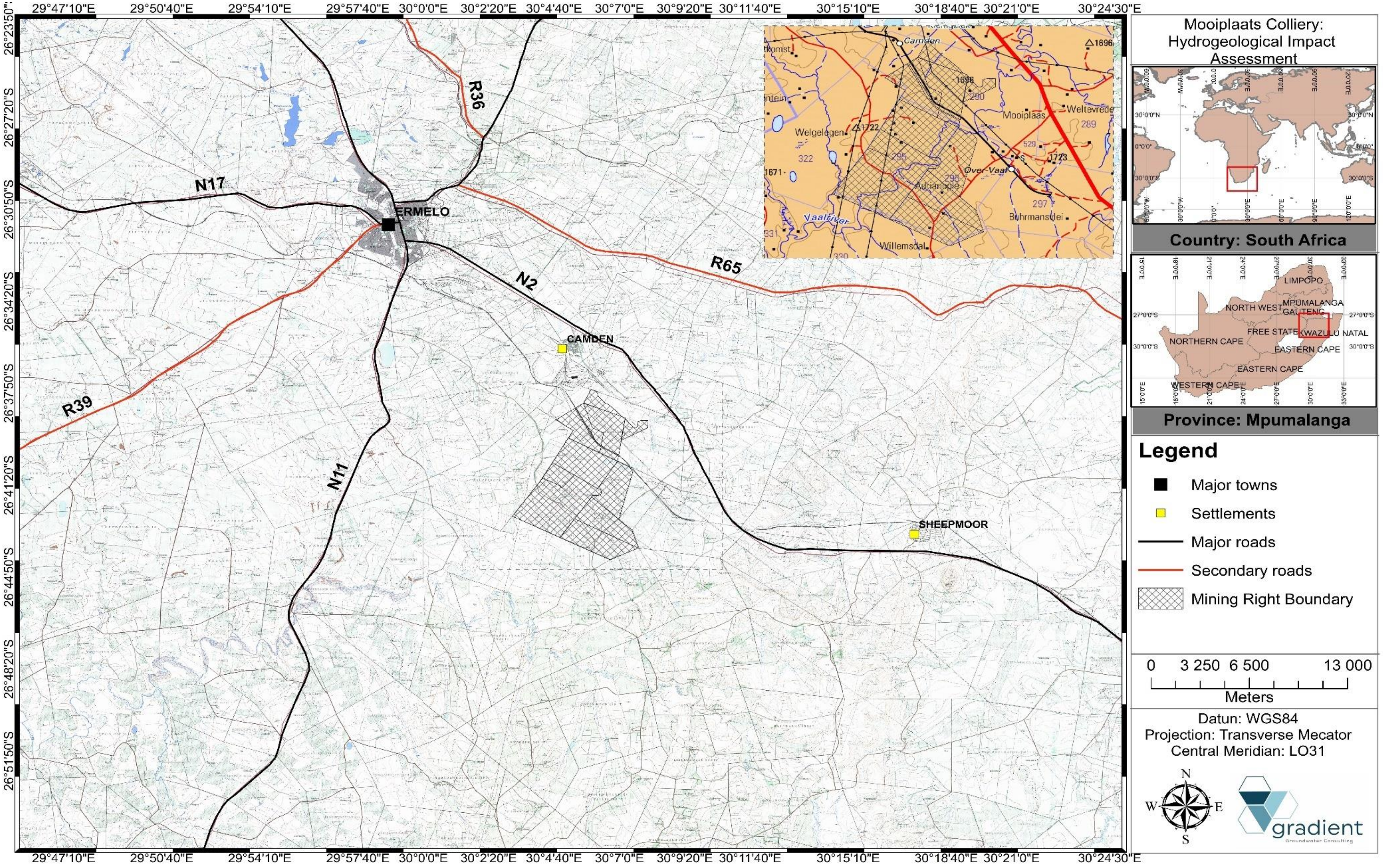


Figure 4-1 **Greater study area and project boundary (topographical mapsheet 2630CA).**

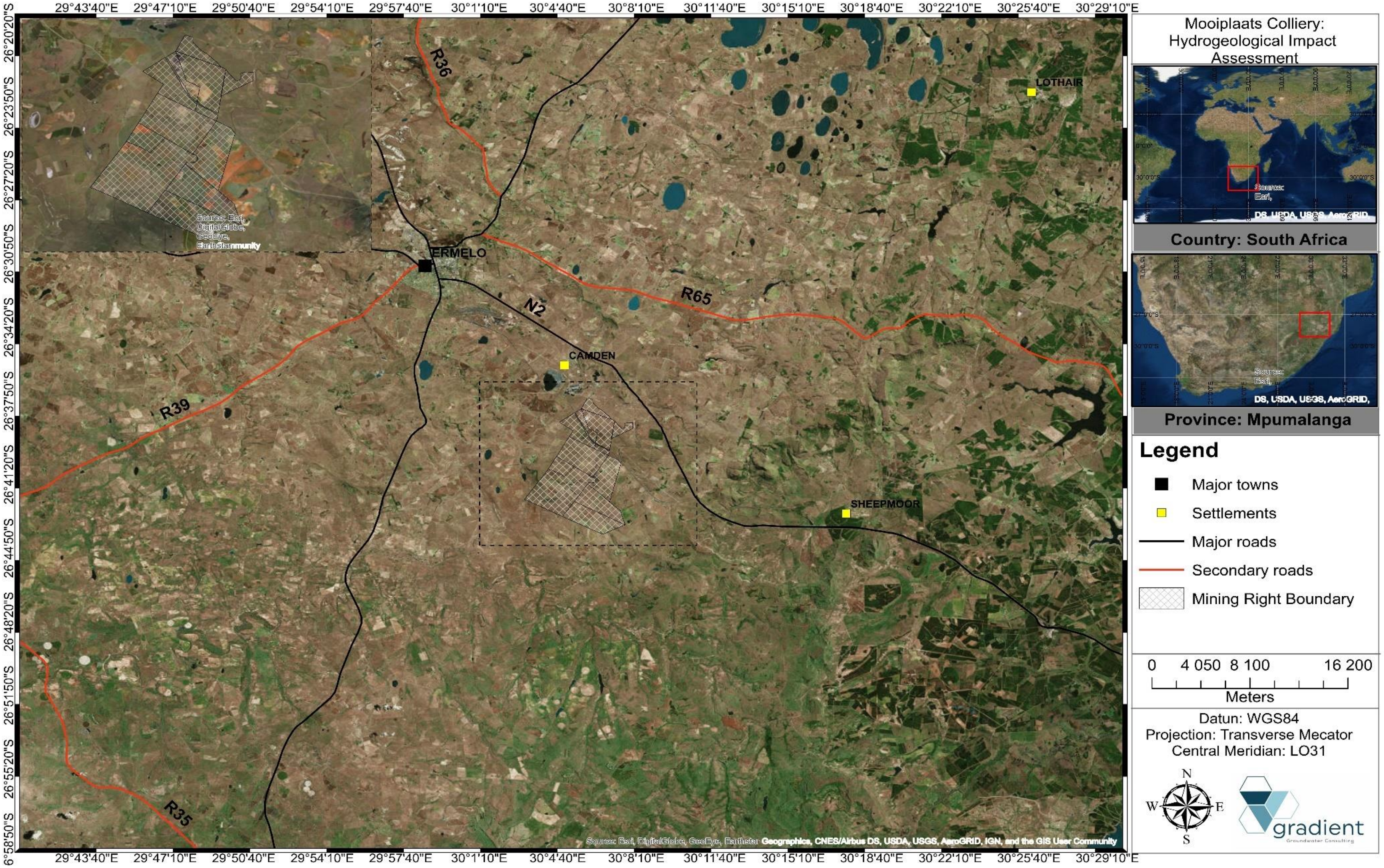


Figure 4-2 **Aerial extent and mining right boundary.**

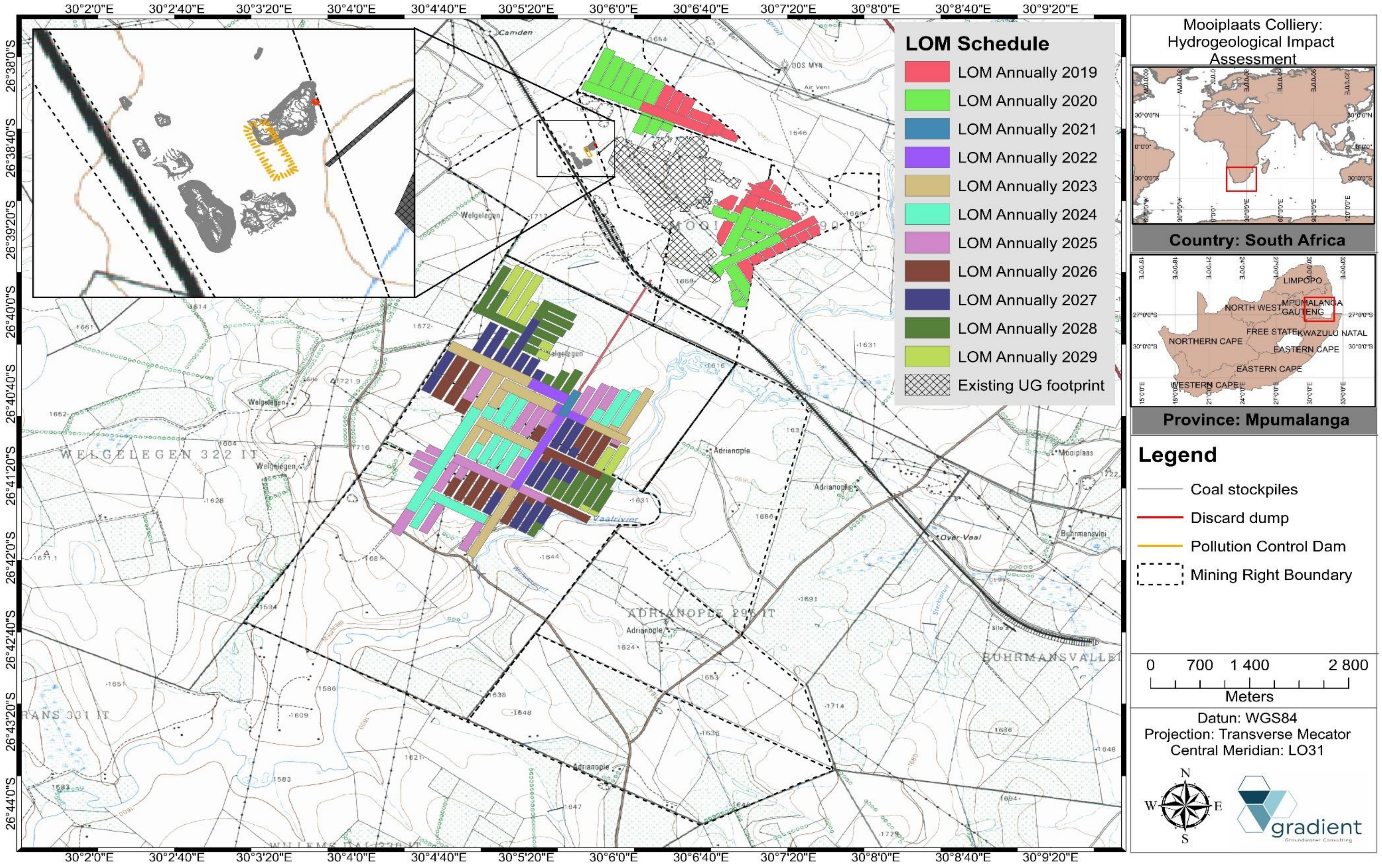


Figure 4-3 Mining LOM schedule and infrastructure.

5. PHYSIOGRAPHY

5.1. Topography

The topography of the greater study area is strongly undulating with surrounding hills and plains. Topographical high areas are usually shaped by more resistant post-Karoo dolerite intrusions while valleys are underlain by Karoo sediments cut by local drainage patterns as evident at the study area. The regional landscape gradually flattens out towards the lower laying drainage system to the eastern perimeter, also forming the groundwater and surface water divide of this catchment area. The highest topographical elevation on-site is 1724.0 mamsl to the northern boundary of the mine lease area while other topographical high areas also exist to the northwest and south-eastern perimeters (1714.0 mamsl). The lowest topographical elevation within the study area is at 1587.0 mamsl forming part of the lower laying drainage system towards the southwestern part of the mine lease area.

On-site gradients are relatively gentle to moderate with the average slope calculated at 3.0% and –3.10% respectively. The Vaal River drainage system enters the project area at an approximate elevation of 1626.0 mamsl and exists at 1598.0 mamsl, an elevation loss of 28.0 m over a lateral distance of ~6.50 km. respectively with an elevation loss of 129.0 m over a lateral distance of 2.70 km. Refer to Figure 5-1 for a topographical cross-section of the greater study area and Figure 5-2 depicting the regional topographical contours.

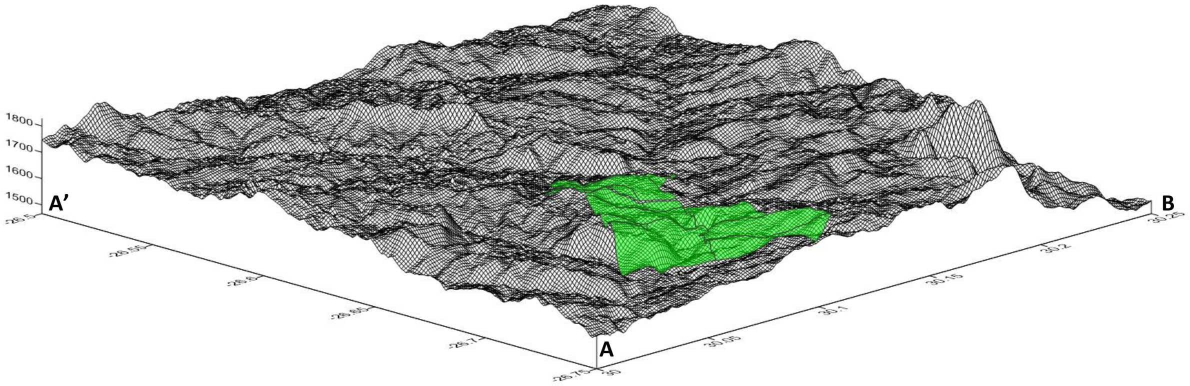


Figure 5-1 Topographical cross-sections of the greater study area (Figure 5-2).

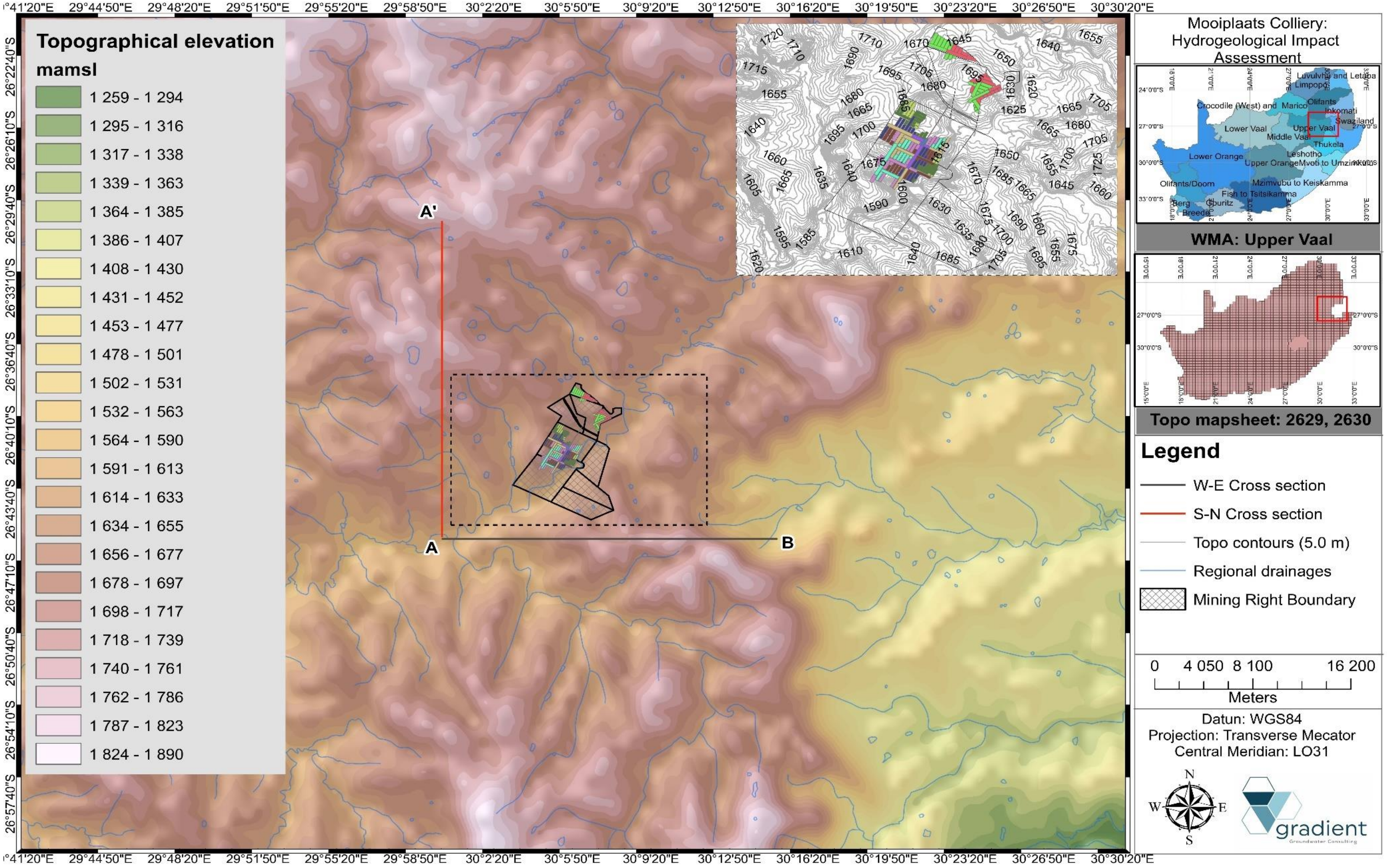


Figure 5-2 Regional topography (Figure 5-1).

5.2. Drainage and catchment

The project area is situated in primary catchment (C) of the Wilge, Liebenbergsvlei and Vaal River drainage systems. The resource management falls under the Upper Vaal Water Management Area (WMA) which is situated in the south western part of Mpumalanga Province, north-eastern part of the Free State as well as parts of Gauteng and a relatively small area in the North West Province. The study area is situated within quaternary catchment C11B (nett surface area of 534.7 km^2), falls within hydrological zone D and has an estimated mean annual runoff (MAR) of 35.4 mcm (million cubic metres) (WR 2012). The regional drainage occurs in a southwestern direction via the Vaal River transecting the greater project area. The Witpuntspruit convergence with the Vaal River before entering the mine lease area and the Wolwespruit joins the Vaal River just before it exists the mine lease boundary. From here the Vaal River continues draining in a western to south-westerly direction where the Klein Vaal River joins the drainage pattern approximately 6.5 km southwest of the project area. Refer to Figure 5-3 for a spatial layout of the project area in relation the water management area, quaternary catchments as well as regional drainage patterns. Table 5-1 provides a summary of relevant climatological and hydrogeological information for quaternary catchment C11B.

Table 5-1 Quaternary catchment information: C11B.

Attribute	Catchment information
Water Management Area (WMA)	Upper Vaal
Primary catchment	C
Secondary catchment	C1
Tertiary catchment	C11
Quaternary catchment	C11B
Major rivers	Wilge, Liebenbergsvlei, Vaal
Hydro-zone	D
Rainfall zone	C1A
Area (km^2)	534.7
Mean annual rainfall (mm)	705.3
Mean annual evaporation (mm)	1400
Mean annual runoff (mm)	66
Baseflow	6.92
Population	1554
Total groundwater use (l/s)	2.8
Present Eco Status Category	Category B
Recharge	6.70
Average water level (mbgl)	8.8
Soil type	LmSa-SaLm
Groundwater General Authorization	150 m^3/ha/a

Note: Catchment based information sourced from Aquiworx 2014.

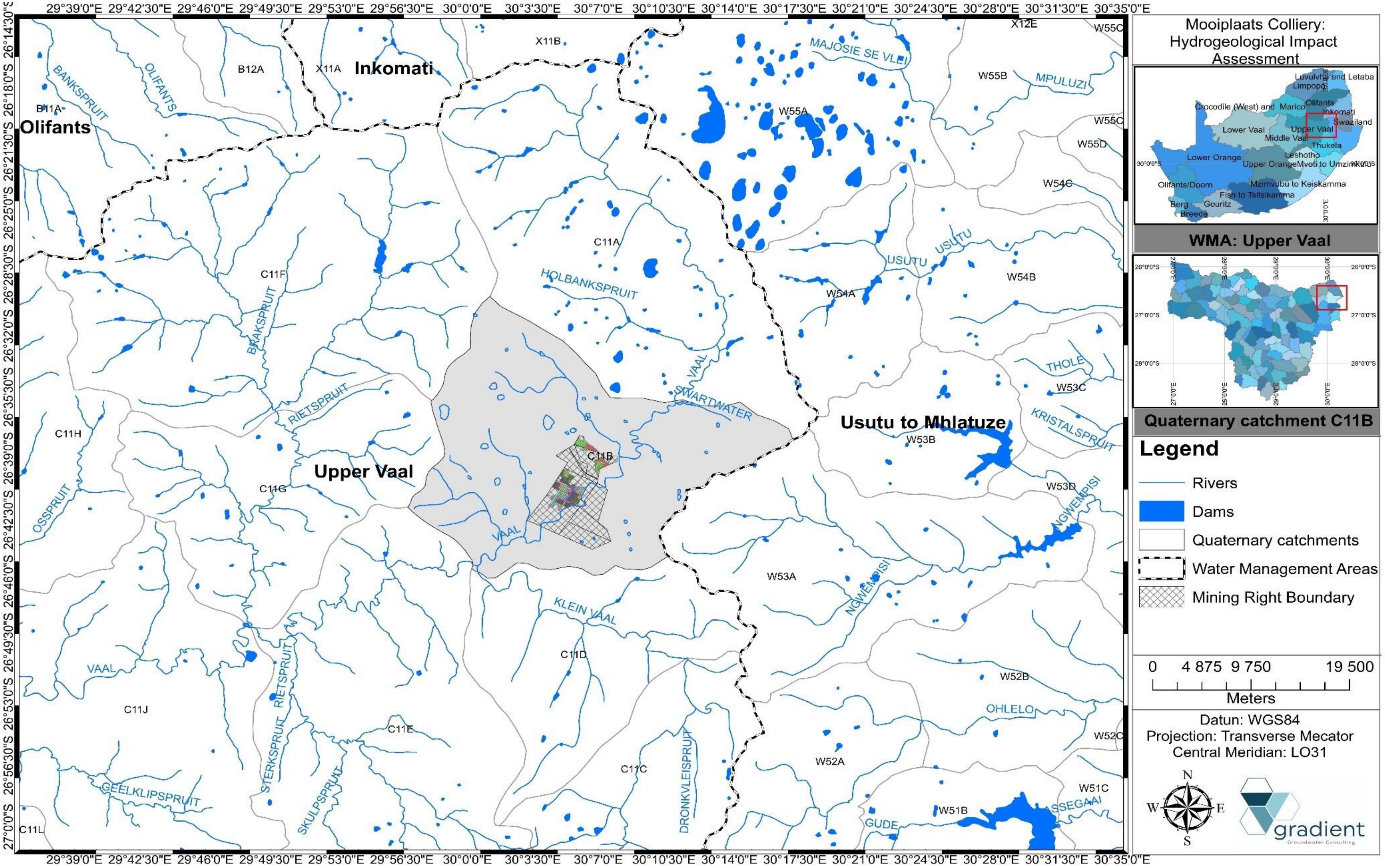


Figure 5-3 **Quaternary catchments and water management area.**

5.3. Climate

The study area's weather pattern reflects a typical summer rainfall region, with > 84.0% of precipitation occurring as high-intensity thunderstorms from October to March. Patched rainfall and evaporation data were sourced from the WR2012 database (Rainfall zone C1A) and span a period of some 90 years (1920 – 2009). The calculated mean annual precipitation (MAP) for this rainfall zone is 700.16 mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 521.72 mm/a and the 95th percentile (representing a ~1:20 flood period) 866.03 mm/a. The highest MAP for the 90 years of rainfall data was recorded as of 1128.35 mm (1995) while the lowest MAP of 453.74 mm was recorded during 1991. This quaternary catchment is categorised under evaporation zone 13B which have a mean annual evaporation (s-pan) of 1400.0 mm/a, more than double the annual precipitation for the greater study area. Figure 5-4 depicts a bar chart of the yearly rainfall distributions with Figure 5-5 indicating monthly rainfall patterns. Figure 5-6 provides a comparison of monthly precipitation and evaporation volumes. A summary of rainfall data used as part of this statistical analysis is summarised in Appendix A: Rainfall data.

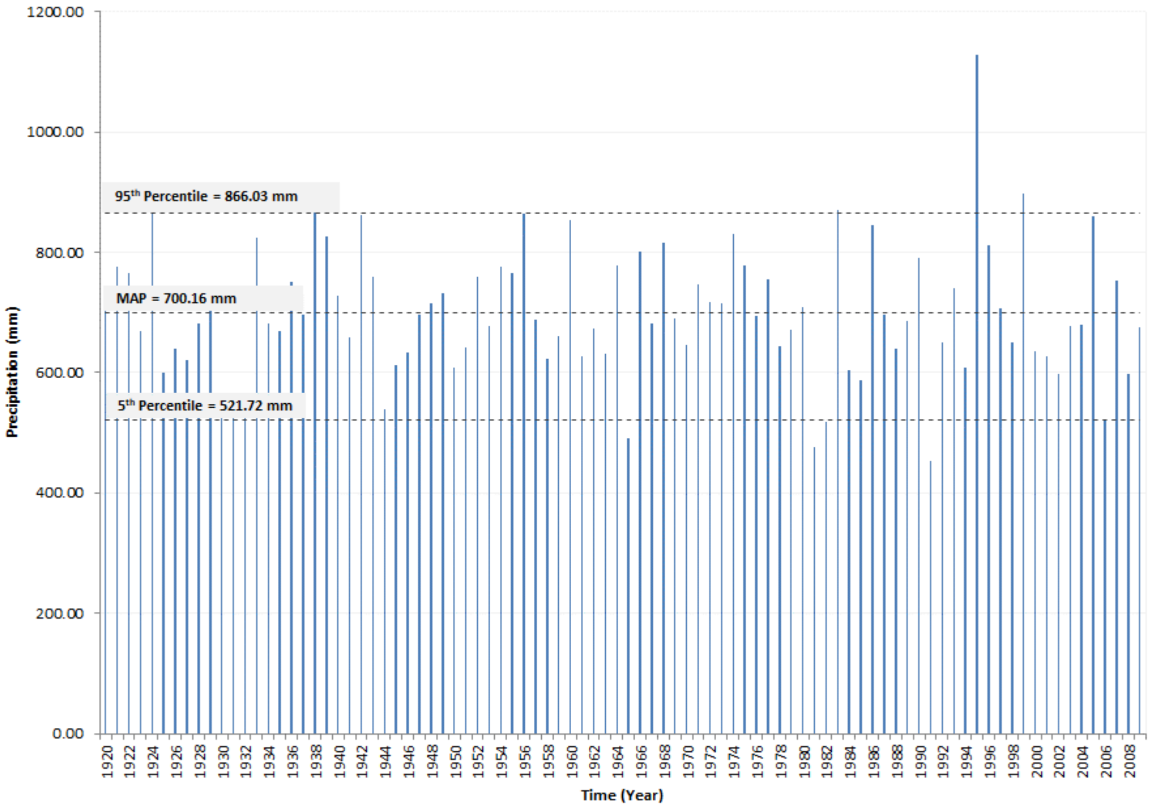


Figure 5-4 **Bar chart indicating yearly rainfall distribution for rainfall zone C1A (WR2012).**

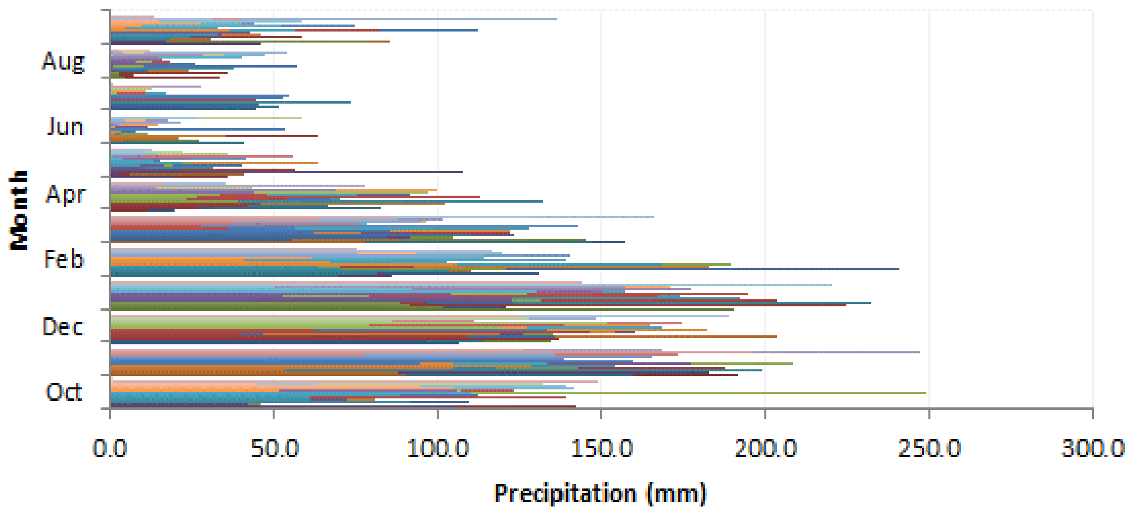


Figure 5-5 Bar chart indicating monthly rainfall distribution for rainfall zone C1A (WR2012).

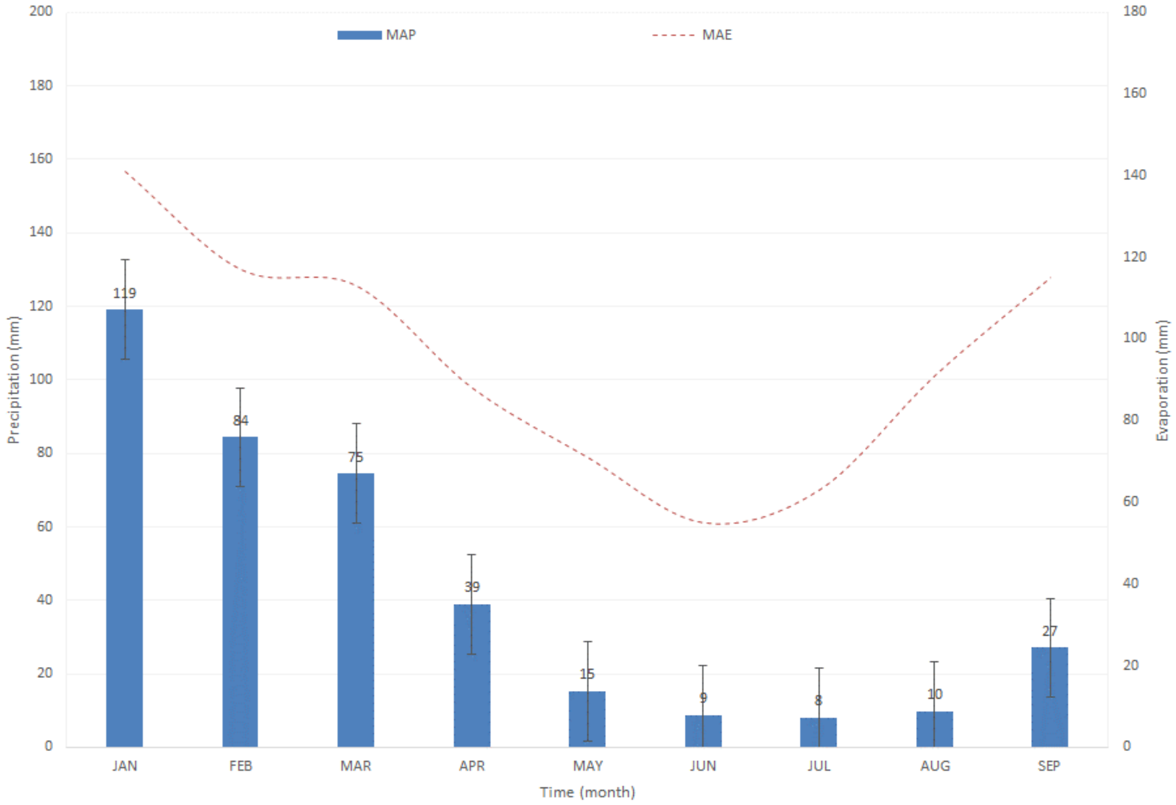


Figure 5-6 Bar chart and curve comparing monthly rainfall and evaporation distribution (WR2012).

5.4. Geological setting

5.4.1. Regional geology

The greater study area falls within the Ecca Group of the Karoo Supergroup, which consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic (Schlüter and Thomas, 2008). The Permian Ecca Group follows conformably after the Dwyka Group in certain sections, however in some localities overlies unconformably over older basement rocks. The Ecca Group underlies the Beaufort Group in all known outcrops and exposures and comprises a total of 16 formations consisting largely of shales and sandstones. The latter can be grouped in three geographical areas i.e. southern, western/north-western as well as north-eastern areas.

5.4.2. Local geology

According to the geological map (2630, Mbabane) the study area falls within the Vryheid Formation (Pv) which is covered in various areas throughout the mine lease area by dolerite of the Karoo Dolerite Suite (Jd). The Vryheid Formation consists mainly of fine-grained mudstone, carbonaceous shale with alternating layers of bituminous coal seams, and coarse-grained, bioturbated immature sandstones respectively (arenaceous and argillaceous strata). The uneven pre-Karoo topography along the northern and north-western margins of the basin, where the formation rests directly on pre-Karoo rocks or the Dwyka Group, which gives rise to marked variations in thickness. The different lithofacies of the Vryheid Formation are mainly arranged in upward-coarsening cycles which are deltaic in origin (Johnson et al, 2009).

The Karoo Basin is characterised by a vast network of intrusive dolerite sills and dykes that rapidly intruded at 183.0 to 182.3Ma (Svensen et al., 2012). The intrusive Karoo dolerite suite represents a shallow feeder system which occurs as an interconnected network of dykes, sills as well as sheets which typically form resistant caps of hills compromising softer sedimentary strata (Chevallier and Woodford, 1999).

Isolated patches within the study area are covered by aeolian sand (Qw) of the period. Refer to Figure 5-7 for a summary of the generalised stratigraphic column of the Ermelo Coalfield while Figure 5-8 indicate the regional geology.

5.4.3. Structural geology

On a regional scale, various southwest northeast striking geological lineaments occur throughout the larger study area. A geological lineament and inferred dyke structure transect the northern footprint of the proposed underground workings striking in a general southwest-northeast direction. The latter may play a major role in aquifer compartmentalisation as they can act as semi- to impermeable barriers to the movement of groundwater. The number of spring localities observed during the hydrocensus user survey may confirm this assumption. Dolerite dykes are vertical to sub-vertical discontinuities which represent linear zones of relatively higher permeability which may act as conduits for groundwater flow within the aquifer. According to the geological map no major faults in the direct vicinity of the project area are evident.

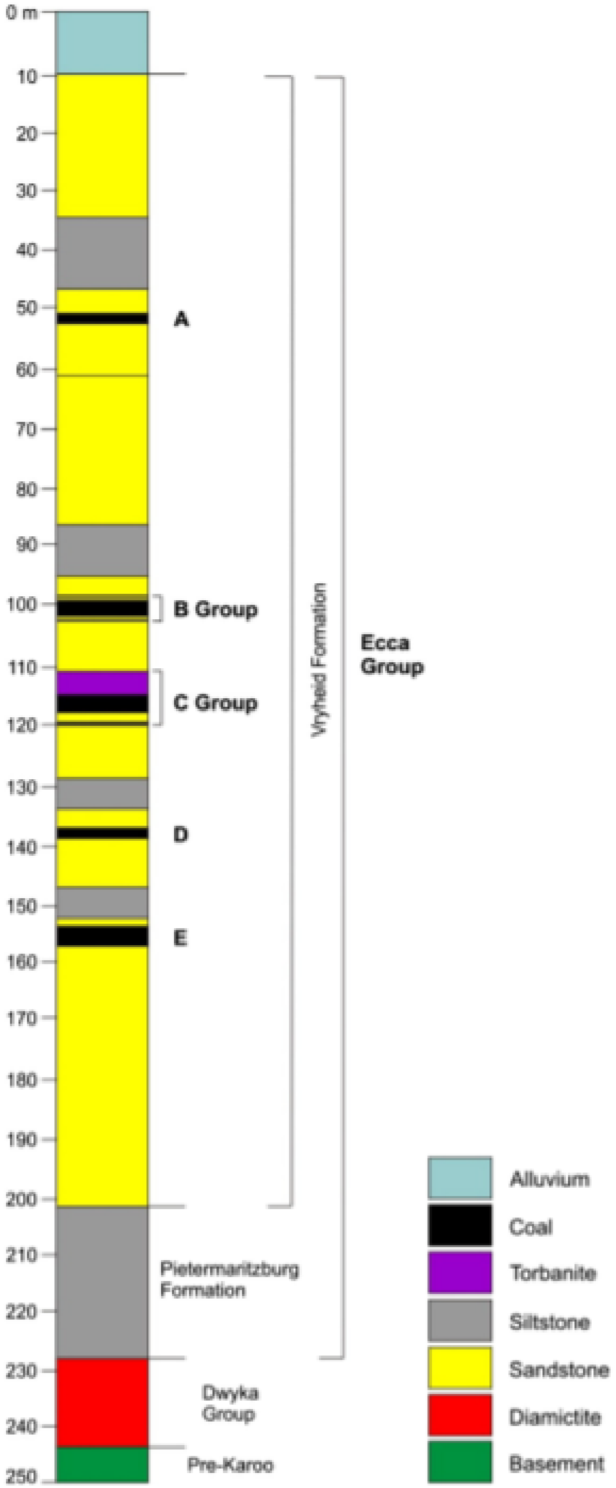


Figure 5-7 Stratigraphic column of the Karoo Supergroup in the Ermelo Coalfield (after Greenshields, 1986).

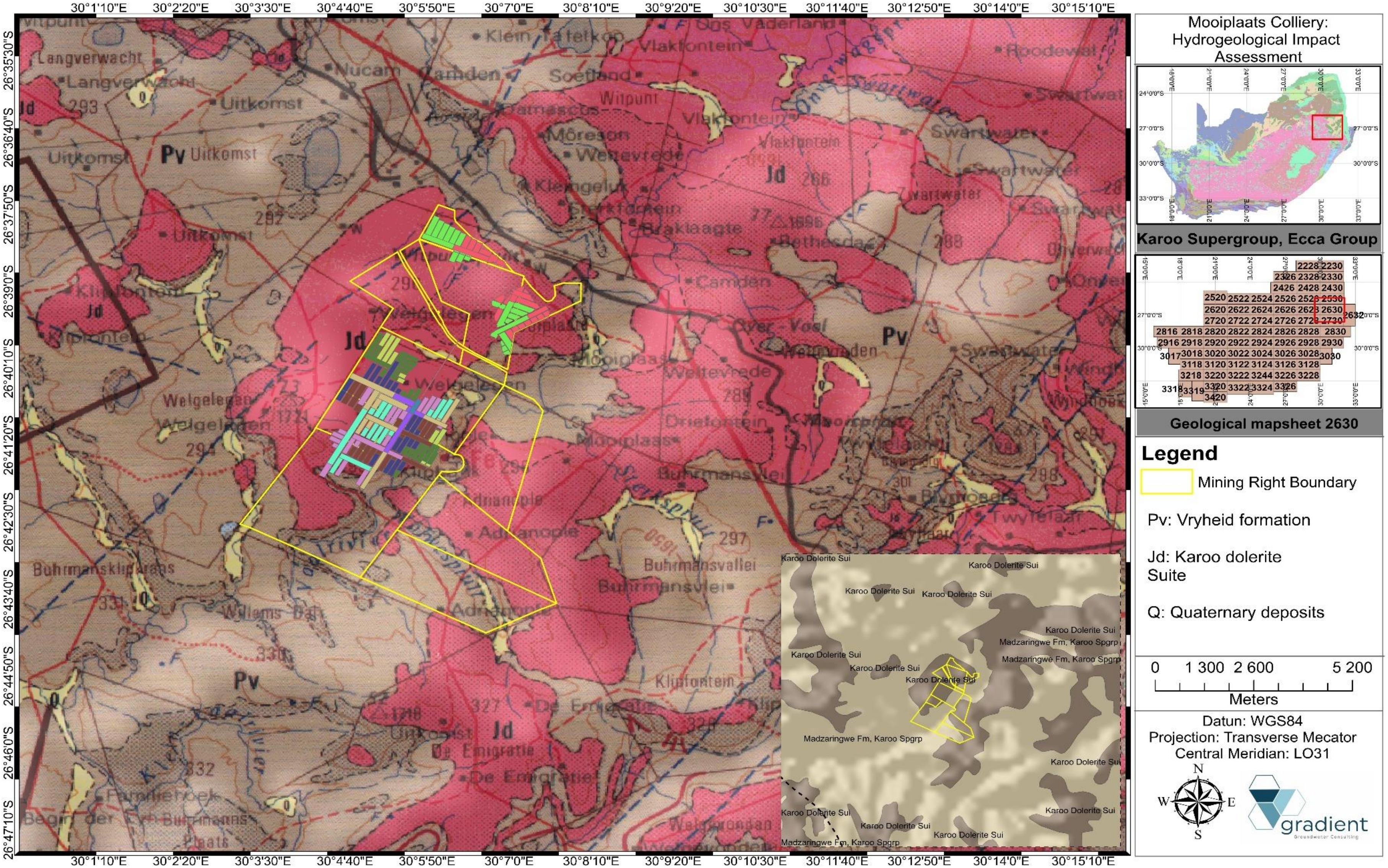


Figure 5-8 Regional geology and stratigraphy (Geological mapsheets 2630).

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

6.1. Desktop study

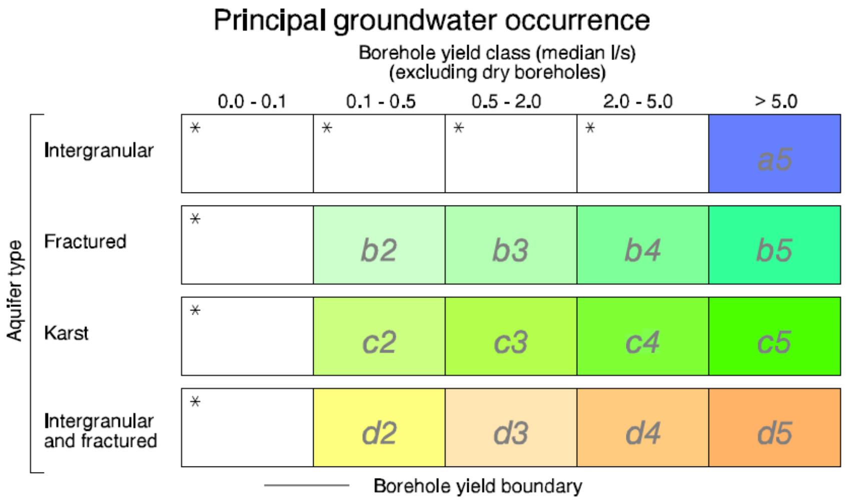
The Department have characterised South African aquifers based on host-rock formations in which it occurs together with its capacity to transmit water to boreholes drilled into relative formations. The water bearing properties of respective formations can be classified into four aquifer classes defined as:

a. **Class A:** Intergranular o Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.

b. **Class B:** Fractured o 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.

c. **Class C:** Karst o 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.

d. **Class D:** Intergranular and fractured o 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 are stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into it. 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 6-1).



Principal groundwater occurrence

Borehole yield class (median l/s)
(excluding dry boreholes)

Aquifer type	0.0 - 0.1	0.1 - 0.5	0.5 - 2.0	2.0 - 5.0	> 5.0
Intergranular	*	*	*	*	a5
Fractured	*	b2	b3	b4	b5
Karst	*	c2	c3	c4	c5
Intergranular and fractured	*	d2	d3	d4	d5

Note: Groundwater occurrence depicts the aquifer type(s) with the highest borehole yield which does not always correlate with surface lithology.

Figure 6-1 **Principal groundwater occurrences in South Africa.**

6.1.1. Regional hydrogeology

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2530 Nelspruit) the site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly arenaceous rock of the Ecca Formation with a compact nature (Figure 6-2). Karoo sediments of the Ecca and Beaufort Groups, which consist of mainly sandstones, mudstones and shales, cover a large portion of the WMA. The aquifers are secondary aquifers with water associated with fracturing. Natural springs and seepages, although their flows are markedly seasonally affected, are extensively exploited as domestic water supply sources in the rural residential and agricultural portions of the WMA (DWS ISP, 2004). The aquifer has an extremely low to medium development potential (DWA, 2008) with borehole yields ranging from 0.5 – 2.0 l/s, while higher yielding boreholes (> 5.0 l/s) may occur along intruding dyke contact zones and other structural features i.e. fault zones etc (Barnard, 2000). Faults, joints and intrusive Karoo dolerite contacts in the regional 'hard rocks', are zones usually of increased groundwater presence (DWS ISP, 2004).

The maximum aquifer depth (i.e. shallow/weathered aquifer system) ranges between 30.0 – 50.0 mbgl with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level. The aquifer media consist mainly of fractured and weathered compact sedimentary rock as depicted in Figure 6-3.

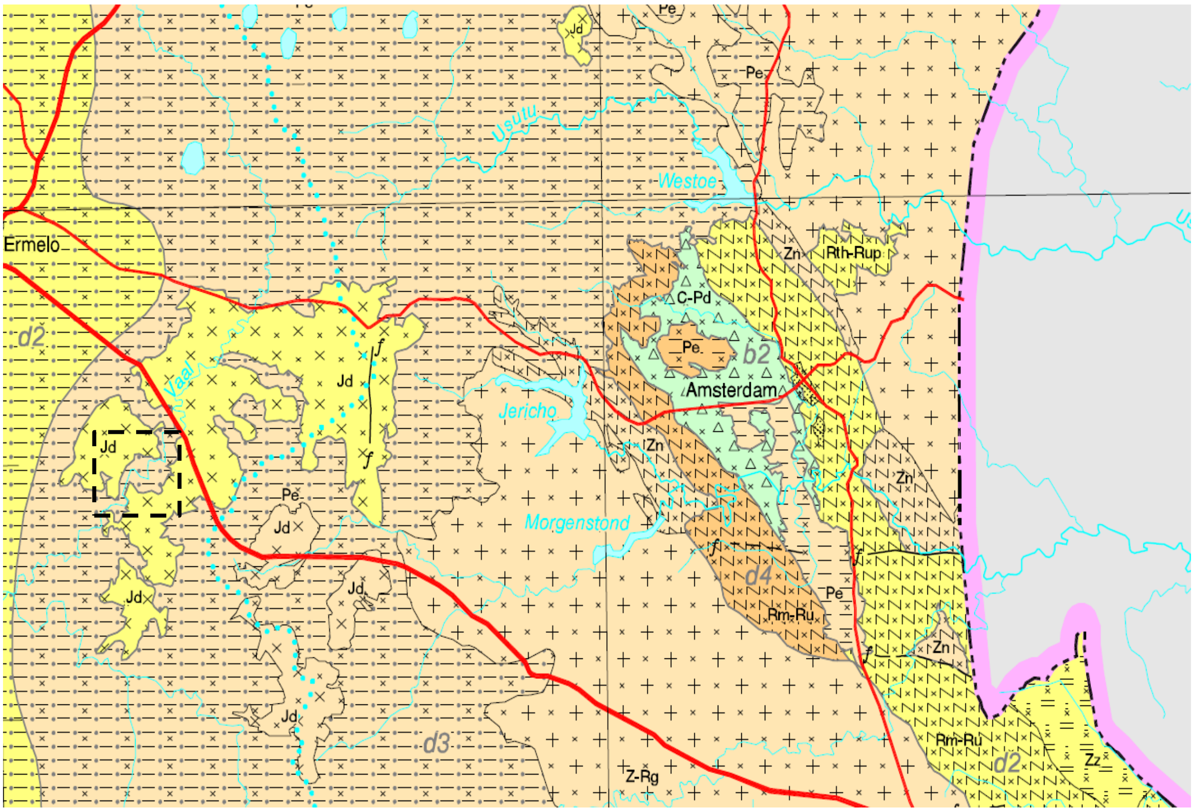


Figure 6-2 Hydrogeological map illustrating the typical groundwater occurrence for the study region.

6.1.2. Hydrostratigraphic units

For the purposes of this investigation, three main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone[4]:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually this aquifer can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. Due to higher effective porosity (*n)* this aquifer is most susceptible to impacts from contaminant sources.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock. Fractured sandstones, mudstones and shales sequences are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

iii. Shallow quaternary and recent types of sediments (perched, unconfined) are characteristically a primary porosity aquifer. These aquifers are formed by the alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth (Driscoll, 1986).

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[4] it should be noted that no site characterisation boreholes have been drilled to confirm this assumption and this is based on historical hydrogeological investigation in this area and/or similar environments.

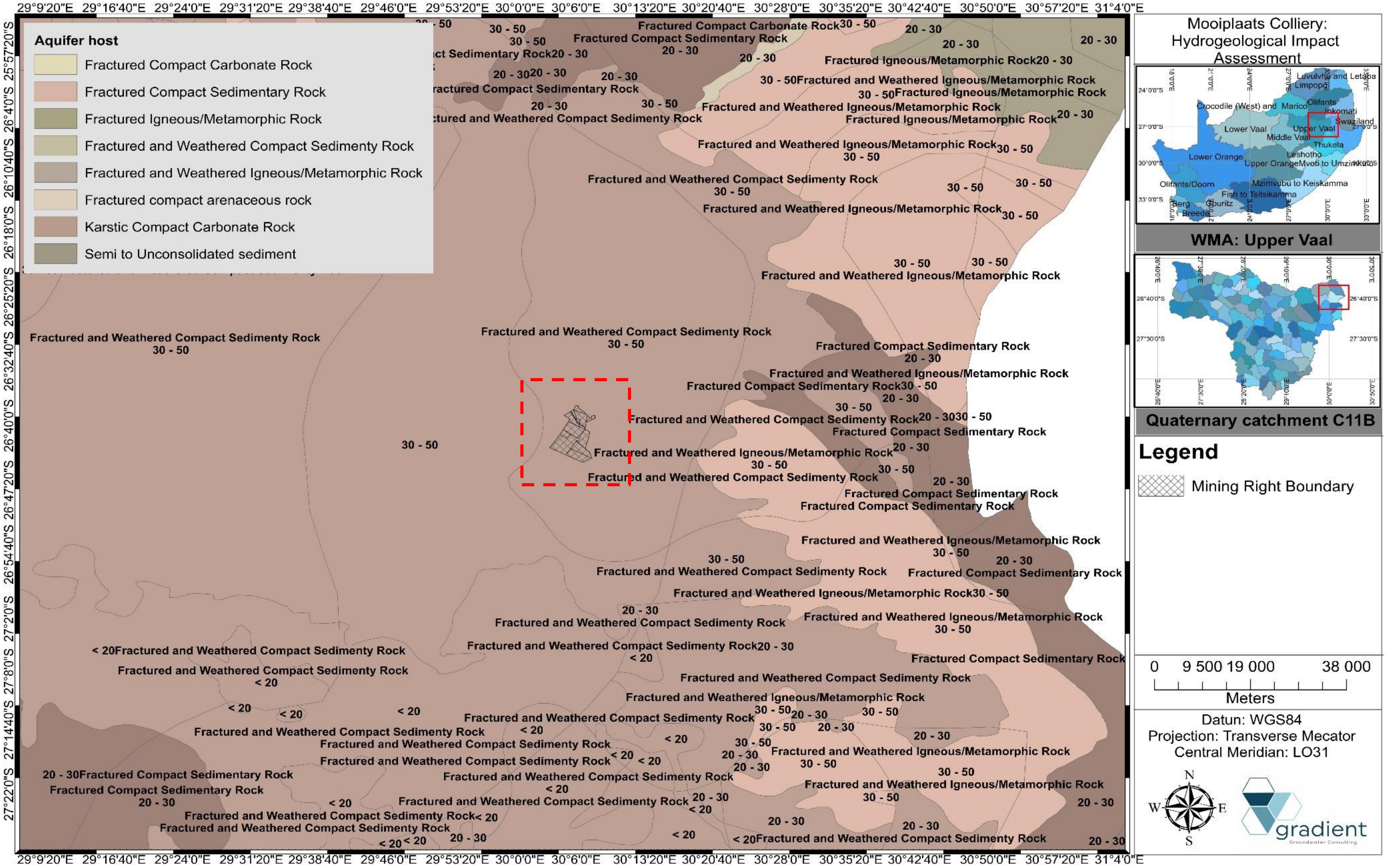


Figure 6-3 Hydrostratigrpahical units.

6.2. Hydraulic parameters

To follow is a brief overview of aquifer hydraulic parameters based on published literature for similar hydrogeological conditions as well as historical reports.

6.2.1. Hydraulic conductivity and Transmissivity

Hydraulic conductivity is the constant of proportionality in Darcy's Law which states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path as indicated in the following equation:

Equation 6-1 Hydraulic Conductivity (Darcy's Law).

$$\boldsymbol{K} = \frac{\boldsymbol{Q}}{\boldsymbol{A}\left(\frac{\boldsymbol{dh}}{\boldsymbol{dl}}\right)}$$

where:

K = Hydraulic Conductivity (m/d).

Q = Flow of water per unit of time (m^3/d).

dh/dl = Hydraulic gradient.

A = is the cross-sectional area, at a right angle to the flow direction, through which the flow occurs (m^2)

The hydraulic conductivity of sedimentary formations such as evident on site can range from $10^{-5} – 10^{0}$. Hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10^{-1} – 10^{2}$ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10^{-10} – 10^{-6}$ m/d. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e. riverbed aquifers can be orders higher and can vary between $10^{-3} – 10^{3}$ m/d (Freeze and Cherry, 1979). The calculated hydraulic conductivity for the alluvial zones is 4.0 m/d (Geostratum, 2011).

Transmissivity can be expressed as the product of the average hydraulic conductivity (K) and thickness (b) of the saturated portion of an aquifer and expressed by:

Equation 6-2 Transmissivity.

$$\boldsymbol{T} = \boldsymbol{Kb}$$

where:

T = Transmissivity (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

6.2.2. Storativity

Typical storativity values for fractured rock systems is in the order of $10^{-5} – 10^{-3}$, while Storativity values of the shallow, weathered aquifer can be slightly higher i.e. 10^{-2} (Freeze and Cherry, 1979).

6.2.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. The porosity of fractured crystalline rocks ranges between 0.03 – 0.10, while porosity of weathered formations can be as high as 15% depending on the nature and state of weathering (Freeze and Cherry, 1979). The average calibrated effective porosity for the shallow, weathered aquifer and deeper, fractured aquifer is 0.03 and 0.003 respectively (Geostratum, 2011).

6.2.4. Recharge

An approximation of recharge for the study area is estimated at ~6.0 % of MAP i.e. ~42.0 mm/a as summarised in Table 6-1. Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride Mass Balance (CMB) method (ii) Geology (iii) Vegter Groundwater Recharge Map (Figure 6-4) (iv) Harvest Potential Map (v) Baseflow Map (Figure 6-5) (vi) Literature review ; and (vii) Qualified opinion. Using the simplified CMB method as proposed by Bean (2003), the following equation applies to calculating recharge.

Equation 6-3 Chloride Mass Balance formula.

$$R = \frac{Cl_{p+D}}{Cl_g}$$

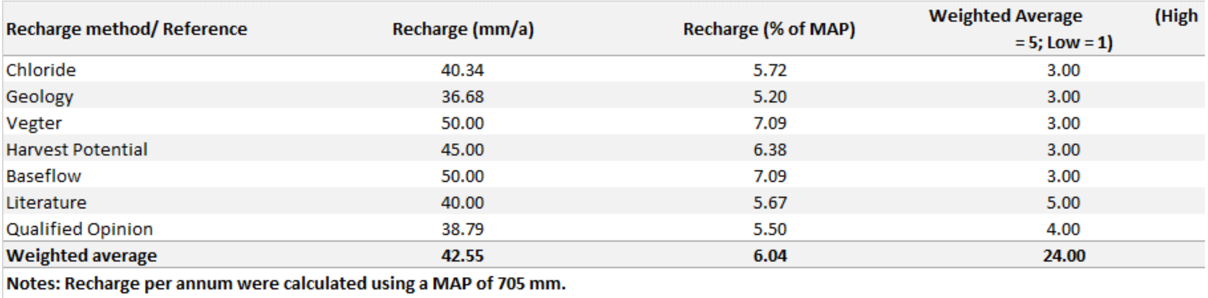
where:

R = Recharge (mm/a)

Cl_p = Representative mean chloride concentration in rainwater including contributions from dry deposition

Cl_g = Chloride concentration in groundwater resulting from diffuse recharge

Table 6-1 Recharge estimation (after van Tonder and Xu, 2000).



Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Chloride	40.34	5.72	3.00
Geology	36.68	5.20	3.00
Vegter	50.00	7.09	3.00
Harvest Potential	45.00	6.38	3.00
Baseflow	50.00	7.09	3.00
Literature	40.00	5.67	5.00
Qualified Opinion	38.79	5.50	4.00
Weighted average	**42.55**	**6.04**	**24.00**

Notes: Recharge per annum were calculated using a MAP of 705 mm.

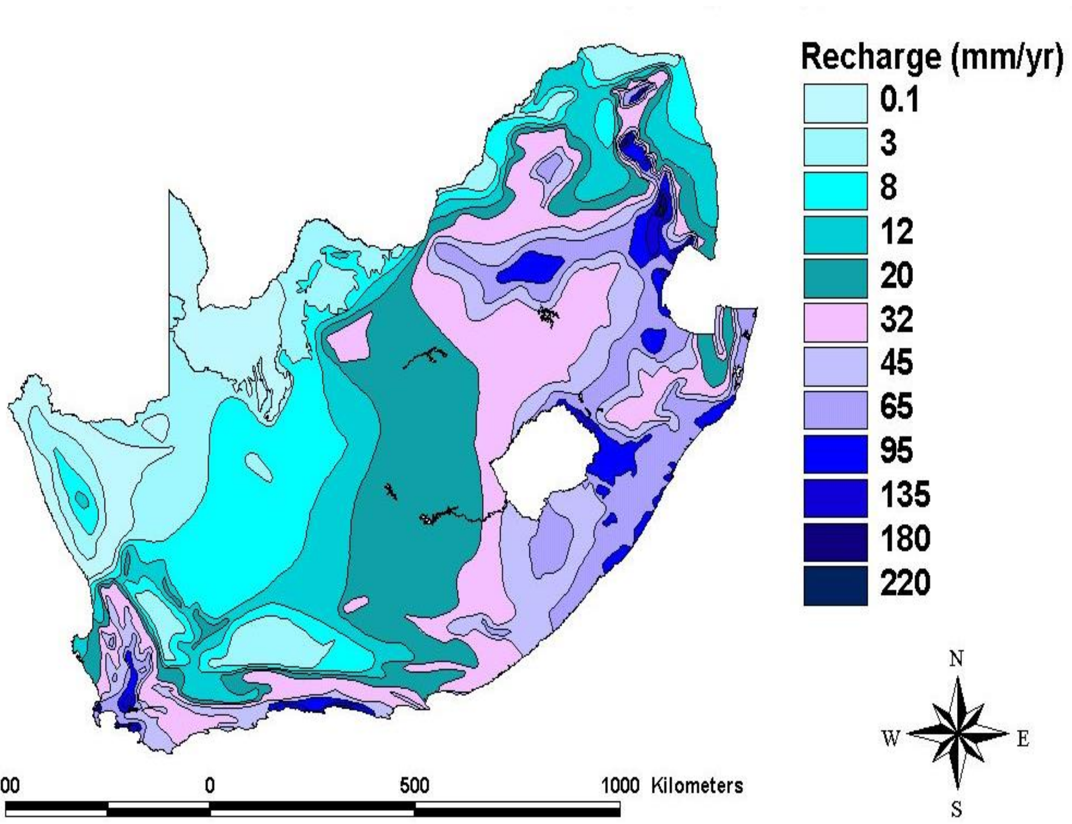


Figure 6-4 Groundwater recharge distribution in South Africa (After Vegter, 1995).

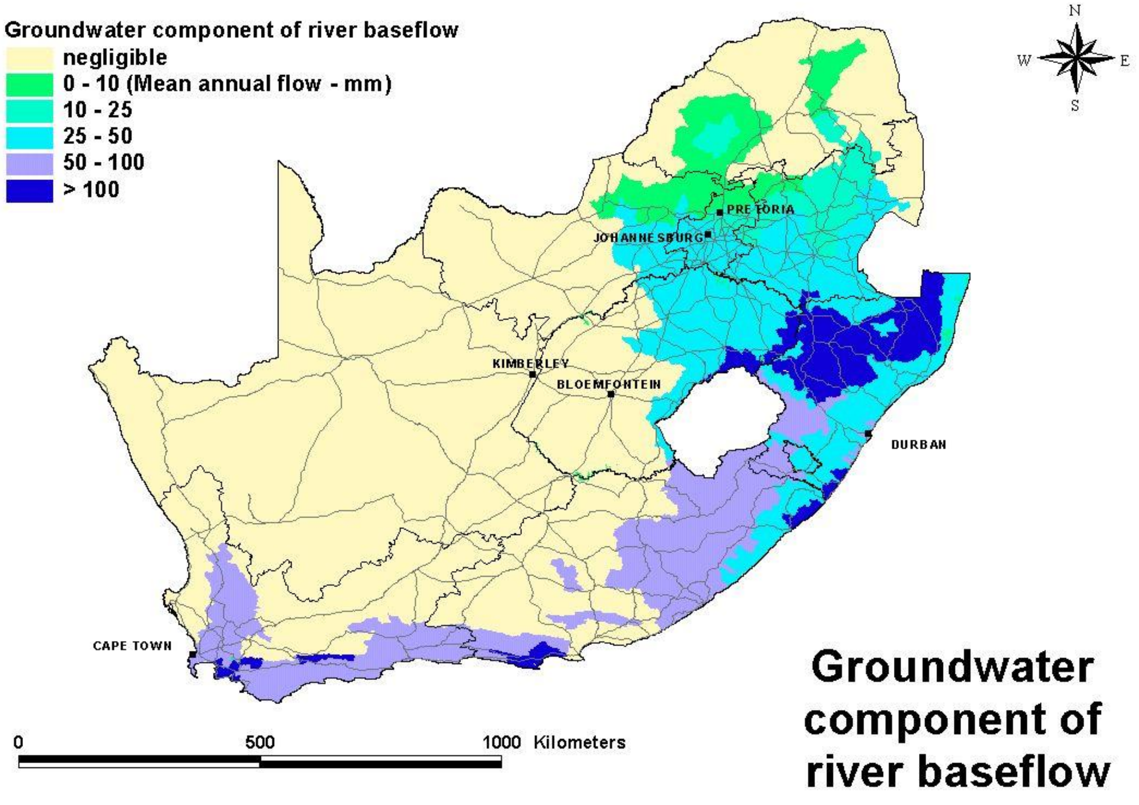


Figure 6-5 Groundwater component of river baseflow in South Africa (DWS, 2013).

6.3. Site investigation

A hydrocensus user survey within the greater study area was conducted during May 2019 where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater conditions and applications prior to the proposed expansion activities and to identify potential sensitive environmental receptors i.e. groundwater users in the direct vicinity of the operations. Geosites visited include nine (9) boreholes, thirteen (13) spring localities, five (5) streams/rivers as well as a neighboring farm dam. Refer to Figure 6-10 for a map depicting the spatial distribution of geosites with relevant information summarised in Table 6-2. Appendix C provide a photographic record of geosites visited

6.3.1. Groundwater status

Of the boreholes and spring localities visited, the majority are in use (>90.0%) with only the two core and exploration boreholes not in use Figure 6-7.

6.3.2. Groundwater application

According to the Upper Vaal ISP the fractured rock aquifers within this WMA are well utilised for rural domestic water supplies and stock watering (DWAF 2004). The groundwater application for domestic purposes is >45.0% while stock watering accounts for ~45.0% as summarized in Figure 6-8.

6.3.3. Borehole equipment

Most boreholes visited are equipped with submersible pumps (~67.0%) while only one borehole is fitted with a handpump. The two exploration boreholes (HBH04 and HBH09) are not equipped (Figure 6-9).

Table 6-2 Hydrocensus user survey: relevant geosite information.

Site ID	Latitude	Longitude	Water level (mbgl)	Water level status	Site type	Site status	Equipment	Water application	Owner	Contact details
F 01	-26.66728	30.15877	0.00	Static	Spring	In use		Domestic	J, Roberts	0731989099
SW 01	-26.66286	30.13757			River				J, Roberts	0731989099
HBH 01	-26.64752	30.11161	94.58	Dynamic	Borehole	In use	Submersible pump	Domestic and livestock	J, Roberts	0731989099
F 02	-26.64674	30.10903	0.00		Spring	In use		Livestock	J, Roberts	0731989099
HBH 02	-26.64503	30.14264	7.38	Static	Borehole	In use	Submersible pump	Domestic and livestock	J, Roberts	0731989099
HBH 03	-26.69440	30.08751	3.75		Borehole	In use	Submersible pump	Domestic	J, Roberts	0731989099
F 03	-26.69637	30.08089	0.00		Spring	In use		Domestic	J, Roberts	0731989099
HBH 04	-26.67525	30.09233	0.00	Static	Borehole	Not in use	Not equipped	Exploration	J, Roberts	0731989099
F 05	-26.67289	30.09085	0.00		Spring	In use		Livestock	J, Roberts	0731989099
HBH 06	-26.67018	30.08004	nawl		Borehole	In use	Handpump	Domestic	J, Roberts	0731989099
F 06	-26.67058	30.07984	0.00		Spring	In use		Domestic	J, Roberts	0731989099
SW 02	-26.70205	30.08271			River				J, Roberts	0731989099
F 07	-26.67981	30.07348	0.00		Spring	In use		Livestock	L. Reyneke	0828851816
HBH 07	-26.67817	30.05782	2.03	Static	Borehole	In use	Submersible pump	Domestic	L. Reyneke	0828851816
F 08	-26.67961	30.05802	0.00		Spring	In use		Domestic	L. Reyneke	0828851816
SW 03	-26.64658	30.09697			Stockpile runoff				Mooiplaats Colliery	
SW 04	-26.64086	30.09761			Dam				Mooiplaats Colliery	
HBH 08	-26.68478	30.11271	9.76	Static	Borehole	In use	Submersible pump	Domestic and livestock	R. Saaiman	0734121967
HBH 09	-26.68044	30.72183	0.00	Static	Borehole	Not in use	Not equipped	Exploration	R. Saaiman	0734121967
F 09	-26.68115	30.12129	0.00		Spring	In use		Livestock	R. Saaiman	0734121967
F 10	-26.68630	30.11962	0.00		Spring	In use		Livestock	R. Saaiman	0734121967
F 11	-26.69017	30.11881	0.00		Spring	In use		Livestock	R. Saaiman	0734121967
F 12	-26.69087	30.11912	0.00		Spring	In use		Livestock	R. Saaiman	0734121967
F 13	-26.70819	30.10675	0.00		Spring	In use		Domestic	J.J. Greetch	0725851650
HBH 10	-26.69237	30.12935			Borehole	In use	Submersible pump	Domestic	Ignis van Rooyen	0826032810
SW 06	-26.64820	30.13124			River				Ignis van Rooyen	0826032810
F 14	-26.62659	30.12177	0.00		Spring	In use		Domestic	W. Meyer	0828004913
SW 07	-26.62673	30.12038			River				W. Meyer	0828004913
SW 08	-26.63563	30.13084			River				W. Meyer	0828004913

Note: NAWL (No Acess to the Water Level) is noted when the water level probe could not reach the static water level due to obstruction, equipment or no access

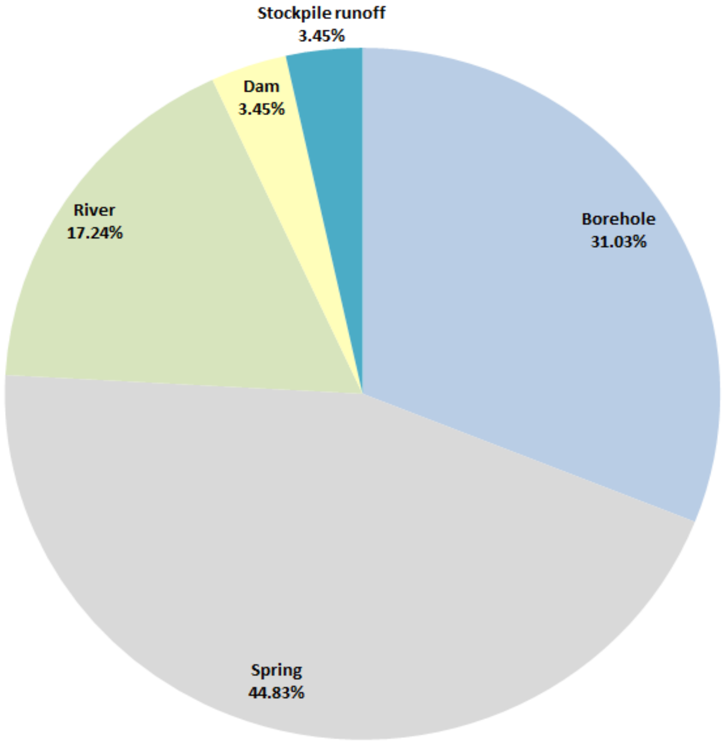


Figure 6-6 **Hydrocensus user survey: Geosite recorded.**

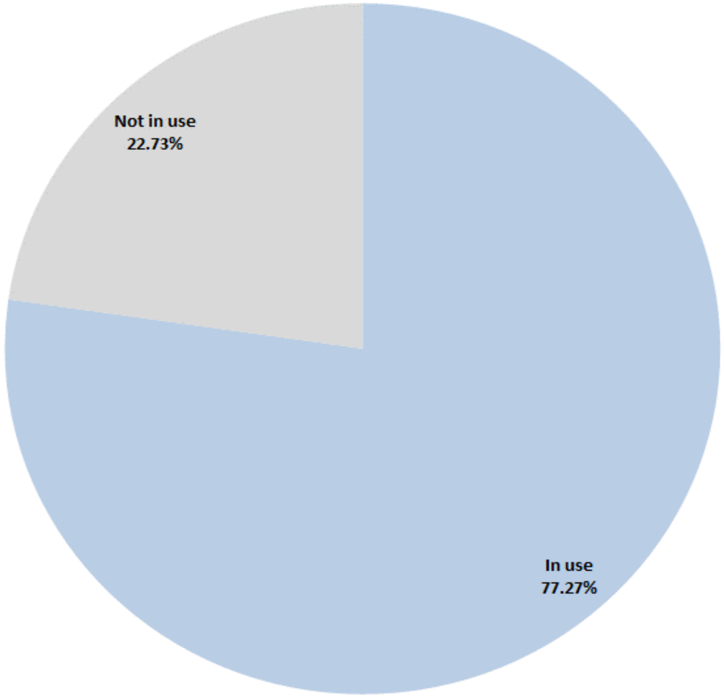


Figure 6-7 **Hydrocensus user survey: Groundwater status.**

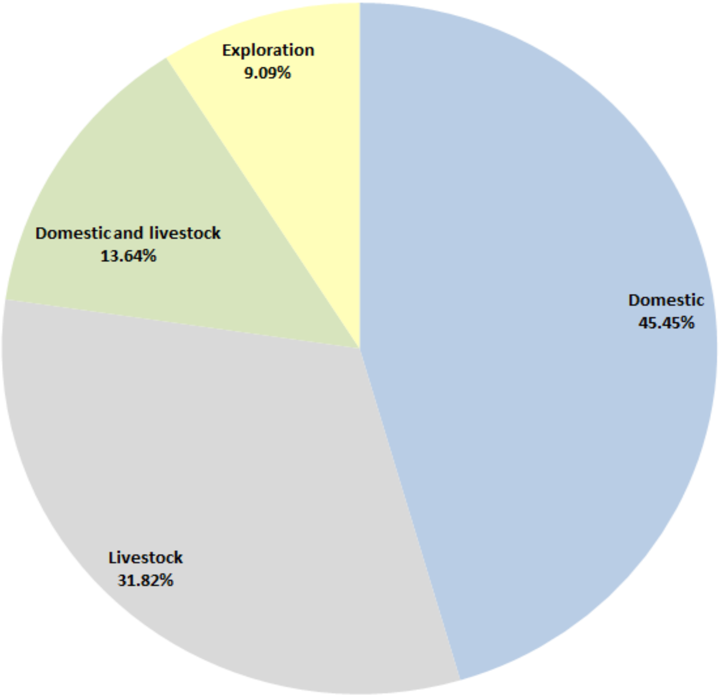


Figure 6-8 **Hydrocensus user survey: Groundwater application.**

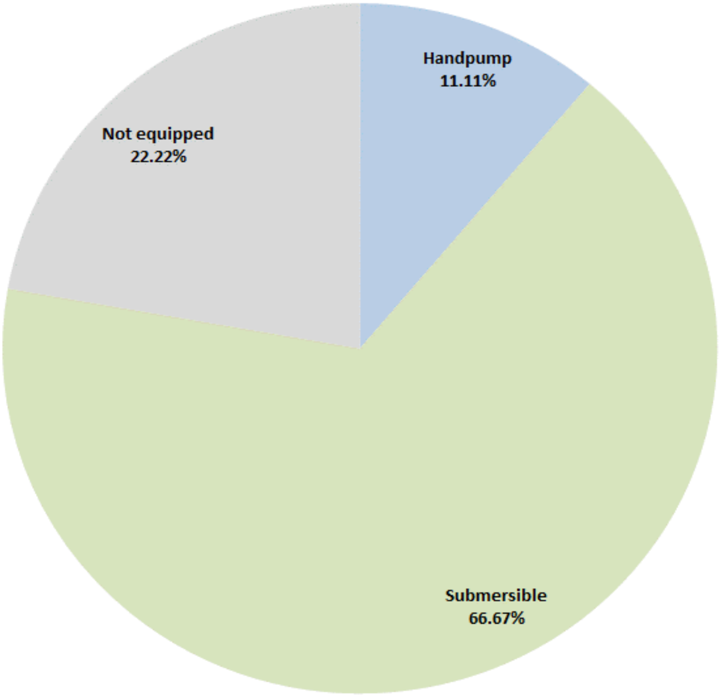


Figure 6-9 **Hydrocensus user survey: Equipment type.**

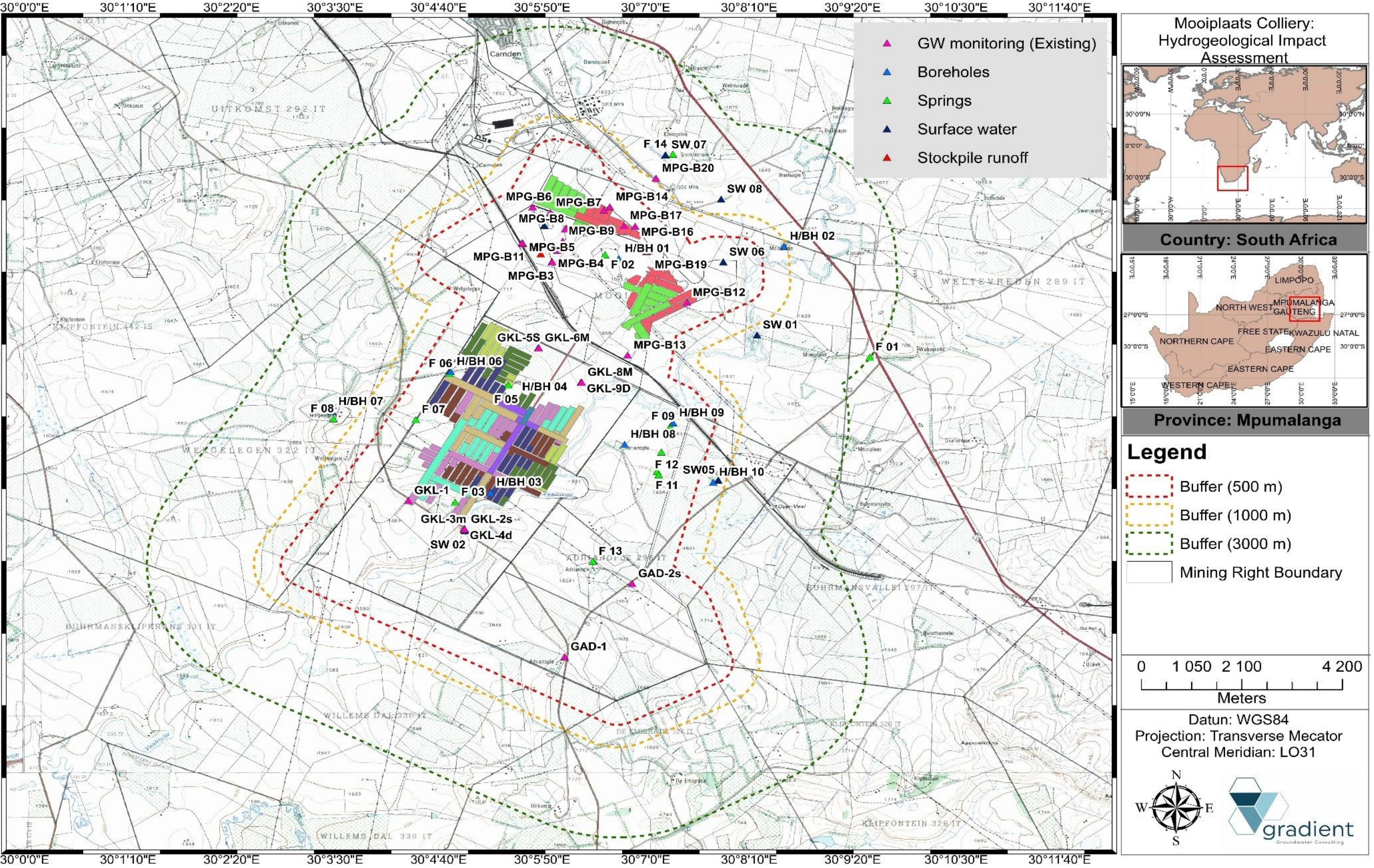


Figure 6-10 **Spatial distribution of hydrocensus user survey geosites.**

7. GROUNDWATER FLOW EVALUATION

The following sub-sections outline the site-specific hydrogeology of the study area.

7.1. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water level elevation from corresponding surface topography. The latter will govern the infiltration rate, as well as effective recharge of rainfall to the aquifer. Furthermore, the nature of the formation(s) forming the unsaturated zone will significantly influence the mass transport of surface contamination to the underlying aquifer(s). The unsaturated zone within the study area is in the order of ~0.0 mbgl to ~29.56 mbgl[5] with a mean thickness of approximately 8.0 m.

7.2. Depth to groundwater

A distribution of borehole water levels recorded as part of the hydrocensus user survey as well as boreholes forming part of the existing groundwater monitoring network were considered and used to interpolate local groundwater elevation and hydraulic head contours. The groundwater levels available from the hydrocensus survey and monitoring boreholes in and around the mining areas are summarized in Table 7-1 and depicted in Figure 7-1.The minimum water level recorded is artesian, 0.0 mbgl, various spring localities were also recorded within the greater study area, with the deepest static water level measured at borehole locality MPG-B16, 29.56 mbgl[6]. The relatively low standard deviation compared to the mean depth to groundwater i.e. Coefficient of Variation (CV) < 100%, suggest a relative steady state groundwater environment.

Table 7-1 **Regional water level summary.**

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)	Water level status
MPG-B1	1671.52	1.73	1669.79	Static
MPG-B2	1663.78	1.97	1661.81	Static
MPG-B3	1691.56	11.33	1680.23	Static
MPG-B4	1691.56	12.12	1679.44	Static
MPG-B5	1691.56	5.44	1686.12	Static
MPG-B6	1671.52	3.87	1667.65	Static
MPG-B7	1671.52	1.69	1669.83	Static
MPG-B8	1663.78	2.11	1661.67	Static
MPG-B9	1669.93	11.55	1658.38	Static
MPG-B11	1691.56	4.40	1687.16	Static
MPG-B13	1658.02	3.62	1654.40	Static
MPG-B14	1660.51	17.12	1643.39	Static
MPG-B15	1660.51	9.56	1650.95	Static
MPG-B16	1660.51	29.56	1630.95	Static
MPG-B17	1660.51	6.31	1654.20	Static
MPG-B18	1686.58	27.23	1659.35	Static
MPG-B19	1686.58	23.89	1662.69	Static
MPG-B20	1637.44	2.73	1634.71	Static
GAD-1	1674.68	3.09	1671.59	Static
GAD-2S	1653.83	6.93	1646.90	Static
GAD-3S	1628.05	1.67	1626.38	Static

---

[5] This is based on groundwater levels measured at surveyed boreholes.

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)	Water level status
GAD-4M	1628.05	1.76	1626.29	Static
GAD-5D	1628.05	0.00	1628.05	Static
GKL-2S	1638.34	2.87	1635.47	Static
GKL-3m	1638.34	3.70	1634.64	Static
GKL-5s	1679.57	1.81	1677.76	Static
GKL-6m	1679.57	1.41	1678.16	Static
GKL-8m	1651.74	4.61	1647.13	Static
HBH02	1623.39	7.38	1616.01	Static
HBH03	1621.87	3.75	1618.12	Static
HBH07	1633.08	2.03	1631.05	Static
HBH08	1654.91	9.76	1645.15	Static
HBH10	1683.18	5.76	1645.15	Static
Harmonic mean	**1660.49**	**4.98**	**1652.50**	
Minimum	**1621.87**	**0.00**	**1616.01**	
Maximum	**1691.56**	**29.56**	**1687.16**	
Standard deviation	**21.73**	**7.36**	**20.05**	
Correlation		**0.91**		

7.3. Groundwater flow direction and hydraulic gradients

Analysed data indicate that the majority of surveyed water levels correlate very well to the topographical elevation ($R^2 > 0.91$) (Figure 7-1). Accordingly, it can be assumed that the regional groundwater flow direction is dictated by topography. As suggested, the inferred groundwater flow direction will be towards the lower laying drainage system of the Vaal River transecting the project area and will flow in a general southern to south-eastern direction. Groundwater flow path lines are lines perpendicular to groundwater contours, flow generally occurs faster where contours are closer together and gradients are thus steeper as depicted in Figure 7-2.

The groundwater or hydraulic gradient is the change in the hydraulic head over a certain distance, mathematically it is the difference in hydraulic head over a distance along the flow path between two points. The latter provides an indication of the direction of groundwater flow. The following equation can be applied:

Equation 7-1 Hydraulic gradient.

$$\boldsymbol{i} = \frac{\boldsymbol{dh}}{\boldsymbol{dl}}$$

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points.

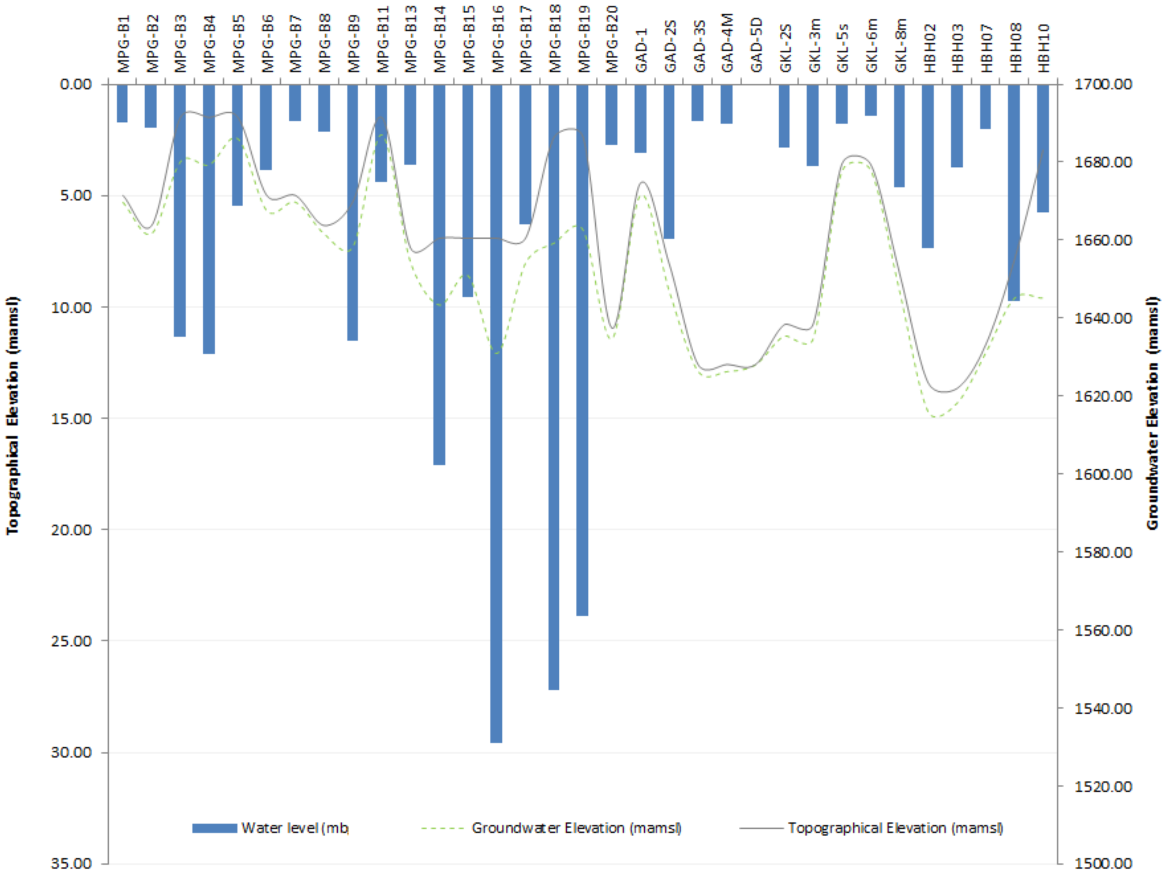


Figure 7-1 **Topographical elevation vs. groundwater elevation correlation graph.**

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas is moderately flat and calculated at approximately 0.008, with a maximum of 0.018 towards the east while a gentler gradient of 0.004 exists to the south as summarized in Table 7-2.

Table 7-2 **Inferred groundwater gradient and seepage direction.**

Inferred seepage direction	Hydraulic gradient (i)
South	0.004
East	0.018
Southwest	0.010
North	0.010
Minimum	**0.004**
Maximum	**0.018**
Standard deviation	**0.005**
Harmonic Mean	**0.008**

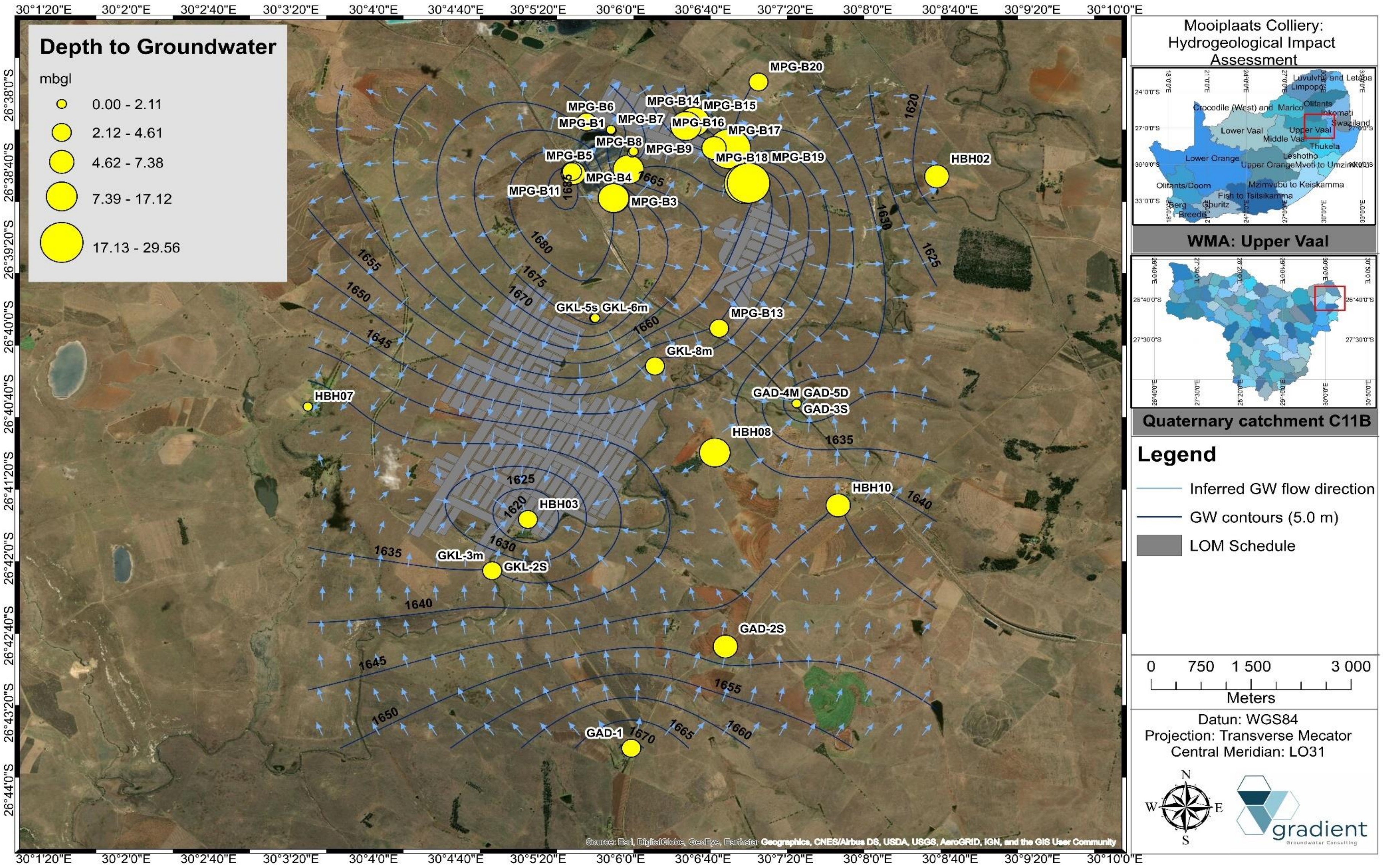


Figure 7-2 **Regional groundwater flow direction and depth to groundwater.**

7.4. Darcy flux and groundwater flow velocity

The Darcy flux (or velocity) is a function of the hydraulic conductivity (K) and the hydraulic gradient as suggested by Equation 7-2 whereas the seepage velocity can be defined as the Darcy flux divided by the effective porosity (Equation 7-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

Equation 7-2 **Darcy flux.**

$$v = Ki$$

Equation 7-3 **Seepage velocity.**

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

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

The expected seepage rate from contamination originating at the mine discard dump is estimated at an average of 8.6 m/a depending on the local groundwater gradient and direction as summarized in Table 7-3[7].

Table 7-3 **Darcy flux and seepage rates.**

Shallow, weathered aquifer	Hydraulic gradient (i)	Hydraulic conductivity (K)	Darcy flux (m/d)	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
South	0.004	0.030	0.0001	0.01	0.01	4.38
East	0.018	0.030	0.0005	0.01	0.05	19.71
Southwest	0.010	0.030	0.0003	0.01	0.03	10.95
North	0.010	0.030	0.0003	0.01	0.03	10.95
Minimum	**0.004**	**0.030**	**0.000**	**0.01**	**0.01**	**4.38**
Maximum	**0.018**	**0.030**	**0.001**	**0.01**	**0.05**	**19.71**
Standard deviation	**0.005**	**0.000**	**0.000**	**0.00**	**0.01**	**5.45**
Harmonic Mean	**0.008**	**0.030**	**0.000**	**0.01**	**0.02**	**8.66**

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[7] This estimate does however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by faults and fracture zones or igneous contact zones like the intrusive dykes that have higher transmissivities than the general aquifer matrix. Such structures may cause flow velocities to increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

8. HYDROCHEMISTRY

8.1. Water quality analysis

The South African National Standards (SANS 241: 2015) have been applied to assess the water quality within the project area. The standards specify a maximum limit based on associated risks for constituents (Refer to Table 8-1). Water samples were submitted for analysis at a SANAS accredited laboratory (Aquatico Laboratories) for inorganic analysis. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health), elemental concentrations above this range are classed as unsuitable for domestic consumption without treatment whereas yellow highlighted cells indicate parameters above aesthetic limits. These standards were selected for use as the current and future water uses in the area are primarily domestic application and/or livestock watering. Refer to Appendix B for laboratory analysis certificates.

Table 8-1 **SANS 241:2015 risks associated with constituents occurring in water.**

Risk	Effect
Aesthetic	Determinant that taints water with respect to taste, odour and colour and that does not pose an unacceptable health risk if present at concentration values exceeding the numerical limits specified.
Operational	Determinant that is essential for assessing the efficient operation of treatment systems and risks to infrastructure.
Acute Health – 1	Routinely quantifiable determinant that poses an immediate health risk if consumed with water at concentration values exceeding the numerical limits specified.
Acute Health – 2	Determinant that is presently not easily quantifiable and lacks information pertaining to viability and human infectivity which, however, does pose immediate unacceptable health risks if consumed with water at concentration values exceeding the numerical limits specified.
Chronic Health	Determinant that poses an unacceptable health risk if ingested over an extended period if present at concentration values exceeding the numerical limits specified.

Table 8-2 **SANS 241:2015 physical aesthetic, operational and chemical parameters.**

Parameter	Risk	Unit	Standard limits [a]
Physical and aesthetic determinants			
Electrical conductivity (EC)	Aesthetic	mS/m	≤170
Total Dissolved Solids (TDS)	Aesthetic	mg/l	≤1200
Turbidity [b]	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH [c]	Operational	pH units	≥5 to ≤9,7
Chemical determinants – 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 determinants – micro			
Antimony as Sb	Chronic health	mg/l	≤0.02
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

Parameter	Risk	Unit	Standard limits [a]
	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^-.

Table 8-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
HBH 01	3.54	3.57	-0.45%
HBH 02	3.64	3.42	3.12%
HBH 03	3.79	3.75	0.60%
HBH 04	1.64	1.74	-2.87%
F 05	0.88	0.96	-4.18%
HBH 06	1.07	1.14	-3.08%
F 06	2.62	2.72	-2.04%
F 08	1.80	1.75	1.52%
HBH 08	3.11	3.09	0.32%
F 13	2.85	2.66	3.43%
HBH 09	21.10	22.12	-2.37%
HBH 10	2.07	1.96	2.66%

Note: E.N. < 5.0% generally reflect an accurate laboratory analysis.

8.2. Groundwater quality

The overall water quality of groundwater samples analysed is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Isolated sampling localities indicate above limit nitrate (NO_3) concentrations which can be indicative of either mine blasting activities or nearby, up-gradient anthropogenic activities. It should be noted that certain sampling locality HBH09 suggest older, more stagnant water due to the elevated sodium signature observed. The latter can also be characteristic of an evaporative and low recharge zone. Furthermore, certain samples indicate elevated levels of fluoride. Table 8-4, Table 8-5 as well as Table 8-6 classify water quality according to pH, Total Dissolved Solids (TDS) as well as hardness.

Table 8-7 summarises water quality analysis per sampling locality with Figure 8-9 indicating a spatial distribution map of hydrochemical composition per sampling locality. Figure 8-1 depicts a bar-chart of major anion and cation composition[8]. To follow is a brief description of the water quality for each sample analysed. Table 8-7 summarises water quality analysis per sampling locality with Figure 8-1 depicting a bar-chart of major anion and cation composition.

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[8] It should be note that due to the relative chemical composition of borehole locality HBH09 compared to the other samples, it was excluded from the bar-chart summary.

Table 8-4 **Hydrochemical classification according to pH-values.**

pH Values used to indicate alkalinity or acidity of water	
pH: > 8.5	Alkaline/Basic
pH: 6.0- 8.5	Neutral
pH: < 6	Acidic

Table 8-5 **Hydrochemical classification according to salinity.**

TDS Concentrations to indicate the salinity of water	
TDS < 450 mg/l	Non-saline
TDS 450 - 1 000 mg/l	Saline
TDS 1 000 - 2 400 mg/l	Very saline
TDS 2 400 - 3 400 mg/l	Extremely saline

Table 8-6 **Hydrochemical classification according to hardness.**

Hardness concentrations to indicate softness or hardness of water	
Hardness < 50 mg/l	Soft
Hardness 50 – 100 mg/l	Moderately soft
Hardness 100 – 150 mg/l	Slightly hard
Hardness 150 – 200 mg/l	Moderately hard
Hardness 200 – 300 mg/l	Hard
Hardness 300 – 600 mg/l	Very hard
Hardness > 600mg/l	Extremely hard

8.2.1. Sampling locality HBH01

Water quality can be described as alkaline, non-saline and slightly hard:

- pH of 8.60.
- TDS of 179.00 mg/l.
- Total Hardness ($CaCO_3$/l) of 126.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.2. Sampling locality HBH02

Water quality can be described as neutral, non-saline and slightly hard:

- pH of 8.41.
- TDS of 193.00 mg/l.
- Total Hardness (CaCO3/l) of 147.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.3. Sampling locality HBH03

Water quality can be described as neutral, non-saline and slightly hard:

- pH of 7.61.
- TDS of 194.00 mg/l.
- Total Hardness (CaCO3/l) of 135.00 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- Mn of 0.41 mg/l.

8.2.4. Sampling locality HBH04

Water quality can be described as neutral, non-saline and soft:

- pH of 7.41.
- TDS of 90.00 mg/l.

- Total Hardness (CaCO3/l) of 38.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.5. Sampling locality F05

Water quality can be described as neutral, non-saline and soft:

- pH of 6.57.
- TDS of 52.00 mg/l.
- Total Hardness (CaCO3/l) of 13.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.6. Sampling locality HBH06

Water quality can be described as neutral, non-saline and soft:

- pH of 6.57.
- TDS of 58.00 mg/l.
- Total Hardness (CaCO3/l) of 33.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.7. Sampling locality F06

Water quality can be described as neutral, non-saline and moderately soft:

- pH of 7.56.
- TDS of 124.0 mg/l.
- Total Hardness (CaCO3/l) of 79.00 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- F of 2.36 mg/l.
- Mn of 0.18 mg/l.

8.2.8. Sampling locality F08

Water quality can be described as neutral, non-saline and moderately soft:

- pH of 7.09.
- TDS of 90.0 mg/l.
- Total Hardness (CaCO3/l) of71.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.9. Sampling locality HBH08

Water quality can be described as neutral, non-saline and slightly hard:

- pH of 7.36.
- TDS of 165.0 mg/l.
- Total Hardness (CaCO3/l) of 114.00 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.2.10. Sampling locality F13

Water quality can be described as neutral, non-saline and slightly hard:

- pH of 7.23.
- TDS of 164.0 mg/l.
- Total Hardness (CaCO3/l) of 121.00 mg/l

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- NO3-N of 11.10 mg/l

8.2.11. Sampling locality HBH09

Water quality can be described as alkaline, very saline and soft:

- pH of 8.75.
- TDS of 1156.0 mg/l.
- Total Hardness (CaCO3/l) of 5.00 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- EC of 190.0 mS/m.
- F of 11.60 mg/l.
- Na of 479.0 mg/l.
- Fe of 1.43 mg/l.

8.2.12. Sampling locality HBH10

Water quality can be described as neutral, non-saline and moderately soft:

- pH of 7.85.
- TDS of 108.0 mg/l.
- Total Hardness (CaCO3/l) of 81.00 mg/l

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

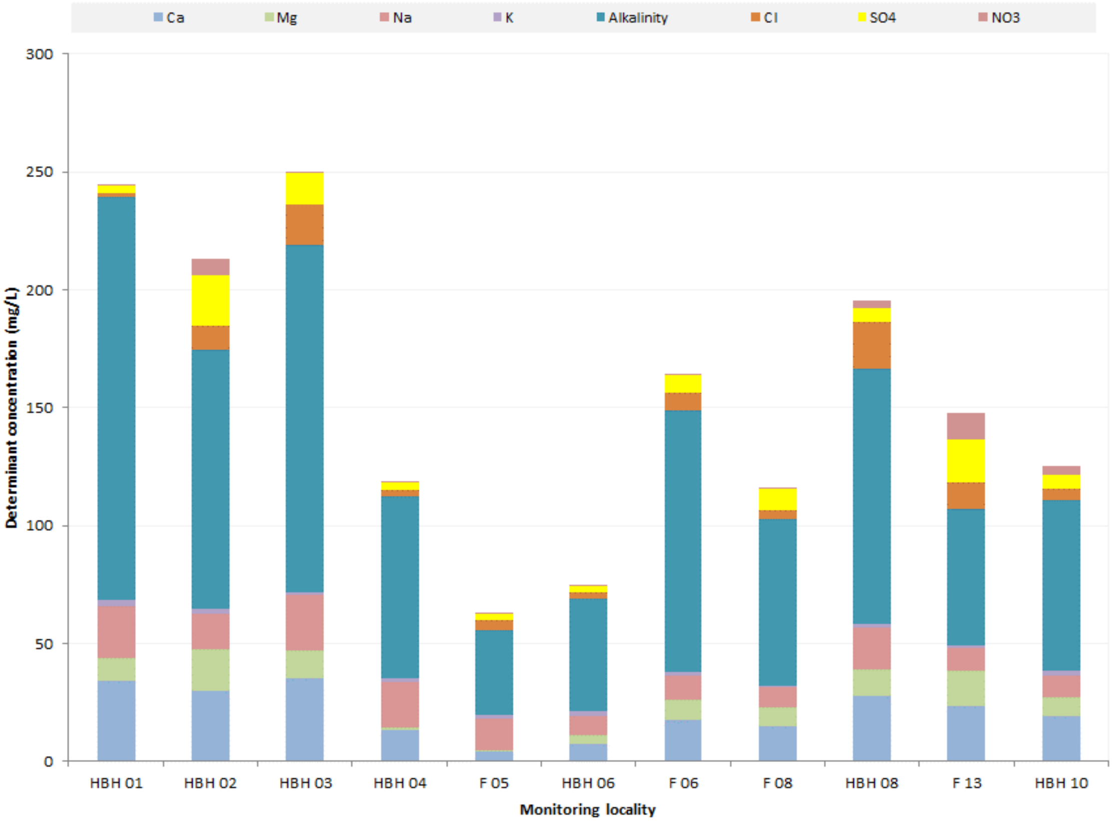

Figure 8-1 **Hydrochemistry: Composite bar-chart indicating sample major anion cation composition (mg/l).**

Table 8-7 **Hydrochemistry: Hydroccensus user survey geosite water quality evaluation (SANS 241:2015).**

Determinant	Unit	Risk	SANS 241:2015 limits	HBH 01	HBH 02	HBH 03	HBH 04	F 05	HBH 06	F 06	F 08	HBH 08	F 13	HBH 09	HBH 10
General parameters															
pH	-	Operational	≥5.0 ≤ 9.5	8.6	8.41	7.61	7.41	6.57	6.57	7.56	7.09	7.36	7.23	8.75	7.85
EC	mS/m	Aesthetic	≤170.0	30.5	33.10	34.50	16.50	10.10	11.50	21.70	17.20	30.30	29.20	190.00	20.50
TDS		Aesthetic	≤ 1 200.0	179.0	193.00	194.00	90.00	52.00	58.00	124.00	90.00	165.00	164.00	1156.00	108.00
Total Alkalinity	CaCO3/l	-	-	171.0	110.00	147.00	77.20	35.90	47.80	111.00	71.20	108.00	57.70	1042.00	72.40
Total Hardness	mg/l	-	-	126.0	147.00	135.00	38.00	13.00	33.00	79.00	71.00	114.00	121.00	5.00	81.00
Anions															
Cl	mg/l	Aesthetic	≤300.0	1.86	10.00	17.10	3.01	4.65	2.79	7.20	3.63	20.20	11.50	21.00	5.08
SO_4	mg/l	Aesthetic	≤250.0	3.23	21.70	13.90	3.18	2.48	2.40	7.50	9.02	5.42	18.20	2.00	5.92
F	mg/l	Acute health	≤1.50	<0.263	<0.263	0.40	0.28	<0.263	<0.263	2.36	<0.263	<0.263	<0.263	11.60	<0.263
NO_3< N	mg/l	Acute health	≤11.0	0.22	6.61	0.21	0.28	0.68	0.59	0.30	0.25	3.43	11.10	0.42	3.34
PO_4	mg/l	-	-	<0.005	<0.005	<0.005	0.10	<0.005	0.02	<0.005	<0.005	<0.005	<0.005	0.05	<0.005
Cations and metals															
NH_4	mg/l	Aesthetic	≤1.50	0.065	0.031	0.059	0.074	0.049	0.027	0.024	0.225	0.023	0.058	0.760	0.026
Na	mg/l	Aesthetic	≤200.0	21.900	14.800	23.900	19.200	13.200	7.960	10.100	8.210	18.000	9.240	479.000	9.370
K	mg/l	-	-	2.540	2.300	1.080	1.390	1.600	2.240	1.820	0.482	1.560	1.260	2.040	1.770
Ca	mg/l	-	-	33.900	30.100	35.500	13.100	3.970	7.450	17.500	15.100	28.000	23.500	1.760	19.200
Mg	mg/l	-	-	10.000	17.400	11.300	1.320	0.801	3.530	8.640	8.010	10.800	15.100	0.172	7.980
Al	mg/l	Operational	0.3	<0.002	<0.002	0.002	0.012	<0.002	0.022	0.004	0.013	<0.002	0.002	0.011	<0.002
Fe	mg/l	Aesthetic	0.3	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	1.430	<0.004
Mn	mg/l	Aesthetic	0.1	<0.001	<0.001	0.41	0.001	<0.001	<0.001	0.18	<0.001	<0.001	<0.001	0.007	<0.001

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.

"< " indicate that results analysed are below the detection limits.

Shaded cells exceed SANS 241:2015 drinking water guidelines.

8.3. Hydrochemical signature

In order to assess future impacts of the proposed mining expansion activities on the groundwater it is necessary to develop a baseline for groundwater prior to onset. The following section serves to characterise ambient groundwater conditions and develop a relevant baseline[9]. Three types of diagnostic plots were used to characterise analysed water samples based on hydrochemistry.

8.3.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 8-2). Different water types derived from different environments plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area generally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and coordinated regimes. Figure 8-3 depicts a piper diagram developed from the hydrocensus water quality analysis results. Two distinct water categories can be distinguished i.e. Category A (Calsium-Bi-carbonate dominance, indicative of recently recharged groundwater) and Category B (Sodium/Potassium- Bi-carbonate dominance suggestive of a dynamic and coordinated environment).

Figure 8-4 shows a piper diagram of the existing groundwater monitoring data analysed (June 2019). It is evident that monitoring localities MPG-B2 and MPG-B7 is impacted on due to their close proximity to the existing discard dump. It should be note that the majority of other monitoring localities samples analysed is good and suggest an unimpacted aquifer system.

8.3.2. Stiff diagrams

A Stiff diagram, or Stiff pattern, is a graphical representation of chemical analyses and major anions and cations, first developed by H.A. Stiff in 1951. STIFF diagrams plot the equivalent concentrations of major anions and cations on a horizontal scale on opposite sides of a vertical axis. The plot point of each parameter is linked to the adjacent point creating a polygon around the vertical axis. Water with similar major ion ratios will show similar geometries.

Figure 8-5 depicts Stiff diagrams compiled from the hydrocensus user survey sampling analysis. It is evident that sampling locality HBH09 indicate a different hydrochemical signature compared to the other sampling localities. The latter borehole was used for exploration purposes and potentially drilled into the deeper, fractured aquifer as it displays a piezometric surface and semi-confined nature. It is assumed that the other sampling localities represents the shallow, weathered aquifer. The stiff diagrams of the spring localities correlate well with the shallow aquifer signature and it can be inferred that spring water discharges from the shallow, weathered aquifer.

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[9] It should be noted that the term “baseline” referred to in this context suggest current background conditions and may already be influenced by existing mining activities.

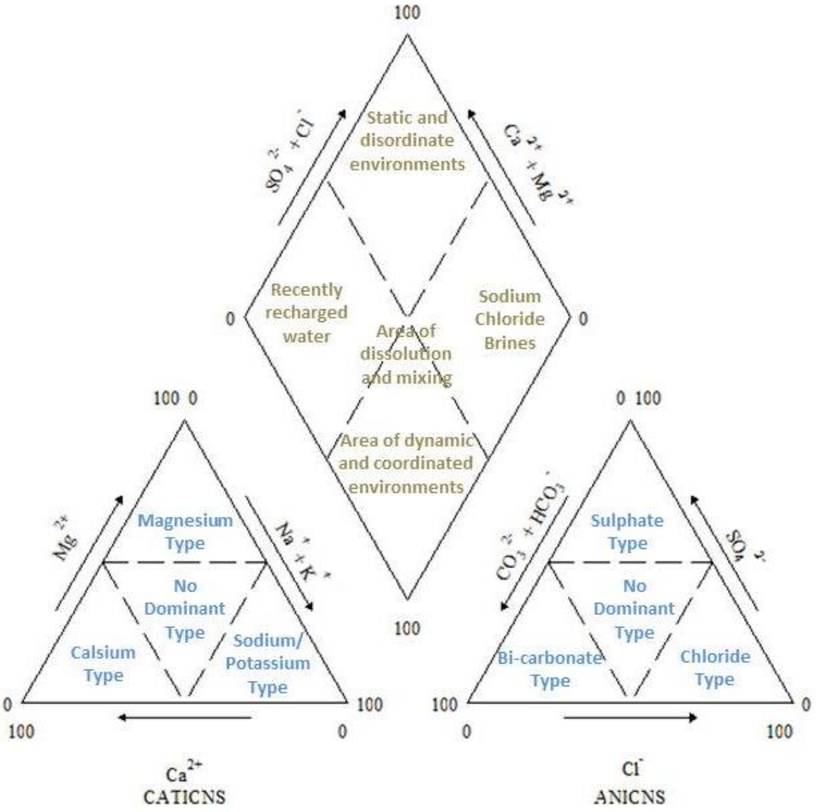

Figure 8-2 Piper diagram indicating classification for anion and cation facies in terms of ion percentages.

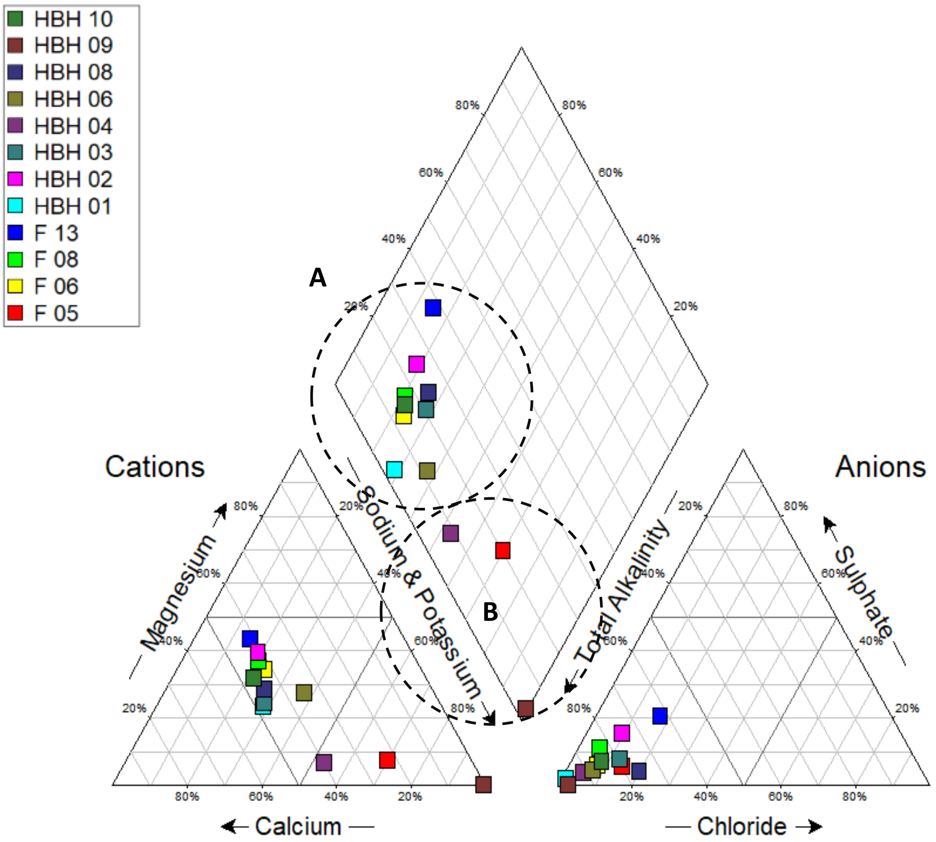

Figure 8-3 Piper diagram indicating major anions and cations of hydrocnesus water samples.

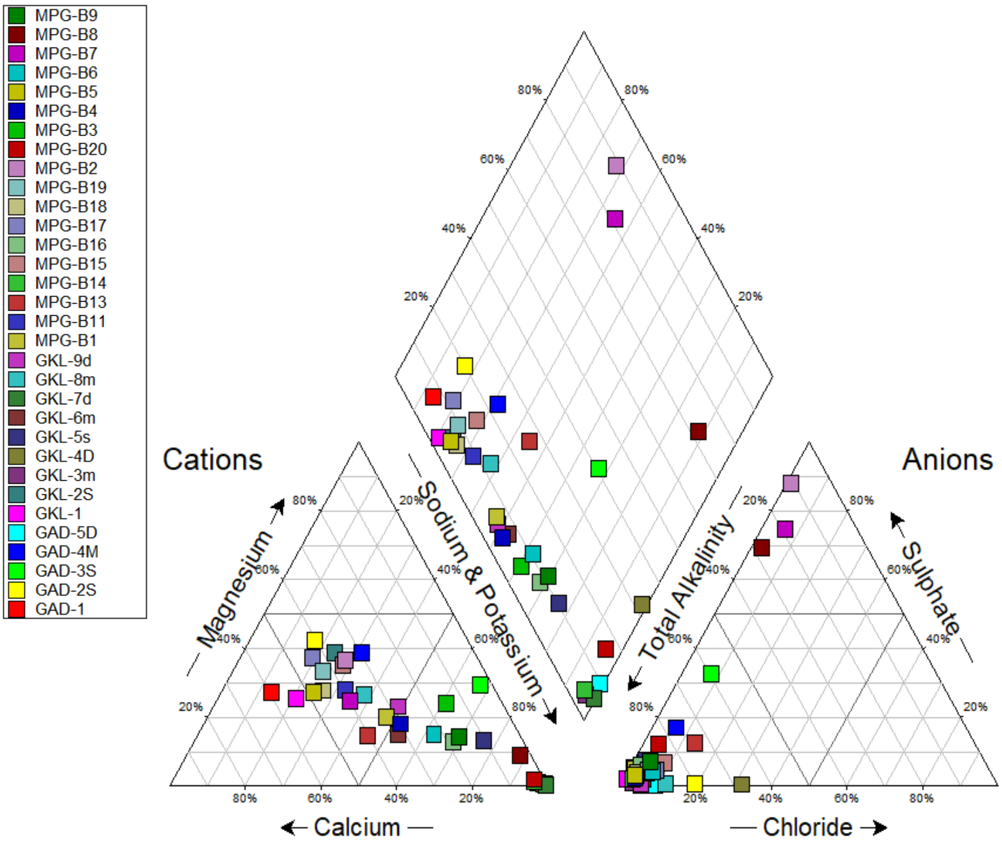

Figure 8-4 **Piper diagram indicating major anions and cations of groundwater monitoring samples analysed.**

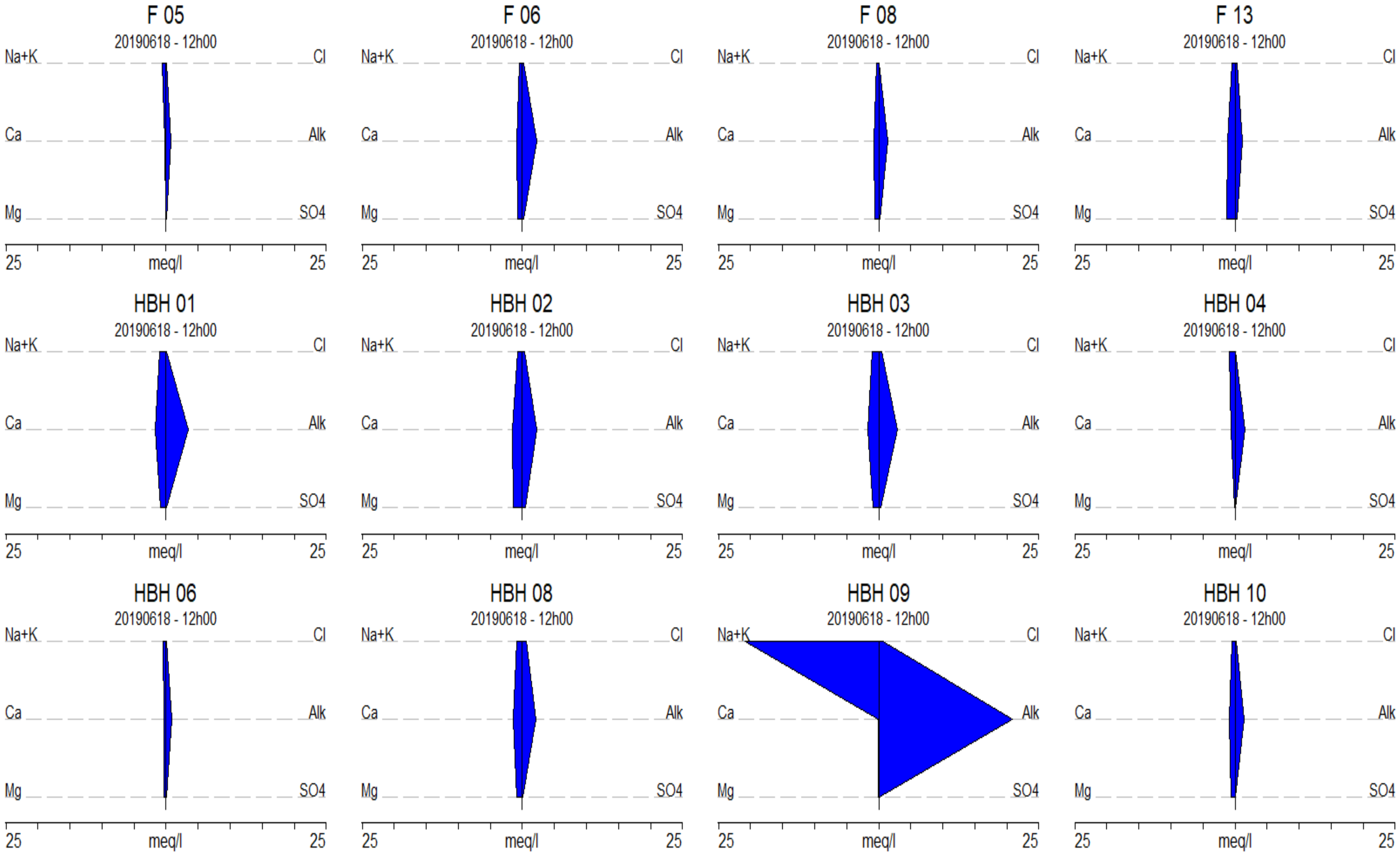

Figure 8-5 **Stiff diagrams representing hydrocenus sampling localities analysed.**

8.4. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems. Different fields of the diagram could be summarized as follows:

Field 01: Water (mostly fresh, clean and recently recharged) with HCO_3- and CO_3 as dominant anion and Ca as dominant cation.

Field 02: Water (mostly fresh, clean, and relatively young) that also has an Mg signature, often found in dolomitic terrain.

Field 03: Often associated with Na ion exchange between groundwater and aquifer material (sometimes in Na-enriched granites or other felsic rocks) or because of contamination effects from a source rich in Na.

Field 04: Often associated with mining related SO_4 contamination.

Field 05: Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing/contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 06: Groundwater from field 5 that has been contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 07: Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 08: Groundwater that is usually a mix of different type, for example water from 2 that has undergone Cl mixing/contamination or old stagnant NaCl-dominated water that has mixed with water richer in Mg.

Field 09: Seawater or very old stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.), or water that has moved a long time and/or distance through the aquifer and has undergone significant ion exchange.

The majority of samples can be classified as Field 02 i.e. mostly fresh, clean and relatively young with HCO_3- and CO_3 dominance evident. Sampling localities HBH04 and HBH09, both of which were applied for exploration purposes and potentially targets a deeper, fractured aquifer unit(s) suggest Na ion exchange between groundwater and potentially aquifer material and/or another external contamination source rich in Na. Refer to Figure 8-7 for a summary of hydrochemical signatures pertaining to the hydrocensus samples analysed and Figure 8-8 for the groundwater monitoring samples analysed.

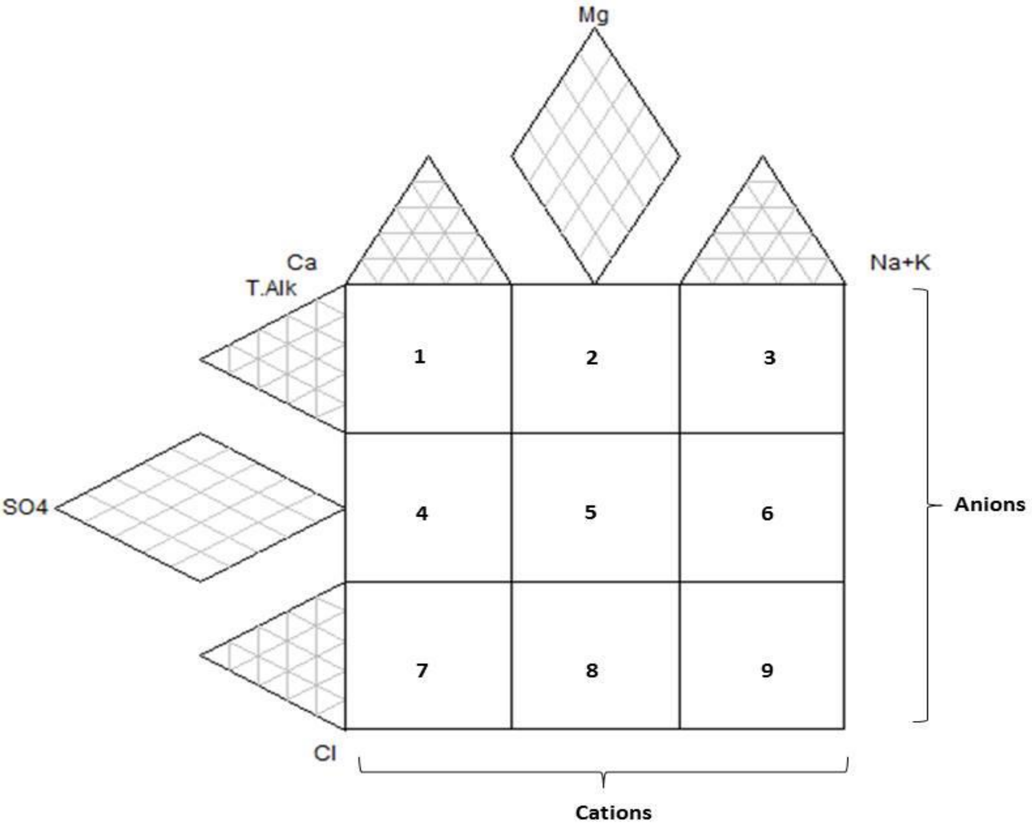

Figure 8-6 **Extended Durov diagram indicating major anions and cations.**

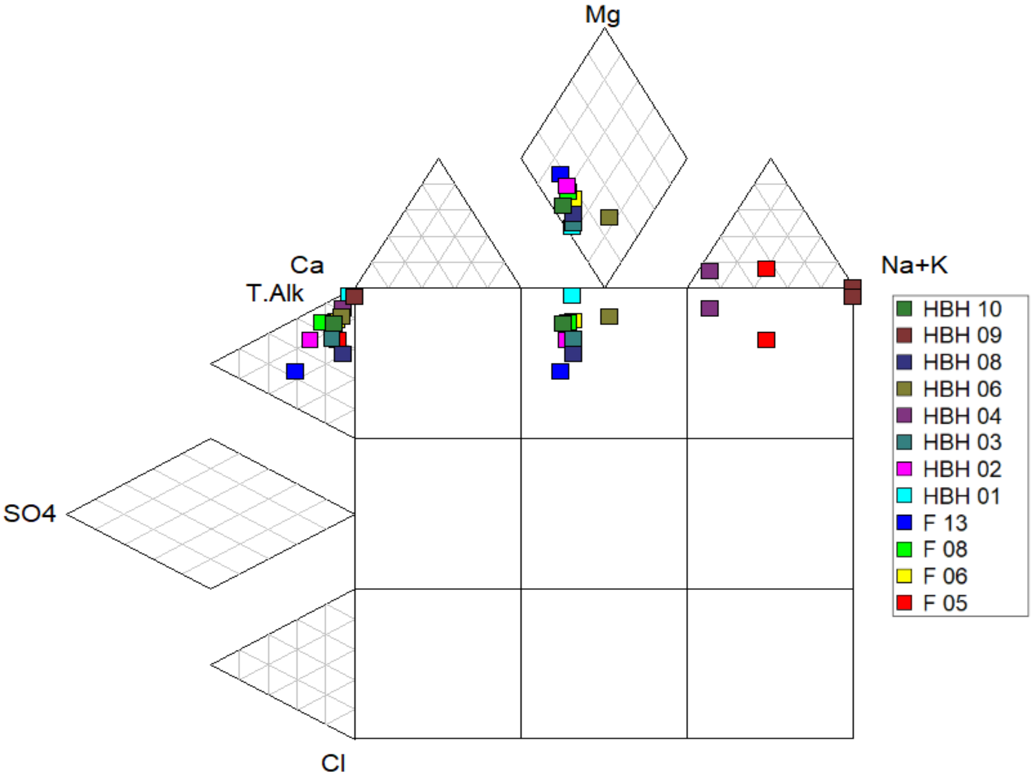

Figure 8-7 **Extended Durov diagram of hydrocenus sampling localities analysed.**

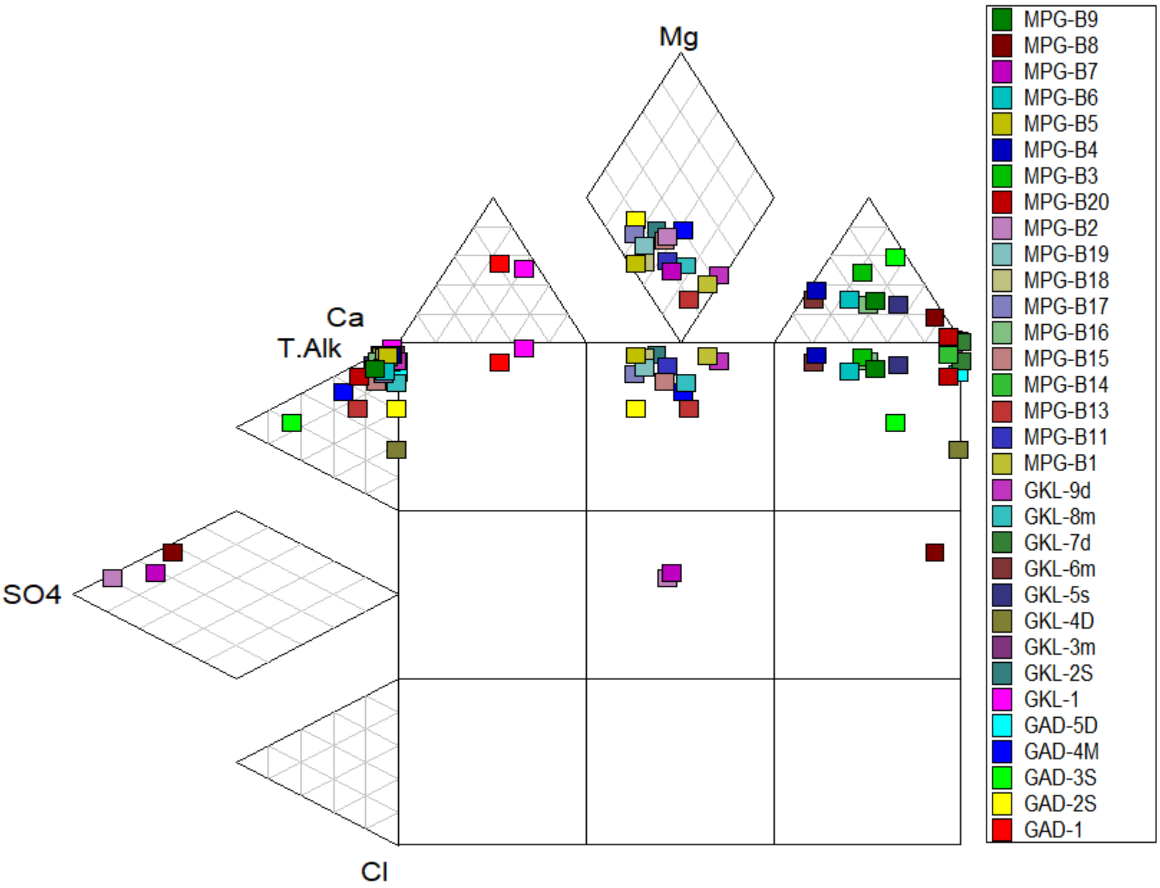

Figure 8-8 **Extended Durov diagram of groundwater monitoring samples analysed.**

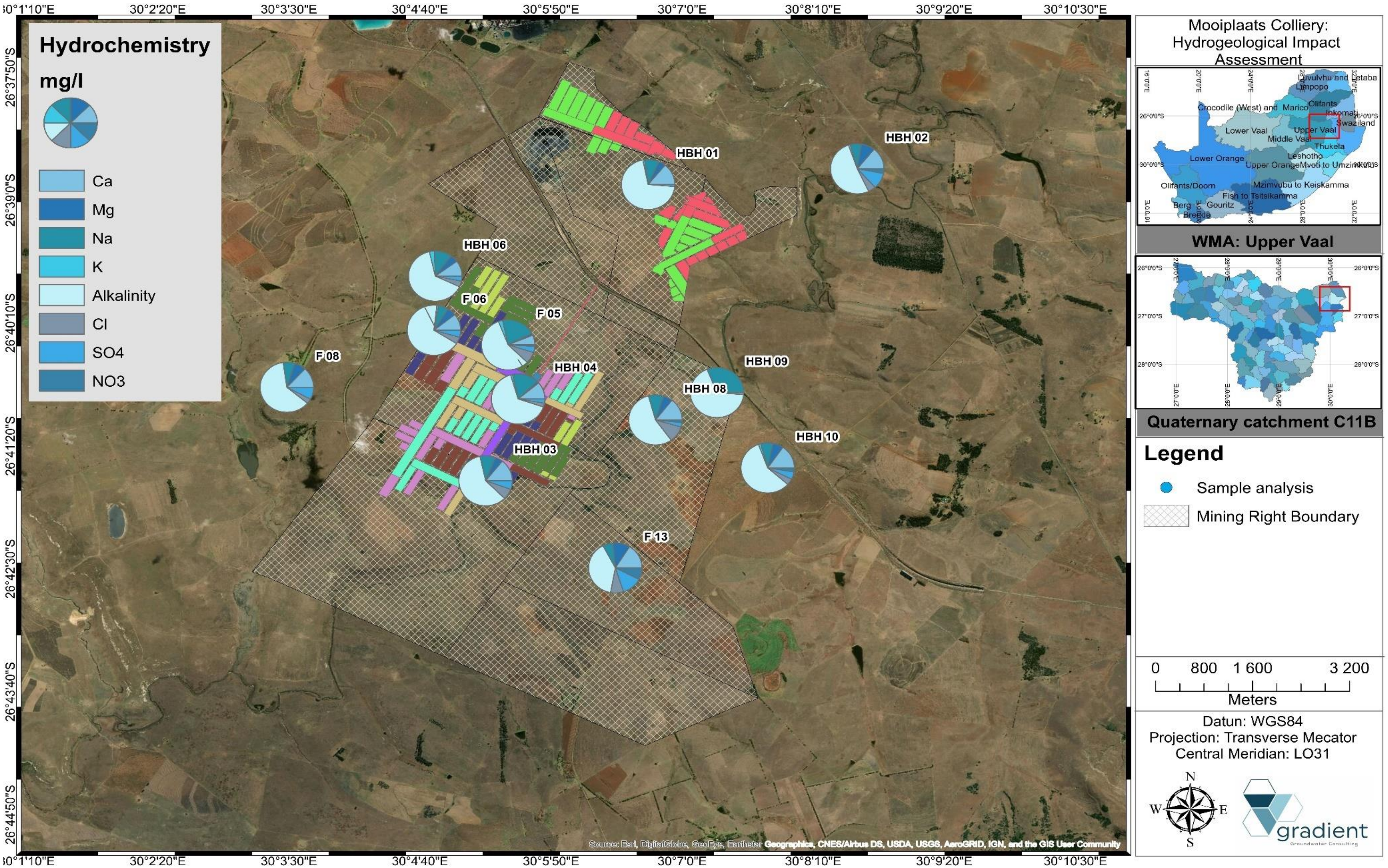

Figure 8-9 **Hydrochemical analysis spatial distribution (mg/l).**

9. GEOCHEMISTRY

The primary objective of this geochemical assessment is to determine the chemical nature and character of the lithologies to be mined, evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for Acid Rock Drainage (ARD) occurring. It should be note that geochemical characterisation was conducted on various lithological units previously (Geostratum, 2011). Accordingly, additional geochemical analysis was performed on composite discard dump as well as coal product samples. Refer to Appendix C for laboratory results and certificates and Table 9-1 for a summary of geochemical test methodologies applied and Table 9-2 for an outline of samples analysed as well as specific tests per sample.

Table 9-1 Geochemical analysis test methodologies.

Test procedure	Objectives	Methodology
X-Ray diffraction (XRD)	Minor to dominant minerals present in rocks.	PANalytical Aeris diffractometer
X-Ray fluorescence (XRF)	Major oxides and trace elements present in rocks.	ASTM D4326-13
Nett Acid Generation (NAG Tests)	To indicate the net potential for ARD after oxidation with hydrogen peroxide.	ASTM E1915-13.
Sulphur Speciation	To determine the sulphide content of samples analysed.	ASTM E1915-11.
Distilled water leach: Australian Standard Leaching, ICP-OES/MS	To determine chemicals of concern that may potentially leach from sample.	Based on ASTM D3987-12 with additional ICP-OES/MS and IC analysis.

Table 9-2 Description of geochemical samples analysed.

Sample ID	Sample type	Depth (mbgl)	*	Test procedure	Description
MP DD	Composite	Surface	⬛	XRD, XRF, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/1:20)	Discard dump
MP SS	Composite	Surface	🟦	XRD, XRF, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/1:20)	Coal stockpile

9.1. Minerology and total element analysis

The mineralogy and total element analysis of the samples was determined through X-Ray diffraction (XRD)[10]and X-Ray fluorescence (XRF) as discussed below.

9.1.1. XRD Analysis

The results from the XRD analyses of the minerals for the composite samples are presented in Table 9-3 and Table 9-4 . The following is noted:

i. The discard dump sample (MP DD) consist mainly of organic carbon (65.80 %), kaolinite (17.20 %) quartz (9.80 %). Minor amounts of gypsum, muscovite, microcline, calcite, dolomite as well as pyrite (0.2 %) were also present within this sample.

ii. The coal product sample (MP SS) consist mainly of organic carbon (73.50 %), kaolinite (10.50 %) quartz (6.60 %). Minor amounts of pyrite (2.80 %), muscovite, gypsum, microcline, calcite as well as dolomite were also present within this sample.

Table 9-3 **Description of major minerals identified.**

Mineral	*	Formula	Mineral type (Group)	Sub-group
Calcite	🟦	$CaCO_3$	Anhydrous Carbonates	Calcite group
Dolomite	🟦	$CaMgCO_3$	Anhydrous Carbonates	Dolomite group
Gypsum	🟨	Ca(sulphate).H_2O	Hydrated Sulphates	Gypsum
Microcline	⬛	$KAl_2Si_3O_8$	Tectosilicate	K-Feldspar subgroup
Kaolinite	🟥	$Al_2Si_2O_5(OH)_4$	Phyllosilicate	Clay mineral group
Muscovite	🟥	$KAl_2(AlSi_3O_{10})(OH,F)_2$	Phyllosilicate	Mica group
Quartz	⬛	SiO_2	Tectosilicate	Tectosilicate
Pyrite	🟩	FeS	Sulfides	Pyrite Group

Table 9-4 **XRD Analyses of the composite samples.**

Mineral	Chemical composition	Sample (weight %)	
		MP DD	MP SS
Calcite	$CaCO_3$	0.80	1.10
Dolomite	$CaMgCO_3$	0.70	0.90
Gypsum	$CaSO_4$	2.80	1.30
Kaolinite	$Al_2Si2O_5(OH)_4$	17.20	10.50
Microcline	$KAlSi_3O_8$	1.20	1.20
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_2$	1.50	2.10
Quartz	SiO_2	9.80	6.60
Organic Carbon	C	65.80	73.50
Pyrite	FeS_2	0.20	2.80

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[10] It should be noted that the amorphous phases (carbonaceous minerals), if present, are not taken into account in the quantification. The results therefore reflect the proportion of minerals in the non-carbonaceous phases. The proportion of carbonaceous minerals can be derived from the loss on ignition (LOI) percentages included in the XRF results.

9.1.2. XRF Analysis

The element specific concentrations were obtained from the XRF analyses as summarised in Table 9-5. Also referenced in Table 9-5 are the Alloway Crustal Abundance (ACU) concentrations of the particular elements. The latter provides an indication of the average abundance of an element in the earth's crust (Alloway *et al*, 1995). By calculating the ratio of the trace element concentrations to the average composition of the earth's crust (Crustal Abundances) an indication can be obtained whether the concentration of a particular element is raised above the average for the earth or enriched above the average due to some process. The comparison to the average Crustal Abundance is geochemically accepted as a means of highlighting elements, which may possibly be enriched in the various lithologies[11]. The following is noted:

iii. Silicon, expressed as silica (SiO_2), was, as expected from the XRD results, dominant in terms of the major elements in both the samples, followed by aluminium (III) oxide (Al_2O_3), iron (III) oxide (Fe_2O_3) as well as calcium oxide (CaO).

iv. The majority of samples analysed correlate relatively well with published ACU values with the exception of aluminium (III) oxide, phosphorus pentoxide (P_2O_5), calcium oxide as well as titanium dioxide ($Ti0_2$) being slightly elevated.

Table 9-5 XRF analysis and Major Element Concentrations

Mineral	Major element concentration (wt %) [s]		**AUC
	MP DD	MP SS	
Fe_2O_3	7.274	8.897	11.2
SiO_2	53.246	54.064	66.6
Al_2O_3	**21.61**	**21.75**	15.4
K_2O	1.644	1.465	2.8
P_2O_5	**0.50**	**0.72**	0.15
Mn_3O_4	0.025	0.017	
CaO	**7.42**	**5.51**	3.59
MgO	1.552	1.410	2.48
TiO_2	**1.20**	**1.16**	0.64
Na_2O	0.570	0.404	3.27
V_2O_5	0.025	0.021	
BaO	0.124	0.166	
Cr_2O_3	0.020	0.020	
SrO	0.172	0.235	
ZrO_2	0.059	0.061	
MnO	0.024	0.016	0.1
SO_3	5.224	4.824	
Total XRF	**99.03**	**99.48**	

****AUC = Average Upper Crust (Rudnick and Gao, 2003)**

Shaded cells exceed SANS 241:2015 drinking water guidelines.

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[11] Although enrichment does not necessarily indicate that the element is likely to be an environmental risk, it does, however, indicate where attention should be focussed when assessing metal mobility/solubility.

9.2. Acid rock drainage

Acid rock drainage (ARD) (or acid mine drainage, AMD) is considered the most significant environmental issue related to mine waste management. As ARD has the potential to impact significantly on surface and groundwater quality, it is necessary to quantify the potential that waste material may have to generate ARD as part of the geochemical characterisation process.

Acid rock drainage is produced through the natural oxidation of sulfidic minerals by air and water, accelerated by bacterial action (*thiobacillus*); thus, exposed sulphide-bearing tailings/discard (and waste rock) are prone to ARD generation. Pyrite and pyrrhotite are the main ARD generating sulphide minerals and are found in many deposits associated with coal. The resulting acid leaches other heavy and toxic metals into the ARD (Weisener et al., 2003). Coal mining is associated with ARD and mining activities usually expose pyrite to oxidising agents such as oxygen and ferric iron (Fe^{3+}). 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.

The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

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

Reaction 1

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

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

Reaction 2.

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

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

Reaction 3.

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

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

Reaction 4.

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

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.

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

Reaction 5.

$$FeS_2(s) + 3.75O_2 + 3.5H_2O \rightarrow Fe\,(OH)_2(s) + 2SO_4^{2-} + 4H^+$$

Leaching from carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity (H^+), sulphates (SO_4^{2-}) and ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron species and the movement of other conservative contaminants with groundwater in a downgradient direction from the source. The resulting acidity will mobilise reactive metal contaminants which will create a pollution plume and can migrate in a downgradient direction polluting aquifers and surfacing at seepage points, contaminating surface waters along the way. Within wetland systems, oxidation of Fe^{2+} to Fe^{3+} will result in the precipitation of ferric hydroxide (FeOH), typically as a gel, which can coat the reactive surfaces of the plants and sediment, thereby greatly reducing the ability of the wetland to remove pollutants by adsorption. In addition, the high salt load is often toxic to aquatic life. Figure 9-1 indicates a site conceptual geochemical model summarising the dynamics of ARD within the greater hydrogeological regime.

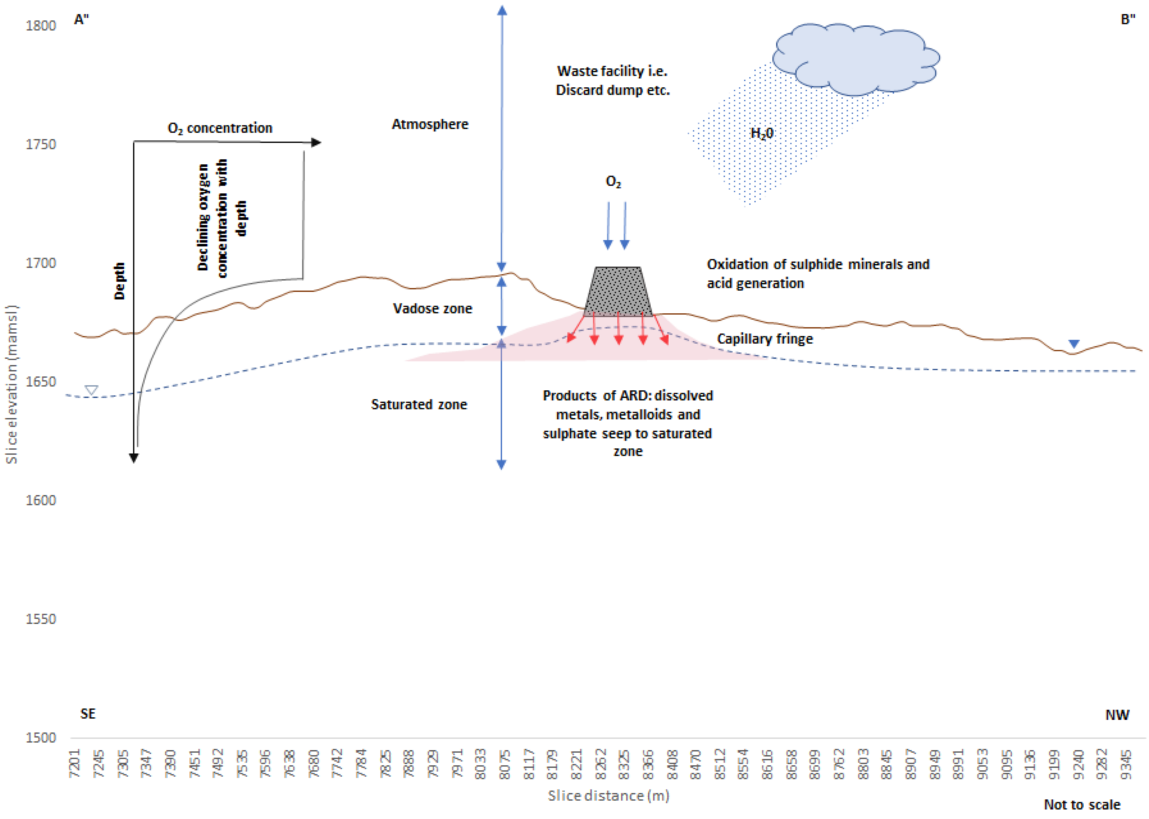

Figure 9-1 **Conceptual geochemical model (Slice A"-B").**

9.2.1. Acid Base Accounting

Acid-base accounting (ABA) is a static test where the net potential of the rock to produce acidic drainage is determined. The percentage sulphur (%S), the Acid Potential (AP), the Neutralization Potential (NP) as well as the Net Neutralization Potential (NNP) of the rock material are determined in this test and can be used as an important first order assessment of the potential leachate that could be expected from the rock material. To follow is a brief description of the different ABA components:

- If pyrite is the only sulphide in the rock, the AP (acid potential) is determined by multiplying the percentage sulphur (%S) with a factor of 31.25. The unit of AP is kg $CaCO_3$/t rock and indicates the theoretical amount of calcite neutralized by the acid produced.
- The NP (Neutralization Potential) is determined by treating a sample with a known excess of standardized hydrochloric or sulfuric acid (the sample and acid are heated to ensure reaction completion). The paste is then back titrated with standardized sodium hydroxide in order to determine the amount of unconsumed acid. NP is also expressed as kg $CaCO_3$/t rock as to represent the amount of calcite theoretically available to neutralize the acidic drainage.
- NNP is determined by subtracting AP from NP.

For the material to be classified in terms of their acid-rock drainage potential, the ABA results can be screened in terms of its NNP, %S and NP:AP ratio as follows:

- A rock with NNP < 0 kg $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg $CaCO_3$/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg $CaCO_3$/t to 20 kg $CaCO_3$/t exists that is defined as a “grey” area in determining the net acid generation or neutralization potential of a rock. Material with an NNP above this range is classified as R*ock Type IV - No Potential for Acid Generation,* and material with an NNP below this range as *Rock Type I - Likely Acid Generating*. Table 9-6 summarises the deduced acid generating potential based on the net neutralising potential (NNP).
- Further screening criteria could be used that attempts to classify the rock in terms of its net potential for acid production or neutralization. Table 9-7 summarises the criteria against which the acid forming potential is measured based on the neutralisation potential ratio (NPR) as proposed by Price (1997).

Soregaroli and Lawrence (1998) further states that samples with less than 0.3% sulphide sulphur are regarded as having insufficient oxidisable sulphides to sustain long term acid generation. According to Li (2006) material with an S% of below 0.1% has no potential for acid generation. Therefore, material with a %S of above 0.3%, is classified as Rock Type I - Likely Acid Generating, 0.2-0.3% is classified as Rock Type II, 0.1-0.2% is classified as Rock Type III, and below 0.1% is classified as Rock Type IV - No Potential for Acid Generation (Table 9-8).

Table 9-6 **Net Neutralising Potential (NPP) guideline.**

Net neutralising potential (NNP) NNP = NP-AP	Acid generating potential
< -20.0	Likely to be acid generating.
> 20.0	Not likely to be acid generating.
Between -20.0 and 20.0	Uncertain range.

Table 9-7 **Neutralisation Potential Ratio (NPR) guidelines (Price, 1997).**

Potential for acid generation	NP: AP screening criteria	Comments
Rock Type I. Likely Acid Generating.	< 1:1	Likely AMD generating.
Rock Type II. Possibly Acid Generating.	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides.
Rock Type III. Low Potential for Acid Generation.	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficient reactive NP
Rock Type IV. No Potential for Acid Generation. >4:1 No further AMD testing required unless materials are to be used	> 4.1	No further AMD testing required unless materials are to be used as a source of alkalinity.

Table 9-8 **Rock classification according to S% (Afetr Li, 2006).**

Classification	Acid forming potential	Criteria
Type I	Likely acid generating	Total S (%) > 0.3%
Type II	Potential acid forming	Total S (%) 0.2 - 0.3%
Type III	Intermediate	Total S (%) 0.1 - 0.2%
Type IV	No potential for acid generation	Total S (%) <0.1 %

9.2.2. Net-acid Generation (NAG)

The Net-acid Generating (NAG) test provides a direct assessment of the potential for a material to produce acid after a period of exposure (to a strong oxidant) and weathering. The test can be used to refine the results of the ABA predictions. In the NAG-test hydrogen peroxide (H_2O_2) is used to oxidize sulphide minerals in order to predict the acid generation potential of the sample. The following relates to the methodology:

- In general, the static NAG test involves the addition of 25 ml of 15% H_2O_2 to 0.25 g of sample in a 250 ml wide mouth conical flask or equivalent. The sample is covered with a watch glass and placed in a fume hood or well-ventilated area.
- Once "boiling" or effervescing ceases, the solution can cool to room temperature and the final pH (NAG pH) is determined.
- A quantitative estimation of the amount of net acidity remaining (the NAG capacity) in the sample is determined by titrating it with sodium hydroxide (NaOH) to pH 4.5 (and/or pH 7.0) to obtain the NAG Value. In order to determine the acid generation potential of a sample, the screening method of Miller et al. (1997) is used. Refer to Table 9-9 below:

Table 9-9 **NAG test screening method (edited from Miller et al., 1997).**

Rock Type	NAG pH	NAG Value (H_2SO_4 kg/t)	NNP ($CaCO_3$ kg/t)
Rock Type Ia. High Capacity Acid Forming.	< 4.5	> 10	Negative
Rock Type Ib. Lower Capacity Acid Forming.	< 4.5	≤ 10	-
Uncertain, possibly Ib.	< 4.5	> 10	Positive
Uncertain.	≥ 4.5	0	Negative (Reassess minerology) *
Rock Type IV. Non-acid Forming.	≥ 4.5	0	Positive

Notes: *If low acid forming sulphides is dominant then Rock type IV.

9.2.3. ABA, NAG test and Sulphur speciation results

The ABA analysis, NAG tests as well as sulphur speciation results are summarised in Table 9-10 and Table 9-11. Figure 9-2 provide a comparison of sulphide percentage vs NPR while Figure 9-3 indicate NP:AP ratios of respective samples. Figure 9-4 summarises NAG pH vs NAG value per sample. It is evident that both samples have a high risk to generate acid mine drainage and can sustain long term acid generation. Refer to Table 9-12 for a summary of AMD potential per sample evaluated. To follow is a brief summary of the potential risk of relevant samples analysed to cause ARD.

Discard dump

The discard dump sample analysed record a relatively high sulphide content of 0.71% with a negative NNP value of -28.88. The NPR ratio of 0.52 suggest that the material does not have buffering capacity and is likely to generate acid. The NAG pH is 4.11 with the NAG value 2.31 (at pH 4.5), also indicating capacity for acid formation.

Coal sample

As expected, the coal sample indicate a high sulphide content (1.78%), and negative NNP value of -38.11. The NPR ratio of 0.46 suggest that the material does not have buffering capacity and is likely to generate acid. The NAG pH is 2.60 with the NAG value 15.10 (at pH 4.5).

Table 9-10 **ABA test results summary table.**

Sample ID	Lithology	Paste pH	Total Sulphur (%)	Sulphide (%)	AP CaCO3 (kg/t)	NP CaCO3 (kg/t)	NNP CaCO3 (kg/t)	NPR (NP/AP)
MP DD	🟦	7.22	1.91	0.71	59.70	30.81	-28.88	0.52
MP SS	⬛	8.23	2.24	1.78	70.00	31.89	-38.11	0.46

Table 9-11 **NAG test results summary table.**

Sample ID	Lithology	NAG pH	NAG at pH 4.5 (kg H_2SO_4/t)	NAG at pH 7.0 (kg H_2SO_4/t)
MP DD	🟦	4.11	2.31	17.40
MP SS	⬛	2.60	15.10	31.70

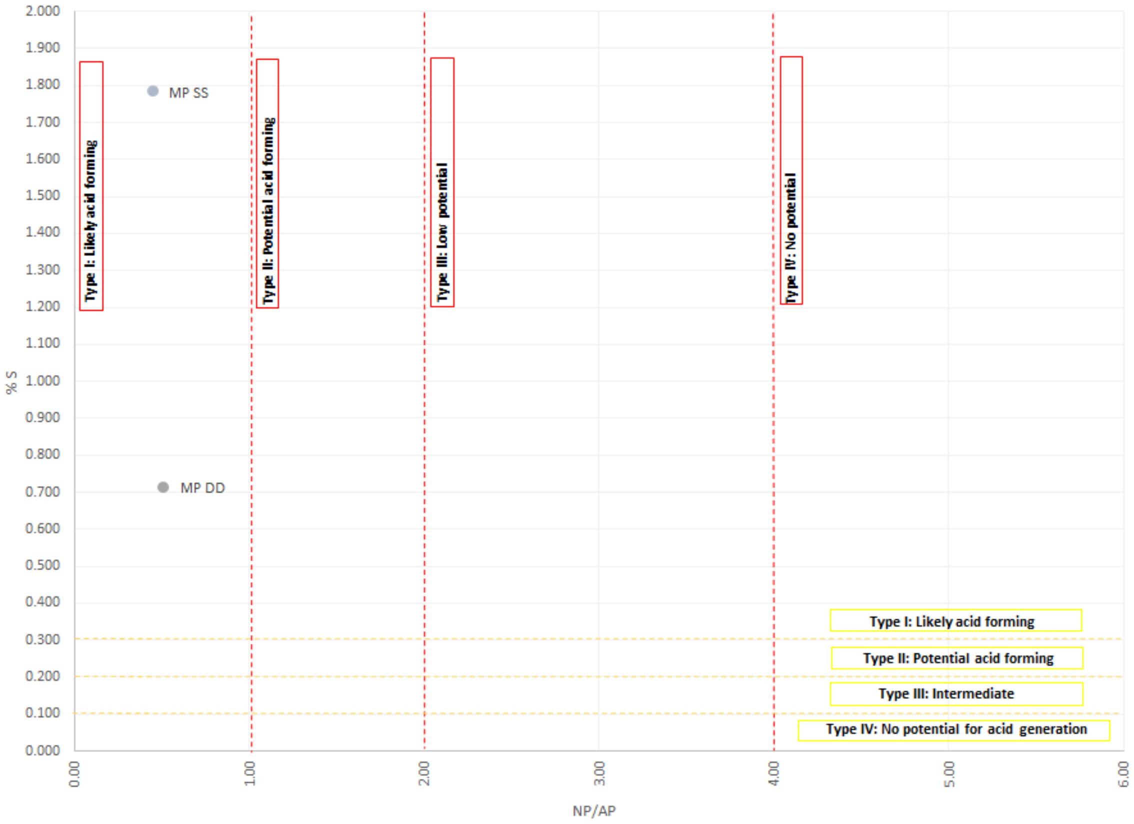

Figure 9-2 Classification of samples in terms of %S (samples below 3%) and NP/AP (samples below 10).

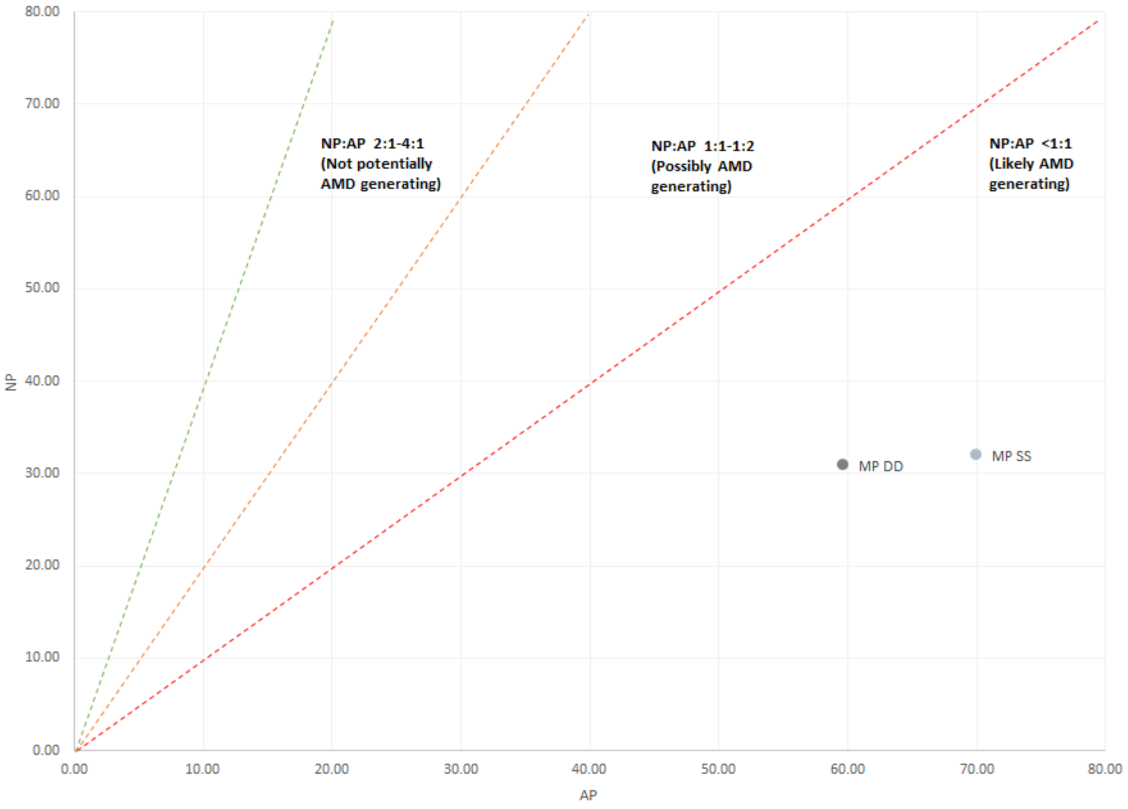

Figure 9-3 Comparison graph: NP vs. AP.

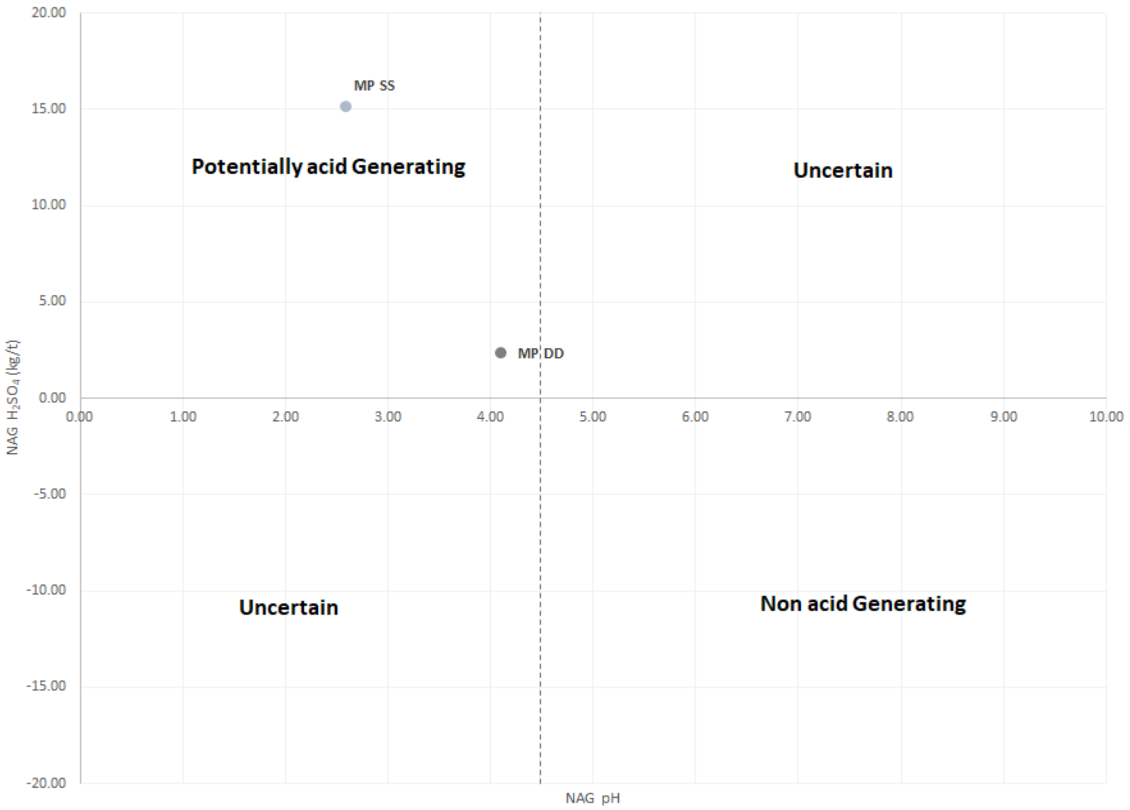

Figure 9-4 **Comparison graph: NAG pH vs NAG Value.**

Table 9-12 Summary table: ARD potential per sample analysed.

Sample	%S >0.3 NP/AP < 2.0	%S > 0.3 NP/AP > 2.0	%S < 0.1 - 0.3 NP/AP < 2.0	%S < 0.1 - 0.3 NP/AP > 2.0	%S < 0.1 NP/AP < 2.0	%S < 0.1 NP/AP > 2.0
MP DD	🟥					
MP SS	🟥					
	🟥	🟧	🟨	🟩	🟩	🟩
Potential for ARD	**Likely/possibly acid generating. High salt load.**	**Medium potential for acid generation. Medium to high salt load**	**Low to medium potential for acid generation. Low to medium salt load.**	**Very low potential for acid generation. Very low to low salt load.**	**No potential for acidic drainage. Very low/no salt load.**	**No potential for acidic drainage. Very low/no salt load.**

9.3. Static leach test: Distilled water leach

A distilled water leach test was performed to identify water soluble chemicals that could potentially be leached from the discard dump as well as coal stockpile areas[12]. The samples were added to a shake flask at a solid to liquid ratio of 1:4 and agitated for 24 hours. Accordingly, inductively coupled plasma optical emission spectrometry (ICP-OES) technique were utilised to analyse the composition of elements in samples obtained from the distilled water extraction.

Refer to Table 9-12 for a summary of the leachate results. The only elevated element detected in the water leach of the discard dump material is sulphate, while no elevated elements were detected for the coal product sample.

Table 9-13 ICP-OES results of ditilled water leach (1:4 dilution).

Elements (mg/l)[ppm]	MP DD	MP SS
Metal ions		
As	<0.001	0.001
B	0.270	0.056
Ba	0.084	0.041
Cd	< 0.003	< 0.003
Co	< 0.025	< 0.025
Cr(Total)	< 0.025	< 0.025
Cr(VI)	< 0.05	< 0.05
Cu	0.053	0.057
Hg	< 0.001	< 0.001
Mn	< 0.025	< 0.025
Mo	< 0.025	< 0.025
Ni	< 0.025	< 0.025
Pb	< 0.01	0.037
Sb	<0.001	0.001
Se	0.001	0.002
V	0.035	0.034
Zn	0.038	< 0.025
Inorganic ions		
pH	7.43	7.98
TDS	1632.00	200.00
Chloride	2.87	2.03
Sulphate as SO4	**965.30**	27.47
NO3 as N	<2.22	<2.22
Fluoride	0.42	<0.05
Cyanide	<0.07	<0.07

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.
"< " indicate that results analysed are below the detection limits.
Shaded cells exceed SANS 241:2015 drinking water guidelines.

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[12] It should be noted that leaching tests identify the elements that will leach out of waste but do not reflect the site-specific concentration of these elements in actual seepage as a different water/rock ratio and contact time will be present in the field.

9.4. Waste assessment

The assessment of waste must be undertaken in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010). The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations (LC) of samples taken. These results are compared to threshold limits specified in R635 and the outcome is used to establish the type of waste and the most suitable disposal method for it.

The TC and LC threshold limits, according to Section 6 of R635, is presented in Table 9-14 and Table 9-15. These concentrations limits are used to classify the waste as explained below. The concentrations were derived from a combination of South African soil screening, land remediation and human health effect values as well as from Australian standards[13]. Different waste categories/types are summarised in Table 9-16.

Table 9-14 Total Concentration Threshold (TCT) Limits (mg/kg).

Elements	TCT0 (mg/kg)	TCT1 (mg/kg)	TCT2 (mg/kg)
Metal ions			
As	5.80	500.00	2 000.00
B	150.00	15 000.00	60 000.00
Ba	62.50	6 250.00	25 000.00
Cd	7.50	260.00	1 040.00
Co	50.00	5 000.00	20 000.00
Cr (Total)	46 000.00	800 000.00	n.a
Cr (VI)	6.50	500.00	2 000.00
Cu	16.00	19 500.00	78 000.00
Hg	0.93	160.00	640.00
Mn	1 000.00	2 500.00	100 000.00
Mo	40.00	1 000.00	4 000.00
Ni	91.00	10 600.00	42 400.00
Pb	20.00	1 900.00	7 600.00
Sb	10.00	75.00	300.00
Se	10.00	50.00	200.00
V	150.00	2 680.00	10 720.00
Zn	240.00	160 000.00	640 000.00
Inorganic ions			
TDS			
Chloride			
Sulphate as SO_4			
NO_3 as N			
Fluoride	100.00	10 000.00	40 000.00
Cyanide	14.00	10 500.00	42 000.00

Notes: TCT1 limits, where appropriate, have been derived from the land remediation values for commercial/ industrial land determined by the Department of Environmental Affairs "Framework for the Management of Contaminant Land ", March 2010. The TCT2 limits by multiplying TCT1 by a factor of 4, as used by the Environmental Protection Agency, Australian State of Victoria. If South African limits for TCT1 were unavailable, in general, the limits published by the Environmental Protection Agency, Australian State of Victoria have been used. Some TC limits have been adjusted because of various attenuation factors that are observed in landfills. Where available, the TCT0 limits have been obtained from SA Soil Screening Values that are protective of water resources. If not available, the State Victoria value for fill material, (EPA Victoria, Classification of Wastes) has been selected. If limits were not available in these references a conservative value was obtained by dividing the TCT1 value by 100.

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[13] The National Environmental Management: Waste Act (Act 59 of 2008) (NEMWA) and the Waste Classification and Management Regulations (R635) require that all waste generated is classified in accordance with SANS 10234 within 180 days of generation. It should be noted that this waste assessment does not serve to classify waste but rather aim to assess the potential environmental hazard of the waste generated.

Table 9-15 **Leachable Concentration Threshold (LCT) Limits (mg/l).**

Elements	LCT0 (mg/l)	LCT1 (mg/l)	LCT2 (mg/l)	LCT3 (mg/l)
Metal ions				
As	0.01	0.50	1.00	4.00
B	0.50	25.00	50.00	200.00
Ba	0.70	35.00	70.00	280.00
Cd	0.00	0.15	0.30	1.20
Co	0.50	25.00	50.00	200.00
Cr(Total)	0.10	5.00	10.00	40.00
Cr(VI)	0.05	2.50	5.00	20.00
Cu	2.00	100.00	200.00	800.00
Hg	0.01	0.30	0.60	2.40
Mn	0.50	25.00	50.00	200.00
Mo	0.07	3.50	7.00	28.00
Ni	0.07	3.50	7.00	28.00
Pb	0.01	0.50	1.00	4.00
Sb	0.02	1.00	2.00	8.00
Se	0.01	0.50	1.00	4.00
V	0.20	10.00	20.00	80.00
Zn	5.00	250.00	500.00	2 000.00
Inorganic ions				
TDS	1 000.00	12 500.00	25 000.00	100 000.00
Chloride	300.00	15 000.00	30 000.00	120 000.00
Sulphate as SO_4	250.00	12 500.00	25 000.00	100 000.00
NO_3 as N	11.00	550.00	1 100.00	4 400.00
Fluoride	1.50	75.00	150.00	600.00
Cyanide	0.07	3.50	7.00	28.00

Notes: The LCT1 limits have, where possible, have been derived from the lowest value of the standard for human health effects listed for drinking water (LCT0) in South Africa (DWAF, SANS) by multiplying with a Dilution Attenuation Factor (DAF) of 50 as proposed by the Australian State of Victoria, "Industrial Water Resource Guideline: Solid industrial Waste Hazard Categorisation and Management", June 2009 (www.epa.vic..gov.aus). If no standard was available in South Africa then the limits given by the WHO or other appropriate drinking water standard, such as those published in the California Regulations have been used. LCT2 limits were derived by multiplying the LCT1 value with a factor of 2, and the LCT3 limits have been derived by multiplying the LCT2 value with a factor of 4. The factors applied represents a conservative assessment of the decrease in risk achieved by the increase in environmental protection provided by more comprehensive liner designs in higher classes of landfill and landfill operating requirements.

Table 9-16 **Waste types.**

Criteria	Waste Type
LC > LC3; or TC > TC2	Type 0
LCT2 < LC ≤ LCT3; or TCT1 < TC ≤ TCT2	Type 1
LCT1 < LC ≤ LCT2; and TC ≤ TCT1	Type 2
LCT0 < LC ≤ LCT1; and TC ≤ TCT1	Type 3
LC ≤ LCT0; and TC ≤ TCT0	Type 4

Figure 9-5 indicate a bar-chart comparison of the Total Concentration analysis of elements per sample whereas Figure 9-6 show a bar-chart comparison of Leachable Concentrations analysis per sample. The following is noted regarding the waste assessment results:

Discard Dump Sample (MP DD): In terms of the LC's, none of the constituents exceed the Leach Concentration Threshold 0 (LCT0) values;

In terms of the TC's, however, the concentrations barium as well as mercury exceed their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

MP SS Coal Sample: In terms of the LC's, none of the constituents exceed the Leach Concentration Threshold 0 (LCT0) values;

In terms of the TC's, however, the concentrations barium as well as mercury exceed their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 9-18 for a summary of leachate results compared to TC and LC thresholds.

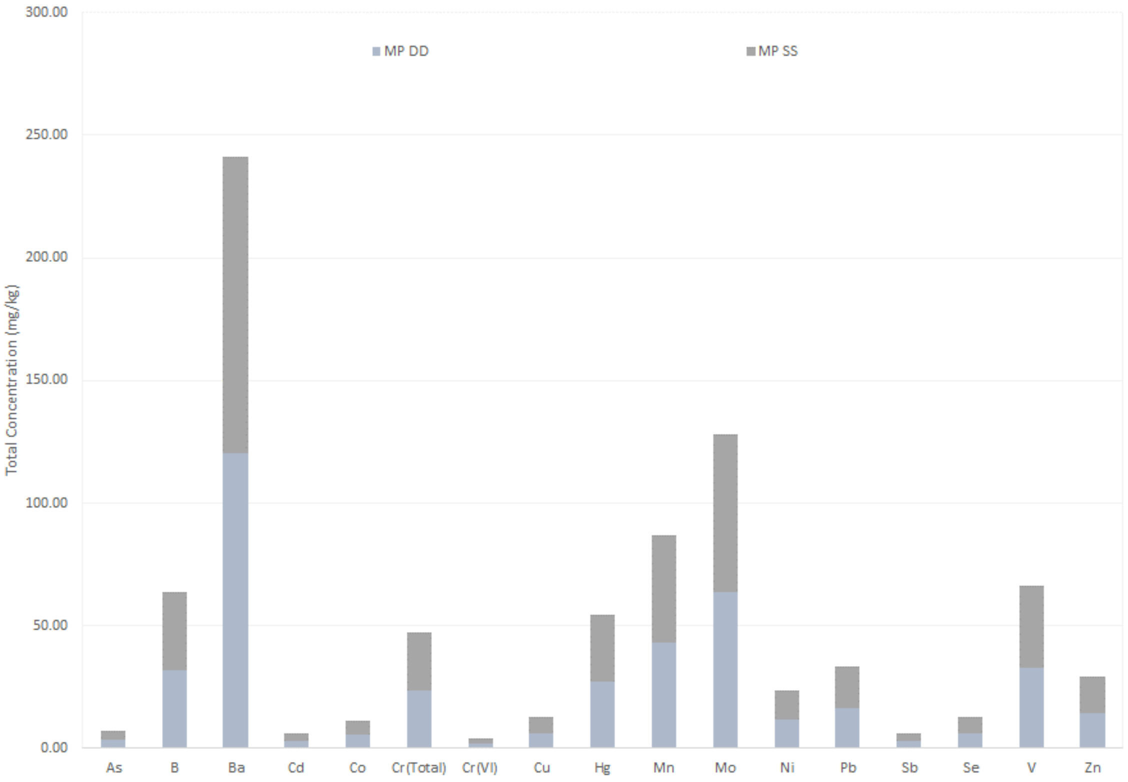


Figure 9-5 **Comparison of Total Concentration analysis of Elements.**

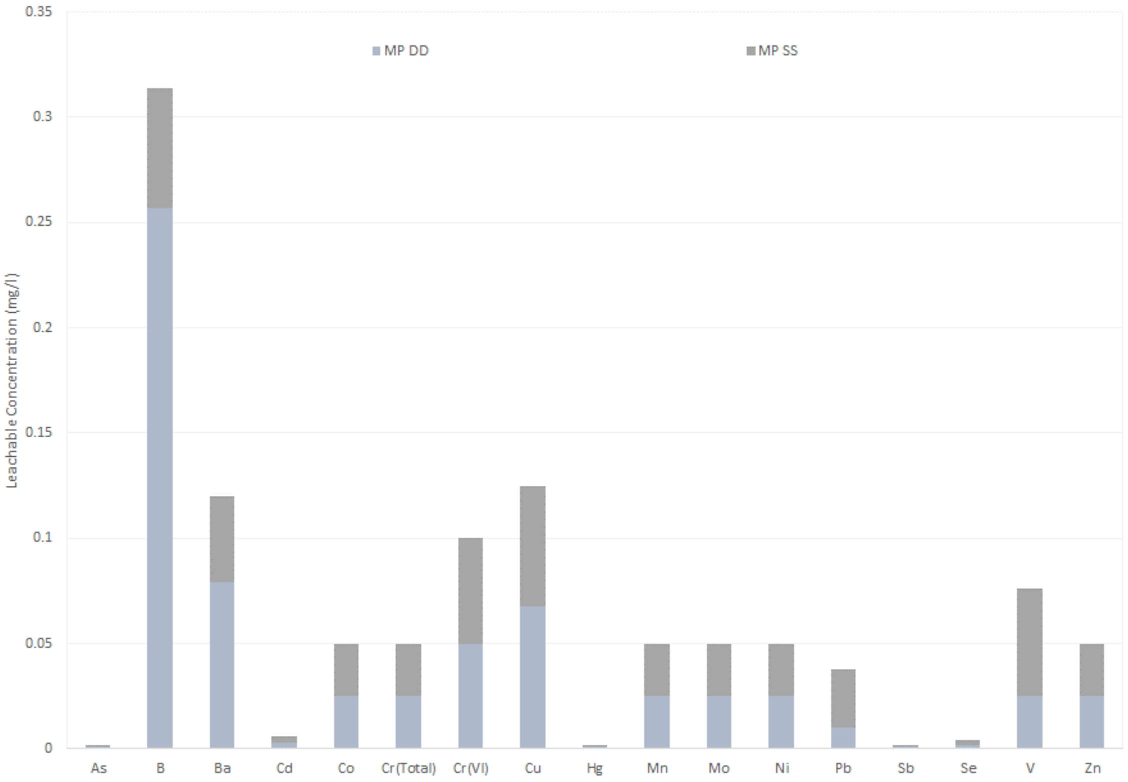


Figure 9-6 **Comparison of Leachable Concentrations analysis of samples.**

Table 9-17 **Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MP DD (1:20 dilution).**

Elements	Total concentration (TC)(mg/kg)	Distilled water leach concentration (LC)(mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	3.52	0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32.00	0.257		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**120.50**	0.079		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.20	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	5.73	< 0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	23.59	< 0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2.00	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	6.36	0.068		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**27.23**	< 0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	43.36	< 0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<64.00	< 0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	11.93	< 0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	16.6	< 0.01		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<3.20	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	<6.40	0.002		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	33.16	< 0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	14.53	< 0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	8.17	7.49													
TDS		1069.00			1000.00			12500.00			25000.00			100000.00	
Chloride		1.60			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		**682.70**			250.00			12500.00			25000.00			100000.00	
NO_3 as N		< 0.50			11.00			550.00			1100.00			4400.00	
Fluoride	5.56	0.34		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<0.10	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

Table 9-18 **Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MP SS (1:20 dilution).**

Elements	Total concentration (TC)(mg/kg)	Distilled water leach concentration (LC)(mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	3.52	< 0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32.00	0.057		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**120.50**	0.041		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.20	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	5.73	< 0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	23.59	< 0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2.00	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	6.36	0.057		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**27.23**	< 0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	43.36	< 0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<64.00	< 0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	11.93	< 0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	16.6	0.028		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<3.20	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	<6.40	0.002		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	33.16	0.051		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	14.53	< 0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	9.66	7.97													
TDS		162.00			1000.00			12500.00			25000.00			100000.00	
Chloride		< 2.00			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		**28.82**			250.00			12500.00			25000.00			100000.00	
NO_3 as N		< 0.50			11.00			550.00			1100.00			4400.00	
Fluoride	5.56	0.06		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<0.10	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

10. AQUIFER CLASSIFICATION AND GROUNDWATER MANAGEMENT INDEX

The most widely accepted definition of groundwater contamination is defined as the introduction into water of any substance in undesirable concentration not normally present in water e.g. microorganisms, chemicals, waste or sewerage, which renders the water unfit for its intended use (UNESCO, 1992). The objective is to formulate a risk-based framework from geological and hydrogeological information obtained as part of this investigation. Two approaches were followed in an estimation of the risk of groundwater contamination as discussed below. As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. A summary of the GQM index for the greater study area is presented in Table 10-2 with cells shaded in blue indicating the rating of the aquifer. A **GQM Index = 4** was estimated for the aquifer system and according to this estimate, a "**Medium**" level groundwater protection is required for this aquifer system.

Equation 10-1 GMQ Index.

$$\textit{GQM Index} = \boldsymbol{Aquifer\ system\ management\ x\ Aquifer\ vulnerability}$$

10.1. Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). Aquifer classification forms a very useful planning tool which can be applied to guide the management of groundwater systems. According to the aquifer classification map of South Africa the project area is underlain by a poor to "**Minor aquifer**" (DWS, 2013). The classifications and definitions for each aquifer system are summarised in Table 10-1 cells shaded in blue indicate the classification of the aquifer.

Table 10-1 Aquifer System Management Classes (After Parsons , 1995).

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

10.2. Aquifer vulnerability

Aquifer vulnerability can be defined as the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a "**Moderate**" vulnerability rating (DWS, 2013).

10.3. Aquifer susceptibility

Aquifer susceptibility is a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities. According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a "**Medium**" susceptibility rating (DWS, 2013).

Table 10-2 Groundwater Quality Management Index.

Aquifer system		**Aquifer vulnerability**	
Management qualification		**Classification**	
Class	**Points**	**Class**	**Points**
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	**Moderate**	**2**
Minor Aquifer System	**2**	Low	1
Non-Aquifer System	0		
Special Aquifer System	0-6		
GQM INDEX = 4			
Index	**Level of protection**		
<1	Limited Protection		
1 to 3	Low Level Protection		
3 to 6	**Medium Level Protection**		
6 to 10	High Level Protection		
>10	Strictly Non- Degradation		

10.4. Groundwater contamination risk assessment

The concept of groundwater vulnerability to contamination by applying the DRASTIC methodology was introduced by Aller et al. (1987) and refined by the US EPA (United States Environmental Protection Agency). DRASTIC is an acronym for a set of parameters that characterise the hydrogeological setting and combined evaluated vulnerability: Depth to water level, Net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and Hydraulic Conductivity. This method provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeological parameters.

Lynch *et al* (1994) suggests a considerable variation in terms of hydraulic conductivity in hard rock aquifers and revised this methodology to accommodate local aquifer conditions accordingly. Parameters used as part of the index are summarised in Table 10-4 while the aquifer risk matrix is summarised in Table 10-4 below. The DRASTIC index (DI) can be computed using the following formula.

Equation 10-2 DRASTIC Index (Di).

$$\mathbf{Di} = \boldsymbol{DrD\lambda + RrR\lambda + ArA\lambda + Sr\,S\lambda + TrT\lambda + IrI\lambda}$$

where:

D = Depth to Water Table

R = Recharge

A = Aquifer media.

S = Soil media.

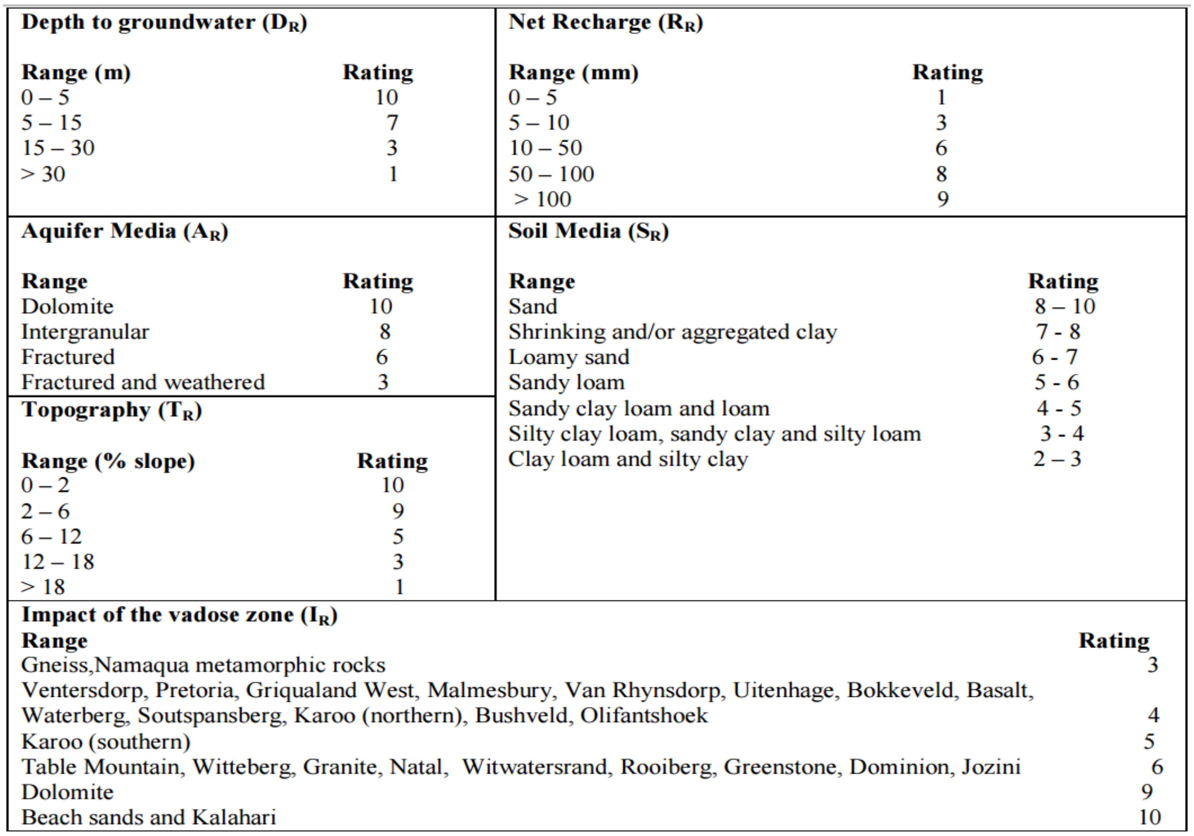
T = Topographic aspect.

I = Impact of vadose zone media.

C = Conductivity.

Where **D, R, A, S, T, I**, and **C** are the parameters, r is the rating value, and λ the constant weight assigned to each parameter as summarised in Table 10-3 below (Lynch et al, 1994).

Table 10-3 Ratings assigned to groundwater vulnerability parameters (Lynch et al, 1994).



Depth to groundwater (D_R)

Range (m)	Rating
0 – 5	10
5 – 15	7
15 – 30	3
> 30	1

Net Recharge (R_R)

Range (mm)	Rating
0 – 5	1
5 – 10	3
10 – 50	6
50 – 100	8
> 100	9

Aquifer Media (A_R)

Range	Rating
Dolomite	10
Intergranular	8
Fractured	6
Fractured and weathered	3

Soil Media (S_R)

Range	Rating
Sand	8 – 10
Shrinking and/or aggregated clay	7 - 8
Loamy sand	6 - 7
Sandy loam	5 - 6
Sandy clay loam and loam	4 - 5
Silty clay loam, sandy clay and silty loam	3 - 4
Clay loam and silty clay	2 – 3

Topography (T_R)

Range (% slope)	Rating
0 – 2	10
2 – 6	9
6 – 12	5
12 – 18	3
> 18	1

Impact of the vadose zone (I_R)

Range	Rating
Gneiss,Namaqua metamorphic rocks	3
Ventersdorp, Pretoria, Griqualand West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutspansberg, Karoo (northern), Bushveld, Olifantshoek	4
Karoo (southern)	5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6
Dolomite	9
Beach sands and Kalahari	10

Table 10-4 DRASTIC Index.

Risk/ Vulnerability	DRASTIC Index (Di)
Low	50-87
Moderate	87-109
High	109-183

According to the DRASTIC index methodology applied, this mining activities and associated infrastructure’s risk to groundwater pollution is rated as “**High**”, **Di** = 121 due to the relatively shallow groundwater table/ piezometric head as well as fairly flat topographical slopes within the greater study area (Table 10-5).

Table 10-5 **DRASTIC weighting factors.**

Parameter	Range	Rating	Description	Relative weighting
Depth to water (D) (mbgl)	**0 - 5**	**10**	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5
	5 -15	7		
	15 - 30	3		
	> 30	1		
Net recharge (R) (mm/a)	0-5	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer.	3
	5-10	3		
	10-50	**6**		
	50-100	8		
	> 100	9		
Aquifer media (A)	Dolomite	10	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings within an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential.	4
	Intergranular	8		
	Fractured	6		
	Fractured and weathered	**3**		
Soil media (S)	Sand	10	Refers to the uppermost weathered portion of the vadose zone characterised by significant biological activity. Soil has a significant impact on the amount of recharge.	2
	Shrinking and/or aggregated clay	8		
	Loamy sand	**6**		
	Sandy loam	5		
	Sandy clay	4		
	Silty loam	3		
	Silty clay and clay loam	2		
Topography (T) (Slope %)	0 - 2	10	Refers to the slope of the land surface. It helps a pollutant to runoff or remain on the surface in an area long enough to infiltrate it.	1
	2 - 6	**9**		
	6 - 12	5		
	12 - 18	3		
	> 18	1		
Impact of vadose zone (I)	Gneiss, Namaqua metamorphic rocks	3	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5
	Ventersdorp, Pretoria, Griekwaland West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (Northern), Bushveld, Olifantshoek	**4**		
	Karoo (Southern)	5		
	Table Mountain, Witteberg Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6		
	Dolomite	9		
	Beach sands and Kalahari	10		
DRASTIC Index (Di) = 121				

10.5. Source-pathway-receptor evaluation

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors. The pollution linkage concept relies on the identification of a potential pollutant (i.e. source) on-site which is likely to have the potential to cause harm on a receptor by means of a pathway by which the receptor may be exposed to the contaminant (Figure 10-1).

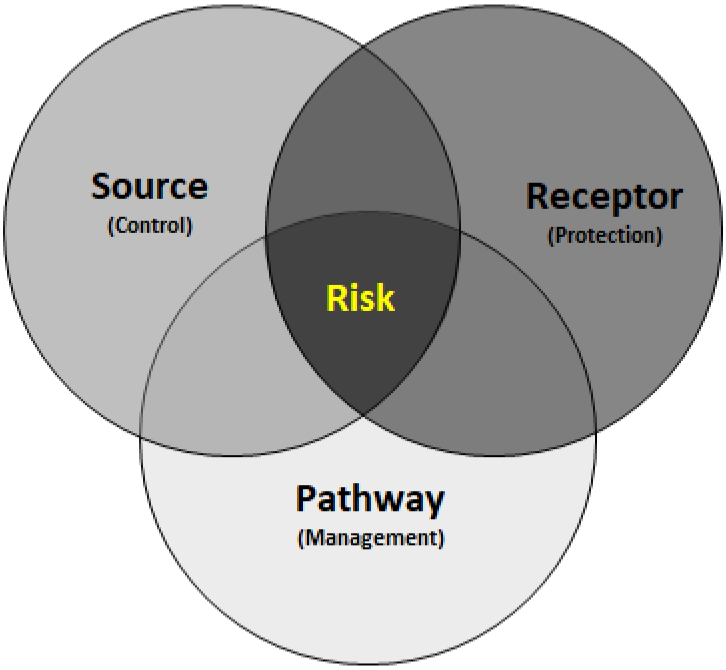


Figure 10-1 **Source pathway receptor principle.**

10.5.1. Potential sources

The following potential sources have been identified:

i. Leachate of poor-quality water from waste material i.e. discard dump into local water resources and host aquifers.

ii. Seepage and overflow of poor-quality water from mine wastewater management facilities including dirty stormwater runoff.

iii. Hydrocarbon pollution from mine filling bays and workshop areas.

10.5.2. Potential pathways

The following aquifer pathways have been identified:

i. Vertical flow through the unsaturated/vadose zone from the mine waste facilities to the underlying weathered and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.

ii. Preferential flow-paths include the contact between the depth of weathering and fresh unweathered rock, fractures, faults, joints and bedding planes. The local southwest-northeast striking dyke structure transecting the northern perimeter of the project area. The latter represent zones of relatively higher permeability which may act as conduits for groundwater flow within the aquifer.

10.5.3. Potential receptors

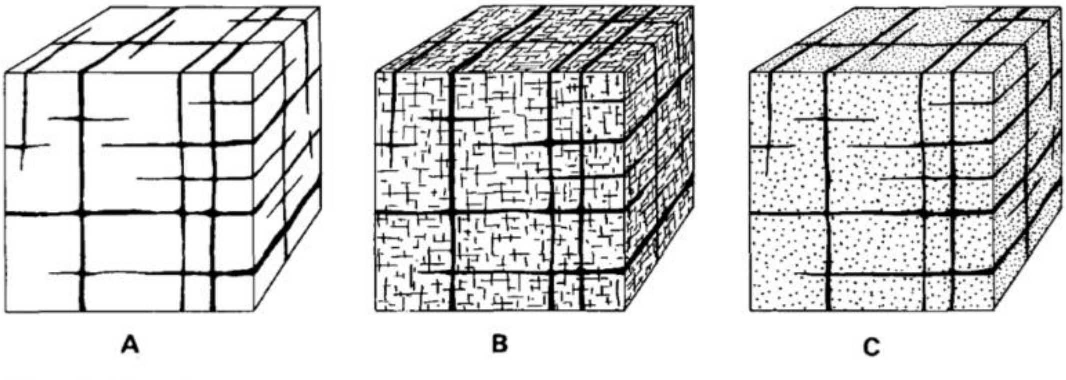
The following receptors were identified:

i. Neighbouring groundwater users i.e. private boreholes including springs.

ii. Local rivers and streams down-gradient of the mine waste facilities. Furthermore, the expected cone of depression and lowering of the regional groundwater levels may have a decreasing impact in groundwater contribution to baseflow.

11. HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. The latter defines the hydrogeological environment and is used to design and construct the numerical model. Data gathered during the desk study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system. Figure 11-1 depicts a generalised hydrogeological conceptual model for similar environments and illustrate the concept of primary porous media aquifers and secondary fractured rock media aquifers. In porous aquifers, flow occurs through voids between unconsolidated rock particles whereas in double porosity aquifers, the host rock is partially consolidated, and flow occurs through the pores as well as fractures in the rock. In secondary aquifers the host rock is consolidated, and porosity is generally restricted to fractures that have formed after consolidation of the rock. The weathered zone aquifer and secondary rock aquifer in the area could be classified as double porosity aquifers. Figure 11-2 depicts a southwest-northeast cross section of the study area with relevant data and information included (refer to Figure 12-2 for spatial reference).



A: Primary porosity aquifer B: Double porosity aquifer C: Secondary porosity aquifer

Figure 11-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

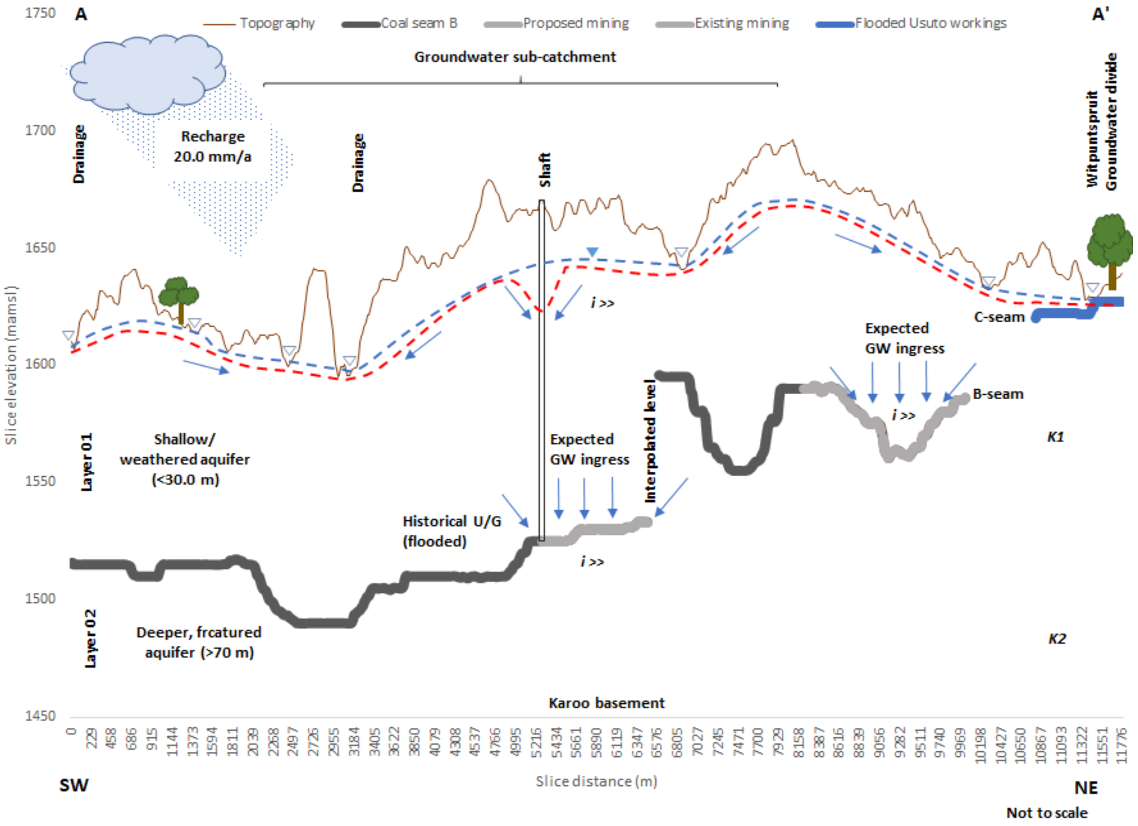


Figure 11-2 **Conceptual hydrogeological model (Figure 12-2).**

12. HYDROGEOLOGICAL NUMERICAL MODEL

The purpose of a groundwater model is to serve as a tool to evaluate various water management options and scenarios.

12.1. Approach to modeling

The typical workflow and modelling approach employed is summarised in Figure 12-1 below and encompass a conceptualisation phase, calibration phase as well as a prediction phase.

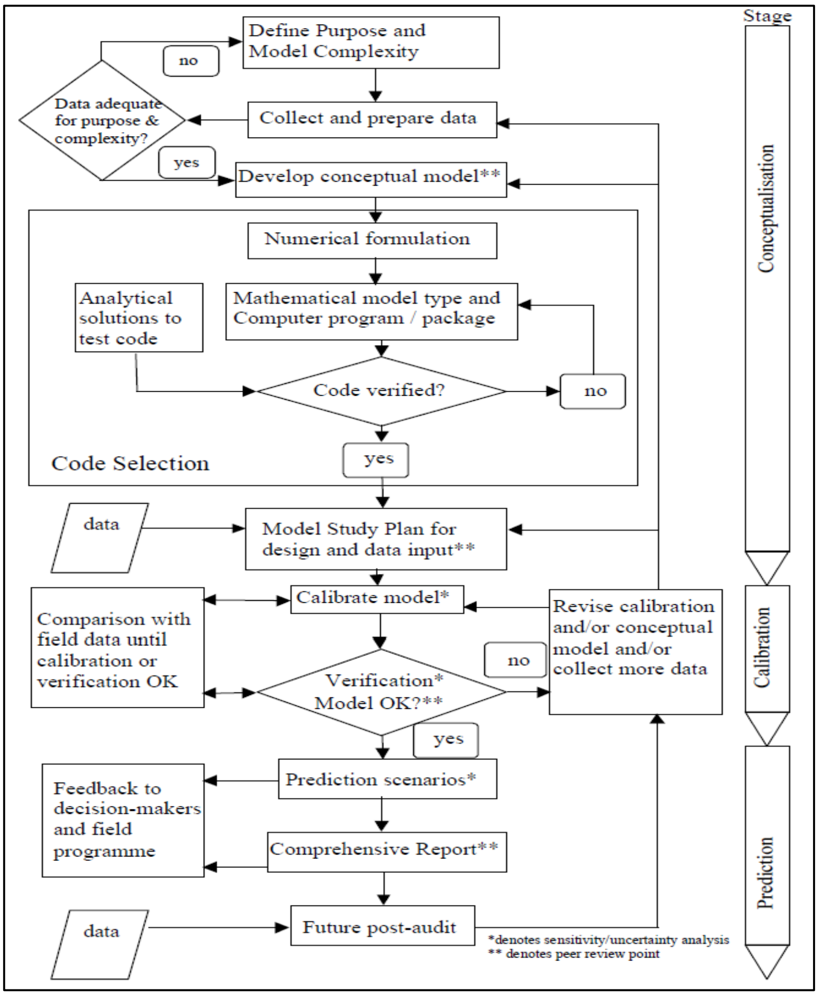


Figure 12-1 **Workflow numerical groundwater flow model development.**

In natural steady-state conditions, the net groundwater inflow from recharge is balanced by base flow and losses. The groundwater balance is given by:

Equation 12-1 **Simplified groundwater balance.**

$$Q_{\text{Recharge}} - Q_{\text{Baseflow}} + Q_{\text{Losses}} = 0$$

where:

$Q_{Recharge}$ = Groundwater inflow from rainfall recharge (m^3/d).

$Q_{Baseflow}$ = Groundwater outflow as baseflow (m^3/d).

Q_{Losses} = Groundwater outflow from other losses (m^3/d).

The piezometric gradient, which can be measured from site characterization and monitoring boreholes are known and the boreholes can be pump tested to determine the transmissivity and hydraulic conductivity. The outflow per unit length (L) of aquifer are given by Darcy's law as, $q=K\ dh/dL$ where q is the Darcy flux in m/d (or $m^3/m^2/d$) and K is the hydraulic conductivity, D the aquifer thickness and dh/dl the piezometric gradient. Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small error (usually <10.0 % of the aquifer thickness).

12.2. Software application

A dynamic flow model was developed by applying the modelling package FEFLOW (Finite Element Flow) and interface (Diersch, 1979). This modelling software has been developed by WASY and is based on the partial differential equation principle. The finite element method is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations.

12.3. Model development

12.3.1. Model domain

A model grid was created with global origin X: -90103.13 [m] and Y: -2950804.97 [m] using triangular prism type of elements. The model has a width of 20268.7 [m], height of 20823.4 [m], depth of 405.76 [m] and spans an area of $2.65E^{+8}\ m^2$ with a volume of $\sim 3.76E^{+10}$. The model domain was delineated based on regional drainages as well as topographical highs i.e. discharge zones and no-flow zones (Figure 12-2). Figure 12-3 shows the model finite element mesh (FEM) construction with Figure 12-4 depicting a SW-NE cross section.

12.3.2. Model construction

The model was constructed from FEM and consist of two layers i.e. three slices, 495 056 triangular prism elements per layer, a total of 990 112 elements for the model domain, with 249 236 nodes per slice. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 0.90%.
- Interior holes: 0.
- Obtuse angled triangles: 0.30% > 120°, 6.40% > 90°.

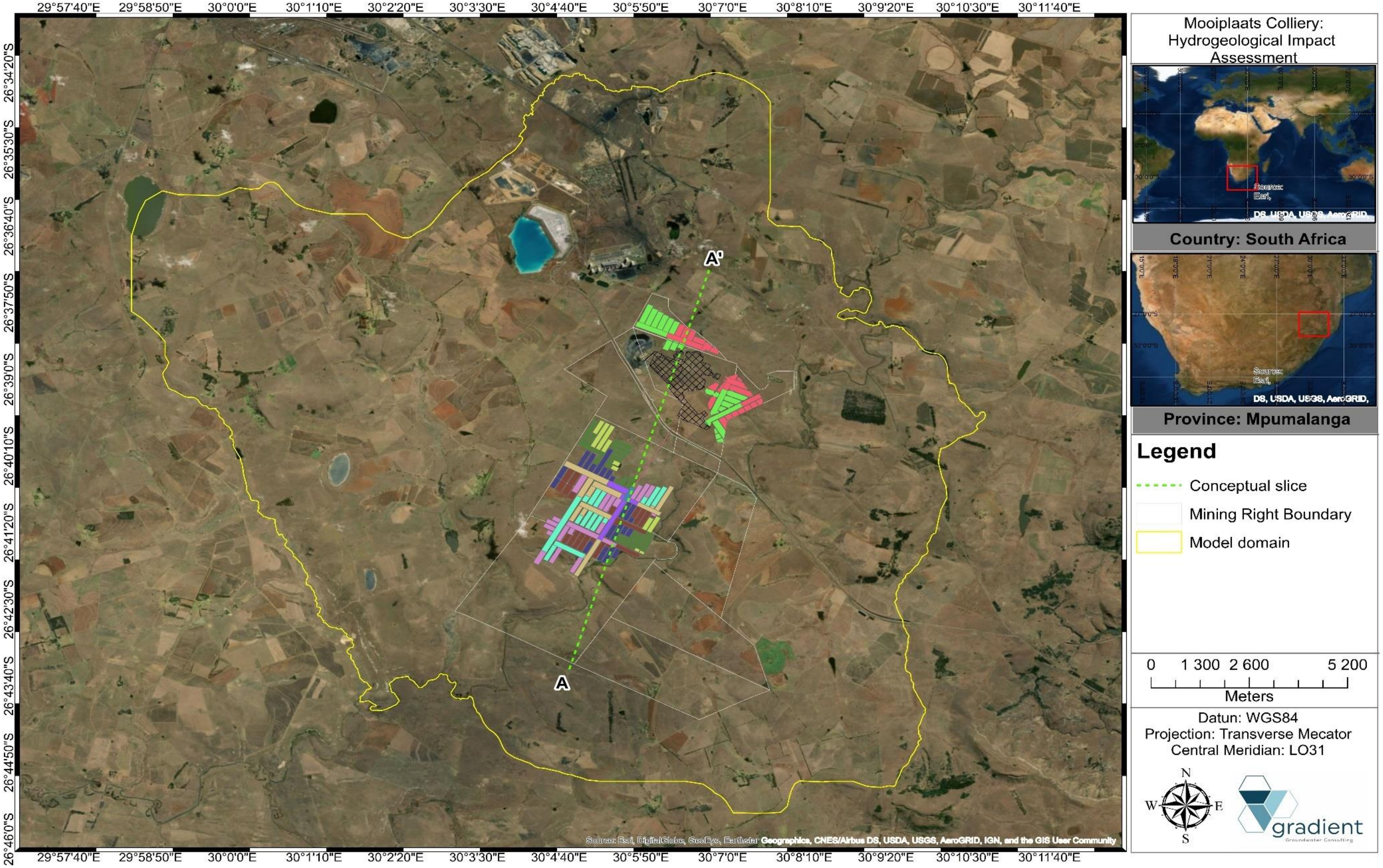


Figure 12-2 **Model domain: Aerial extend (Figure 11-2).**

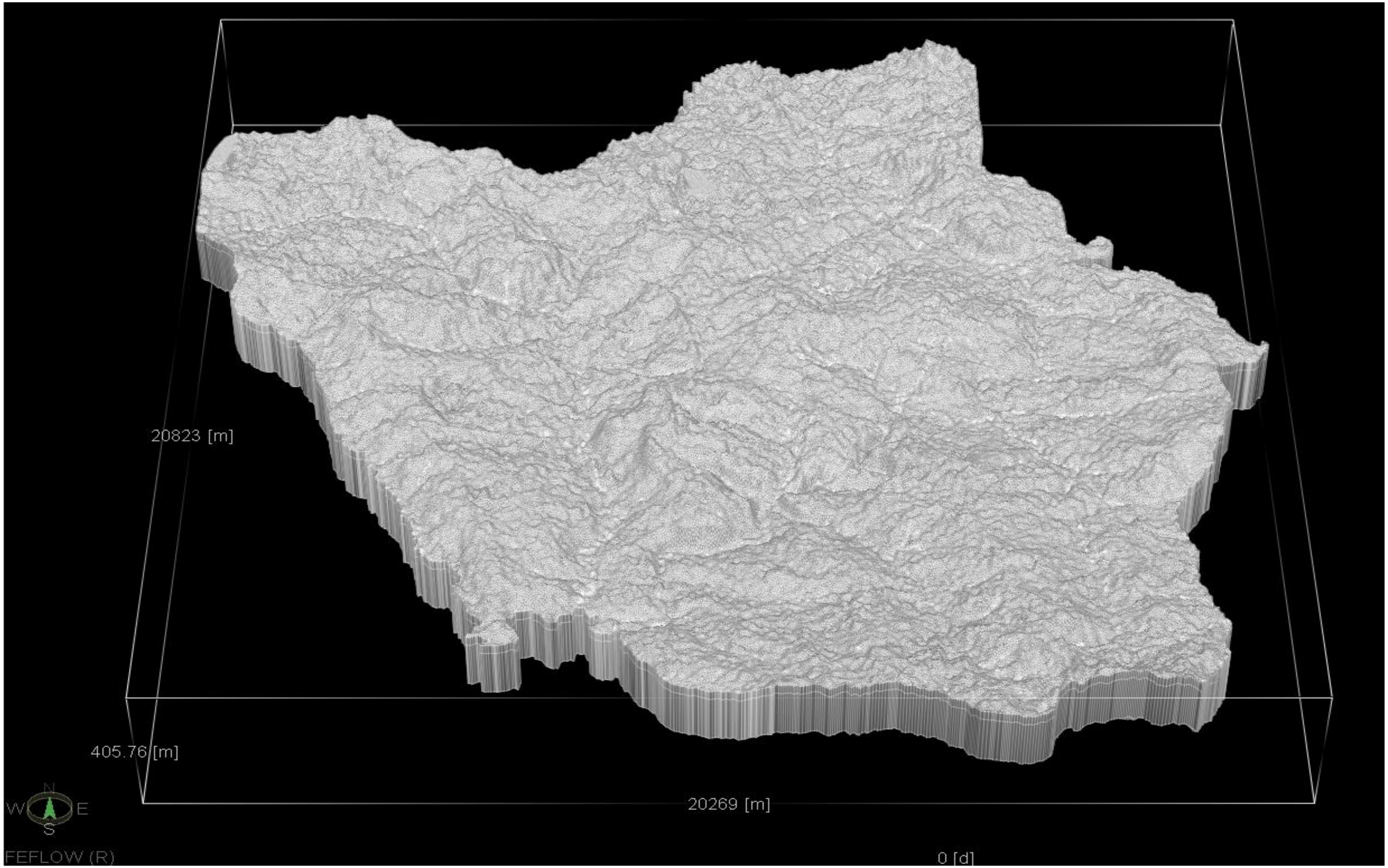


Figure 12-3 **Model domain 3-D FEM mesh view (plan-view south-north orientation).**

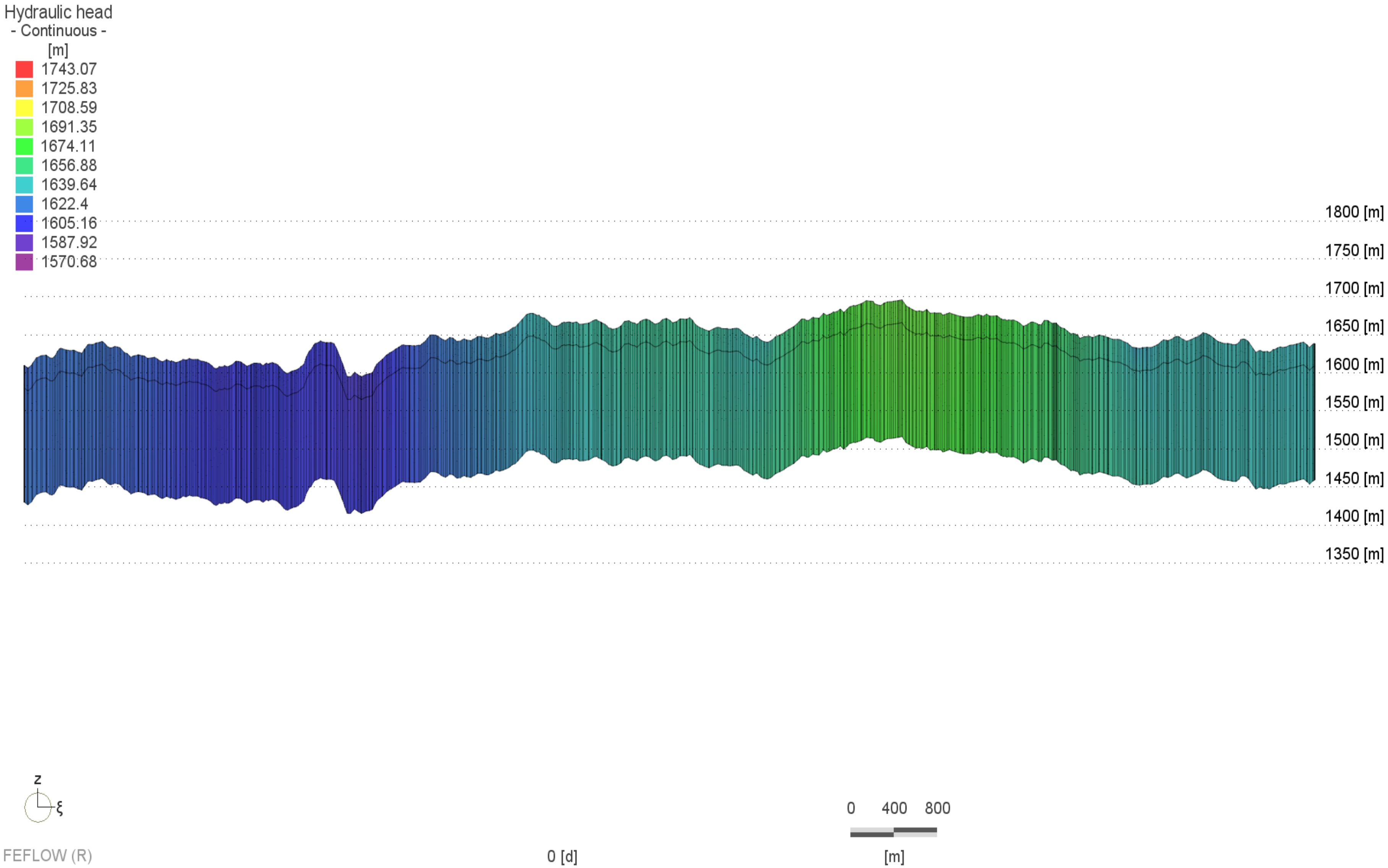


Figure 12-4 **Model domain 3-D FEM mesh view (cross sectional view north-west south-east orientation B-B').**

12.3.3. Model layers

The groundwater model consists of two layers, representing identified hydrostratigraphical units. The top layer was based on surface topography with succeeding layers developed horizontally parallel to this layer[14]. Layer sequence and average thickness are listed below (Table 12-1):

i. Layer 01: A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations (Average thickness = 30.0 m).

ii. Layer 02: An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock (Average thickness = ~150.0 m).

12.3.4. Boundary conditions

For the purposes of this model, it is assumed that the lower perimeter of the model domain i.e. competent Karoo basement is generally impermeable. Accordingly, this boundary is represented numerically as a “no-flow” boundary condition and was assigned as such. Topographical high perimeters (groundwater divides) were assigned as no-flow boundaries while major rivers i.e. Vaal Rivers and Witpuntspruit were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[15]. Neighbouring boreholes identified as part of the regional hydrocensus survey were assigned as pumping well boundary conditions[16]. Following the steady state calibration phase, well boundary conditions were adjusted catering for scenario specific outcomes. Figure 12-5 indicates different boundary conditions assigned within the model domain.

12.3.5. Model hydraulic properties

The following sections provide a brief overview of the model hydraulic parameters assigned.

12.3.6. Hydraulic Conductivity

Hydraulic conductivity (K) values were sourced from historical aquifer characterisation data as well as literature values published for similar hydrogeological environments. The model calibration was also used to guide refinement of aquifer parameter values [17] . Hydraulic conductivity values range from 0.015 m/d for dyke matrices, to 0.20 m/d for more permeable alluvial deposit zones. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in Figure 12-6. A ratio of 1:1 for hydraulic conductivity (K) in x and y directions have been assigned, with a 1:10 ratio in the z direction i.e. anisotropic aquifer. Table 12-1 provides a summary of parameter values per layer.

---

[14] Zones where relevant coal seam contours were available i.e. within the mine lease area, floor elevations were assigned as such.

[15] Refer to “gaining stream” assumption.

[16] Abstraction volumes assigned were based on existing pumping rates. It should be stated that no other abstraction boreholes within the model catchment was simulated and additional abstraction points, if any, should be included as part of the model update.

[17] It should be noted that hydraulic parameters assigned for various hydrostratigraphical units correlate well to historical models and literature values published for similar geological environments.

12.3.7. Sources and sinks

The primary source to groundwater is through recharge. Recharge refers to the addition of water to the saturated zone either through downward percolation from the unsaturated zone or from seepage from an adjacent aquifer. An approximation of recharge for the study area is estimated at ~3.0 % of MAP i.e. ~20.0 mm/a. Sinks in the model domain include groundwater abstraction from privately owned and community boreholes[18] as well as groundwater discharge to baseflow.

12.3.8. Storativity and specific storage

Specific storage values where assigned per layer (Layer01 = 3.00E^{-3}, Layer02 = 3.00E^{-5}) as listed in Table 12-1 below.

12.3.9. Porosity

A porosity value of 3.0 % was assigned for the matrix of the weathered formations whereas fractured formations of layer 2 was assigned a porosity value of 1.0 %.

12.3.10. Longitudinal and Transversal Dispersivities

A longitudinal dispersivity value of 5 m was specified for the simulations (Spitz and Moreno, 1996). Bear and Verruijt (1992) estimated the average transversal dispersity to be 10 to 20 times smaller than the longitudinal dispersity. An average value of 0,5 m was selected for this parameter during the simulations.

Table 12-1 Model set-up: Hydraulic Parameters.

Model Layer	Hydrostratigraphic unit	Layer thickness (m)	Hydraulic Conductivity (K) Kx,y 1:1 (m/d)	Hydraulic Conductivity (K) Kz 1:10 (m/d)	Recharge (Re) In/Outflow on top/bottom (mm/a)	Specific storage (Sc) Sc (1/m)
Layer 01	Vryheid	30.00	0.050	0.005	20.0	1.00E-03
	Dolerite		0.015	0.002		
	Alluvium		0.200	0.200		
Layer 02	Vryheid	150.00	0.025	0.003	0.0	1.00E-05
	Dolerite		0.008	0.001		

---

[18] The volume of groundwater abstraction from boreholes is based on data recorded during the hydrocensus as well an assumption for the entire model catchment. Abstraction volumes as well as localities throughout the entire model domain should be verified as part of an updated hydrocensus user survey.

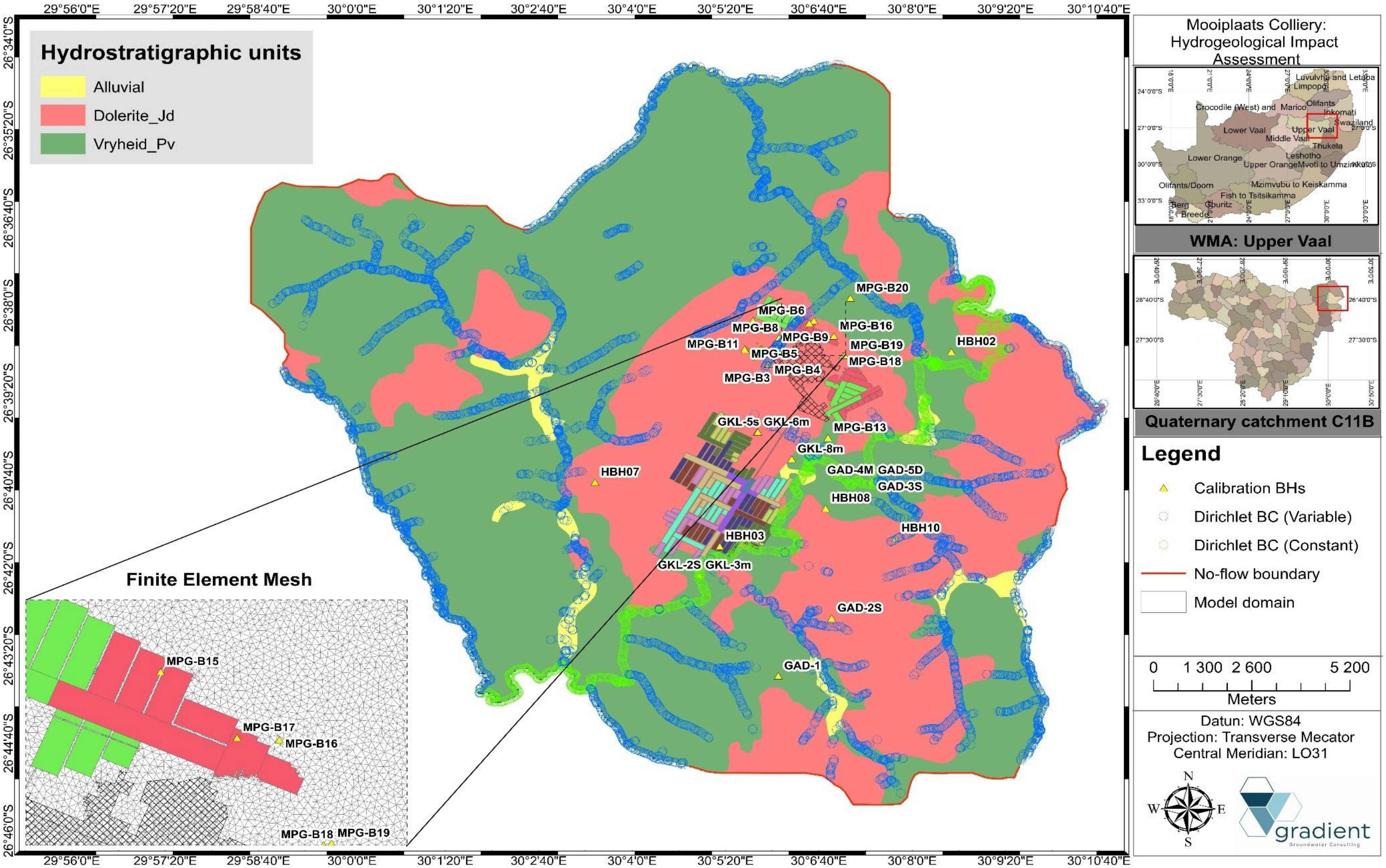


Figure 12-5 **Model domain and boundary conditions.**

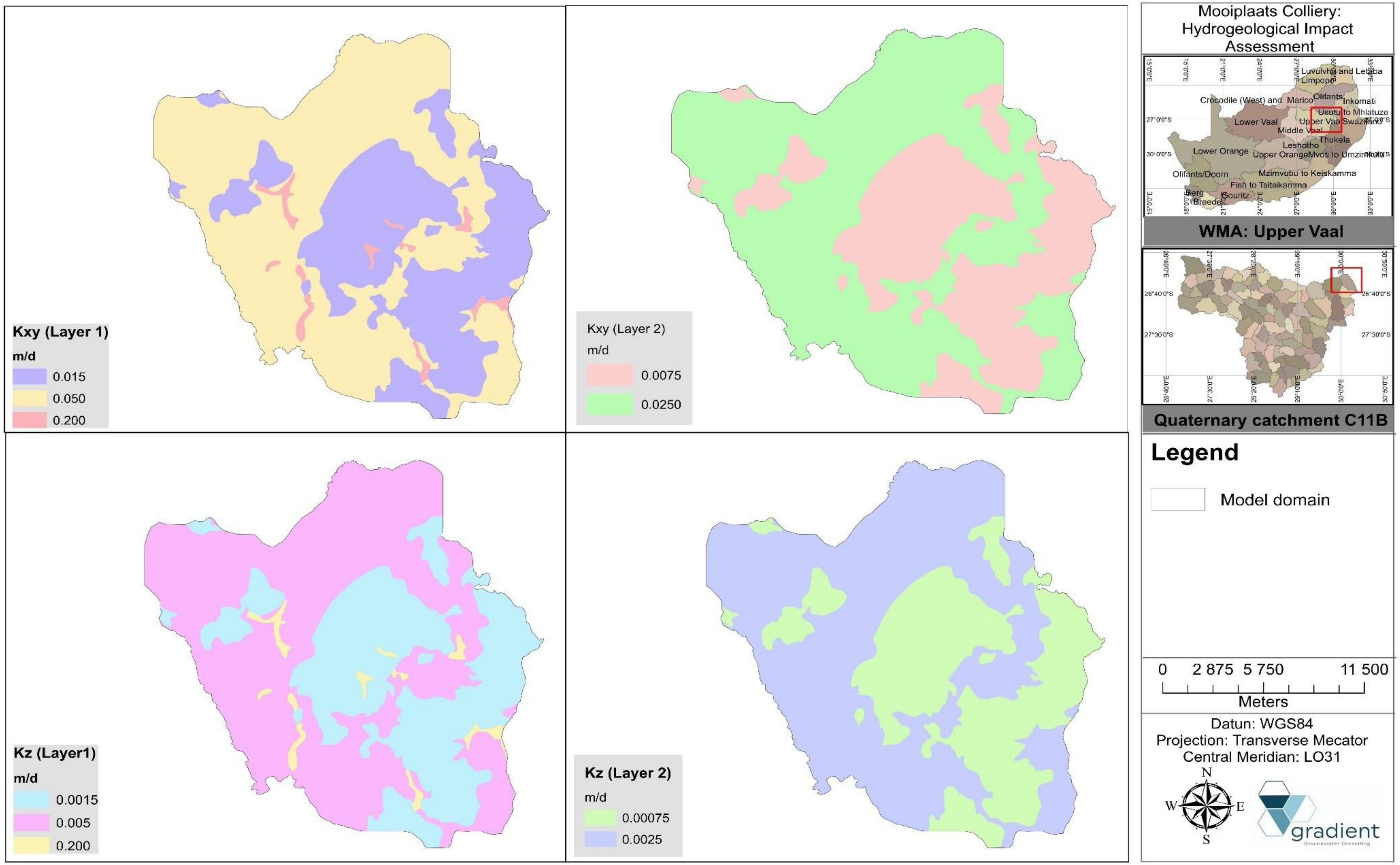


Figure 12-6 **Numerical groundwater flow model: Hydraulic properties.**

12.4. Model calibration

A steady state groundwater flow model was developed to simulate equilibrium conditions, i.e. pre-mining conditions, which will be used as initial hydrogeological conditions for transient simulations. The model was standardised by applying the American Society for Testing Materials (ASTM) guidelines (1993), as well as methods presented in Anderson and Woesner (1992) and Spitz and Moreno (1996) case studies. Under steady state conditions, the groundwater flow equation is reduced to exclude storativity. 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 was obtained. Figure 12-7 depicts steady state hydraulic head contours and groundwater flow directions. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.95 was obtained (Figure 12-8, Figure 12-9 and Figure 12-10). A good correlation indicates that the developed groundwater model will accurately represent on-site conditions. The residual calibration error is expressed through the calculated; mean error (ME), 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:

i. Mean Error (ME): -0.91 m.

ii. Mean Absolute Error (MAE): 5.64 m.

iii. Normalised Root Mean Square Deviation (NRMSD): 7.84 % i.e. represents the deviation between observed and calibration water levels across the model domain.

Table 12-2 **Steady State Model Calibration – Statistical Summary.**

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
MPG-B1	1668.33	1.73	1666.60	1666.29	0.31	0.31	0.10
MPG-B2	1659.21	1.97	1657.24	1659.90	-2.66	2.66	7.06
MPG-B3	1663.03	11.33	1651.70	1666.31	-14.61	14.61	213.48
MPG-B4	1663.34	12.12	1651.22	1667.09	-15.87	15.87	251.86
MPG-B5	1684.71	5.44	1679.27	1684.00	-4.72	4.72	22.33
MPG-B6	1668.86	3.87	1664.99	1668.97	-3.98	3.98	15.82
MPG-B7	1665.98	1.69	1664.29	1666.26	-1.97	1.97	3.90
MPG-B8	1663.47	2.11	1661.36	1660.80	0.56	0.56	0.32
MPG-B11	1685.90	4.40	1681.50	1684.04	-2.54	2.54	6.45
MPG-B14	1656.24	17.12	1639.12	1645.88	-6.76	6.76	45.74
MPG-B15	1649.79	9.56	1640.23	1647.44	-7.21	7.21	52.04
MPG-B17	1671.65	6.31	1665.34	1656.05	9.29	9.29	86.32
MPG-B18	1680.44	27.23	1653.21	1661.04	-7.83	7.83	61.28
MPG-B19	1684.20	23.89	1660.31	1660.42	-0.11	0.11	0.01
MPG-B20	1640.66	2.73	1637.93	1637.17	0.76	0.76	0.58
GAD-2S	1670.96	6.93	1664.03	1665.70	-1.67	1.67	2.78
GAD-3S	1629.08	1.67	1627.41	1624.98	2.43	2.43	5.91
GKL-2S	1596.76	2.87	1593.89	1596.73	-2.84	2.84	8.07
GKL-5s	1648.34	1.81	1646.53	1642.59	3.94	3.94	15.51
GKL-6m	1648.64	1.41	1647.23	1642.64	4.59	4.59	21.06
GKL-8m	1624.78	4.61	1620.17	1624.27	-4.10	4.10	16.79
HBH02	1631.58	7.38	1624.20	1629.20	-5.00	5.00	25.01
HBH03	1604.26	3.75	1600.51	1603.78	-3.27	3.27	10.69
HBH07	1661.78	2.03	1659.75	1643.09	16.66	16.66	277.46
HBH08	1650.62	9.76	1640.86	1628.91	11.95	11.95	142.85
HBH10	1668.31	5.76	1662.55	1651.59	10.96	10.96	120.23
Average	**1655.42**	**6.90**	**1648.52**	**1649.43**	**-0.91**	**5.64**	**54.37**
Minimum	**1596.76**	**1.41**	**1593.89**	**1596.73**	**-15.87**	**0.11**	**0.01**
Maximum	**1685.90**	**27.23**	**1681.50**	**1684.04**	**16.66**	**16.66**	**277.46**
Correlation			**0.941**				
∑					**-23.68**	**146.60**	**1413.64**
1/n					**-0.79**	**4.89**	**47.12**
Root Mean Square Deviation (RMSD)					**0.89**	**2.21**	**6.86**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**7.84**

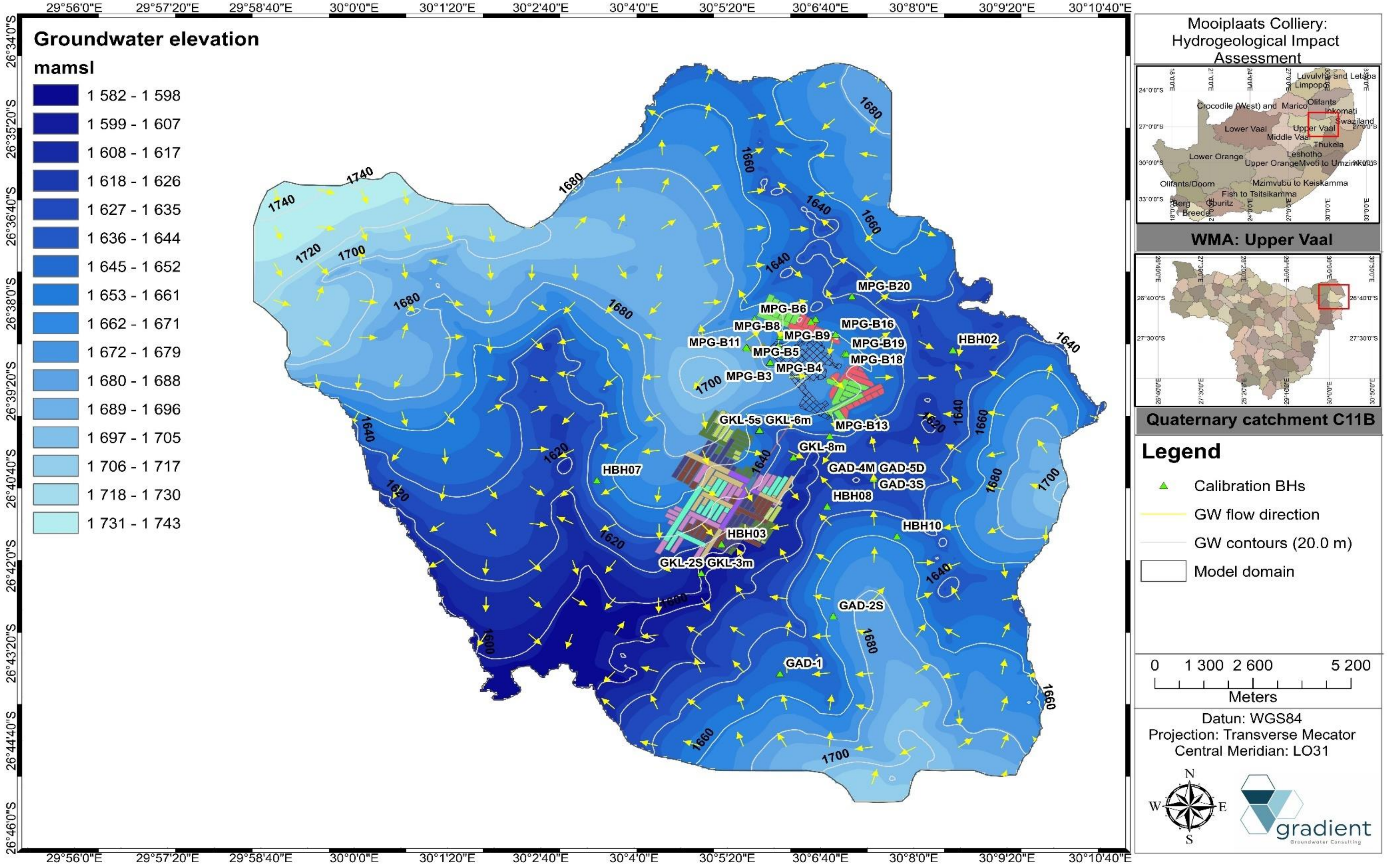


Figure 12-7 **Model calibration: steady state hydraulic heads and groundwater flow direction.**

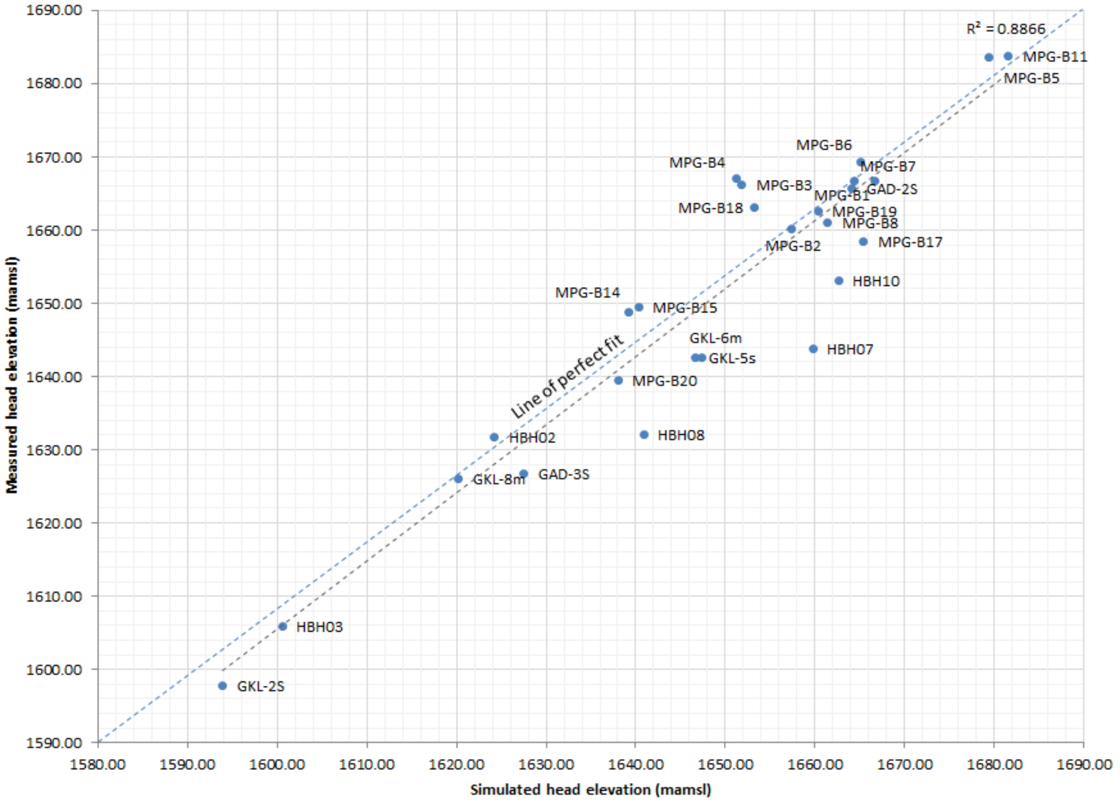


Figure 12-8 **Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.**

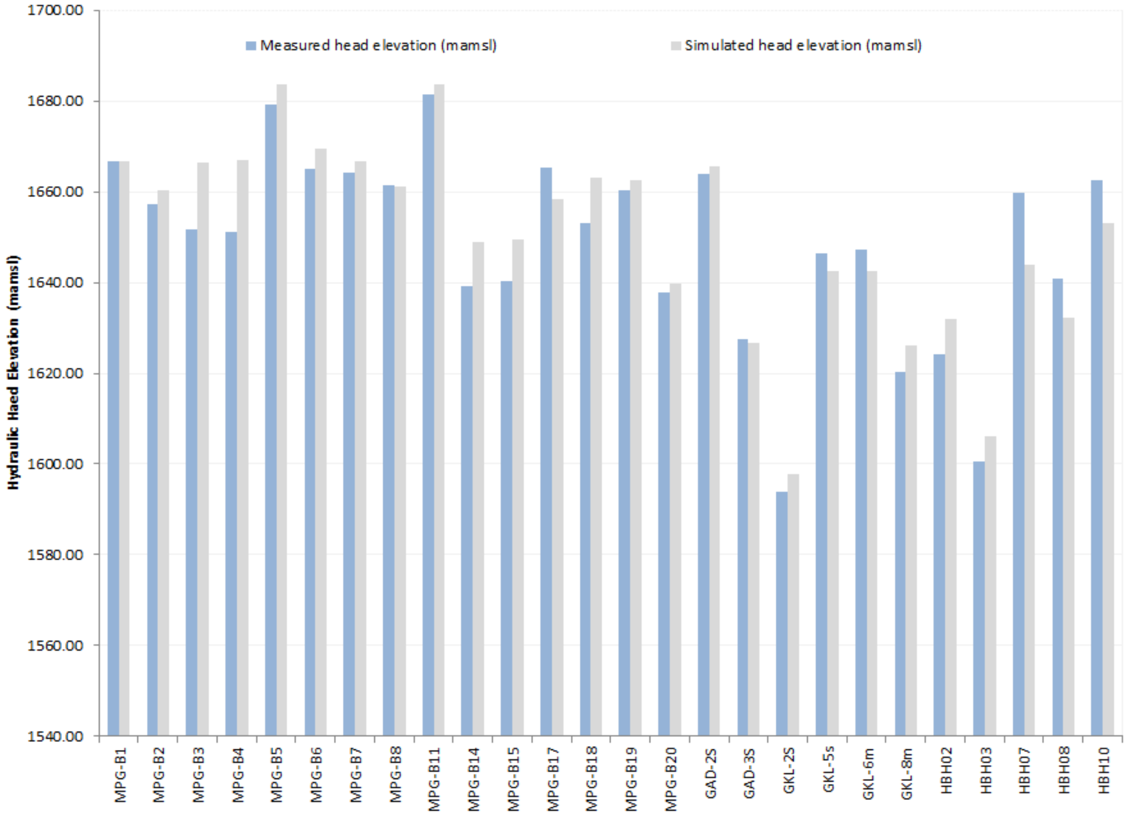


Figure 12-9 **Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.**

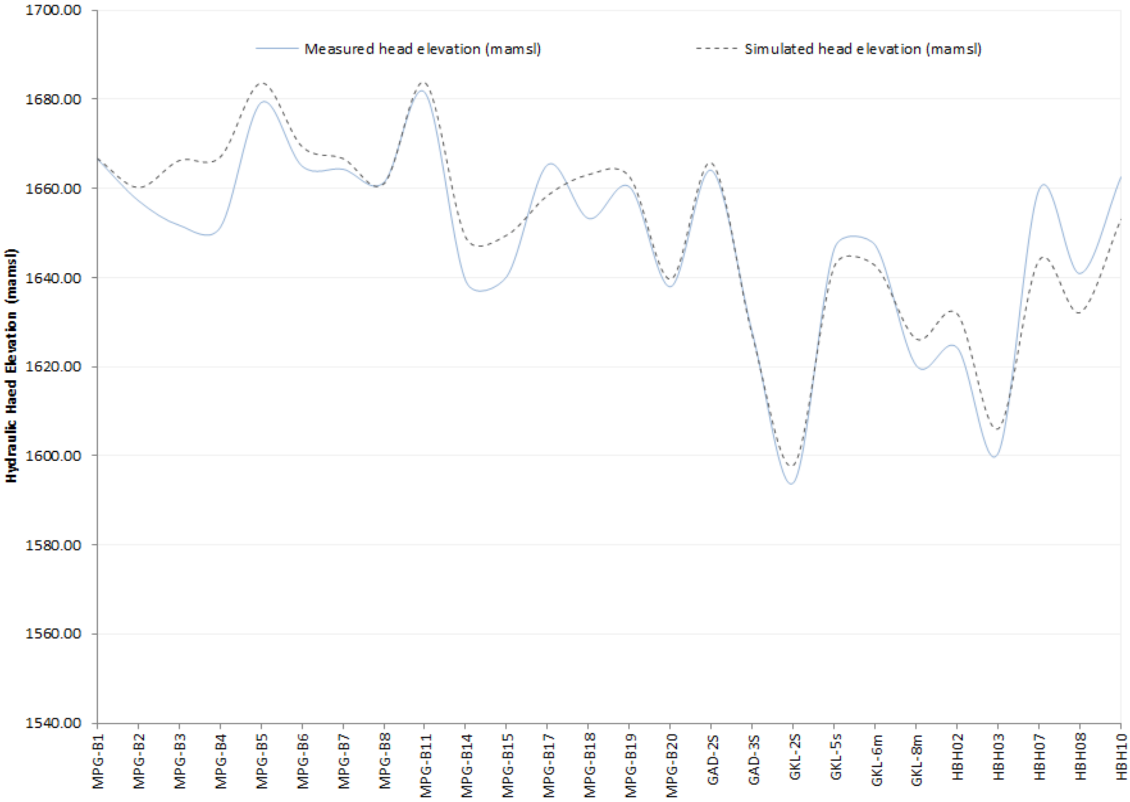


Figure 12-10 **Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.**

12.4.1. Model sensitivity analysis

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs (Saltelli, 2002). The process of recalculating outcomes under alternative assumptions to determine the impact of a variable under sensitivity analysis can increase the understanding of the relationships between input and output variables in a system or model as well as reduce the model uncertainty (Pannell, 1997). In order to verify the sensitivity of the calibrated model in terms of hydraulic stresses, aquifer parameters (i.e. recharge and transmissivity) were adjusted while the impact on the hydraulic head elevation evaluated at relevant on-site borehole localities. As summarised in Table 12-3 it is noted that the model tend to be more sensitive to variations in recharge volumes especially an upward change (Figure 12-11, Figure 12-12 and Figure 12-13)[19].

Table 12-3 **Steady State Model Calibration – Sensitivity analysis.**

Parameter	Scenario: Base Case	Scenario: 0.9K-value	Scenario: 1.1K-value	Scenario: 0.9Rech	Scenario: 1.1Rech
Correlation	0.94	0.95	0.94	0.94	0.95
Mean Error	-0.91	-3.27	-2.11	-2.73	-6.07
Mean Abs Error	5.64	6.80	5.97	6.29	8.15
RMSD	6.86	7.45	6.97	7.12	8.87
NRMSD	7.84%	8.50%	7.95%	8.13%	10.12%

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[19] Recharge remains an uncertain parameter and it is difficult to estimate groundwater recharge accurately. The accurate quantification of natural recharge uncertainty is critical for groundwater management.

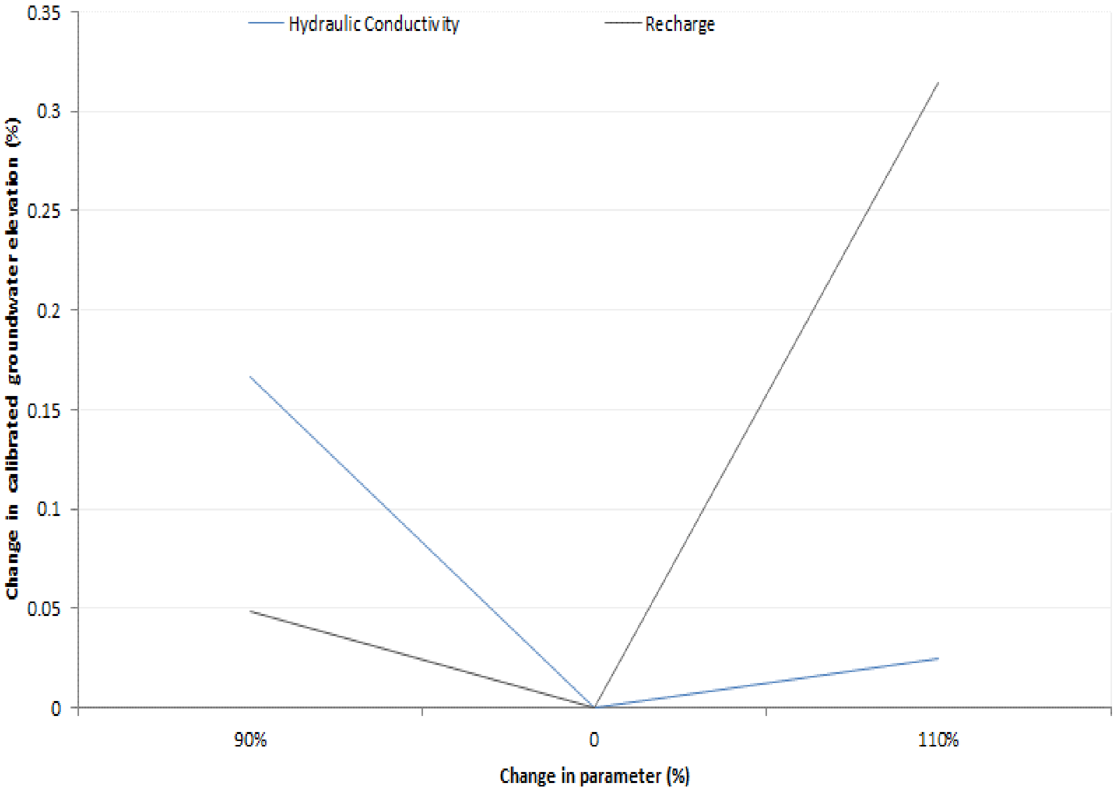

Figure 12-11 **Model steady state calibration: sensitivity analysis for monitoring locality MPG-B06.**

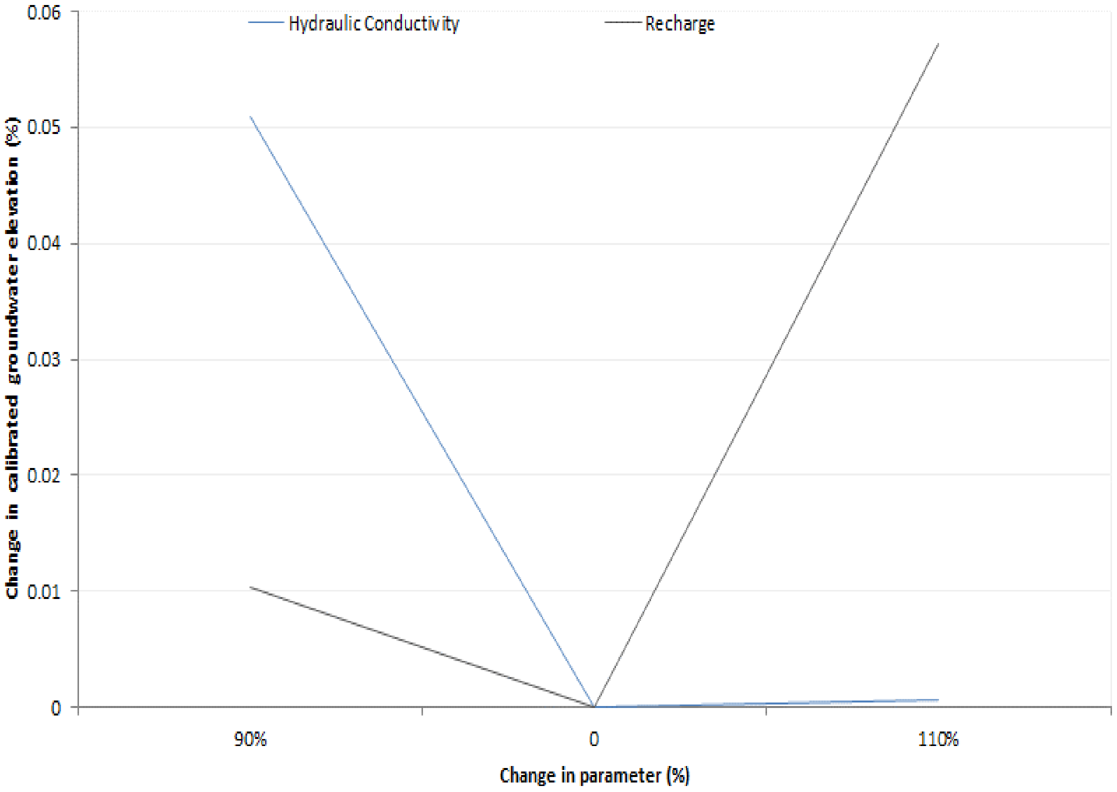

Figure 12-12 **Model steady state calibration: sensitivity analysis for monitoring locality GKL-05s.**

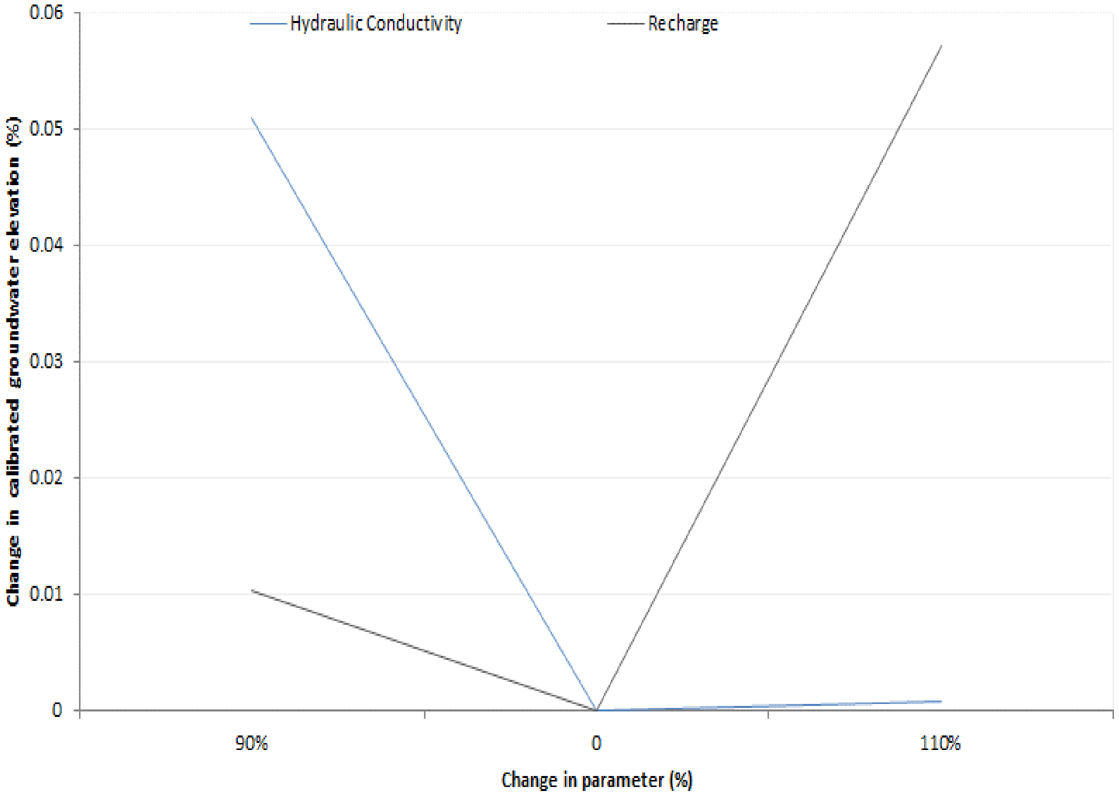

Figure 12-13 **Model steady state calibration: sensitivity analysis for monitoring locality HBH03.**

12.5. Numerical groundwater flow model

The groundwater model is based on three-dimensional groundwater flow and may be described by the following equation (Darcy, 1856):

Equation 12-2 **Groundwater flow.**

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})\pm W=S\frac{\partial h}{\partial t}$$

where:

h = hydraulic head [L]

Kx,Ky,Kz = Hydraulic Conductivity [L/T]

S = storage coefficient

t = time [T]

W = source (recharge) or sink (pumping) per unit area [L/T]

x,y,z = spatial co-ordinates [L]

12.5.1. Model simulation scenarios

Various management scenarios were modelled for the purposes of planning and decision making with stress periods listed in Table 12-4:

i. **Scenario 01:** Steady pre-mining water balance (∞).

ii. **Scenario 02a:** Base-case scenario – LOM underground dewatering operational phase(s).

iii. **Scenario 02b:** Post-closure underground void re-watering and hydraulic head rebound.

iv. **Scenario 03a:** LOM sulphate pollution plume migration with source term 965 mg/l.

v. **Scenario 03b:** LOM sulphate pollution plume migration with source term 2500 mg/l.

vi. **Scenario 03c:** Post-closure sulphate pollution plume migration (100-years).

vii. **Scenario 04a:** Mitigation alternative – Seepage capturing/ scavenger boreholes.

viii. **Scenario 04b:** Mitigation alternative – Cut-off trench.

ix. **Scenario 04c:** Implementation of a barrier system for coal stockpile areas.

Table 12-4 Model stress-periods.

Stress period	Description
2019-2029	LOM Operational underground
2030-2080	50-years post closure
2081-2130	100-years post closure

12.5.2. Scenario 01: Steady state pre-mining water balance (∞)

Table 12-5 summarises the groundwater catchment water balance representing pre-mining steady state conditions. Recharge is assumed the only source of inflow to the system and has been simulated at 1.50E^{+04} m^3/d, while the largest loss to the groundwater system is via baseflow, 1.40E^{+04} m^3/d. An assumption has been made for the total volume of groundwater abstraction from privately owned and community supply borehole accounts to 5.00E^{+02} m^3/d.

Table 12-5 Catchment water balance: Scenario 01 – Steady state pre-mining.

	Scenario 01 – Steady state pre-mining		
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	1.5E+04	0.0E+00	1.5E+04
Abstraction (m^3/d)	0.0E+00	5.0E+02	-5.0E+02
Baseflow (m^3/d)	0.0E+00	1.4E+04	-1.4E+04
Imbalance ignoring internal transfer (m^3/d)	0.0E+00	3.5E-01	-3.5E-01
Total (m^3/d)	**1.5E+04**	**1.5E+04**	**0.0E+00**

12.5.3. Scenario 02a: Base-case scenario – LOM underground dewatering operational phase(s)

Table 12-6 summarises the groundwater catchment water balance for stress periods representing the mining operational phase. Model simulations suggest the average groundwater ingress and underground dewatering volume will be approximately 5.10E^{+02} m^3/d. Figure 12-14 depicts respective time-series dewatering curves while Figure 12-17 shows the simulated groundwater catchment i.e. zone of influence. It is expected that the groundwater drawdown will range from 2.0 m to ~ 7.0 m below the static water level (mbsl) i.e. pre-mining water levels covering an estimated area of approximately 13.0 km^2, propagating towards a western as well as north-eastern direction, reaching a maximum distance of ~750 m to the west and 1050 m to the northeast. Figure 12-15 depicts the influence of underground dewatering on neighbouring borehole water levels. It is noted that there is not a significant influence on water levels of neighbouring boreholes for the duration of the proposed mining operation. This can be attributed to the proposed underground void depth and hence dewatering levels and proximity of the boreholes to the pit footprints. Baseflow discharges[20] to the Vaal Rivers and Witpuntspruit accounts to approximately 1 326.0 m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1 117.0 m^3/d. This accounts for an average loss of ~16.0% (refer to Figure 12-16 below).

Table 12-6 **Catchment water balance: Scenario 01- Base-case scenario.**

Scenario 02: Underground dewatering- LOM operational phase			
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	1.5E+04	0.0E+00	1.5E+04
Abstraction (m^3/d)	0.0E+00	5.0E+02	-5.0E+02
Baseflow (m^3/d)	0.0E+00	1.4E+04	-1.4E+04
Underground dewatering (m^3/d)	0.0E+00	5.1E+02	-5.1E+02
Storage Capture(-)/Release(+)(m^3/d)	-4.0E+01	0.0E+00	-4.0E+01
Total (m^3/d)	**1.5E+04**	**1.5E+04**	**-6.8E-13**

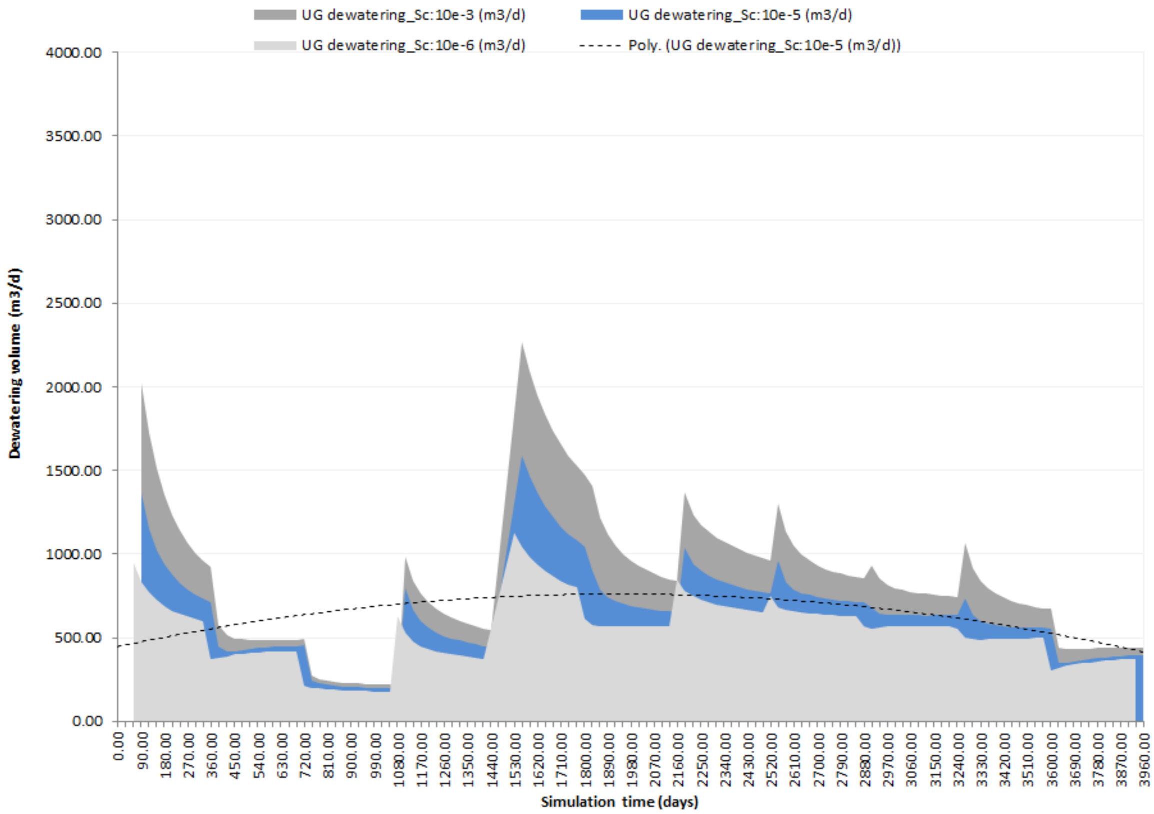

Figure 12-14 **Scenario 02a: Underground time-series dewatering/ groundwater ingress curve.**

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[20] It should be noted that baseflow calculations is based on major drainage segments within the expected groundwater zone of influence.

Figure 12-15 **Scenario 02a : Curve indicating influence of dewatering on neighbouring borehole water levels.**

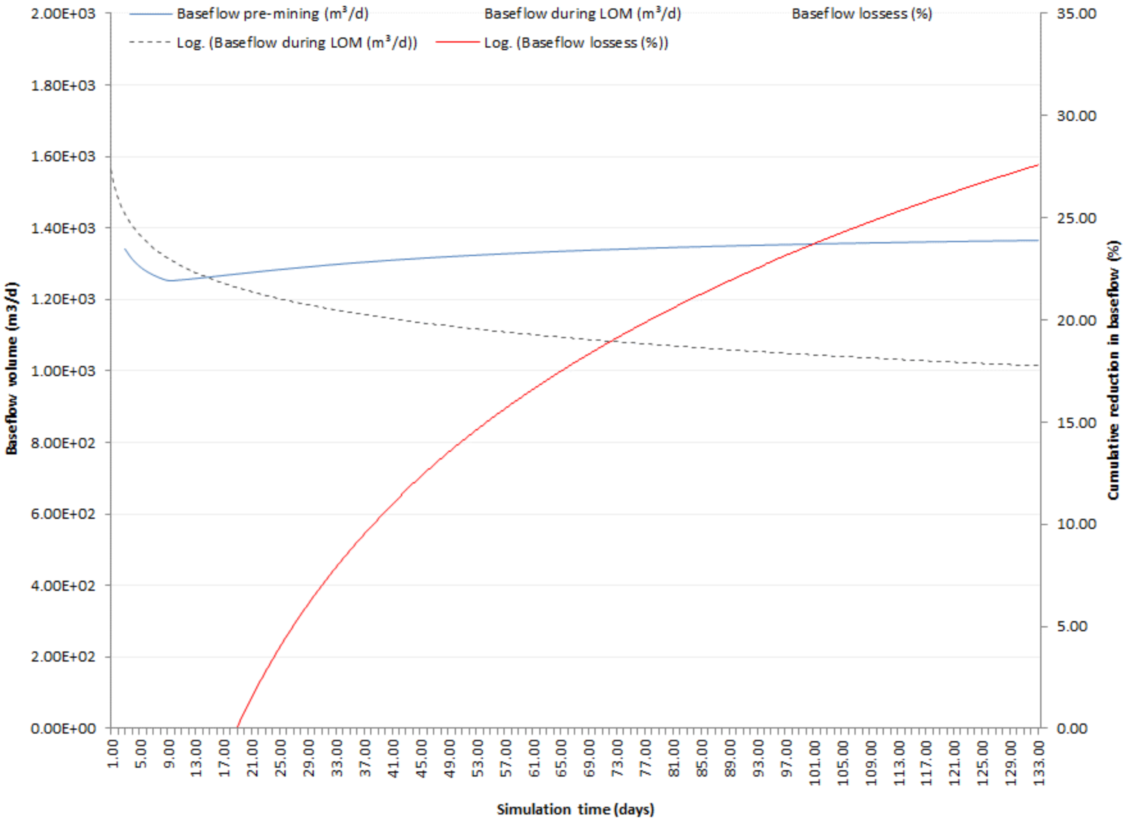

Figure 12-16 **Scenario 02a: Baseflow comparison curve: Pre-mining vs underground dewatering.**

Figure 12-17 **Scenario 02a: Water level drawdown and groundwater capture zone.**

12.5.4. Scenario 02b: Post-closure underground void re-watering and hydraulic head rebound.

A mine post-closure scenario was simulated wherein hydraulic head recovery within the zone of influence was evaluated. In order to work out the time the underground void will take to be flooded, and potentially decant, the mine void space must be determined for the underground operations as shown in Figure 12-18. The expected average groundwater infiltration for the LOM underground operation is estimated at ~ 500.0 m^3/d. In addition to groundwater infiltration there is also flow contribution from groundwater ingress reporting to the underground void (variable depending on specific storativity scenario applied). The flooding curves for the underground operation are depicted in Figure 12-19. From these volumes it is estimated that under average rainfall conditions and Sc values of 10E^{-6}, the underground will be flooded in approximately 30 years after ceasing mining activities. it is estimated that for Sc values of 10E^{-5}, the underground operations will be flooded in approximately 34 years whereas for Sc values of 10E^{-3}, the underground void will be flooded after approximately 37 years (Table 12-7).

The proposed depth and geometry of the underground operations allows for the entire footprint to be flooded without any decant expected. Generally, the decant point/zone is the lowest topographical point of the proposed mining footprint which is in direct connection with surface topography. The latter usually occur via a preferred groundwater flow pathway such as shafts/ adits and/or unrehabilitated exploration boreholes. However, if these features are fully rehabilitated no point will exist for surface decant to occur post-closure.

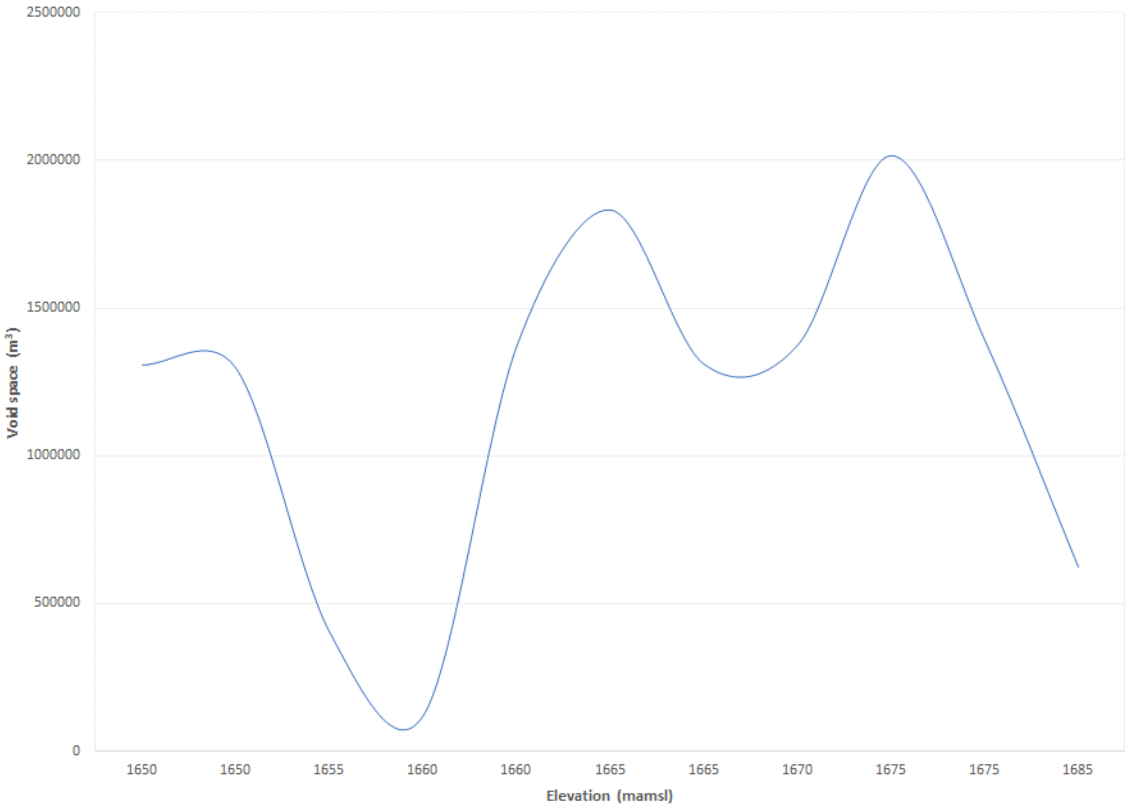

Figure 12-18 **Mine void space for the underground operartions.**

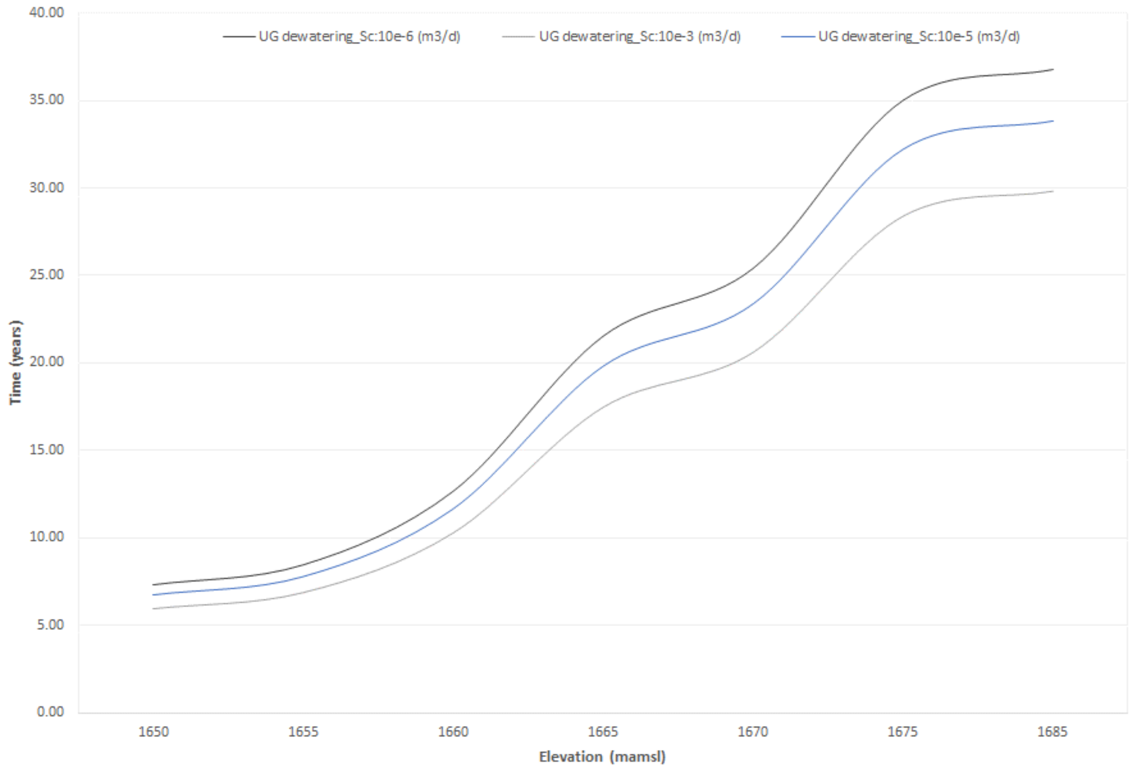

Figure 12-19 **Scenario 02b: Flooding curve for the underground operartions.**

Table 12-7 **Post-closure flooding of underground void.**

Time to flood under MAP conditions (years)		
Sc:10e^{-6} (m^3/d)	**Sc:10e^{-5} (m^3/d)**	**Sc:10e^{-3} (m^3/d)**
36.75	33.81	29.80

12.6. Numerical mass transport model

The mass balance equation (Bear and Verruijt, 1992) (advection-dispersion equation) of a pollutant can be expressed as follows:

Equation 12-3 **Advection-dispersion.**

$$\frac{\delta nc}{\delta t} = -\Delta \bullet q_{c,total} - f + n\rho\Gamma - P_c + R_c$$

where:

nc = mass of pollutant per unit volume of porous medium;

n = porosity of saturated zone;

c = concentration of pollutant (mass of pollutant per unit volume of liquid (water));

$\Delta \bullet q_{c,total}$ = excess of inflow of a considered pollutant over outflow, per unit volume of porous medium, per unit time;

f = quantity of pollutant leaving the water (through adsorption, ion exchange etc.);

$n\rho\Gamma$ = mass of pollutant added to the water (or leaving it) as a result of chemical interactions among species inside the water, or by various decay phenomena[21];

Γ = rate at which the mass of a pollutant is added to the water per unit mass of fluid;

p = density of pollutant;

Pc = total quantity of pollutant withdrawn (pumped) per unit volume of porous medium per unit time;

Rc = total quantity of pollutant added (artificial recharge) per unit volume of porous medium per unit time.

Advection and hydrodynamic dispersion are the major processes controlling transport through a porous medium. Advection is the component of contaminant movement described by Darcy's Law. If uniform flow at a velocity V takes place in the aquifer, Darcy's law calculates the distance (x) over which a labelled water particle migrates over a time period t as x = Vt. Hydrodynamic dispersion refers to the stretching of a solute band in the flow direction during its transport by an advecting fluid and comprises mechanical dispersion as well as molecular diffusion. It should be noted that contaminant transport scenarios serve as tool for management purposes and the simulation results indicate the expected plume migration. The latter can be used to establish additional monitoring points to be applied as transient input for model updates and re-calibration.

12.6.1. Scenario 03a: LOM sulphate pollution plume migration with source term 965.0 mg/l

The calibrated groundwater flow model was used as basis to perform the solute/mass transport scenarios. Sulphate (SO_4) is a good indicator for coal mine pollution and is generated as a product from ARD (Rikard and Kunkle 1990). This anion is very stable i.e. relatively little decay and/or retardation and was used as source term and contaminant proxy. The source term concentration was derived from the geochemical characterisation (refer to Section 9) and assigned as 965.0 mg/l. Model domain background values were interpreted from the hydrochemical data analysis as gathered during the hydrocensus user survey and assigned as ~ 30.0 mg/l.

Figure 12-20 indicates a time-series graph of the mass load of neighbouring boreholes in proximity to the waste facilities (MPG-BH01 and MPG-BH07). Monitoring locality MPG-BH01 exceeds the SANS 241:2015 threshold for sulphate after a period of approximately eight years, reaching a maximum concentration of 560.0 mg/l. Figure 12-21 depicts the expected sulphate pollution plume migration emanating from the existing discard dump and coal stockpile footprints. The pollution plume extend covers an area of approximately 0.72 km^2, reaching a maximum distance of 180.0 m in a general eastern to north-eastern direction. The simulation indicates that no neighbouring boreholes as identified during the hydrocensus user survey are impacted on during the operational life of mine. Figure 12-22 shows a cross section of the plume migration and it is evident that the shallow, weathered aquifer is the primary pathway as expected.

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[21] This investigation and contaminant transport model are based on a "worst-case" scenario and as such, it is assumed that no decay and/or retardation of sulphate are taking place in the aquifer.

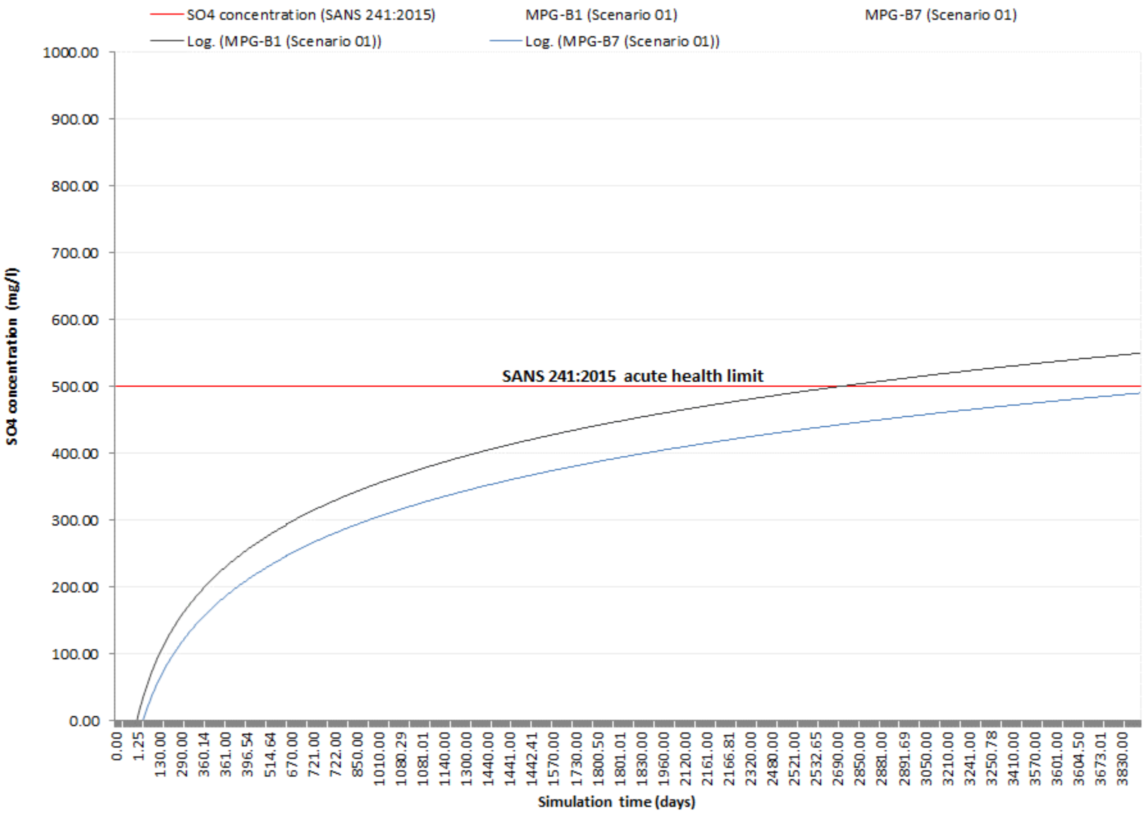


Figure 12-20 Scenario 03a: Graph indicating impact on receptors in the vicinity of the source term(s).

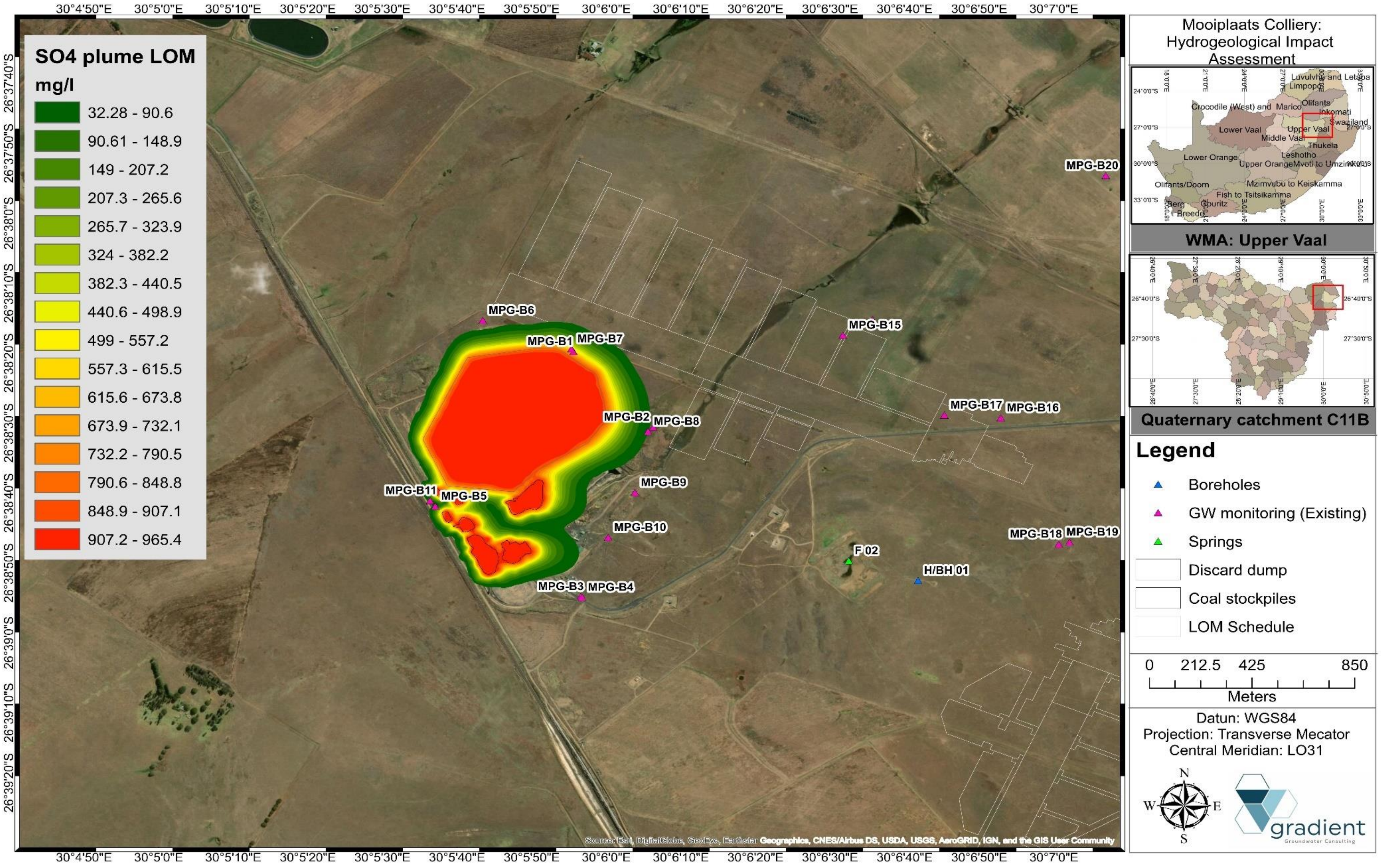


Figure 12-21 **Scenario 03a: LOM Sulphate pollution plume for the discard dump and coal stockpiles.**

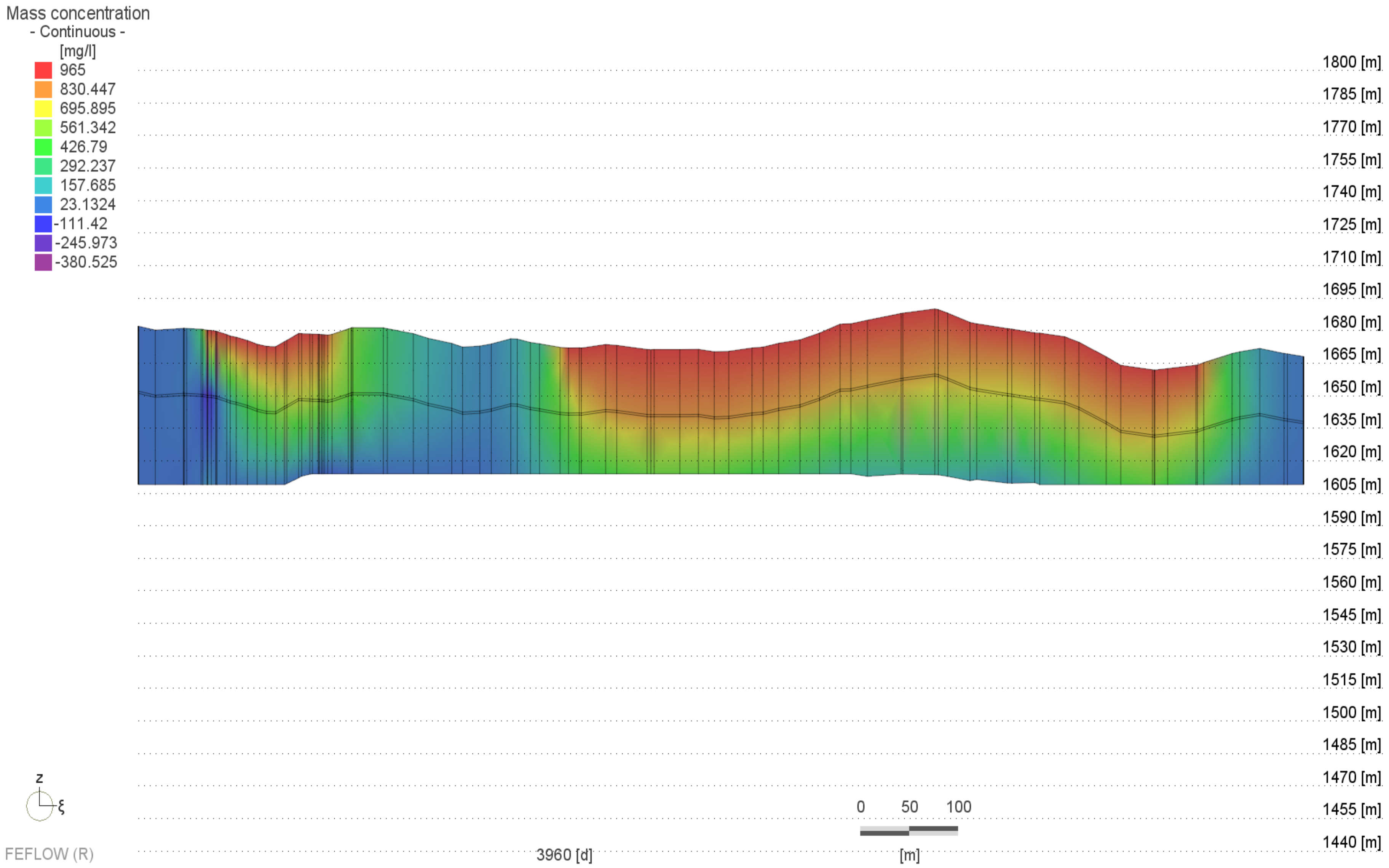


Figure 12-22 **Scenario 03a: LOM Sulphate pollution plume cross section.**

12.6.2. Scenario 03b: LOM sulphate pollution plume migration with source term 2500 mg/l

Scenario 03b was simulated to evaluate the "worst-case" scenario of the sulphate source term and was assigned at 2500 mg/l. Figure 12-20 indicates a time-series graph of the mass load of neighbouring boreholes in proximity to the waste facilities (MPG-BH01 and MPG-BH07). Both monitoring localities exceeds the SANS 241:2015 threshold after a period of only one year's mining and reaches a maximum concentration of ~1430.0 mg/l and 1310.0 mg/l respectively. **Error! Reference source not found.** depicts the expected sulphate pollution plume m igration emanating from the existing discard dump and coal stockpile footprints. The pollution plume extend covers an area of approximately 0.78 km^2, reaching a maximum distance of <200.0 m in a general eastern to north-eastern direction. Figure 12-25 shows the expected pollution plume migration potentially emanating from the underground mined out faces. The pollution plume does not migrate more than ~100.0 m – 150.0 m from the mining footprint for the operational life of mine. The simulation indicates that no neighbouring boreholes as identified during the hydrocensus user survey are impacted on during the operational life of mine.

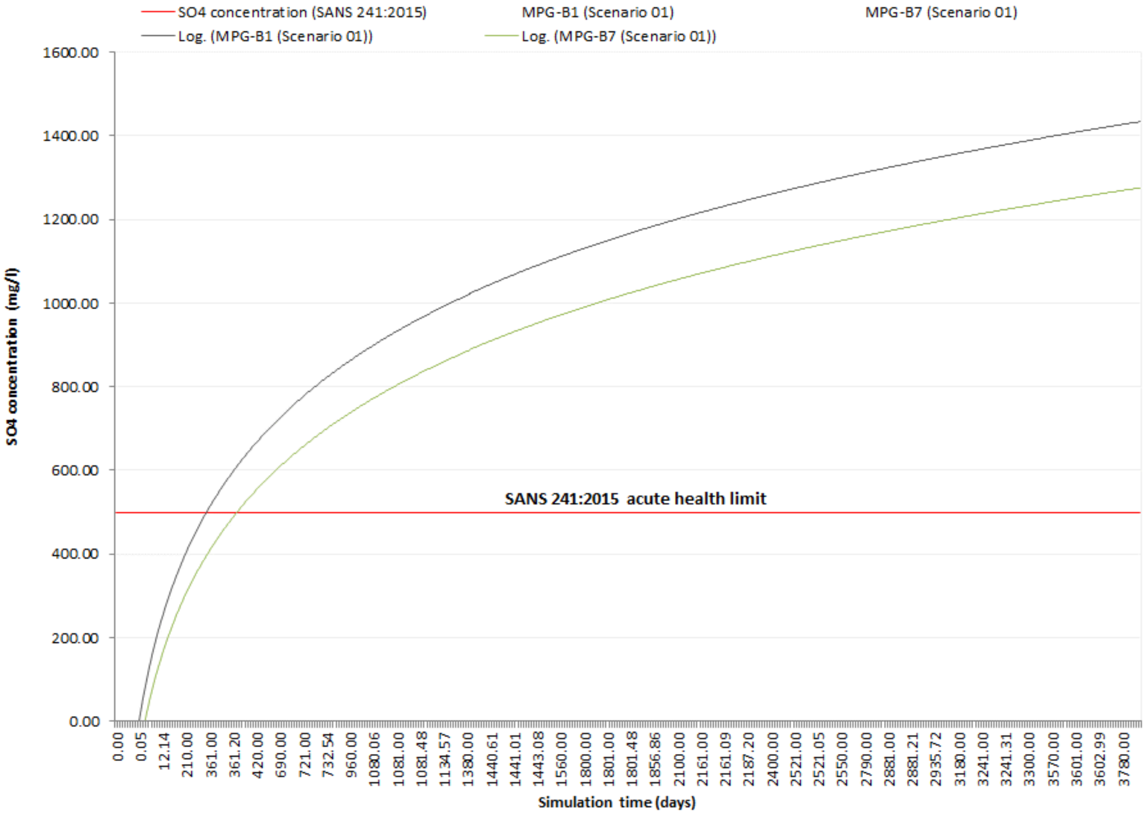


Figure 12-23 **Scenario 03b: Graph indicating impact on receptors in the vicinity of the source term(s).**

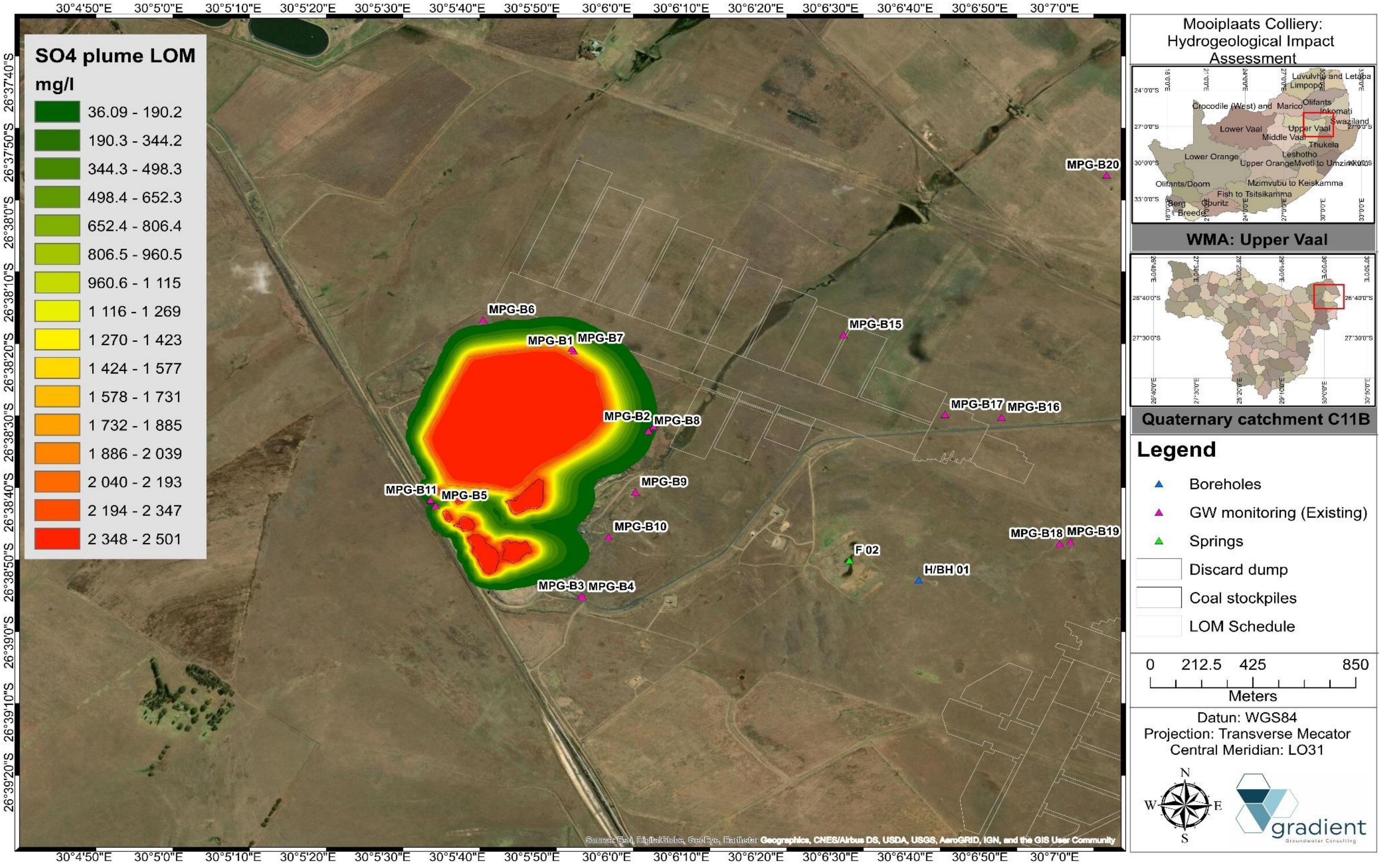


Figure 12-24 Scenario 03b: LOM Sulphate pollution plume for the discard dump and coal stockpiles (weathered aquifer).

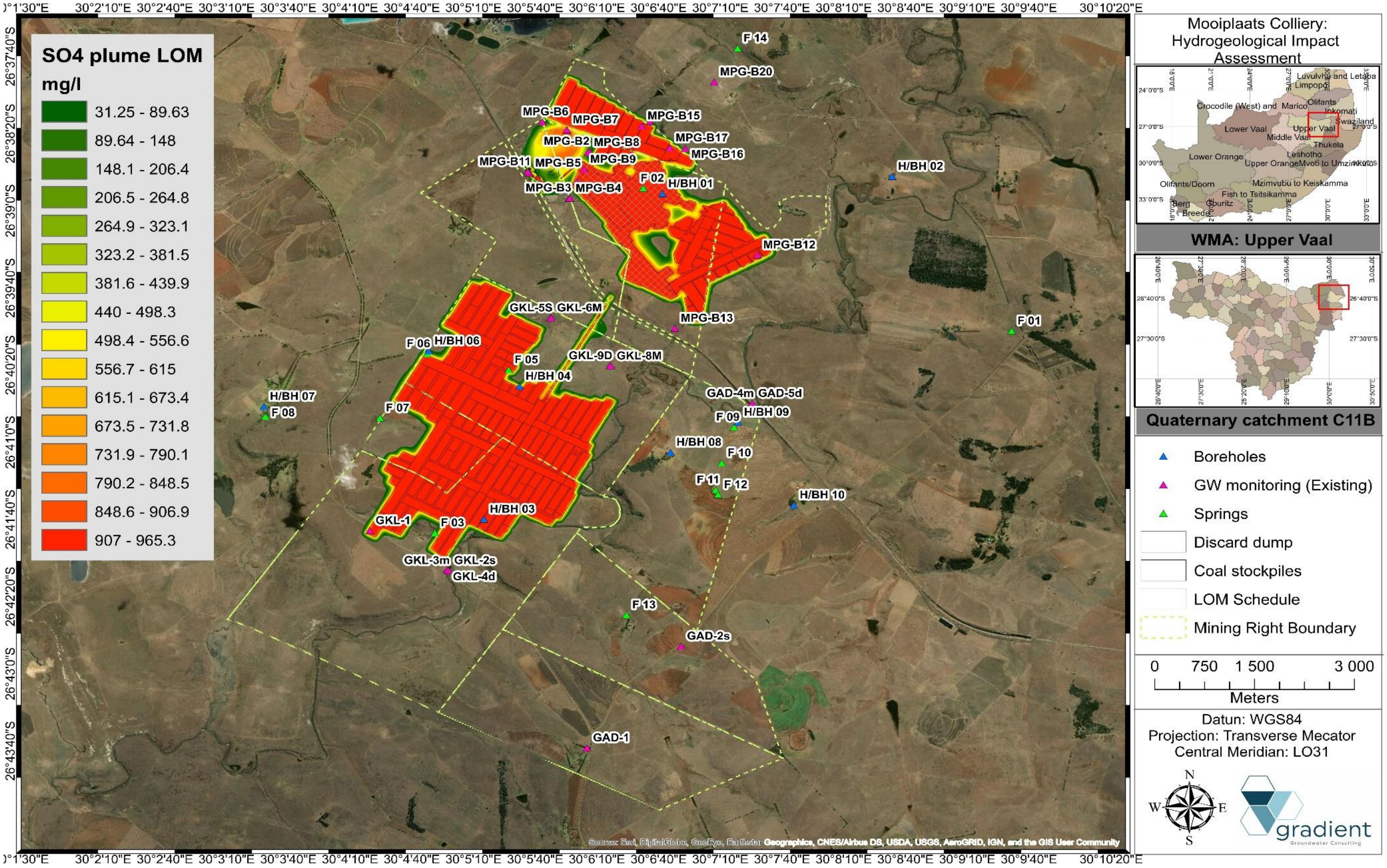


Figure 12-25 Scenario 03b: LOM Sulphate pollution plume for the underground mining operations (fractured aquifer).

12.6.3. Scenario 03c: Post-closure sulphate pollution plume migration.

A 50-year post-closure as well as 100-year post-closure scenario was simulated for each source term in order to evaluate the pollution plume migration after discontinuing of mining activities. It should be noted that the plume extend will represent a worst case and conservative footprint as the source term was simulated a constant concentration for the duration of the simulation period.

Figure 12-20 indicates a time-series graph of the mass load of neighbouring boreholes in proximity to the waste facilities (MPG-BH01 and MPG-BH07). Both monitoring localities exceeds the SANS 241:2015 threshold after a period of four years and seven years after mining respectively. A maximum concentration of ~790.0 mg/l and 780.0 mg/l are reached respectively.

After a 50-year period the pollution plume extend is approximately 1.23 km^2 reaching a total distance of ~530 m in a general north-eastern to eastern direction (Figure 12-27). After a 100-year period the pollution plume footprint increases to approximately 1.55 km^2 and reaches a maximum distance of 680 m towards the north-eastern perimeter and also migrates to the north (Figure 12-28). It should be noted that plume migration stretches beyond the mine lease area to the north. The plume still does not reach any neighbouring boreholes, however two drainages and tributaries of the Witpunt-spruit towards the northern and eastern border can potentially be affected post-closure.

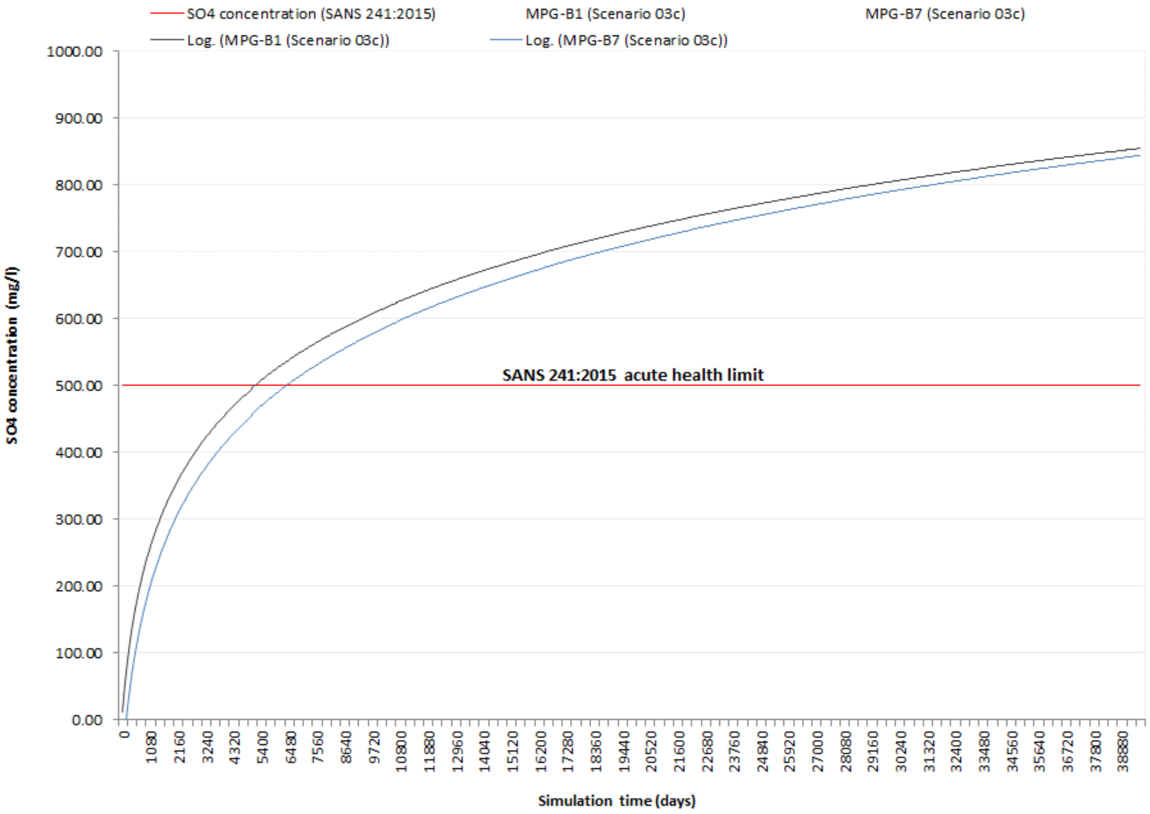


Figure 12-26 **Scenario 03c: Graph indicating impact on receptors in the vicinity of the source term(s).**

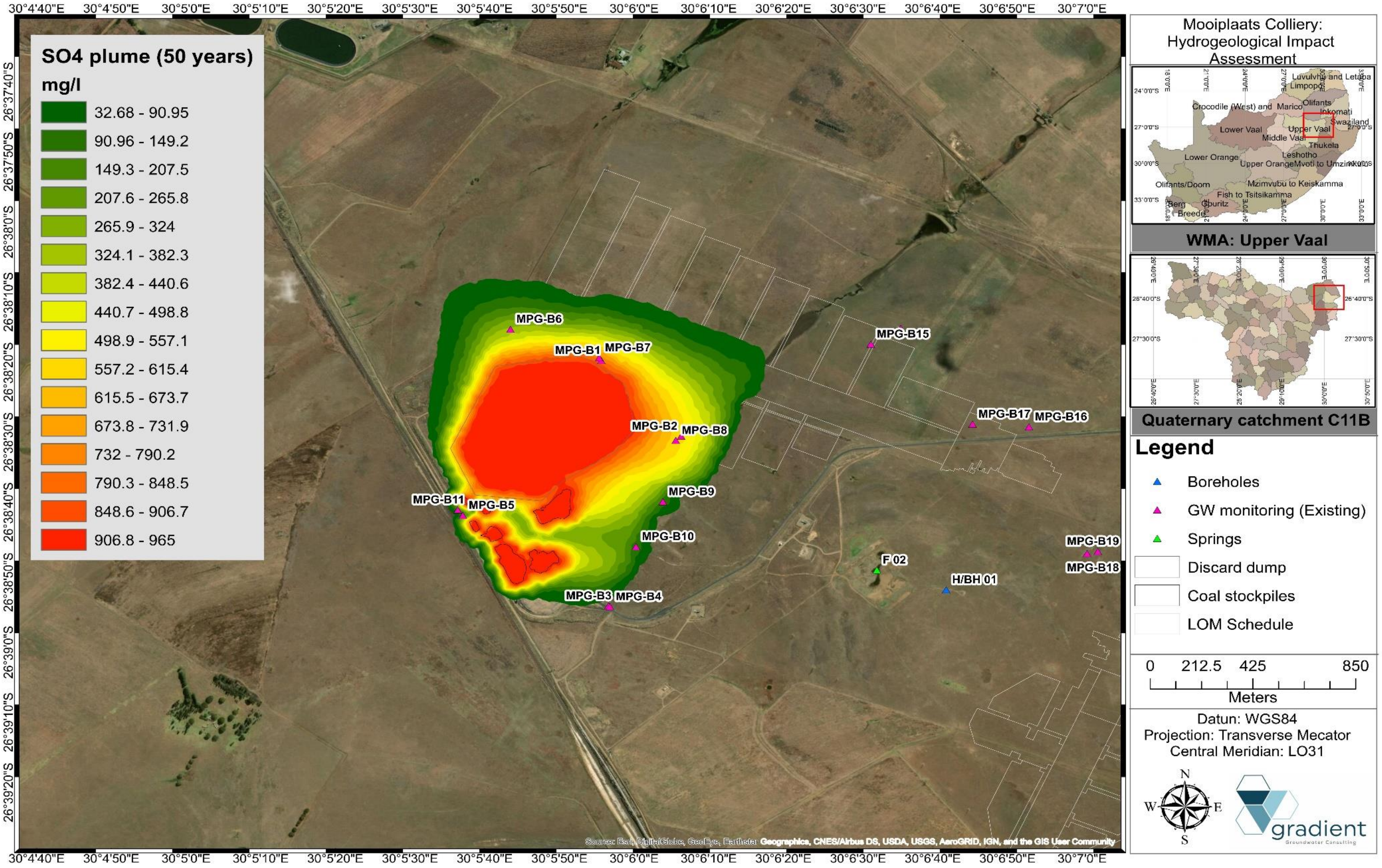


Figure 12-27 Scenario 03c: Post-closure sulphate pollution plume (50 years).

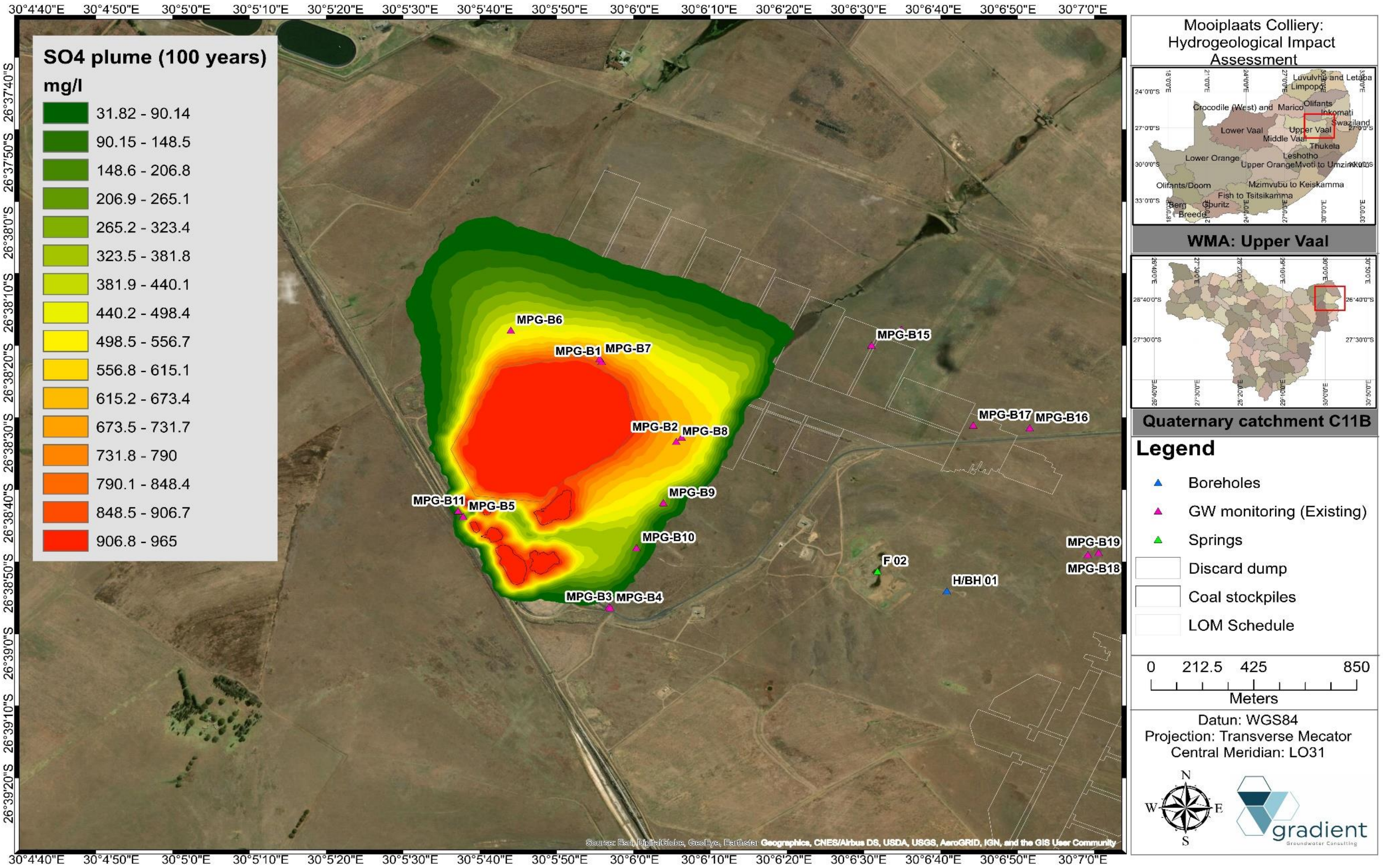


Figure 12-28 **Scenario 03c: Post-closure sulphate pollution plume (100 years)**

12.6.4. Scenario 04: Mitigation and management

Various alternative management and mitigation scenarios were simulated in order to evaluate the remedial options available. Table 12-8 provides a summary of the mitigatory effect of proposed alternatives on the pollution plume migration.

12.6.5. Scenario 04a: Mitigation alternative 01 - Seepage capturing/scavenger boreholes

A management scenario evaluating the mitigating effect of seepage capturing boreholes i.e. scavenger boreholes on the plume migration were simulated. Boreholes were established down-gradient of both the mine discard dump as well as coal stockpiles as indicated in Figure 12-29. The pollution plume footprint is reduced by approximately 19.0% with an abstraction volume of ~0.25 l/s per borehole. Increased abstraction will further decrease and constraint the plume footprint, however this will be highly dependent on borehole specific hydraulic parameters as well as functionality. It is recommended that constant discharge aquifer tests be conducted on newly established seepage capturing boreholes in order to optimise borehole yields.

12.6.6. Scenario 04b: Mitigation alternative 02 - Implementation of a cut-off trench

A management scenario evaluating the mitigating effect of a sub-surface cut-off trench/sub-surface drain on the plume migration were simulated as depicted in Figure 12-30. The pollution plume footprint is reduced by approximately >20.0% and is deemed the preferred mitigation alternatives due to operational as well as post-closure management.

12.6.7. Scenario 04c: Mitigation alternative 03 - Lining of coal stockpiles with a barrier system.

A management scenario evaluating the mitigating effect of a Class C or GLB+ containment barrier design i.e. Type 3: Low-risk waste for all ROM stockpiles on the plume migration were simulated (Figure 12-31). The mitigation effect and constraint of the pollution plume is not significant, and the plume is only reduced by ~5 %. This can possibly be attributed to the small footprint of the coal stockpiles and its contribution to the plume.

Table 12-8 Mitigation alternatives pollution plume areas and effectiveness.

Mitigation Scenario	Plume area (pre-mitigation)(km^2)	Plume area (post-mitigation)(km^2)	Improvement (%)
Scenario 04a: Seepage capturing/scavenger boreholes	0.72	0.58	19.4%
Scenario 04b: Implementation of a cut-off trench	0.72	0.57	20.8%
Scenario 04c: Lining of coal stockpiles with a barrier system	0.72	0.68	5.6%

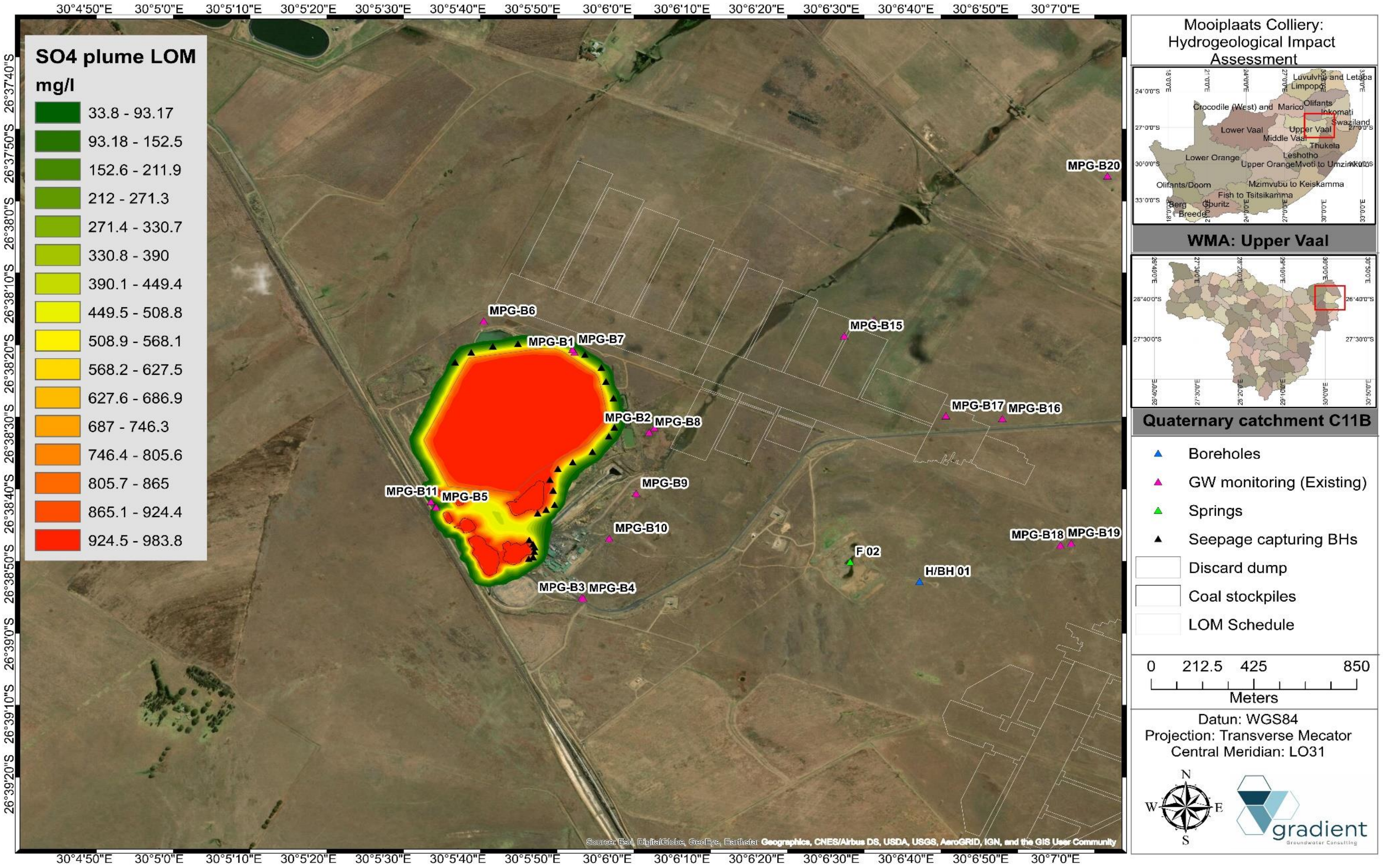


Figure 12-29 **Scenario 04a: Mitigation alternative 01: Seepage capturing boreholes.**

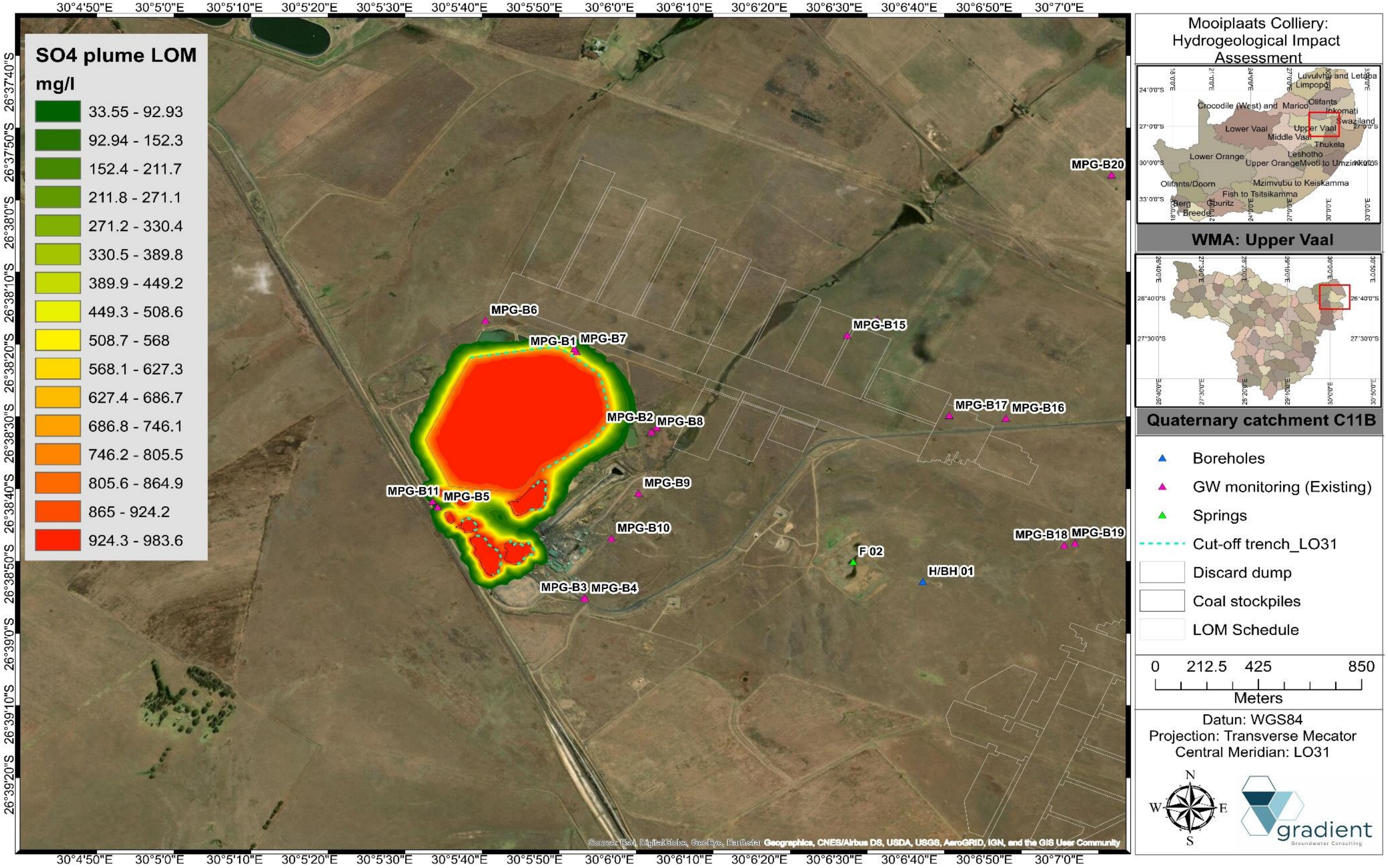


Figure 12-30 Scenario 04b: Mitigation alternative 02: Implementation of a cut-off trench.

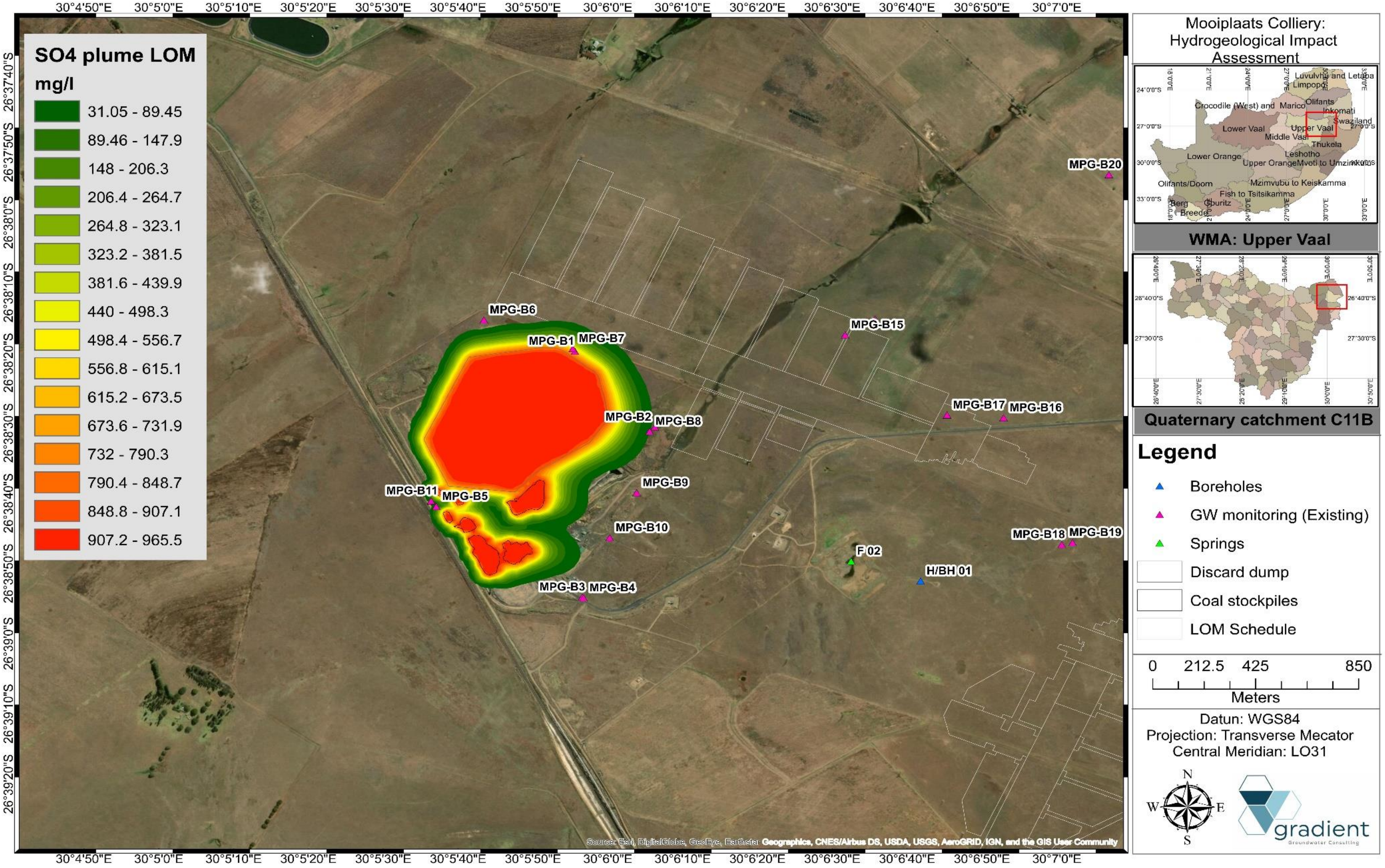


Figure 12-31 **Scenario 04c: Mitigation alternative 03: Lining of coal stockpiles with a barrier system.**

13. ENVIRONMENTAL IMPACT ASSESSMENT

Identification of potential impacts and ratings related to the proposed activities are briefly discussed below.

13.1. Methodology

An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human and/or other related activities. The impact significance rating methodology is guided by the requirements of the NEMA EIA Regulations 2014 (as amended). The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/ likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S). The impact assessment will be applied to all identified alternatives. Where possible, mitigation measures will be recommended for impacts identified.

13.2. Determination of Environmental Risk

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER). The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and reversibility (R) applicable to the specific impact. For the purpose of this methodology the consequence of the impact is represented by the following equation:

Equation 13-1 Impact Consequence.

$$\mathrm{C} = (\boldsymbol{E} + \boldsymbol{D} + \boldsymbol{M} + +\boldsymbol{R})(\boldsymbol{N4})$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 13-1 below.

Table 13-1 **Criteria for Determining Impact Consequence.**

Aspect	Description	Weight
Nature	Likely to result in a negative/ detrimental impact.	-1
	Likely to result in a positive/ beneficial impact.	1
Extend	Activity (i.e. limited to the area applicable to the specific activity)	1
	Site (i.e. within the development property boundary)	2
	Local (i.e. the area within 5 km of the site)	3
	Regional (i.e. extends between 5 and 50 km from the site)	4
	Provincial/ National (i.e. extends beyond 50 km from the site)	5
Duration	Immediate (< 1 year)	1
	Short term (1 – 5 years)	2
	Medium term (6 – 15 years)	3
	Long term (the impact will cease after the operational life span of the project)	4
	Permanent (no mitigation measure of natural process will reduce the impact after construction).	5
Magnitude	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected)	1
	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected)	2
	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way)	3
	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease), or	4
	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease).	5
Reversibility	Impact is reversible without any time and cost	1
	Impact is reversible without incurring significant time and cost	2
	Impact is reversible only by incurring significant time and cost	3
	Prohibitively high time and cost	4
	Irreversible	5

Table 13-2 **Probability scoring.**

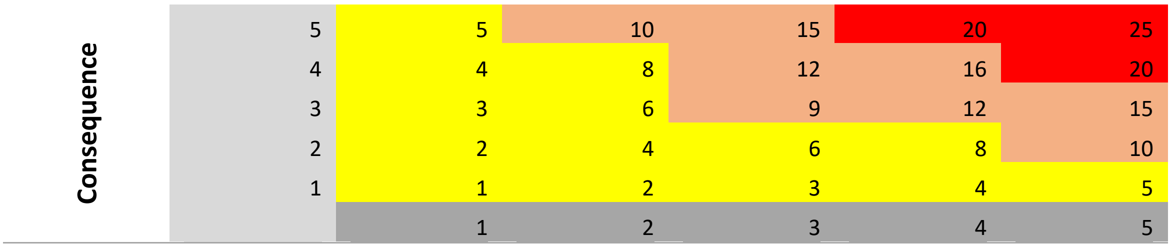
Probability	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%)	1
	Low probability (there is a possibility that the impact will occur; >25% and <50%)	2
	Medium probability (the impact may occur; >50% and <75%)	3
	High probability (it is most likely that the impact will occur- > 75% probability) or	4
	Definite (the impact will occur)	5

The result is a qualitative representation of relative ER associated with the impact. ER is therefore calculated by applying the following equation:

Equation 13-2 **Impact Consequence.**

$$ER = C \cdot P$$

Table 13-3 **Determination of Environmental Risk.**



Consequence	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in Table 13-4.

Table 13-4 **Significance classes.**

Environmental Risk Score	Low (i.e. where this impact is unlikely to be a significant environmental risk)	< 9
	Medium (i.e. where the impact could have a significant environmental risk)	≥ 9 - <17
	High (i.e. where the impact will have a significant environmental risk)	≥ 17

The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post implementation of relevant management and mitigation measures (post-mitigation). This allows for a prediction in the degree to which the impact can be managed/mitigated.

13.3. Impact prioritization

Further to the assessment criteria presented in the section above, it is necessary to assess each potentially significant impact in terms of:

i. Cumulative impacts; and

ii. The degree to which the impact may cause irreplaceable loss of resources.

To ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented.

Table 13-5 **Criteria for Determining Prioritisation.**

Cumulative Impact (C)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change	Low (1)
	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change	Medium (2)
	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/ definite that the impact will result in spatial and temporal cumulative change	High (3)
Irreplaceable loss of Resource (LR)	Where the impact is unlikely to result in irreplaceable loss of resources	Low (1)
	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources but the value (services and/or functions) of these resources is limited	Medium (2)
	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions)	High (3)

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in Table 13-5 . The impact priority is therefore determined as follows:

Equation 13-3 **Impact Consequence.**

$$\textbf{Priority} = \boldsymbol{CI + LR}$$

The result is a priority score which ranges from 3 to 9 and a consequent PF ranging from 1 to 2 (Refer to Table 13-6 below).

Table 13-6 **Determination of Prioritisation Factor.**

Priority	Ranking	Prioritisation factor
2	Low	1
3	Medium	1.125
4	Medium	1.25
5	Medium	1.375
6	High	1.5

In order to determine the final impact significance, the PF is multiplied by the ER of the post mitigation scoring. The ultimate aim of the PF is an attempt to increase the post mitigation environmental risk rating by a full ranking class, if all the priority attributes are high (i.e. if an impact comes out with a medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

Table 13-7 Final Environmental Significance Rating.

Value	Description
≤ -20	High negative (i.e. where the impact must have an influence on the decision process to develop in the area).
> -20 ≤ -10	Medium negative (i.e. where the impact could influence the decision to develop in the area).
> -10	Low negative (i.e. where this impact would not have a direct influence on the decision to develop in the area).
0	No impact
< 10	Low positive (i.e. where this impact would not have a direct influence on the decision to develop in the area).
≥ 10 < 20	Medium positive (i.e. where the impact could influence the decision to develop in the area).
≥ 20	High positive (i.e. where the impact must have an influence on the decision process to develop in the area).

The significance ratings and additional considerations applied to each impact will be used to provide a quantitative comparative assessment of the alternatives being considered. In addition, professional expertise and opinion of the specialists and the environmental consultants will be applied to provide a qualitative comparison of the alternatives under consideration. This process will identify the best alternative for the proposed project.

13.4. Impact Identification and significance ratings

Impacts and significant ratings associated different project phases are briefly discussed below and summarised in Table 13-8 and Table 13-9.

13.4.1. Construction phase: Associated activities and impacts

As Mooiplaats Colliery is an existing and operational mine, construction-phase infrastructure is already established and utilised, and as such, this phase is not relevant.

13.4.2. Operational phase: Associated activities and impacts

The main impacts associated with operational phase activities include the following:

1. Mine dewatering can potentially have a negative impact on groundwater and surface water quantities. Lowering of regional groundwater levels due to a depletion in aquifer storage will cause the formation of a cone of depression i.e. groundwater zone of influence and consequently lowering of the regional phreatic/ piezometric levels.
2. Should the groundwater zone of influence i.e. capture zone reach local drainages, a reduction in groundwater contribution to baseflow of local rivers and streams will occur.
3. Poor quality leachate may emanate from underground mined out faces which will have a negative impact on water quality.
4. Poor quality leachate may emanate from various source areas and waste generated, e.g. coal stockpiles, discard dump, pollution control dam, slurry ponds, dirty roads, etc. which will have a negative impact on water quality.
5. Mobilisation and maintenance of mine heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.

6. Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.
7. Surface and groundwater deterioration and siltation due to contaminated stormwater run-off.

13.4.3. Operational phase: Management and mitigation measures

Mitigation and management measures associated with the operational phase activities include the following:

i. Due to mine inflow and dewatering anticipated, depletion of groundwater in storage is inevitable. The board and pillar mining method does however usually not have a significant impact on water levels of the shallow, weathered aquifer. Development and implementation of an integrated groundwater monitoring program assessing regional groundwater levels will serve as early warning mechanism to implement mitigation measures. Should neighbouring water levels and yields be affected, necessary actions such as provision of alternative water supply and/or compensation should be taken to ensure continual water supply.

ii. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry will serve as early warning mechanism to implement mitigation measures such as seepage capturing trenches in the vicinity of the waste facilities in order to constrain the contamination plume migration.

iii. Mining vehicles and machinery must be serviced and maintained regularly in order to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted.

iv. Hazardous substance containment facilities to be used during operational phase should comply with the relevant hazardous substance storage legislation in order to ensure spillages are contained.

v. The use of all materials, fuels and chemicals which could potentially leach into groundwater must be controlled.

vi. Spill trays must be provided if refuelling of mining vehicles. Further to this spill kits must be readily available in case of accidental spillages.

vii. Employees must be trained in terms of emergency response towards bulk chemical and hydrocarbon spillages.

viii. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits.

ix. Any water use activity exercised in terms of Section 21 of the National Water Act (Act 36 of 1998) should be authorised.

x. Stockpiling of material shall not be done within a 1:100-year flood line.

xi. Monitoring should be conducted by suitably qualified and experienced persons according to an approved water monitoring program. Water samples should be analysed by an accredited laboratory.

xii. Storm water from the discard dump should be contained in a process water dam and included in a closed dirty water system in accordance with GN704.

xiii. Annual external audits should be conducted to ensure that waste facilities are maintained and functioning effective and according to licence conditions.

xiv. All water retention structures, including tailings disposal facilities, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events.

xv. The Licensee shall appoint a suitably qualified and responsible person to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities in order to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.

13.4.4. Post-operational phase: Associated activities and impacts

The main impacts associated with mine post-operational phase activities include the following:

1. Mine dewatering effects lessening, post-operational re-watering and flooding of underground mine void.
2. Poor quality leachate may emanate from underground mined out faces which will have a negative impact on water quality.
3. Seepage of poor water quality caused by leachate of sulphide bearing minerals from mine waste facilities including discard dumps as well as defunct waste facilities.
4. Alteration to stormwater drainage and increase in recharge of aquifer due to poor and incorrect rehabilitation.

13.4.5. Post-operational phase: Management and mitigation measures

Mitigation and management measures associated with the post-operational phase activities include the following:

i. Monitoring of surface water and groundwater in accordance with the implemented protocol should be continued throughout the post operational phase.

ii. Ensure that rehabilitation is properly conducted and in accordance with the approved mine closure and rehabilitation plan.

iii. The groundwater capture zone should return back to the pre-mining equilibrium after cessation of mine dewatering and replenishment of groundwater in storage, however the lasting effect and subsequent impact on neighbouring borehole water levels and yields should be monitored with alternative water supply sources or compensation measures available for nearby users if impacted on.

Table 13-8 Impact assessment and significance rating: Operational phase.

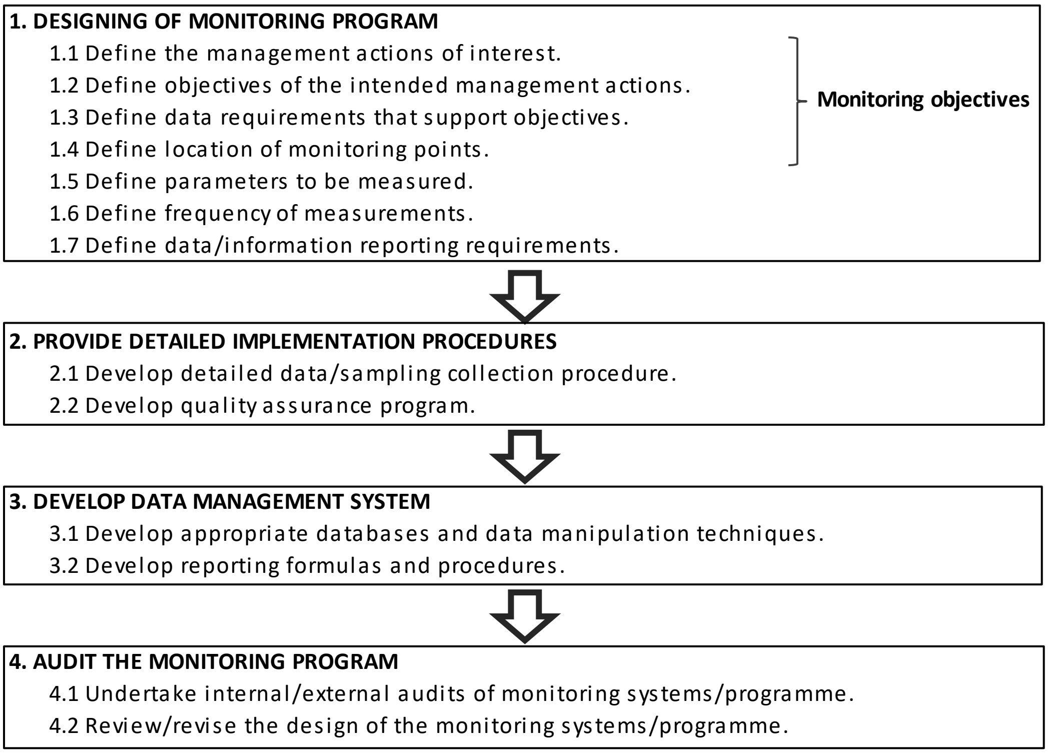
IMPACT DESCRIPTION		Pre-Mitigation							Post Mitigation								Priority Factor Criteria			
Identifier	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score
1.1.1	Mine dewatering can potentially have a negative impact on groundwater and surface water quantities. Lowering of regional groundwater levels due to a depletion in aquifer storage will cause the formation of a cone of depression i.e. groundwater zone of influence and consequently lowering of the regional phreatic/ piezometric levels.	-1	3	3	2	1	4	-9	-1	3	3	2	1	4	-9	High	2	2	1.25	-11.25
1.1.2	Should the groundwater zone of influence i.e. capture zone reach local drainages, a reduction in groundwater contribution to baseflow of local rivers and streams will occur.	-1	2	3	4	2	4	-11	-1	2	3	4	2	4	-11	Medium	1	2	1.13	-12.38
1.1.3	Poor quality leachate may emanate from underground mined out faces which will have a negative impact on water quality.	-1	2	3	3	2	3	-7.5	-1	2	3	3	2	3	-7.5	High	2	2	1.25	-9.38
1.1.4	Poor quality leachate may emanate from various source areas and waste generated, e.g. coal stockpiles, discard dump, pollution control dam, slurry ponds, dirty roads, etc. which will have a negative impact on water quality.	-1	4	4	4	3	4	-15	-1	1	3	2	2	3	-6	High	2	2	1.25	-7.50
1.1.5	Mobilisation and maintenance of mine heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.Impact on groundwater quality due to hydrocarbon contamination caused by mine heavy vehicles and machinery.	-1	2	4	4	4	3	-10.5	-1	1	3	2	2	3	-6	High	2	2	1.25	-7.50
1.1.6	Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.	-1	2	4	4	2	3	-9	1	1	2	2	2	2	3.5	High	2	2	1.25	4.375
1.1.7	Surface and groundwater deterioration and siltation due to contaminated stormwater run-off.	-1	3	4	3	2	3	-9	-1	2	3	2	2	3	-6.75	High	2	2	1.25	-8.44

Table 13-9 Impact assessment and significance rating: Post-closure phase.

IMPACT DESCRIPTION		Pre-Mitigation							Post Mitigation								Priority Factor Criteria			
Identifier	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score
1.1.8	Mine dewatering effects lessening, post-operational re-watering and flooding of underground mine void.	1	3	3	2	1	4	9	1	3	3	2	1	4	9	High	2	2	1.25	11.25
1.1.9	Poor quality leachate may emanate from underground mined out faces which will have a negative impact on water quality.	-1	3	4	3	2	2	-6	-1	3	4	3	2	2	-6	High	2	2	1.25	-7.50
1.1.10	Seepage of poor water quality caused by leachate of sulphide bearing minerals from mine waste facilities including discard dumps as well as defunct waste facilities.	-1	4	4	4	3	4	-15	-1	2	3	3	2	2	-5	High	2	2	1.25	-6.25
1.1.11	Alteration to stormwater drainage and increase in recharge of aquifer due to poor and incorrect rehabilitation.	-1	2	3	3	2	3	-7.5	-1	2	2	3	2	2	-4.5	Medium	2	2	1.25	-5.63

14. MONITORING

A monitoring program consists of taking regular measurements of the quantity and/or quality of a water resource at specified intervals and at specific locations to determine the chemical, physical and biological nature of the water resource and forms the foundation on which water management is based. Monitoring programmes are site-specific and need to be tailored to meet a specific set of needs or expectations. DWAF Best Practice Guideline – G3: Water Monitoring Systems (DWA, 2006), as illustrated in Figure 14-1 used as guideline for the development of this water monitoring program.



1. DESIGNING OF MONITORING PROGRAM
1.1 Define the management actions of interest.
1.2 Define objectives of the intended management actions.
1.3 Define data requirements that support objectives.
1.4 Define location of monitoring points.
1.5 Define parameters to be measured.
1.6 Define frequency of measurements.
1.7 Define data/information reporting requirements.

Monitoring objectives

2. PROVIDE DETAILED IMPLEMENTATION PROCEDURES
2.1 Develop detailed data/sampling collection procedure.
2.2 Develop quality assurance program.

3. DEVELOP DATA MANAGEMENT SYSTEM
3.1 Develop appropriate databases and data manipulation techniques.
3.2 Develop reporting formulas and procedures.

4. AUDIT THE MONITORING PROGRAM
4.1 Undertake internal/external audits of monitoring systems/programme.
4.2 Review/revise the design of the monitoring systems/programme.

Figure 14-1 Monitoring programme (DWA, 2006).

14.1. Monitoring Objectives

Monitoring, measuring, evaluating and reporting are key activities of the monitoring programme. These actions are designed to evaluate possible changes in the physical and chemical nature of the aquifer and geo-sphere in order to detect potential impacts on the groundwater. This will ensure that management is timely warned of problems and unexpected impacts that might occur and can be positioned to implement mitigation measures at an early stage. Key objectives of monitoring are:

i. To provide reliable groundwater data that can be used for management purposes.

ii. The early detection of changes in groundwater quality and quantity.

iii. Provide an on-going performance record on the efficiency of the Water Management Plan.

iv. Obtain information that can be used to redirect and refocus the Water Management Plan.

v. Determine compliance with environmental laws, standards and the water use licence and other environmental authorizations.

14.2. Monitoring network

Table 14-1 summarises the proposed monitoring network and program along with relevant information and are depicted in Figure 14-2.

Table 14-1 Monitoring network and programme.

Site ID	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
Existing monitoring boreholes						
GKL-1	-26.696030	30.072080	IWUL Borehole	Quarterly	Monthly	As in Chapter 14.3.1
GKL-4d	-26.701670	30.082530	IWUL Borehole	Quarterly	Monthly	
GKL-3m	-26.701780	30.082690	Borehole	Quarterly	Monthly	
GKL-2s	-26.701780	30.082690	IWUL Borehole	Quarterly	Monthly	
GAD-2s	-26.712690	30.114140	IWUL Borehole	Quarterly	Monthly	
GAD-1	-26.727330	30.101440	IWUL Borehole	Quarterly	Monthly	
GKL-9D	-26.672310	30.104500	IWUL Borehole	Quarterly	Monthly	
GKL-8M	-26.672330	30.104640	IWUL Borehole	Quarterly	Monthly	
GKL-5S	-26.665420	30.096470	IWUL Borehole	Quarterly	Monthly	
GKL-6M	-26.665420	30.096580	IWUL Borehole	Quarterly	Monthly	
GAD-3s	-26.677720	30.123740	Borehole	Quarterly	Monthly	
GAD-4m	-26.677720	30.123740	Borehole	Quarterly	Monthly	
GAD-5d	-26.677720	30.123740	Borehole	Quarterly	Monthly	
MPG-B1	-26.638430	30.098780	Down gradient (north) of the co-disposal facility.	Quarterly	Monthly	
MPG-B2	-26.641430	30.101750	Down gradient (east) of the lined Settling Dams and co-disposal.	Quarterly	Monthly	
MPG-B3	-26.648160	30.099050	Near the security gate.	Quarterly	Monthly	
MPG-B4	-26.648190	30.099100	Near the security gate.	Quarterly	Monthly	
MPG-B5	-26.644570	30.093630	Up-gradient (south-west) of the plant area next to the railway line.	Quarterly	Monthly	
MPG-B6	-26.637190	30.095400	Adjacent to the return water dam.	Quarterly	Monthly	
MPG-B7	-26.638320	30.098700	Down gradient (north) of the co-disposal facility.	Quarterly	Monthly	
MPG-B8	-26.641600	30.101550	Down gradient (east) of the lined Settling Dams.	Quarterly	Monthly	
MPG-B9	-26.644030	30.101070	Down gradient (east) of the plant area.	Quarterly	Monthly	
MPG-B10	-26.645810	30.100070	Down gradient (east) of the plant area.	Quarterly	Monthly	
MPG-B11	-26.644350	30.093440	Up-gradient (south-west) of the plant area next to the railway line.	Quarterly	Monthly	
MPG-B12	-26.656330	30.124430	At MPN Vunene extension	Quarterly	Monthly	
MPG-B13	-26.666890	30.113290	South of the mine next to the railway line.	Quarterly	Monthly	
MPG-B14	-26.637160	30.109920	Between Usutu/MPN	Quarterly	Monthly	
MPG-B15	-26.637780	30.108810	Between Usutu/MPN	Quarterly	Monthly	
MPG-B16	-26.641060	30.114690	Between Usutu/MPN	Quarterly	Monthly	
MPG-B17	-26.640950	30.112590	Between Usutu/MPN	Quarterly	Monthly	
MPG-B18	-26.646080	30.116850	Between Usutu/MPN	Quarterly	Monthly	
MPG-B19	-26.646000	30.117250	Between Usutu/MPN	Quarterly	Monthly	
MPG-B20	-26.631440	30.118600	Usutu UG.	Quarterly	Monthly	

Newly proposed monitoring boreholes						
HBH 01	-26.645030	30.142640	Neighbouring farm: J, Roberts	Quarterly	Monthly	As in Chapter 14.3.1
HBH 02	-26.694400	30.087510	Neighbouring farm: J, Roberts	Quarterly	Monthly	
HBH 03	-26.675250	30.092330	Neighbouring farm: J, Roberts	Quarterly	Monthly	
HBH 04	-26.670180	30.080040	Neighbouring farm: J, Roberts	Quarterly	Monthly	
HBH 06	-26.678170	30.057820	Neighbouring farm: J, Roberts	Quarterly	Monthly	
HBH 07	-26.684780	30.112710	Neighbouring farm: L. Reyneke	Quarterly	Monthly	
HBH 08	-26.680440	30.721830	Neighbouring farm: R. Saaiman	Quarterly	Monthly	
HBH 09	-26.692370	30.129350	Neighbouring farm: R. Saaiman	Quarterly	Monthly	
HBH 10	-27.010470	30.267090	Neighbouring farm: Ignis van Rooyen	Quarterly	Monthly	

14.3. Determinants for analysis

The South African National Standards (SANS 241: 2015) should be applied as benchmark for monitoring purposes. Supplementary guidelines i.e. Water Use Licence (WUL) conditions as well as WMA Resource Quality Objectives (RQO) should also be considered as part of the monitoring protocol. All monitoring localities should be subjected to an initial comprehensive water quality analysis to evaluate hydrochemical composition and identify potentially elevated parameters going forward[22]. Chemical variables to form part of the sampling run are listed below.

14.3.1. Groundwater

Groundwater monitoring boreholes, including shallow dug wells, should be analysed for the following chemical constituents:

i. ***Physical and aesthetic determinants:*** pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Hardness.

ii. ***Macro determinants:*** Total Alkalinity (MAlk), Sulphate (SO_4), Nitrate (NO_3), Chloride (Cl), Fluoride (F), Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na).

iii. ***Micro determinants:*** Aluminium (Al), Iron (Fe), Manganese (Mn), Arsenic (As), Cadmium (Cd), Free Cyanide (CN), Copper (Cu), Lead (Pb), Mercury (Hg), Selenium (Se) and Zinc (Zn).

14.4. Monitoring frequency

Groundwater monitoring i.e. quality analysis should be conducted on a quarterly basis whereas water level monitoring is conducted on a monthly basis. Water quality reports summarising monitoring results should be submitted to the Regional Head: DWS within timeframes as stipulated in the WUL conditions.

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[22] It is recommended that a comprehensive water quality analysis be repeated annually. Also note that should additional parameters be requested in existing permits/licence conditions, these should be adhered to.

14.5. Underground dewatering volumes

A calibrated mechanical or electronic flow meter must be installed at all underground sumps/ abstraction points in order to monitor and record abstraction volumes. The latter should be included into monitoring reports submitted to the Regional Head: DWS and used as part of the groundwater flow model update.

14.6. Sampling procedure

14.6.1. Groundwater

The sampling procedure for groundwater should be done according to the protocol by Weaver, 1992. The actions can be summarised as follows:

1. Calibrate the field instruments before every sampling run. Read the manufacturers manual and instructions carefully before calibrating and using the instrument.
2. Bail the borehole.
3. Sample for chemical constituents – remove the cap of the plastic 1 litre sample bottle, but do not contaminate inner surface of cap and neck of sample bottle with hands. Fill the sample bottle without rising.
4. Leave sample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
5. Replace the cap immediately.
6. Complete the sample label with a water-resistant marker and tie the label to the neck of the sample bottle with a string or rubber band. The following information should be written on the label.
    - A unique sample number and description
    - The date and time of sampling
    - The name of the sampler
7. Place sample in a cooled container (e.g. cool box) directly after collection. Try and keep the container dust-free and out of any direct sunlight. Do not freeze samples.
8. Complete the data sheet for the borehole.

See to it that the sample gets to the appropriate laboratory as soon as possible, samples for chemical analysis should reach the laboratory preferably within seven days.

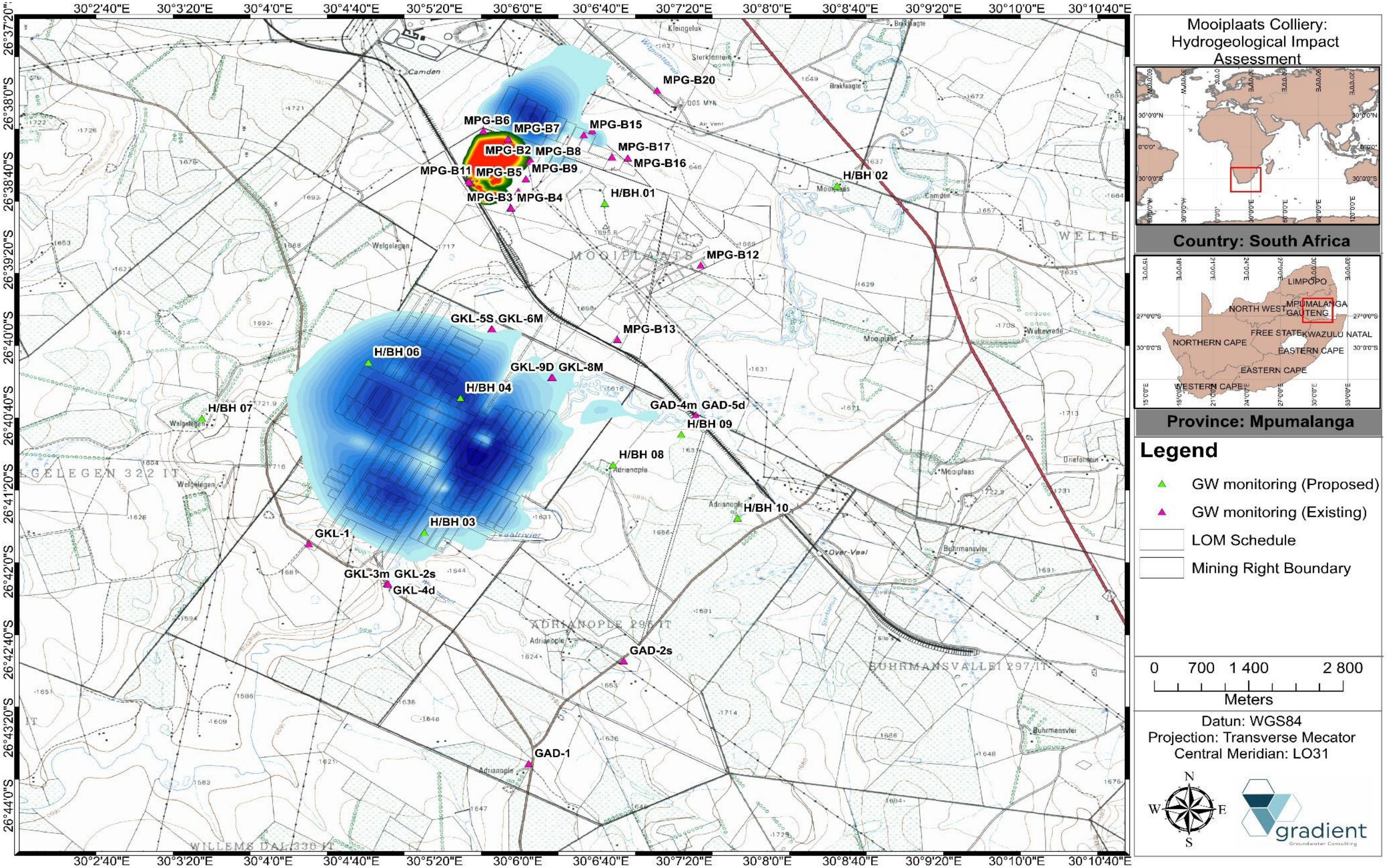

Figure 14-2 Updated groundwater monitoring network.

15. CONCLUSIONS

The following conclusions were derived from the outcomes of this investigation:

1. The site is predominantly underlain by an intergranular and fractured aquifer system comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks. It should be noted that the Ecca Group consists mainly of sandstones, mudstones and shales that are very dense with permeability usually very sluggish due to poorly sorted matrices.
2. On a local scale, three potential aquifer units can be inferred in the saturated zone:
   i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Due to higher effective porosity (*n*) this aquifer is most susceptible to impacts from contaminant sources.
   ii. An intermediate/deeper fractured where the underground mine void is situated.
   iii. Shallow quaternary and recent types of sediments (perched, unconfined) are characteristically a primary porosity aquifer.
3. Various neighbouring boreholes in close proximity (< 500 m) to the mining operations are utilized for domestic purposes and livestock watering.
4. The unsaturated/ vadose zone within the study area is limited (< 5.0 mbgl) with shallow water levels of the weathered aquifer posing a risk to groundwater contamination.
5. Analysed data indicate that the regional groundwater elevation correlates well to the topographical elevation and it can be inferred that groundwater flow direction of the shallow aquifer mimics topography. The regional groundwater flow direction is towards the lower laying drainage system of the Vaal River transecting the project area and will flow in a general southern to south-eastern direction.
6. The relatively low standard deviation compared to the mean depth to groundwater i.e. Coefficient of Variation (CV) < 100%, suggest a relative steady state groundwater environment as confirmed by the monitoring data water levels analysed.
7. The groundwater gradient increases towards the east while a gentler gradient exists to the south. The existing mine waste facilities is located towards the north with moderate gradients to influence seepage rates.
8. The regional ambient groundwater quality of the shallow aquifer is good and suggest an unimpacted groundwater system with water indicative of recently recharged groundwater. It should however also be noted that isolated monitoring localities down0gradient of the existing discard dump and stockpile areas indicate slight impacts from mining activities.
9. It is evident that both discard as well as coal product material analysed have a likely acid generation capacity, and due to the relatively high sulphide concentrations observed, there is enough oxidisable

sulphides to sustain long term acid generation.

10. The groundwater flow model simulations suggest that the average groundwater ingress and underground dewatering volume for the LOM will be relatively low at approximately 5.10E^{+02} m^3/d. It is expected that the groundwater drawdown will range from 2.0 m to ~ 7.0 m below the static water level (mbsl) i.e. pre-mining water levels covering an estimated area of approximately 13.0 km^2, propagating towards a western as well as north-eastern direction, reaching a maximum distance of ~750 m to the west and 1050 m to the northeast. It is noted that there is not a significant influence on water levels of neighbouring boreholes for the duration of the proposed mining operation.
11. It should be noted that no substantial decreases in groundwater levels have been observed since commencement of mining activities in 2018 and it can be assumed that, to date, there has been no significant of observable impact on groundwater levels. It is expected that dewatering of the underground workings will have a slight impact on the weathered aquifer system, but the extent of the dolerite sills observed on site will play a remedial role in the remainder of the site by creating a confining layer and compartment.
12. Baseflow discharges to the Vaal Rivers and Witpuntspruit accounts to approximately 1 326.0 m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1 117.0 m^3/d. This accounts for an average loss of ~16.0%.
13. It is estimated that under average rainfall conditions (MAP) the underground void will be flooded in approximately 34 years after ceasing of mining activities. The proposed depth and geometry of the underground operations allows for the entire footprint to be flooded without any decant expected.
14. The simulated sulphate pollution plume extend emanating from the discard dump as well as coal stockpile dumps covers an area of approximately 0.72 km^2, reaching a maximum distance of 180.0 m in a general eastern to north-eastern direction and suggest that no neighbouring boreholes as identified during the hydrocensus user survey are impacted on during the operational life of mine. Monitoring locality MPG-BH01 exceeds the SANS 241:2015 threshold for sulphate after a period of approximately eight years, reaching a maximum concentration of 560.0 mg/l.
15. The expected pollution plume migration potentially emanating from the underground mined out faces does not migrate more than ~100.0 m – 150.0 m from the mining footprint for the operational life of mine.
16. The preferred mitigation scenario i.e. implementation of a cut-off trench down-gradient of waste facilities reduces the plume extend to 0.57 km^2, with an effective footprint reduction of >20.0 %.
17. It should be noted that post-closure the pollution plume migration stretches beyond the mine lease area to the north. The plume still does not reach any neighbouring boreholes, however two drainages and tributaries of the Witpunt-spruit towards the northern and eastern border can potentially be affected post-closure.

18. The model results were incorporated into a risk rating matrix to determine the significance of potential groundwater related impacts as discussed below:
19. During the operational phase the environmental significance rating of groundwater yield (dewatering) impacts on down-gradient receptors are rated as medium negative whereas the groundwater quality related impacts are rated as low negative. Groundwater quality impacts from the discard dump and coal stockpile areas are rated as medium negative without implementation of remedial measures and low negative with implementation of mitigation measures.
20. Post closure phase impacts resulting from seepage and leachate from mine waste facilities on down-gradient receptors are rated as medium negative without the implementation of remedial measures and low negative with implementation of mitigation measures.

16. RECCOMMENDATIONS

The following recommendations are proposed following this investigation:

1. It is recommended that mitigation and management measures as set out in this report should be implemented as far as practically possible.
2. Furthermore, it is recommended that the monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be initiated at least 12 months prior to any operational activities commence in order to establish a site background benchmark to be applied to serve as an early warning and detection system.
3. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.
4. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.
5. It is imperative that the water level recovery of the underground void should be monitored on a continual basis. Stage re-watering curves should be evaluated in order to aid in the management of the mine post-closure phase.
6. Alternative remedial options, as suggested in this report, should form part of the mine closure and rehabilitation strategy.

17. REFERENCES

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18. APPENDIX A: RAINFALL DATA (RAINFALL ZONE C1A)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	169.2	87.1	106.5	59.3	86.3	157.5	20.1	13.3	0.9	0.0	0.2	19.0
1921	113.9	191.3	118.2	90.5	67.6	63.9	11.6	36.1	20.3	0.0	33.3	30.2
1922	194.2	132.3	134.7	190.1	65.2	6.1	21.0	2.0	7.5	4.9	4.7	3.9
1923	33.1	73.7	109.3	121.3	85.7	138.9	39.8	19.5	0.5	0.0	2.0	45.9
1924	66.7	159.5	113.9	77.6	69.8	147.1	82.7	34.6	40.8	3.9	0.6	69.7
1925	38.7	90.2	66.8	64.5	92.6	77.7	23.1	41.1	19.3	0.3	0.2	85.5
1926	27.1	74.5	96.9	118.9	130.9	89.9	31.9	5.9	0.0	44.6	1.7	17.1
1927	142.1	54.8	98.8	82.7	60.0	102.2	26.7	5.9	0.1	1.1	7.2	38.4
1928	23.0	100.7	104.7	101.4	69.6	145.2	23.5	2.4	27.5	1.1	3.2	79.1
1929	106.1	182.8	118.4	132.8	84.2	26.8	25.3	2.5	1.3	12.1	19.0	17.5
1930	10.3	63.7	102.3	113.5	81.9	63.7	66.6	0.6	0.7	51.9	0.4	4.4
1931	31.3	88.2	79.8	75.4	110.4	87.8	11.4	38.8	4.9	0.1	0.3	30.9
1932	45.6	120.5	89.4	54.2	69.3	55.4	42.4	3.2	2.7	22.6	1.6	17.7
1933	33.8	160.9	137.1	224.7	49.6	56.0	42.6	24.0	17.3	39.0	36.0	4.1
1934	46.2	155.7	166.2	91.7	90.5	104.9	5.4	4.4	4.9	0.7	2.7	9.4
1935	42.5	40.7	91.1	179.1	78.3	91.5	21.2	107.8	0.2	1.1	0.3	16.0
1936	71.8	199.0	66.3	232.1	103.7	43.4	12.8	1.5	0.1	0.1	1.9	18.7
1937	84.2	53.5	203.3	76.6	70.5	39.6	102.3	1.8	21.2	7.3	24.4	11.8
1938	109.7	76.8	135.8	123.6	241.1	84.7	17.1	30.8	0.0	45.4	12.0	33.8
1939	65.6	188.0	109.0	96.6	90.5	50.3	45.9	57.0	63.7	0.1	1.6	58.4
1940	30.2	143.1	135.6	88.7	121.0	97.7	78.7	0.6	0.6	3.1	0.5	28.4
1941	56.0	63.7	125.9	137.1	48.9	123.6	10.4	21.5	24.5	0.0	13.1	33.6
1942	91.9	117.6	93.9	100.7	70.7	84.7	132.3	31.7	1.5	73.7	37.8	24.5
1943	81.1	104.6	118.9	146.6	183.0	37.3	4.2	2.3	35.1	0.0	0.1	46.2
1944	70.8	128.0	46.5	92.1	59.0	110.2	17.9	11.4	2.0	0.0	0.1	1.9
1945	53.2	86.3	39.9	203.7	93.1	122.4	6.8	4.4	0.3	0.1	0.1	2.1
1946	51.5	137.1	114.1	131.8	70.5	61.2	39.4	0.2	11.8	5.6	0.7	8.5
1947	72.4	125.8	160.4	123.2	49.8	91.4	29.5	9.2	0.2	0.1	0.1	34.2
1948	61.1	154.0	62.8	192.3	63.5	62.0	70.3	12.3	3.8	0.1	0.4	33.2
1949	84.1	128.7	153.8	108.7	64.3	76.5	41.8	33.6	1.8	1.5	18.4	18.0
1950	43.0	82.6	97.3	61.1	77.9	62.1	67.3	40.3	8.0	0.8	57.5	10.7
1951	139.0	35.8	146.4	71.7	63.9	67.4	54.4	12.4	2.5	44.8	0.3	2.4
1952	26.2	208.5	126.1	45.5	190.0	95.0	23.7	19.2	0.7	0.0	10.6	14.2
1953	47.4	177.3	66.0	122.6	106.5	41.9	54.1	16.6	0.0	0.0	1.3	42.7
1954	61.1	133.7	53.9	174.1	168.6	121.0	48.0	9.2	2.0	0.1	4.0	0.0
1955	101.6	104.8	182.4	29.0	106.2	122.2	3.2	63.5	3.8	7.5	0.0	41.7
1956	112.3	94.8	133.7	77.4	75.9	85.2	56.2	15.7	22.8	52.7	25.9	112.3
1957	88.1	67.5	62.2	167.3	38.1	61.2	112.7	7.9	0.4	0.1	0.0	82.3
1958	47.5	128.1	144.8	78.9	67.5	61.5	26.9	25.7	0.5	8.2	0.1	32.7
1959	59.8	130.5	109.9	52.7	94.8	76.5	91.6	0.9	1.6	3.5	18.0	21.0
1960	88.7	136.7	168.6	68.1	102.6	127.6	75.6	22.3	6.8	0.5	0.1	56.7
1961	73.0	90.1	127.4	110.7	67.3	54.1	46.5	8.0	1.8	0.0	11.8	36.4
1962	52.1	159.8	92.6	106.0	26.7	56.8	46.6	15.2	53.7	54.8	0.0	9.2
1963	89.6	132.2	37.2	194.9	58.2	36.1	47.9	0.8	5.4	0.0	18.8	9.6
1964	248.9	112.7	119.9	127.5	62.3	27.3	33.3	5.4	4.4	8.5	12.7	15.4
1965	36.5	84.5	125.8	103.9	58.9	7.5	12.0	9.1	12.0	0.4	8.2	31.9
1966	110.5	78.0	133.7	157.1	139.3	61.2	49.1	13.3	1.8	17.1	7.1	32.6
1967	98.6	132.8	165.0	76.9	41.1	113.2	23.9	7.2	1.5	1.3	16.4	4.9
1968	33.0	138.7	116.3	106.7	90.5	143.0	63.8	41.6	0.1	3.7	3.4	74.7
1969	123.5	96.7	138.5	123.3	88.5	27.8	27.5	8.9	7.7	10.9	12.9	24.2
1970	107.2	76.9	79.2	150.2	36.9	29.8	97.4	24.5	0.3	2.3	2.0	39.7
1971	105.8	153.6	122.1	150.5	68.6	47.4	44.1	24.7	1.1	0.0	16.0	11.9
1972	32.0	126.5	76.9	130.3	114.4	78.8	58.0	4.2	0.3	3.6	40.3	52.5
1973	51.5	141.4	115.1	140.0	61.8	49.7	99.8	17.3	14.7	11.2	2.7	9.7
1974	59.9	165.1	175.0	143.3	140.4	46.9	53.4	5.4	3.2	0.4	1.6	36.8

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	59.2	173.4	174.6	109.4	72.2	75.7	51.3	55.9	0.0	0.0	0.0	7.1
1976	78.7	106.9	151.8	154.0	56.3	96.9	19.5	0.3	0.1	0.0	2.2	27.3
1977	55.0	111.6	110.9	177.3	107.7	54.1	69.1	9.9	0.4	1.0	14.8	44.1
1978	141.7	77.9	77.5	92.4	49.5	65.0	31.6	1.1	6.5	13.1	47.4	40.2
1979	105.1	131.1	66.3	171.1	101.4	19.2	34.8	6.4	0.0	0.0	8.2	27.9
1980	55.6	135.8	91.4	128.2	114.1	94.7	22.7	3.7	21.5	1.6	11.4	28.9
1981	66.1	78.0	110.8	135.4	20.2	38.0	7.1	1.7	0.7	7.8	0.0	10.9
1982	97.8	41.8	85.8	77.3	32.5	43.5	43.9	35.9	11.0	13.0	34.5	2.0
1983	83.9	246.9	130.8	157.1	35.7	101.9	14.0	4.8	18.1	28.2	28.4	20.0
1984	139.1	67.2	89.4	50.3	119.5	60.7	2.7	14.7	1.2	0.1	1.3	58.3
1985	94.7	73.4	111.4	105.7	93.3	45.4	36.7	0.4	11.2	0.0	0.7	15.4
1986	101.9	85.4	148.6	130.4	75.6	88.1	17.1	0.2	4.7	2.1	53.9	136.7
1987	123.9	196.0	68.5	101.3	41.5	63.4	24.2	0.9	19.3	12.8	4.0	39.8
1988	132.3	62.1	127.9	77.9	96.5	29.8	9.0	22.0	58.7	0.0	10.6	13.1
1989	60.8	168.6	113.9	65.8	103.1	79.9	78.0	4.6	0.0	1.3	3.9	6.6
1990	63.7	96.7	106.9	220.6	82.4	166.0	7.5	11.1	26.6	1.1	0.4	8.3
1991	44.7	71.6	125.6	69.8	70.8	36.2	18.7	0.0	0.1	0.3	12.3	3.6
1992	63.9	53.0	189.2	69.7	116.7	74.6	35.7	13.0	0.0	0.0	3.2	31.7
1993	149.2	126.2	124.5	143.9	75.2	86.4	16.9	2.2	0.0	0.0	1.9	13.3
1994	66.6	97.7	92.7	119.9	33.1	102.0	73.3	0.8	1.1	1.3	14.5	4.5
1995	115.9	141.4	236.5	168.6	252.3	125.7	44.8	16.4	0.0	19.3	3.7	3.7
1996	168.0	84.5	145.6	78.5	51.5	101.9	36.4	47.8	10.8	7.9	12.1	66.7
1997	108.4	139.1	115.1	126.2	83.6	25.7	41.2	0.1	0.1	0.0	4.8	61.5
1998	77.3	152.1	168.8	115.3	14.3	51.5	12.3	26.4	4.0	2.0	4.5	22.6
1999	84.2	60.3	251.9	155.7	117.5	75.0	89.1	32.6	7.9	1.1	1.2	22.1
2000	114.6	133.4	128.7	32.9	79.5	48.4	49.7	22.6	0.8	3.0	2.3	19.5
2001	108.9	75.1	91.6	107.1	88.3	58.5	11.1	9.9	7.8	14.2	34.0	21.2
2002	58.7	37.5	184.3	122.0	97.0	28.0	28.4	4.6	29.5	0.0	4.7	2.5
2003	46.9	157.9	59.6	116.0	93.3	104.5	24.9	4.7	6.8	42.4	9.2	10.4
2004	56.3	101.6	102.0	163.9	78.6	101.7	38.9	3.2	2.0	0.0	17.2	14.6
2005	60.8	144.2	58.9	209.4	139.4	144.7	49.2	2.0	0.0	3.8	44.2	3.7
2006	31.7	110.8	183.5	91.4	28.5	38.4	15.6	0.0	15.5	0.0	0.0	4.0
2007	187.1	136.7	63.1	137.9	58.2	118.4	23.7	20.2	3.0	0.0	0.0	4.4
2008	39.3	101.2	107.5	142.2	79.0	60.7	2.2	16.9	49.0	0.4	0.0	0.0
2009	138.9	126.5	153.2	190.8	65.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	**81.4**	**115.3**	**117.4**	**119.1**	**84.4**	**74.5**	**38.9**	**15.3**	**8.8**	**8.1**	**9.9**	**27.2**

19. APPENDIX B: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

21. APPENDIX C: GEOCHEMICAL ANALYSIS LABORATORY CERTIFICATES

22. APPENDIX D: SPECIALIST CURICULUM VITAE

aquatico
Laboratories (Pty). Ltd.

ilac-MRA sanas Testing Laboratory T0685

Test Report

Client: Gradient Consulting Pty Ltd
Address: 13 Barnstable Road, Lynnwood Manor, 0081
Report no: 69160
Project: Gradient Consulting Pty Ltd

Date of certificate: 18 June 2019
Date accepted: 11 June 2019
Date completed: 18 June 2019
Date received: 11 June 2019

Lab no:				17910	17911	17912	17913	17914	17915	17916
Date sampled:				10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19
Aquatico sampled:				No	No	No	No	No	No	No
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				HBH 01	HBH 02	HBH 03	HBH 04	F 05	HBH 06	F 06
	Analyses	**Unit**	**Method**							
A	pH @ 25°C	pH	ALM 20	8.58	8.41	7.61	7.41	6.57	6.57	7.56
A	Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	30.5	33.1	34.5	16.5	10.1	11.5	21.7
A	Total dissolved solids (TDS)	mg/l	ALM 26	179	193	194	90	52	58	124
A	Total alkalinity	mg CaCO3/l	ALM 01	171	110	147	77.2	35.9	47.8	111
A	Chloride (Cl)	mg/l	ALM 02	1.86	10.0	17.1	3.01	4.65	2.79	7.20
A	Sulphate (SO_4)	mg/l	ALM 03	3.23	21.7	13.9	3.18	2.48	2.40	7.50
A	Nitrate (NO_3) as N	mg/l	ALM 06	0.223	6.61	0.213	0.279	0.681	0.587	0.300
A	Ammonium (NH_4) as N	mg/l	ALM 05	0.065	0.031	0.059	0.074	0.049	0.027	0.024
A	Orthophosphate (PO_4) as P	mg/l	ALM 04	<0.005	<0.005	<0.005	0.095	<0.005	0.017	<0.005
A	Fluoride (F)	mg/l	ALM 08	<0.263	<0.263	0.396	0.276	<0.263	<0.263	2.36
A	Calcium (Ca)	mg/l	ALM 30	33.9	30.1	35.5	13.1	3.97	7.45	17.5
A	Magnesium (Mg)	mg/l	ALM 30	10.0	17.4	11.3	1.32	0.801	3.53	8.64
A	Sodium (Na)	mg/l	ALM 30	21.9	14.8	23.9	19.2	13.2	7.96	10.1
A	Potassium (K)	mg/l	ALM 30	2.54	2.30	1.08	1.39	1.60	2.24	1.82
A	Aluminium (Al)	mg/l	ALM 31	<0.002	<0.002	0.002	0.012	<0.002	0.022	0.004
A	Iron (Fe)	mg/l	ALM 31	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
A	Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001	0.409	0.001	<0.001	<0.001	0.179
A	Total hardness	mg CaCO3/l	ALM 26	126	147	135	38	13	33	79

M. Swanepoel
Technical Signatory

Test Report

Client: Gradient Consulting Pty Ltd
Address: 13 Barnstable Road, Lynnwood Manor, 0081
Report no: 69160
Project: Gradient Consulting Pty Ltd

Date of certificate: 18 June 2019
Date accepted: 11 June 2019
Date completed: 18 June 2019
Date received: 11 June 2019

Lab no:				17917	17918	17919	17920	17928
Date sampled:				10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19	10-Jun-19
Aquatico sampled:				No	No	No	No	No
Sample type:				Water	Water	Water	Water	Water
Locality description:				F 08	HBH 08	F 13	HBH 10	HBH 09
	Analyses	**Unit**	**Method**					
A	pH @ 25°C	pH	ALM 20	7.09	7.36	7.23	7.85	8.75
A	Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	17.2	30.3	29.2	20.5	190
A	Total dissolved solids (TDS)	mg/l	ALM 26	90	165	164	108	1156
A	Total alkalinity	mg CaCO3/l	ALM 01	71.2	108	57.7	72.4	1042
A	Chloride (Cl)	mg/l	ALM 02	3.63	20.2	11.5	5.08	21.0
A	Sulphate (SO_4)	mg/l	ALM 03	9.02	5.42	18.2	5.92	2.00
A	Nitrate (NO_3) as N	mg/l	ALM 06	0.254	3.43	11.1	3.34	0.420
A	Ammonium (NH_4) as N	mg/l	ALM 05	0.225	0.023	0.058	0.026	0.760
A	Orthophosphate (PO_4) as P	mg/l	ALM 04	<0.005	<0.005	<0.005	<0.005	0.052
A	Fluoride (F)	mg/l	ALM 08	<0.263	<0.263	<0.263	<0.263	11.6
A	Calcium (Ca)	mg/l	ALM 30	15.1	28.0	23.5	19.2	1.76
A	Magnesium (Mg)	mg/l	ALM 30	8.01	10.8	15.1	7.98	0.172
A	Sodium (Na)	mg/l	ALM 30	8.21	18.0	9.24	9.37	479
A	Potassium (K)	mg/l	ALM 30	0.482	1.56	1.26	1.77	2.04
A	Aluminium (Al)	mg/l	ALM 31	0.013	<0.002	0.002	<0.002	0.011
A	Iron (Fe)	mg/l	ALM 31	<0.004	<0.004	<0.004	<0.004	1.43
A	Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001	<0.001	<0.001	0.007
A	Total hardness	mg CaCO3/l	ALM 26	71	114	121	81	5

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

Authenticated signature on first page

UIS SEDIBA LABORATORY

Client Information

Company: Gradient Consulting
Attention: Ferdinand Mostert
Tel: 073 344 3021
Fax: N/A
Address: 13 Barnstable Street
Lynnwood Manor
2780

Analysis Report

Lab No: 8585

Test Information: *Waste Assesment for Disposal, GNR 635 (Gazette No. 36784)*
Australian Standard Leaching
AS4439 - 1997 , ICP-OES/MS and IC

Date Received: 10-06-19
Date Completed: 25-07-19
Date Issued: 25-07-19

Sample Information
Matrix: Solid- DW
Sample ID: MP DD
Ref No: Mooiplaats

Parameters	Results Solids	DW x4	DW x20	TCT	LCT
pH - Leach Fluid	N/A	N/A	N/A		
PH - Sample	8.17	7.43	7.49		
Metal Ions	mg/kg *	mg/liter *	mg/liter *		
As - Arsenic *	3.52	< 0.001	0.001	< TCT0	< LCT0
B - Boron *	< 32	0.27	0.257	< TCT0	< LCT0
Ba - Barium *	120.5	0.084	0.079	< TCT1	< LCT0
Cd - Cadmium *	< 3.2	< 0.003	< 0.003	< TCT0	= LCT0
Co - Cobalt *	5.73	< 0.025	< 0.025	< TCT0	< LCT0
Cr Total - Chromium Total *	23.59	< 0.025	< 0.025	< TCT0	< LCT0
Cr (VI) - Chromium (VI) *	< 2	< 0.05	< 0.05	< TCT0	= LCT0
Cu - Copper *	6.36	0.053	0.068	< TCT0	< LCT0
Hg - Mercury *	27.23	< 0.001	< 0.001	< TCT1	< LCT0
Mn - Manganese *	43.36	< 0.025	< 0.025	< TCT0	< LCT0
Mo - Molybdenum *	< 64	< 0.025	< 0.025	< TCT1	< LCT0
Ni - Nickel *	11.93	< 0.025	< 0.025	< TCT0	< LCT0
Pb - Lead *	16.6	< 0.01	< 0.01	< TCT0	= LCT0
Sb - Antimony *	< 3.2	< 0.001	0.001	< TCT0	< LCT0
Se - Selenium *	< 6.4	0.001	0.002	< TCT0	< LCT0
V - Vanadium *	33.16	0.035	< 0.025	< TCT0	< LCT0
Zn - Zinc *	14.53	0.038	< 0.025	< TCT0	< LCT0
Anions	mg/kg *	mg/liter	mg/liter		
Fluoride - F	5.56	0.42	0.34	< TCT0	< LCT0
Chloride - Cl	N/A	2.87	1.6	N/A	< LCT0
Nitrate as NO3	N/A	< 2.22	< 2.22	N/A	N/A
NO3 as N	N/A	< 0.5	< 0.5	N/A	< LCT0
Sulphate - SO4	N/A	965.3	682.7	N/A	< LCT1
CN - Total Cyanide *	< 0.1	< 0.07	< 0.07	< TCT0	= LCT0
Total Dissolved Solids	mg/kg	mg/liter	mg/liter		
TDS	N/A	1632	1069	N/A	< LCT1

Type Assessment, based only on the inorganic results and not the detection limits

Highest Total Concentration Value	≤ TCT 1
Highest Leachable Concentration Value	≤ LCT 1
Final Waste Type Classification	Type 3

Authorized Signatory

C. Swanepoel

sanas Testing Laboratory
T0584

Disclaimer:

The above-mentioned sample/s were analysed as received by the laboratory on the date stated above. UIS Organic laboratory takes no responsibility for sample/s prior to submission: this includes sampling, sample container, storage and shipping to our testing facility. The sample is analysed per customer request for analysis.
This report may not be reproduced, except in full, without the prior written approval of the laboratory.
Analysis mark with (*), have been outsourced.
UTD – Unable to Determine
NR – Not Requested
RTF – Results to Follow
BDL – Below Detection Limit (Please note that if the results for an analyte is below our detection limit, it does not indicate that the sample is clean or that the analyte result is equal to zero.)
Storage Conditions in the Laboratory: Fridge @ <6 ºC

UIS SEDIBA LABORATORY

Client Information

Company:	Gradient Consulting
Attention:	Ferdinand Mostert
Tel:	073 344 3021
Fax:	N/A
Address:	13 Barnstable Street Lynnwood Manor 2780

Analysis Report

Lab No: 8585

Test Information: *Waste Assesment for Disposal, GNR 635 (Gazette No. 36784)*
Australian Standard Leaching
AS4439 - 1997 , ICP-OES/MS and IC

Date Received: 10-06-19
Date Completed: 25-07-19
Date Issued: 25-07-19

Sample Information

Matrix:	**Solid- DW**
Sample ID:	**MP SS**
Ref No:	**Mooiplaats**

Parameters	**Results** **Solids**	 **DW x4**	 **DW x20**	**TCT**	**LCT**
pH - Leach Fluid	N/A	N/A	N/A		
PH - Sample	9.66	7.98	7.97		
Metal Ions	mg/kg *	mg/liter *	mg/liter *		
As - Arsenic *	3.71	0.001	< 0.001	< TCT0	< LCT0
B - Boron *	37.79	0.056	0.057	< TCT0	< LCT0
Ba - Barium *	114.4	0.048	0.041	< TCT1	< LCT0
Cd - Cadmium *	< 3.2	< 0.003	< 0.003	< TCT0	= LCT0
Co - Cobalt *	5.26	< 0.025	< 0.025	< TCT0	< LCT0
Cr Total - Chromium Total *	15.72	< 0.025	< 0.025	< TCT0	< LCT0
Cr (VI) - Chromium (VI) *	< 2	< 0.05	< 0.05	< TCT0	= LCT0
Cu - Copper *	5	0.057	0.057	< TCT0	< LCT0
Hg - Mercury *	24.81	< 0.001	< 0.001	< TCT1	< LCT0
Mn - Manganese *	25.56	< 0.025	< 0.025	< TCT0	< LCT0
Mo - Molybdenum *	< 6.4	< 0.025	< 0.025	< TCT0	< LCT0
Ni - Nickel *	11.28	< 0.025	< 0.025	< TCT0	< LCT0
Pb - Lead *	10.27	0.037	0.028	< TCT0	< LCT1
Sb - Antimony *	< 3.2	0.001	0.001	< TCT0	< LCT0
Se - Selenium *	< 6.4	0.002	0.002	< TCT0	< LCT0
V - Vanadium *	25.03	0.034	0.051	< TCT0	< LCT0
Zn - Zinc *	14.44	< 0.025	< 0.025	< TCT0	< LCT0
Anions	mg/kg *	mg/liter	mg/liter *		
Fluoride - F	< 0.5	< 0.05	0.06	< TCT0	< LCT0
Chloride - Cl	N/A	2.03	< 2	N/A	< LCT0
Nitrate as NO3	N/A	< 2.22	< 2.22	N/A	N/A
NO3 as N	N/A	< 0.5	< 0.5	N/A	< LCT0
Sulphate - SO4	N/A	27.47	28.82	N/A	< LCT0
CN - Total Cyanide *	< 0.1	< 0.07	< 0.07	< TCT0	= LCT0
Total Dissolved Solids	mg/kg	mg/liter	mg/liter *		
TDS	N/A	200	162	N/A	< LCT0

Type Assessment, based only on the inorganic results and not the detection limits

Highest Total Concentration Value	≤ TCT 1
Highest Leachable Concentration Value	≤ LCT 1
Final Waste Type Classification	Type 3

Authorized Signatory

C. Swanepoel

sanas
Testing Laboratory
T0584

Disclaimer:

The above-mentioned sample/s were analysed as received by the laboratory on the date stated above. UIS Organic laboratory takes no responsibility for sample/s prior to submission: this includes sampling, sample container, storage and shipping to our testing facility. The sample is analysed per customer request for analysis.
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NR – Not Requested
RTF – Results to Follow
BDL – Below Detection Limit (Please note that if the results for an analyte is below our detection limit, it does not indicate that the sample is clean or that the analyte result is equal to zero.)
Storage Conditions in the Laboratory: Fridge @ <6 ºC

ANALYTICAL REPORT: Net Acid Generation (NAG)

To:	**UIS Sediba Laboratory**	Date of Request: 12.06.2018	UIS Analytical Services
Attention:	**Willie / Retha**		Analytical Chemistry
Project ID:			Laboratories 4, 6
Site Location:			
Quote No:			Fax: (012) 665 4294
Order No:	**2943**		

Certificate of analysis: 27632

Note: No unauthorised copies may be made of this report.

Lims ID	**Sample ID**	**NAG pH: (H_2O_2)**	**NAG at pH 4.5**	**NAG at pH 7.0**
			kg H2SO4 / t	**kg H2SO4 / t**
639040	**8585/MP DD/11-JUN-19**	4.11	2.31	17.4
639041	**8585/MP SS/11-JUN-19**	2.60	15.1	31.7
639040 QC	**Duplicate**	4.18	1.89	17.1

		Chemical elements:	Net Acid Generation (NAG)
		Instrument:	Methohm Titrino
		Method:	Single addition NAG test
Date:	28.06.2019	Date:	03.07.2019
Analysed by:	L van der Walt	Authorised :	JJ Oberholzer

ANALYTICAL REPORT: C & S Speciation

To: **UIS Sediba**
Attention: **Willie Havenga**
Project ID:
Site Location:
Order No: **2943**

Date of Request: 12.06.2019

UIS Analytical Services
Analytical Chemistry
Laboratories 4, 6

Fax: (012) 665 4294

Certificate of analysis: 27632

Note: No unauthorised copies may be made of this report.

Lims ID	**Sample ID**	**Total Sulphur**	**S (sulphide)**	**S (sulphate)**
		%	%	%
639040	**8585/MP DD/11-JUN-19**	1.91	0.711	0.511
639041	**8585/MP SS/11-JUN-19**	2.24	1.781	0.032

Chemical elements: S (total), S (sulphide), S (sulphate)
Instrument: ICP-OES LECO CS 230 Spectrophotometer

Date: 28.06.2019
Analysed by: L van der Walt

Date: 28.06.2019
Authorised : JJ Oberholzer

ANALYTICAL REPORT: Acid / Base Accounting (ABA)

To: **UIS Sediba**
Attention: **Willie Havenga**
Project ID:
Site Location:
Order No: **2943**
Quote Number:

Date of Request: 12/06/2019

UIS Analytical Services
Analytical Chemistry
Laboratories 4, 6

Fax: (012) 665 4294

Certificate of analysis: 27632

Note: No unauthorised copies may be made of this report.

Lims ID	**Sample ID**	**Paste pH**	**Total Sulphur**	**Acid Potential (AP)**	**Neutralization Potential (NP)**	**Nett Neutralization Potential (NNP)**	**Neutralising Potential Ratio (NPR) (NP : AP)**	**Total Carbon**
			%	**kg CaCO3/t**	**kg CaCO3/t**	**kg CaCO3/t**	**NP:AP**	%
639040	**8585/MP DD/11-JUN-19**	7.22	1.910	59.7	30.81	-28.878	0.516	49.5
639041	**8585/MP SS/11-JUN-19**	8.23	2.240	70.0	31.89	-38.110	0.456	62.1

Note: Negative NP values are obtained when the volume of NaOH(0.1N) titrated (pH:8.3) is greater than the volume of HCl(1N) to reduce the pH of the sample to 2.0-2.5. Any negative NP values are corrected to 0.00

Chemical elements: ABA
Instrument: Methohm Titrino, LECO CS 230
Method: EPA 600 Modified Sobek

Date: 28.06.2019
Analysed by: L van der Walt

Date: 03.07.2019
Authorised : JJ Oberholzer

Surname:	Mostert
Names:	Joseph Ferdinand Willem
Position:	Director at Gradient Consulting (Pty) Ltd
Nationality:	RSA
Experience:	12 years in Hydrogeological Consulting
Professional Registration/Affiliations:	SACNASP Member (Reg. No 40057/14 – Water Resource Science). Member of the Groundwater Division of the Geological Society of South Africa (MGSSA).
Qualification:	M.Sc. Hydrogeology (2013), Institute for Groundwater Studies (IGS), University of the Free State.

Ferdinand is the founder and director of Gradient Consulting (Pty) Ltd, a consulting company specializing in providing hydrogeological advisory and supporting services. His hydrogeological experience include environmental impact and risk assessments, hydrogeological baseline assessments, development and implementation of groundwater monitoring programs, groundwater and surface water sampling and monitoring, aquifer sustainability studies and development of groundwater balances, contamination risk assessments, waste classification and AMD prediction, numerical groundwater flow and mass transport modeling, mine dewatering designs, groundwater due diligence studies, operational water and salt balances, groundwater resource development, integrated groundwater and surface water management as well as practical implementation and decision making approaches. Ferdinand also have thorough knowledge and understanding of the National Water Act (Act 36 of 1998) and have in excess of 5 years' experience in compliance auditing focusing mainly on external water use licence audits. Ferdinand has worked in all provinces throughout South Africa as well as sub-Saharan Africa countries, and his experience includes commodities such as iron ore, gold, coal and platinum.

KEY AREAS OF EXPERTISE

i. Hydrogeological consulting.

ii. Numerical groundwater flow and solute transport modelling.

iii. Groundwater impact assessments and risk matrices.

iv. Best practise groundwater management and implementation of mitigation measures.

SUMMARY RECENT PROFESSIONAL EXPERIENCE

Consulting projects		
Project	**Date**	**Responsibilities**
De Beers Venetia Mine	2015	Specialist integrated surface and groundwater assessment with emphasis on hydrological modelling and effects of abstraction on riparian habitat. Development of an operating well field management strategy in correlation to water uses permits and authorised abstraction volumes.
Rio Rinto QIT Madagascar Minerals	2015	Perform a detail investigation on mine dewatering and groundwater inflow evaluation for their Mineral Sands Mine in Madagascar. The assessment was conducted as part of a mine dewatering design with focus on numerical modelling of groundwater inflow simulations and predictions. Scientific conclusions on integrated mine water management were derived with recommendations
Kumba Iron Ore Sishen Mine	2014	Specialist investigation on surface water and groundwater interaction from the Gamagara River, numerical integrated water modelling, impact assessment and recommendations and best practise environmental mitigation measures, scientific report writing and conclusions on way forward.
Blackthorn Resources Kitumba Zambia	2014	Project management and client liaison, site visit and field work including hydrocensus survey and sampling, hydrochemistry analysis (including isotope analysis), (DC Shlumberger soundings, DC Wenner soundings, Magnetic technique), siting and drilling of monitoring boreholes, geological logging, aquifer testing (constant discharge, falling head tests and packer testing) and classification, interpretation of all field data, in depth reporting on observations and data interpretations with impact assessment and mitigations measures, scientific conclusions and applicable recommendations.
BHP Billiton Khutala Colliery	2013	Project management and client liaison, site visit to both underground and surface operations, water sampling and hydrochemistry analysis, construction of a hydrogeological conceptual model, development of an analytical salt and water balance (GoldSim ® software package), in depth reporting on observations and data interpretations with impact assessment and mitigations measures, scientific conclusions and applicable recommendations
Anglo Gold Ashanti	2012	Project management and client liaison, performing of a desktop site evaluation and model boundary assessment, construction of a conceptual model indicating the hydrogeological system in relation with geological and structural influences, hydrochemistry analysis and data interpretation, development of a numerical groundwater flow and contaminant transport model (FEFLOW® software package by DHI, model simulations and impact predictions, in depth reporting on observations with scientific conclusions and applicable recommendations

RECENT EMPLOYMENT RECORD

2016-current	**Director** Gradient Consulting (Pty) Ltd
2009-2016	**Hydrogeologist and Unit manager** Exigo Sustainability (EOH)
2007-2009	**Junior hydrogeologist** Aquatico (Pty) Ltd

PROJECT REFERENCES

De Beers Venetia Mine	Andy Cyster (015) 575 2723
Blackthorn Resources Kitumba Copper Mine	George van Dyk 064 418 3680
Kumba Iron Ore Sishen Mine	Dr. Koos Vivier 082 776 6967