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ANKER COAL ELANDSFONTEIN COLLIERY ENVIRONMENTAL AUTHORISATION HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

March 2020

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

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This report has been drafted as per the latest requirements for specialist reports as set by the Department of Environmental Affairs and listed in Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07 April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA).

I, JFW Mostert, hereby declare that:

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

JFW Mostert (Hydrogeologist)

M.Sc. Hydrogeology, Pr.Sci.Nat.

Executive summary

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd to conduct a hydrogeological specialist investigation and groundwater impact assessment in support of an Environmental Authorisation (EA) and amendment process to be followed for Anker Coal and Mineral Holdings SA (Pty) Ltd Elandsfontein Colliery.

The objective of this investigation is to assess the potential impact of the proposed activities and associated facilities on the local and regional groundwater regime.

The objective of this investigation is to determine the status quo of the regional groundwater system and quantify and qualify potential impacts of existing activities and infrastructure on the regional groundwater regime.

The project extent and greater mine lease area is located on a portion of the remaining extent of portion 8; remaining extent of portion 1; a portion of the remaining extent of portion 6; portion 44; portion 14 and the remaining extent of portion 7 of the Farm Elandsfontein 309 JS, situated approximately 4.0 km south of Kwa-Guqa and about 16.0 km west of Emalahleni, Mpumalanga Province, South Africa

The topography of the greater study area is characterised by moderately undulating plains and pans. The north-eastern perimeter is shaped by a topographical high at 1565 mamsl and forms the watershed between quaternary catchments B20G and B11K. The lowest on-site elevation is situated towards the southwest and is recorded at 1476 mamsl. On-site gradients are relatively gentle to moderate with the average slope calculated at 2.30% and –2.20% respectively.

The resource management of the greater study area falls under the Olifants WMA and quaternary catchment B20G.

Although local surface water drainage on site is inferred to be in a general southwestern direction, the regional drainage occurs in a general north to north-western direction. The Grootspruit drainage transects the project area to the southwestern perimeter.

The calculated mean annual precipitation (MAP) for this rainfall zone is 530.76 mm/a, while the mean annual evaporation accounts to 1689.0 mm/a.

The study area is underlain by the Ecca Group of the Karoo Supergroup and fall within the Madzaringwe Formation, consisting mainly of arenaceous strata. On a regional scale, two geological lineaments (potentially faults zones) exist in close proximity to the greater study area, striking in a general north-south and southwest-northeast orientation respectively.

The site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks.

Two main hydrostratigraphic 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.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock.

The hydraulic conductivity of sandstone formations can range from $9e^{-05}$ – $9e^{-01}$ m/d whereas the hydraulic conductivity of denser shale formations is lower and estimated at $9e^{-09}$ – $9e^{-05}$ m/d. It should also be noted that mined out and back-filled areas may have different hydraulic properties as the inherent values have been altered and modified.

An approximation of recharge for the study area is estimated at ~6.21 % of MAP i.e. ~32.93 mm/a.

Off the boreholes visited during the hydrocensus user survey, the majority is in use (>73.0%)) with the groundwater application mostly for monitoring purposes as well as domestic and livestock purposes. It should be noted that there are various neighbouring boreholes in close proximity (< 1.0 km) to the mining operations.

The unsaturated zone within the study area is in the order of ~2.85 to ~22.19m with a mean thickness of approximately 8.50m.

Analysed water level data for the shallow aquifer indicate that the majority of levels correlate very well to the topographical elevation and it can be assumed that the regional groundwater flow direction of the shallow aquifer is dictated by topography. Accordingly, the inferred groundwater flow direction will be in a general southwestern direction towards the lower laying drainage system of the Grootspruit drainage system.

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas i.e. mine discard dump and/or slurry ponds is moderately flat and calculated at approximately 0.004 with gradients increasing towards the southwestern perimeter of the mine lease area.

The expected seepage rate from contamination originating at the mine discard dump is estimated at an average of 0.96 m/a and will be dependent on local groundwater gradients.

The overall ambient groundwater quality of the shallow aquifer is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Isolated sampling localities indicate above limits ammonium (NH_4) concentrations which may suggest nearby anthropogenic activities.

The local groundwater quality is indicative of an impacted groundwater system and suggest coal mine pollution and acid mine drainage (AMD) conditions present. The latter is characterised by a low pH environment increasing the solubility and concentrations of metals i.e. usually aluminum, iron and manganese.

The overall water quality of the upstream surface water samples is poor due to elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) i.e. coal mine pollution indicators. The downstream water quality is unacceptable due to highly elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) causing high salt loads. There is a definite deterioration of water quality evident in a downstream direction and suggest contaminated water ingress from potentially mine decant and interflow zones or seepage from mine discard dumps.

The majority of regional/ neighbouring boreholes suggest either a recently recharged and unimpacted water environment (Calcium-Bi-carbonate dominance), and/or area of dissolution and mixing, whereas current monitoring boreholes on site indicate a static and disordinate environment (Sulphate dominance suggesting impacts from coal mine pollution).

Furthermore, groundwater sampling localities ECBH03, ELNBH03 correlate well to the hydrochemical signature of surface water sampling locality ASW01 and suggest similar water environments and potential origins.

The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.

The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.

A Toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material suggest elevated concentrations of manganese (Mn) as well as sulphate ($S0_4$) for the tailings slurry sample, manganese (Mn) for the coal product sample and barium (Ba), manganese (Mn) as well as zinc (Zn) for the carbonaceous shale sample.

All waste samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly.

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 "**Moderate**", Di = 102.

The numerical groundwater flow model simulations for the proposed opencast operation suggest the average open pit dewatering is approximately $2.57E^{+02}$ m^3/d with a maximum pit water ingress of approximately $5.09E^{+02}$ m^3/d for the duration of the simulation period. It is noted that the opencast groundwater ingress volumes expected is much lower due to the existing groundwater drawdown caused by current dewatering activities. It is expected that the groundwater drawdown will range from 4.0m to ~ 24.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 211.0ha. It should be noted that the simulated impact zone extends slightly beyond the eastern perimeter of the mining right area, however, falls mainly within the mining properties. Baseflow discharges to the model catchment drainages, accounts to approximately 1800.0m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1750.0m^3/d. This accounts for an average loss of ~3.0% with a maximum of >10.0% during the simulation period.

Model simulations for the proposed underground development suggest the average underground void dewatering is approximately $1.44E^{+03}$ m^3/d with a maximum underground water ingress of approximately $2.03E^{+03}$ m^3/d for the duration of the simulation period. It is expected that the groundwater drawdown will range from 4.0m to ~ 30.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 720.90ha. It should be noted that the simulated impact zone extends slightly beyond the eastern and south-eastern perimeters of the mining right area, however, falls mainly within the mining properties. It is not expected that the underground operations will have a significant effect on the baseflow discharge to local drainages.

A mine post-closure scenario was simulated wherein hydraulic head recovery within the proposed opencast areas was evaluated. It is calculated that the newly proposed backfilled opencast pit flooding and associated decant periods ranges between ~5.0years to >20years depending on the geometry of the backfilled pit. Expected decant volumes for the backfilled opencast pits varies from 8.0m^3/d to > 70.0m^3/d depending on the pit effective infiltration volumes. The combined decant volume is approximately ~150.0m^3/d.

It is calculated that the existing/historical backfilled opencast pits decant volumes varies from 40.0m^3/d to > 190.0m^3/d with a combined decant volume of approximately ~626.0m^3/d. It should be noted that there are various decant points potentially discharging into the wetland drainage system traversing the site.

A mine post-closure scenario was simulated wherein hydraulic head recovery within the existing underground voids as well proposed mining areas was evaluated. Simulated average groundwater ingress for the LOM underground operation was combined with the expected groundwater recharge reporting to the underground void and from these volumes it is estimated that under average rainfall conditions, the underground will be flooded in approximately 35 to 40 years after ceasing of mining activities. The proposed depth and geometry of the underground operations allows for the majority of the footprint to be flooded with a low risk of decant occurring. Expected decant volumes for the underground voids are relatively low due to the presence of confining shale and mudstone layers restricting the downward filtration of rainwater recharge into the underground mine void(s) and ranges between 0.85m^3/d to ~17m^3/d with a combined volume of approximately 50.0m^3/d. Thus the combined expected decant volume expected post-closure is approximately 870.0 m^3/d.

It is noted that sulphate concentrations for all monitoring boreholes (ECBH02, ECBH03 and ECBH04) rises above the SANS threshold reaching the LOM, where borehole ECBH03 reaches a maximum concentration of ~1 370 mg/l, correlating well to on-site monitoring results.

The simulated sulphate pollution plume extent for the newly proposed mining footprints for LOM covers a total area of approximately 447.0ha (inclusive of existing opencast footprints), reaching a maximum distance of ~350.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that no neighbouring boreholes, except on-site monitoring boreholes is impacted on during the operational LOM while the unknown tributary of the Grootspuit and associated wetland are affected.

It is evident that sulphate concentrations for all monitoring boreholes is above the SANS threshold for the duration of the LOM, reaching maximum concentrations of between ~1200.0 to ~1 600.0mg/l respectively.

A 50-year post-closure scenario was simulated and covers a total area of approximately 875.0ha, reaching a maximum distance of ~600.0 to 700.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on.

A 100-year post-closure scenario was simulated and covers a total area of approximately 1030.0ha, reaching a maximum distance of 1100.0 to 1300.0m in a general south-western direction. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on. It is evident that sulphate concentrations for all monitoring boreholes stabilises to a maximum sulphate contribution load of between 1600.0 to 1800.0mg/l, which is above the SANS threshold.

Various alternative management and mitigation scenarios were simulated to evaluate the remedial options available. The preferred mitigation scenario entails establishment of scavenger boreholes down-gradient of waste facilities and backfilled opencasts in combination with disposal of carbonaceous waste material in the northern discard pit. The combination of the mitigation effect of the negative groundwater gradient created reduces the pollution plume footprint to ~35.0% to ~738.0ha. Accordingly, this mitigation scenario is the most likely case and preferred scenario.

The model results were incorporated into a risk rating matrix to determine the significance of potential groundwater related impacts.

During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as medium negative without implementation of remedial measure and low negative with implementation of proposed mitigation measures. Groundwater quality impacts from the discard dump, coal stockpile areas, PCD's and related waste facilities are rated as medium negative without implementation of remedial measures and medium/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.

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 revised monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. 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 Human Settlements, Water and Sanitation.
3. It is recommended that additional monitoring boreholes, as indicated in this report, be established down-gradient of potential decant zones in order to evaluate the mass load contribution of decant water to environmental receptors. Proposed monitoring boreholes should be drilled in pairs to target shallow, weathered as well as deeper, fractured aquifer units. Drilling localities should be determined by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.
4. Due to the impact and reduction of baseflow reporting to the on-site wetland, it is recommended that a monitoring borehole(s) be drilled in order to evaluate perched water level recovery of the wetland following rehabilitation.
5. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a bi-annual basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.
6. It is recommended that supplementary geochemical characterisation i.e. kinetic leach test should be performed on carbonaceous waste material to be used as backfill material i.e. northern discard pit, with a dynamic geochemical model developed to aid in calculation of source term depletion timeframes.
7. It is imperative that the water level recovery of the underground voids as well as backfilled opencast pits 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 in terms of decanting.
8. Alternative remedial options to reduce rainfall recharge and effective infiltration, which will lead to an increase in leachate volumes, should form part of the mine closure and rehabilitation strategy. It is recommended that the northern discard pit footprint be compacted and a barrier system (capping)

and/or evapotranspiration cover be established in order to minimise water and oxygen ingress which is the drivers of acid rock drainage conditions.

9. All preferred groundwater flow pathways which are in direct connection with surface topography i.e. adits, ventilation shafts and/or unrehabilitated exploration boreholes should be sealed off and rehabilitated.

List of Abbreviations

ABA	**Acid Base Accounting**
ASLP	**Australian Standard Leaching Procedure**
AP	**Acid Potential**
ARD	**Acid Rock Drainage (also referred to as acid mine drainage (AMD))**
ASTM	**American Society for Testing Materials**
AUC	**Average Upper Crust**
Avg	**Average**
BH	**Borehole**
CMB	**Chloride Mass Balance**
b	**Saturated Thickness**
DMR	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs and Sanitation (currently Department of Human Settlements, Water and Sanitation)**
EC	**Electrical Conductivity (mS/m)**
EA	**Environmental Authorisation**
EIA	**Environmental Impact Assessment**
E.N.	**Electro Neutrality**
EPA	**United States Environmental Protection Agency**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN	**Government Notice**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
IWULA	**Integrated Water Use License Application**
ISP	**Internal Strategic Perspective**
K	**Hydraulic Conductivity (m/d)**
LC	**Leachable Concentration**
LCT	**Leachable Concentration Threshold**
l/s	**Litre per second**
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**
MAP	**Mean Annual Precipitation**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
mcm	**Million Cubic Metres**
ME	**Mean Error**
meq/L	**Mili-equivalents per litre**
mg/l	**Milligrams per litre**

mm/a	**Millimetre per annum**
MPRDA	**Minerals and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
NAG	**Net-Acid Generation**
NAWL	**No Access to Water Level**
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**
ROR	**Rate of Rise**
RWD	**Return Water Dam**
S	**Storage coefficient**
Sc	**Specific Storage**
SoW	**Scope of Work**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
T	**Transmissivity (m2/d)**
TC	**Total Concentration**
TCLP	**Toxicity characteristic leaching procedure**
TCT	**Total Concentration Threshold**
TDS	**Total Dissolved Solids**
TSF	**Tailings Storage Facility**
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**

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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 groundwater impact assessment in support of an Environmental Authorisation (EA) and amendment process to be followed for Anker Coal and Mineral Holdings SA (Pty) Ltd Elandsfontein Colliery.

Elandsfontein Colliery is an existing colliery which was approved in terms the Minerals Act (1999) and currently holds two mining rights (MP 314 MR as well as MP63 MR). The applicant plans to consolidate the two mining right areas into a single mining right with associated consolidated EMPR. Furthermore, the applicant proposes to expand the existing mining operations to include additional mineral resource areas within the consolidated mining right boundary. This report serves as an environmental impact assessment (EIA) level study and focuses on the status quo of the regional groundwater system and aim to quantify and 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 first order assessment on the long-term potential for the occurrence of Acid Mine (Rock) Drainage (AMD).

iv. Waste classification in accordance with Regulation GNR 635 of the National Waste Act (Act 59 of 2008).

v. Development of a numerical groundwater flow model.

vi. Development of a contaminant transport model with of a source term derived from the geochemical assessment.

vii. Hydrogeological impact assessment and risk matrix.

viii. Recommendations on best practise mitigation and management measures to be implemented.

ix. 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-19-050-V1, submitted in September 2019. This project plan and scope of work (SoW) was compiled in accordance with the Environmental Impact Assessment (EIA) Regulations, Government Notice (GN) R982 (NEMA 2014). The scope of work is summarised below.

1.3.1. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

i. Information gathering and data acquisition.

ii. Desk study and review of existing specialist reports as well as newly gathered monitoring data for hydrochemical and water level trend analysis.

iii. Fatal flaw and gap analysis.

1.3.2. Phase B: Update the existing hydrogeological baseline assessment - hydrocensus user survey, hydrochemical analysis and aquifer classification

Phase B will entail the following activities:

i. 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 mining footprints.

ii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of six (6) water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

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

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

v. 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. Review and analysis of existing information.

ii. Laboratory analysis and geochemical assessment of composite waste samples of strategically placed sampling localities (Static leach testing (TCLP), AMD generation, NAG Potential and sulphide speciation (2 samples)).

iii. Processing of geochemical data.

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

v. Formulation of a geochemical conceptual model.

vi. Report writing and AMD strategy.

1.3.4. Phase D: Update the existing numerical groundwater flow and mass transport model

Phase D will entail the following activities:

i. Update the existing conceptual hydrogeological model in conjunction with newly gathered site characterisation information as well as monitoring data.

ii. Update the existing numerical groundwater flow model by applying the Finite Element Flow (FEFLOW) modelling software. Model domain to include proposed infrastructure and mine extension footprint as well as associated activities.

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. Update the current groundwater monitoring network and protocol.

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 data 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.

i. 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.

ii. The numerical groundwater flow model was developed based on existing geological and hydrogeological information.

iii. 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.

iv. Stratigraphical units, as delineated from surface geology within the model domain, are assumed to occur throughout the entire thickness of the model and were incorporated as such.

v. The geological structures (fault zones and dyke contact zones) were modelled as permeable linear zones.

vi. The model basement or lower perimeter of the model domain was delineated based on the competent Karoo basement or Dwyka tillite/diamictite is generally impermeable.

vii. 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.

viii. 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.

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

x. Prior to development, the system is in equilibrium and therefore in steady state.

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

1.5. Details and expertise of the author

The details of the person who prepared this report are summarised in Table 1-1 below.

Table 1-1 Details of the author.

Author	Ferdinand Mostert
Highest qualification	M.Sc. Hydrogeology
Years' experience	13+
Professional registration	SACNASP Member (Reg. No 40057/14 – Water Resource Science). Member of the Groundwater Division of the Geological Society of South Africa (MGSSA).

Ferdinand Mostert 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 has thorough knowledge and understanding of the National Water Act (Act 36 of 1998) and practical application thereof. He 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, diamonds, coal and platinum.

1.6. AVAILABLE INFORMATION

The following information was available and used in this investigation:

i. Anker Coal Elandsfontein Survey Data and DTM.

ii. Aquiworx software. 2016. Version 2.5.2.0. Centre for Water Sciences and Management at the North-West University.

iii. Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2529CC. Edition 9. Scale 1:50,000. Mowbray, South Africa: Chief Directorate of Surveys and Mapping.

iv. Council of Geoscience geological map sheet 2528: Pretoria (1:250 000).

v. Dreyer, J., Moeketsi, B.N., 2019. Ground and Surface Water Monitoring Report for Elandsfontein Colliery. 82/006208/07. 1st Quarterly Report.

vi. DWS. Anker Coal Elandsfontein Colliery Unofficial Water use licence (WUL). Ref.No.: Licence No.:04/B20G/CGI/3843.

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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.

vii. Georoc, 2020. Anker Coal Elandsfontein Colliery Mine Works Program.

viii. Digby Wells, 2018. Amendment to the Environmental Management Programme for the Elandsfontein Colliery. Report No.: ANK3784.

ix. ESRI basemaps, 2020.

x. Google Earth, 2020. 6.0.12032 Beta.

xi. Gradient Consulting, 2019. Elandsfontein Colliery Hydrogeological Baseline Assessment: Scoping Study. Report Ref. HG-R-19-016-V1.

xii. Water Research Commission (WRC), 2012. Water Resources of South Africa.

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.

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.

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

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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

analysis of the total concentrations (TC) and leachable concentrations (LC) of samples taken.

2.5. Numerical groundwater flow and mass transport model update

A numerical groundwater flow and mass transport model was developed and updated 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 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.

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.

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: 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

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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.

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.

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

The project extent and greater mine lease area is located on a portion of the remaining extent of portion 8; remaining extent of portion 1; a portion of the remaining extent of portion 6; portion 44; portion 14 and the remaining extent of portion 7 of the Farm Elandsfontein 309 JS, situated approximately 4.0 km south of Kwa-Guqa and about 16.0 km west of Emalahleni, Mpumalanga Province, South Africa. The site is accessible from the N4 national route and N104 to the north as well as route R547 to the east. General site coordinates are listed in Table 4-1 with the site locality and layout depicted in Figure 4-2.

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

Latitude	-25.904
Longitude	29.092

4.2. Mining infrastructure and schedule

Elandsfontein Colliery holds two mining right areas i.e. MP 314 MR (593 ha) as well as MP63 MR (237 ha). The roll over strip mining method is utilised to extract coal from the shallower No.2 coal seam. The existing opencast operations has an approximate extend of 257 ha while the applicant wishes to authorise an additional 69.47 ha. Deeper coal is extracted by underground bord and pillar mining using decline shafts to access No. 1 coal seam. The historical underground footprint covers an approximate area of 182 ha, while the applicant wishes to authorise an additional 379 ha. Associated infrastructure consists of a discard dump, coal ROM stockpiles, overburden stockpiles, pollution control dams (PCD) and slurry dam. Refer to Figure 4-2 for a summary of existing/ proposed mining zones and infrastructure map.

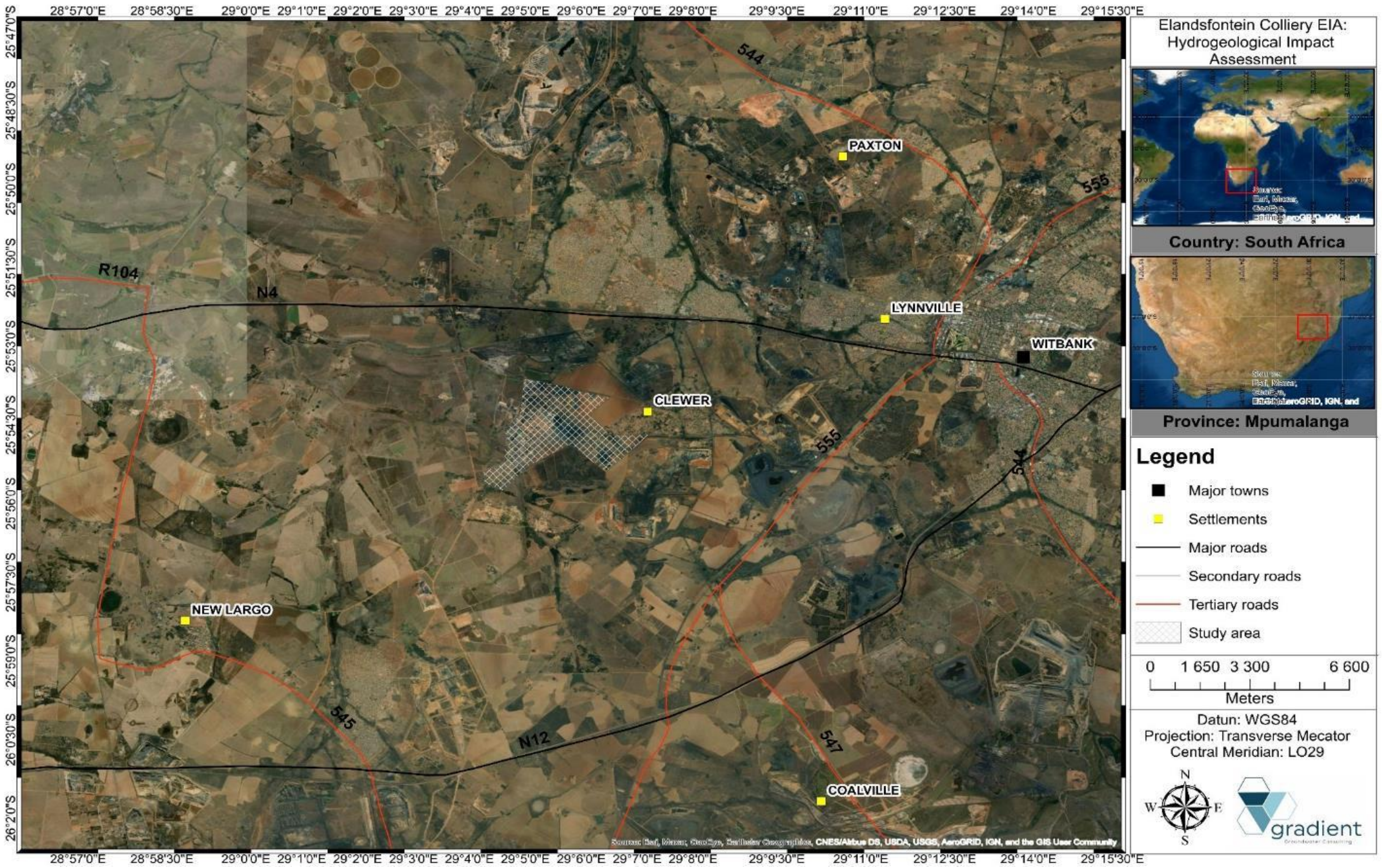


Figure 4-1 **Aerial extent and greater study area.**

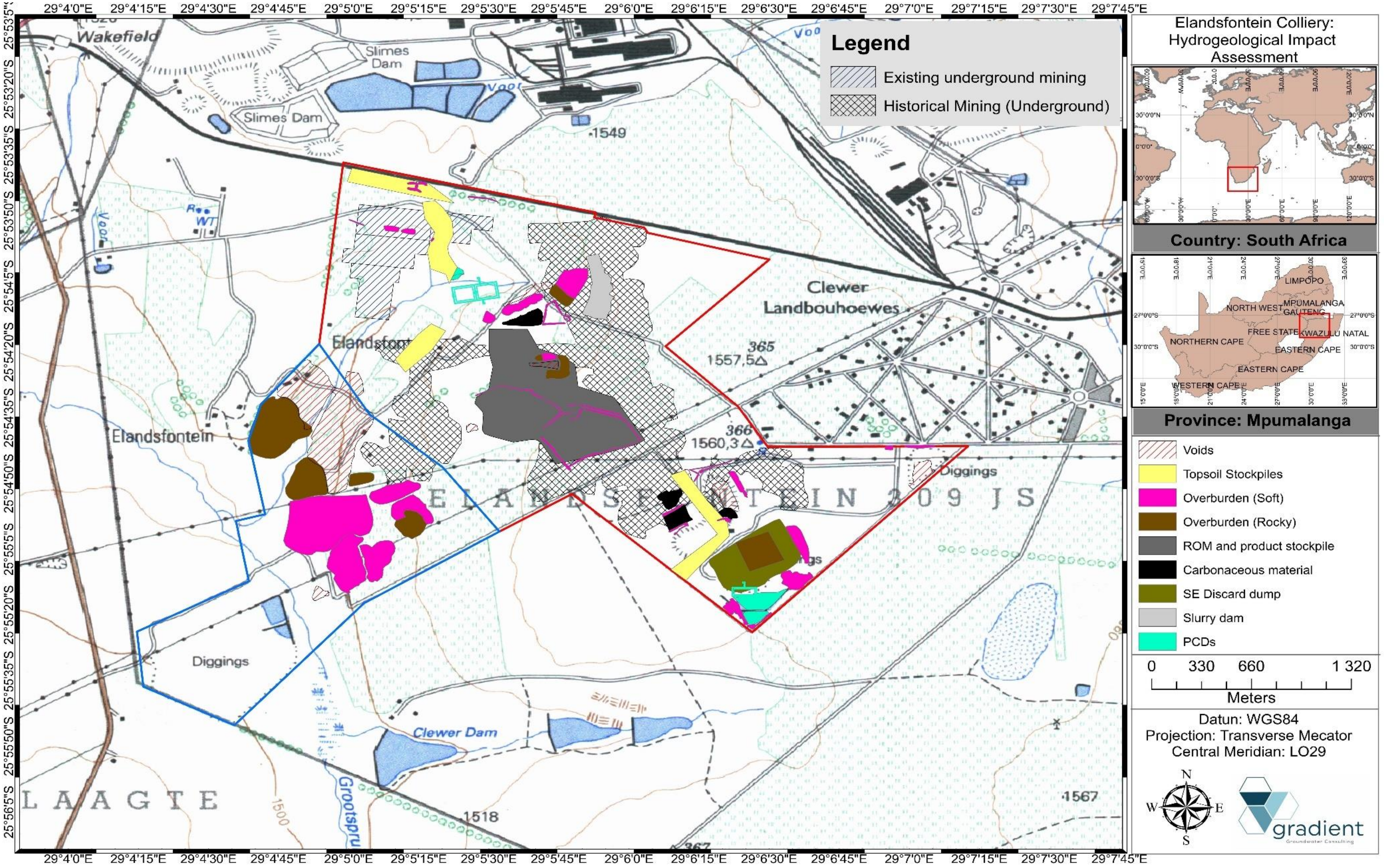


Figure 4-2 Greater study area and mine infrastructure (1:50 000 topographical mapsheet 2529CC).

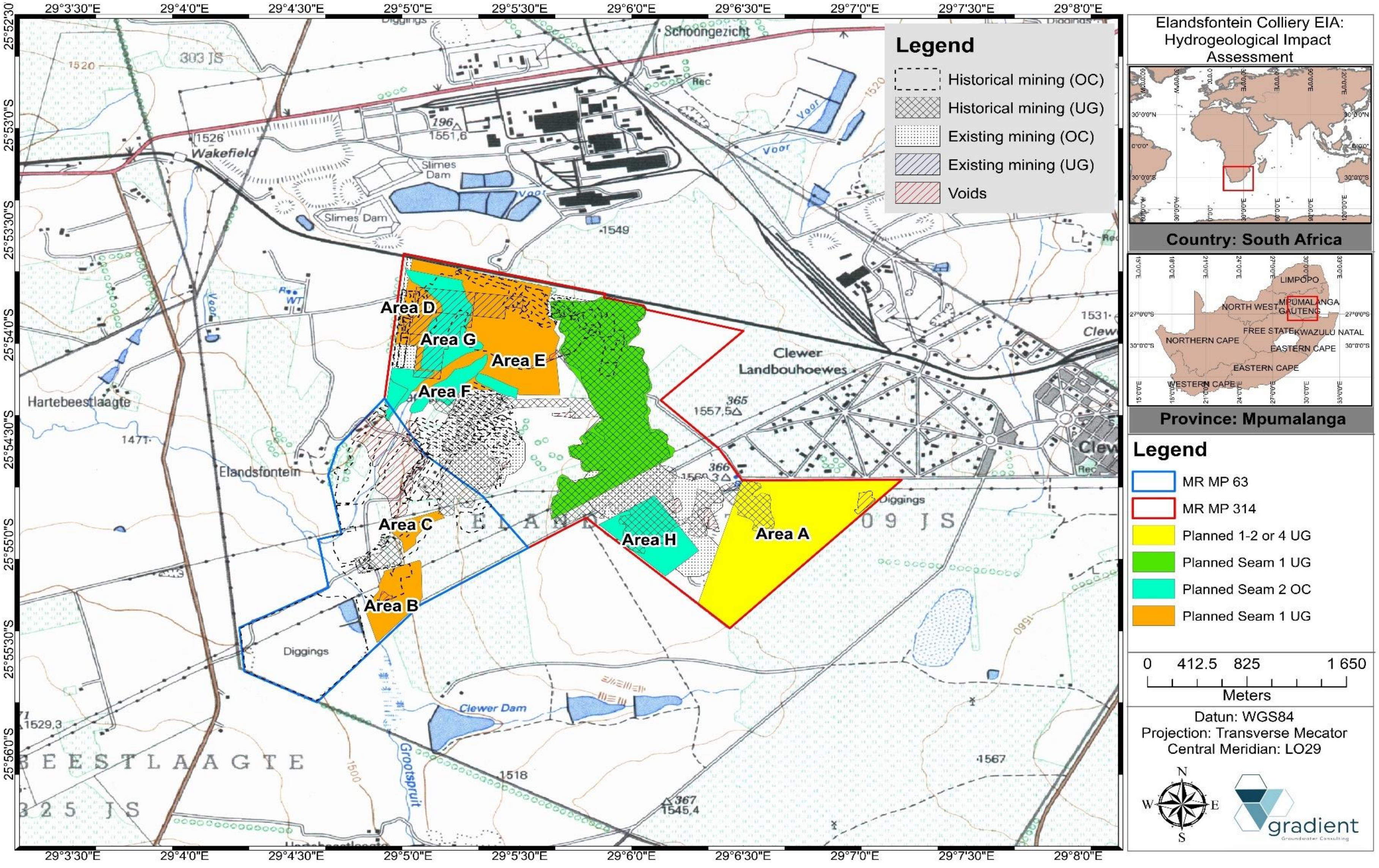


Figure 4-3 **Proposed mining footprints and mining zones.**

5. PHYSIOGRAPHY

5.1. Topography

The topography of the greater study area is characterised by moderately undulating plains and pans. The north-eastern perimeter is shaped by a topographical high at 1565 meters above mean sea level (mamsl) and forms the watershed between quaternary catchments B20G and B11K. To the south and southeast, the landscape gradually flattens out towards the lower laying drainage system with the lowest on-site elevation recorded as 1476 mamsl.

On-site gradients are relatively gentle to moderate with the average slope calculated at 2.30% and –2.20% respectively with an elevation loss of ~30.0 m over a lateral distance of ~3.50 km. Figure 5-1 depicts a NorthSouth EastWest topographical cross-section of the greater study area while Figure 5-2 shows the regional topographical contours and setting.

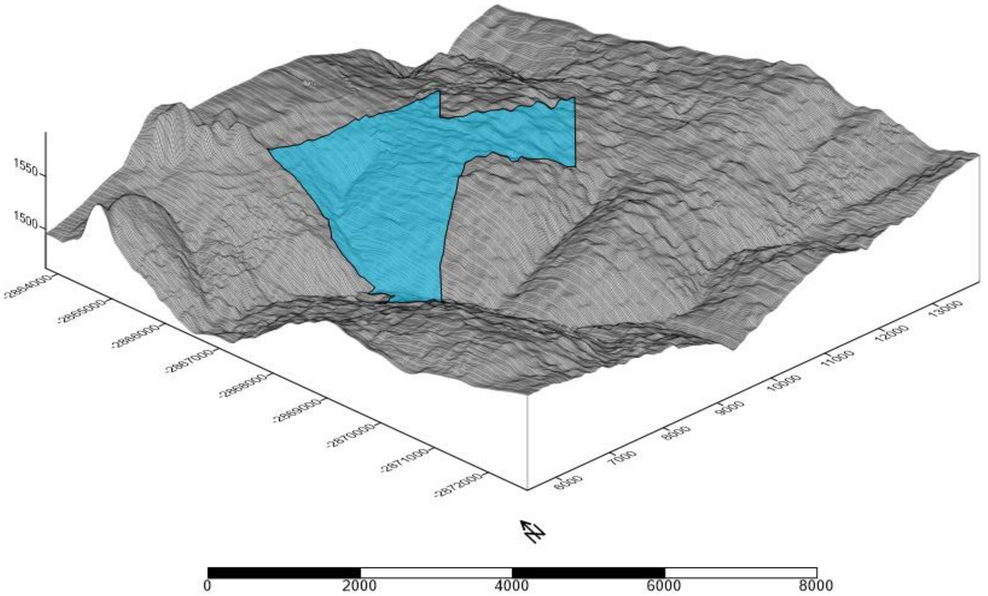


Figure 5-1 **Topographical cross-sections of the greater study area (A'-A-B).**

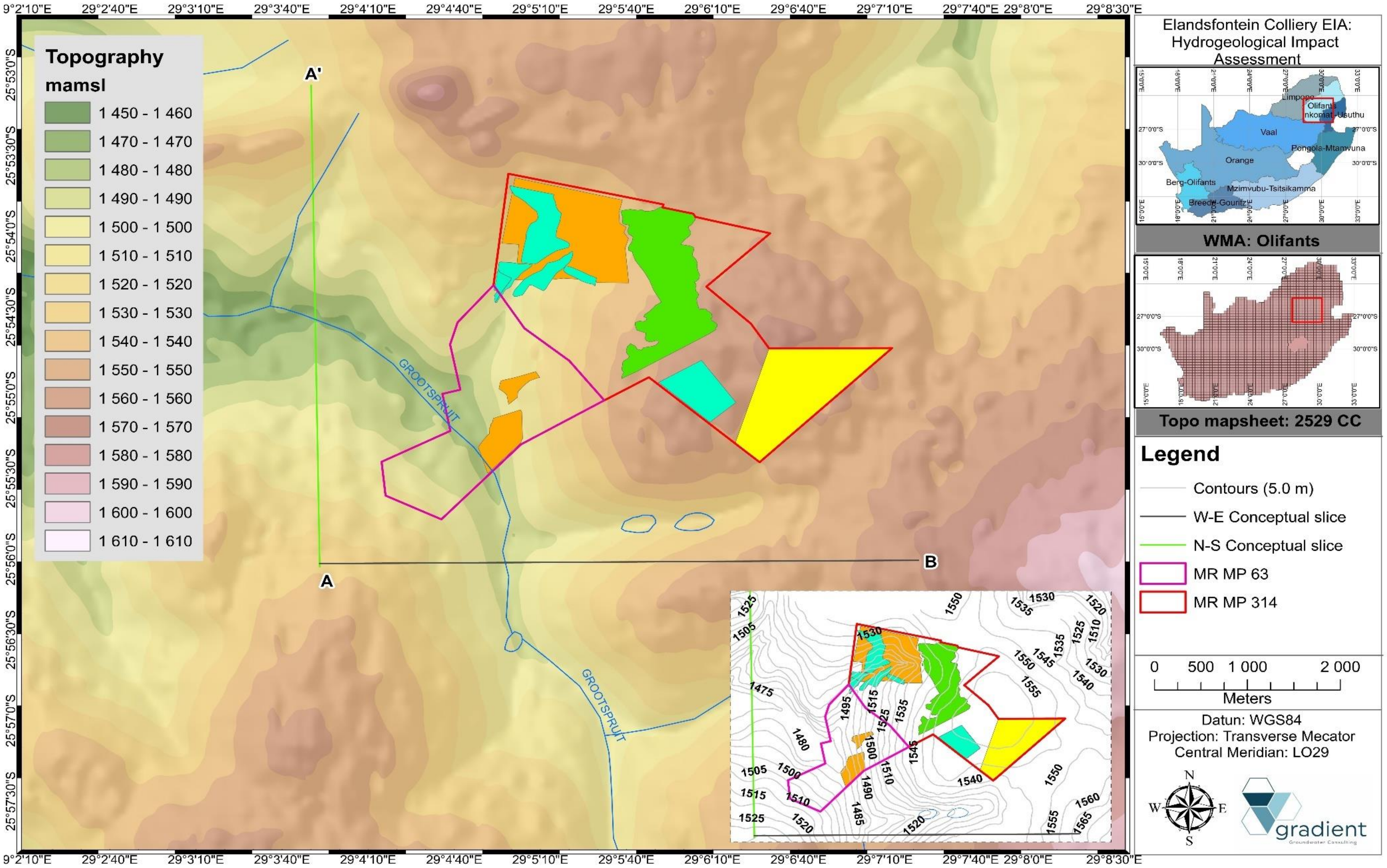


Figure 5-2 **Regional topography (Figure 5-1**Error! Reference source not found.**).**

5.2. Drainage and catchment

The project area is situated in primary catchment (B) of the Elands, Wilge, Steelpoort and Olifants River drainage systems. The resource management falls under the Olifants Water Management Area (WMA) (54 550 km^2) which spans portions of the Limpopo, Mpumalanga as well as Gauteng. The study area is situated within quaternary catchment B20G (nett surface area of 519.4 km^2), falls within hydrological zone J and has an estimated mean annual runoff (MAR) of 44.1 mcm (million cubic metres) (WR 2012).

Although local surface water drainage on site is inferred to be in a general southwestern direction, the regional drainage occurs in a general north to north-western direction. The Grootspruit, transecting the project area to the southwest, convergences with the Saalboomspruit approximately 5.0 km to the northwest of the mine lease area from where it flows in a general northern direction before joining the Kromdraaispruit and Wilge Rivier ~ 20.0 km to the north. Major surface water features within this quaternary catchment include the Clewer dam < 1.0 km up-gradient of the mine lease boundary.

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 B20G.

Table 5-1 Quaternary catchment information: B20G.

Attribute	Catchment information
Water Management Area (WMA)	Olifants
Primary catchment	B
Secondary catchment	B2
Tertiary catchment	B20
Quaternary catchment	B20G
Major rivers	Elands,Wilge,Steelpoort and Olifants
Hydro-zone	J
Rainfall zone	B2C
Area (km^2)	522.0
Mean annual rainfall (mm)	669.0
Mean annual evaporation (mm)	1700.0
Mean annual runoff (mm)	44.1
Baseflow	10.8
Population	34279.0
Total groundwater use (l/s)	5.2
Present Eco Status Category	Category E/F
Recharge	7.0
Average water level (mbgl)	13.4
Soil type	SaClLm
Groundwater General Authorization	0 m^3/ha/a

Note: Catchment based information sourced from Aquiworx 2014

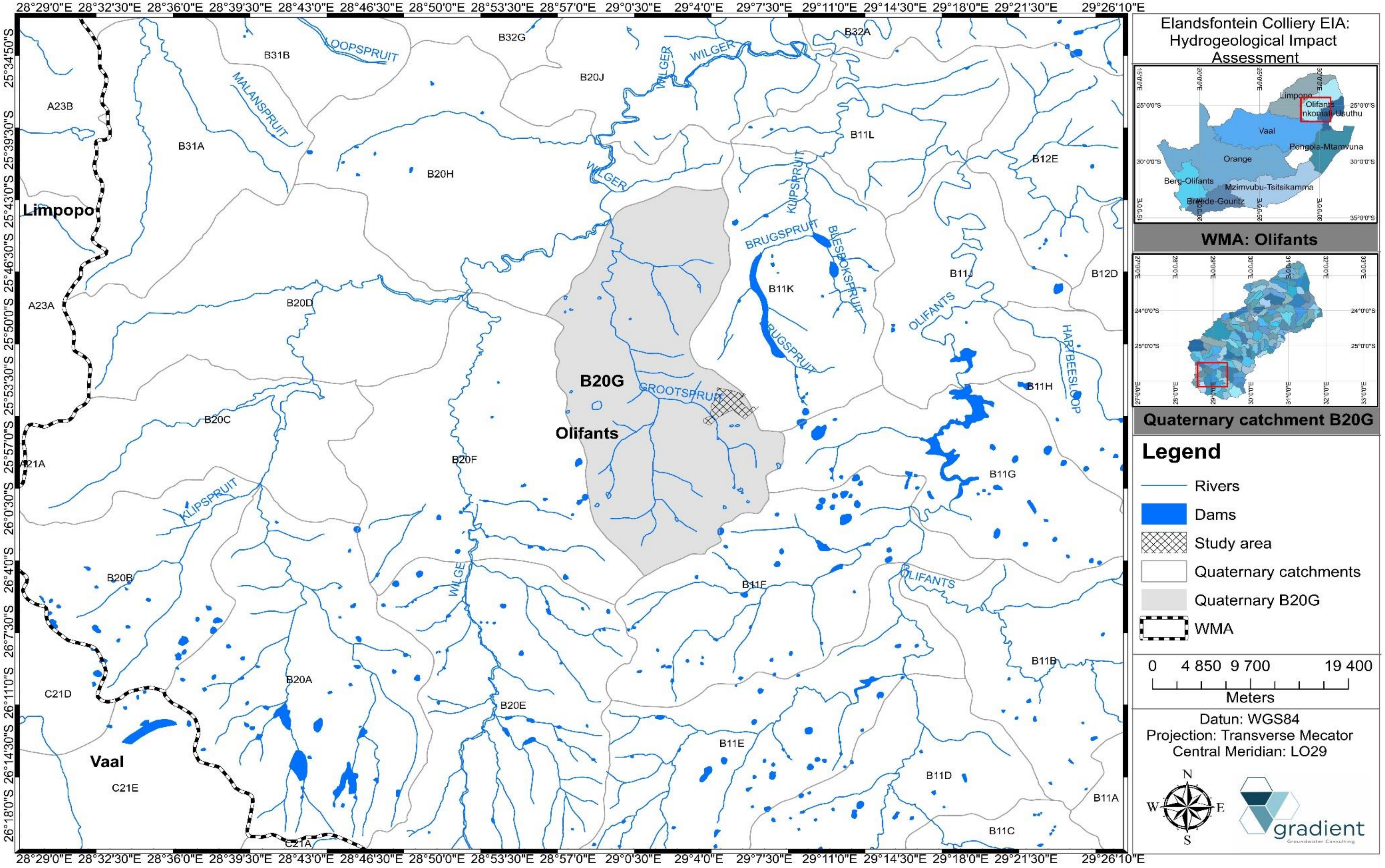


Figure 5-3 Quaternary catchments and water management area.

5.3. Climate

The study area's weather pattern reflects a typical summer rainfall region, with > 85.0% of precipitation occurring as high-intensity thunderstorms from October to March. Patched rainfall and evaporation data were sourced from the WR2012 database (Rainfall zone B2C) and span a period of some 90 years (1920 – 2009). The calculated mean annual precipitation (MAP) for this rainfall zone is 530.76 mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 342.74 mm/a and the 95th percentile (representing a ~1:20 flood period) 717.84 mm/a. The highest MAP for the 90 years of rainfall data was recorded as of 940.85 mm (1995) while the lowest MAP of 291.38 mm was recorded during 1965. This quaternary catchment is categorised under evaporation zone 4A which have a mean annual evaporation (s-pan) of 1689.0 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.

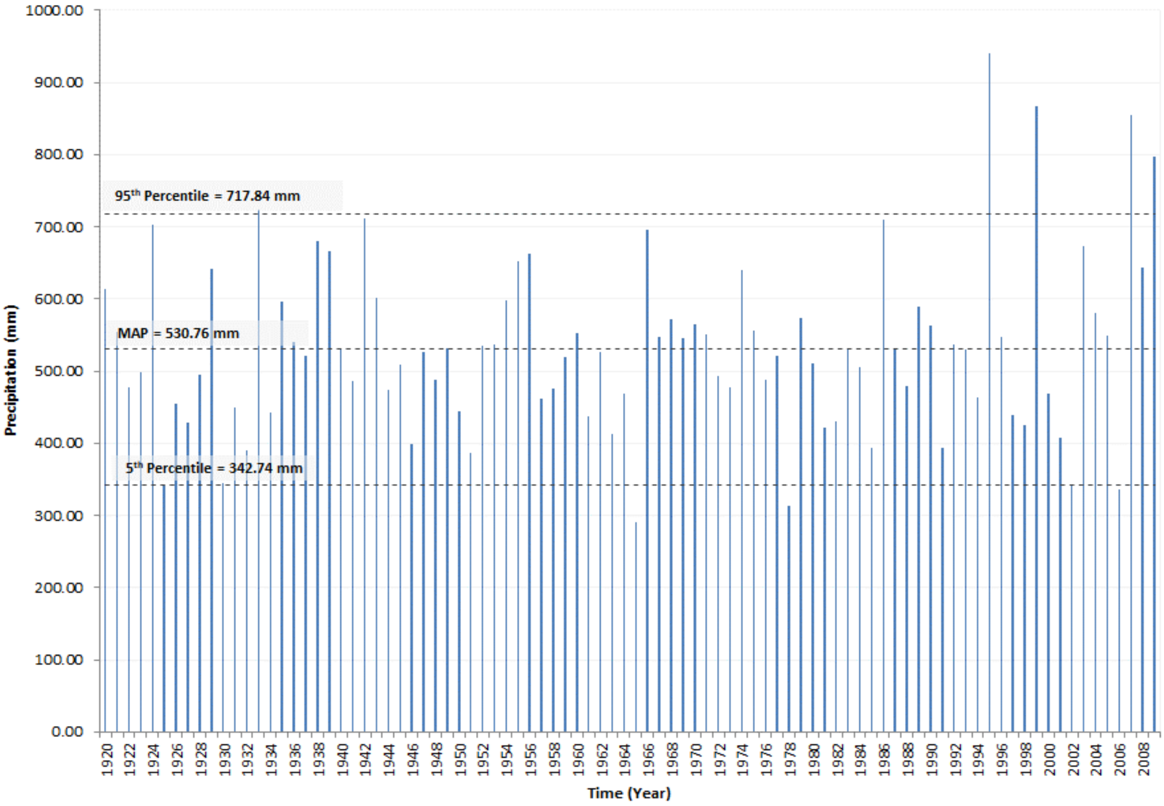


Figure 5-4 Bar chart indicating yearly rainfall distribution for rainfall zone B2C (WR2012).

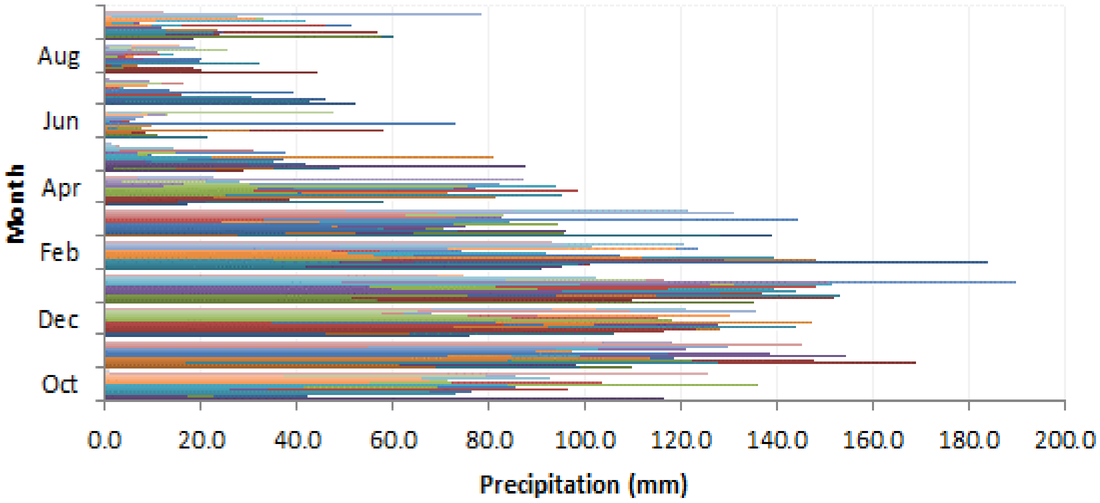


Figure 5-5 Bar chart indicating monthly rainfall distribution for rainfall zone B2C (WR2012).

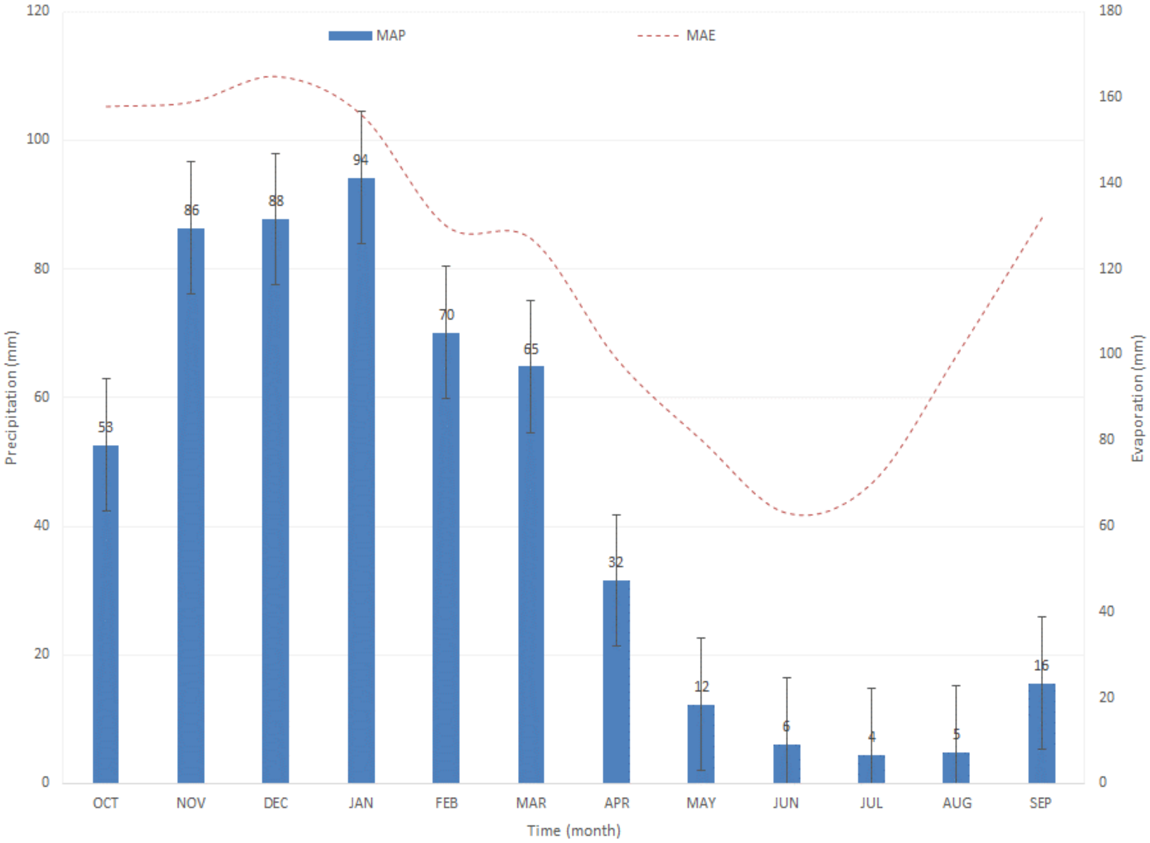


Figure 5-6 Bar chart and curve comparing monthly rainfall and evaporation distribution (WR2012).

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 (Figure 5-7).

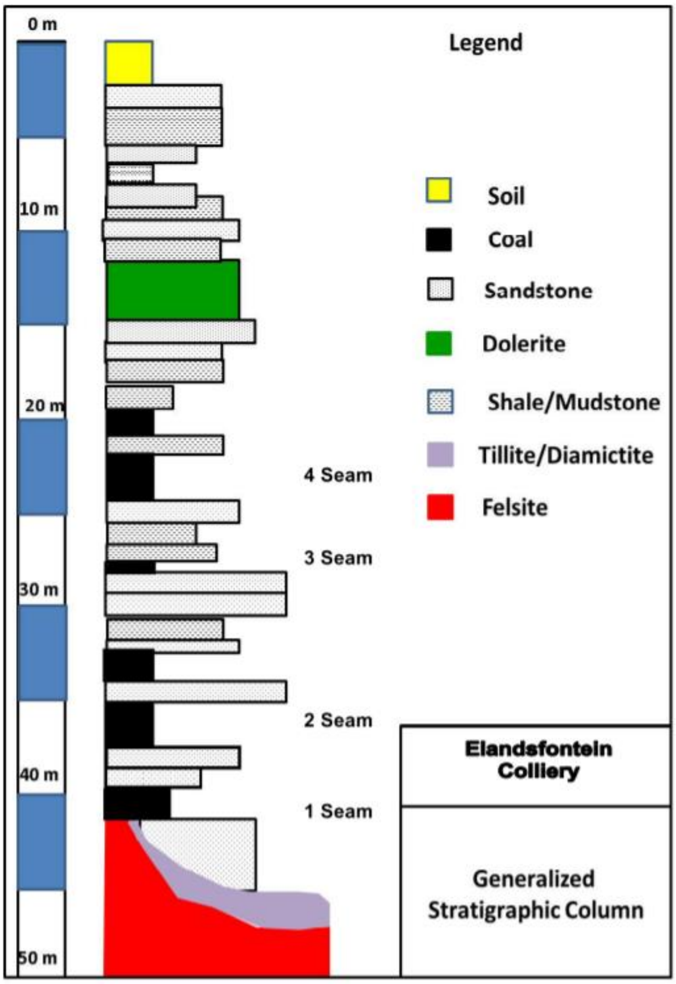
5.4.2. Local geology

According to the 1:250 000 geological mapsheet (2528, Pretoria) the study area falls within the Madzaringwe formation with surficial geology consisting mainly of shale, shaly sandstone, grit, sandstone, conglomerate as well as interlaminated coal layers and entail predominantly arenaceous formations. Refer to Table 5-2 for a simplified stratigraphic column of the study area.

5.4.3. Structural geology

On a regional scale, two geological lineaments (potentially faults zones) exist in close proximity to the greater study area, striking in a general north-south and southwest-northeast orientation respectively. Faults zones may have an impact on the local hydrogeological regime as it can serve as potential preferred pathways for groundwater flow and contaminant transport.

Table 5-2 **Simplified stratigraphic column of the greater study area (after Georoc, 2020).**



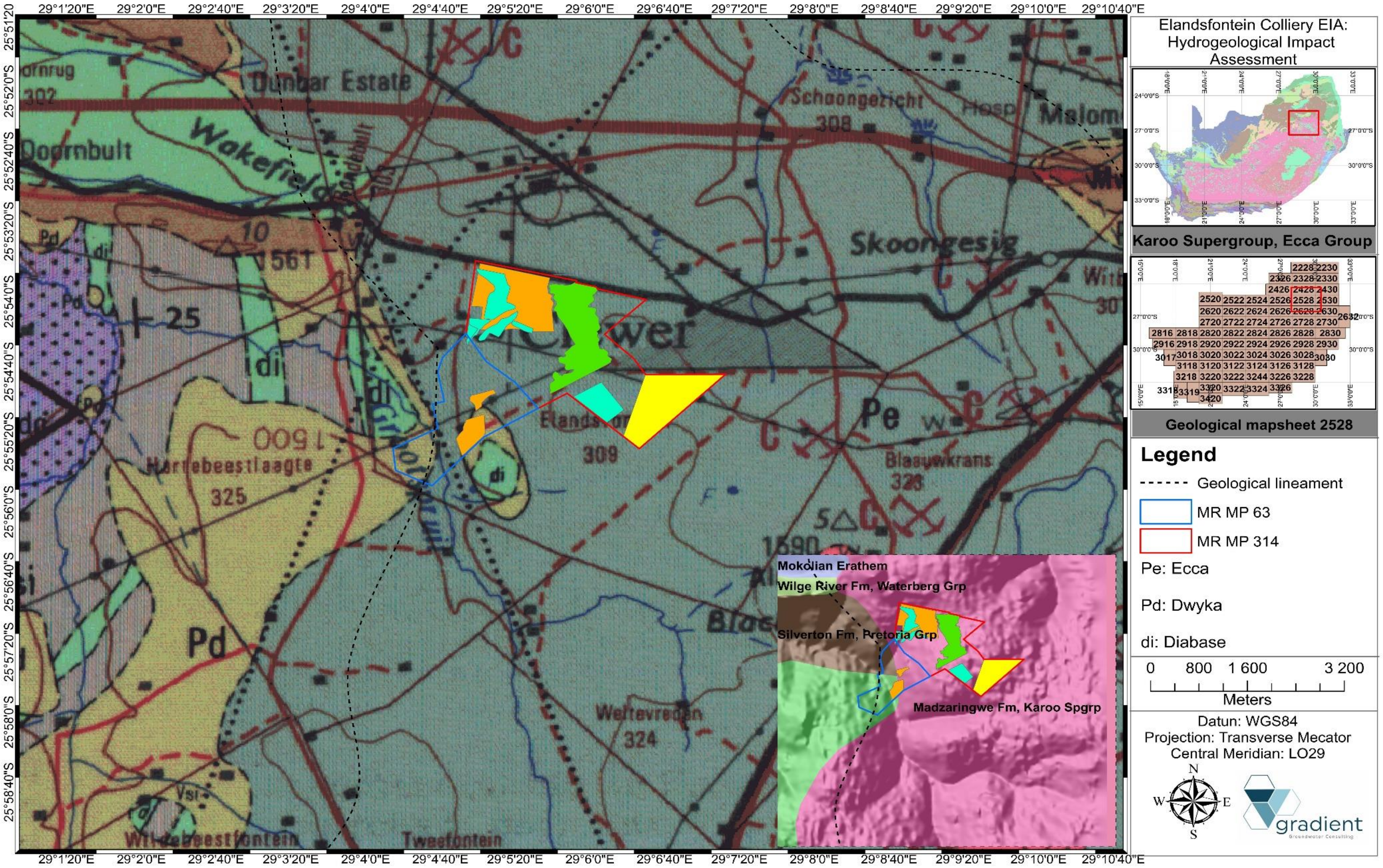


Figure 5-7 **Regional geology and stratigraphy (Geological mapsheets 2630).**

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

6.1. Regional hydrogeology

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.

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2526 Johannesburg) the site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks (Figure 6-1). The Ecca Group consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Water is stored mainly in decomposed/partly decomposed rock and water bearing fractures are principally restricted to a shallow zone below the static groundwater level. Sustainable borehole yields are limited to < 0.5 l/s, while higher yielding boreholes (> 3.0 l/s) may occur along structural features i.e. fault and fracture zones (Barnard, 2000). Water levels are variable and controlled by topography, ranging from 10.0 mbgl (in low laying areas) to > 40.0 mbgl in higher elevated areas (Olifants ISP DWS, 2004). The maximum aquifer depth fluctuates between 30.0 – 50.0 mbgl. depicted in Figure 6-2.

6.2. Local hydrostratigraphic units

For the purposes of this investigation, two main hydrostratigraphic units 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. Ecca sediments are weathered to depths between 5.0 – 15.0 mbgl (Digby Wells, 2018). Groundwater flow patterns usually follow the topography, discharging as natural springs and/or baseflow at topographic low-laying 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 and shales sequences are considered as hard-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.

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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.

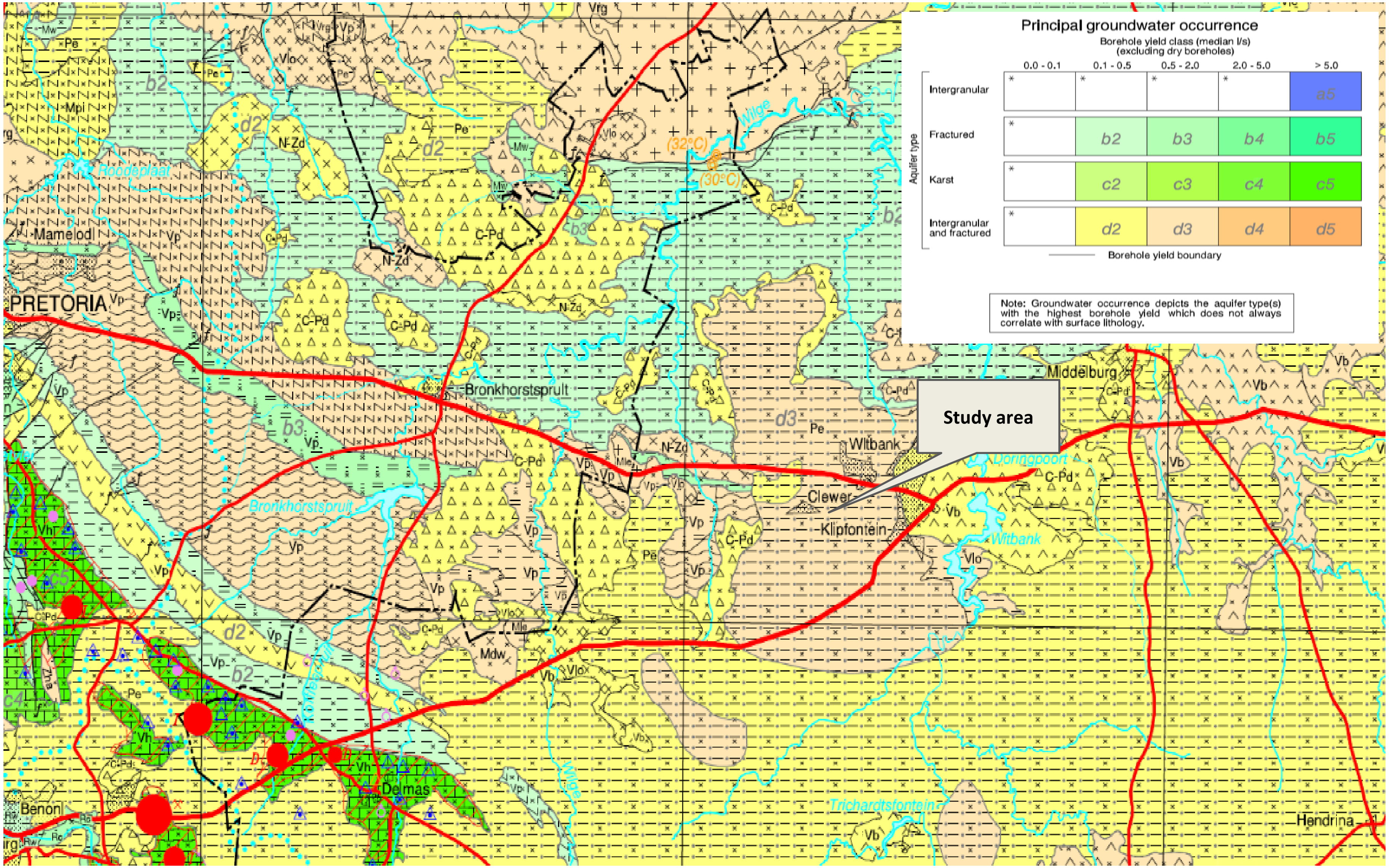


Figure 6-1 **Hydrogeological map illustrating the typical groundwater occurrence for the study region.**

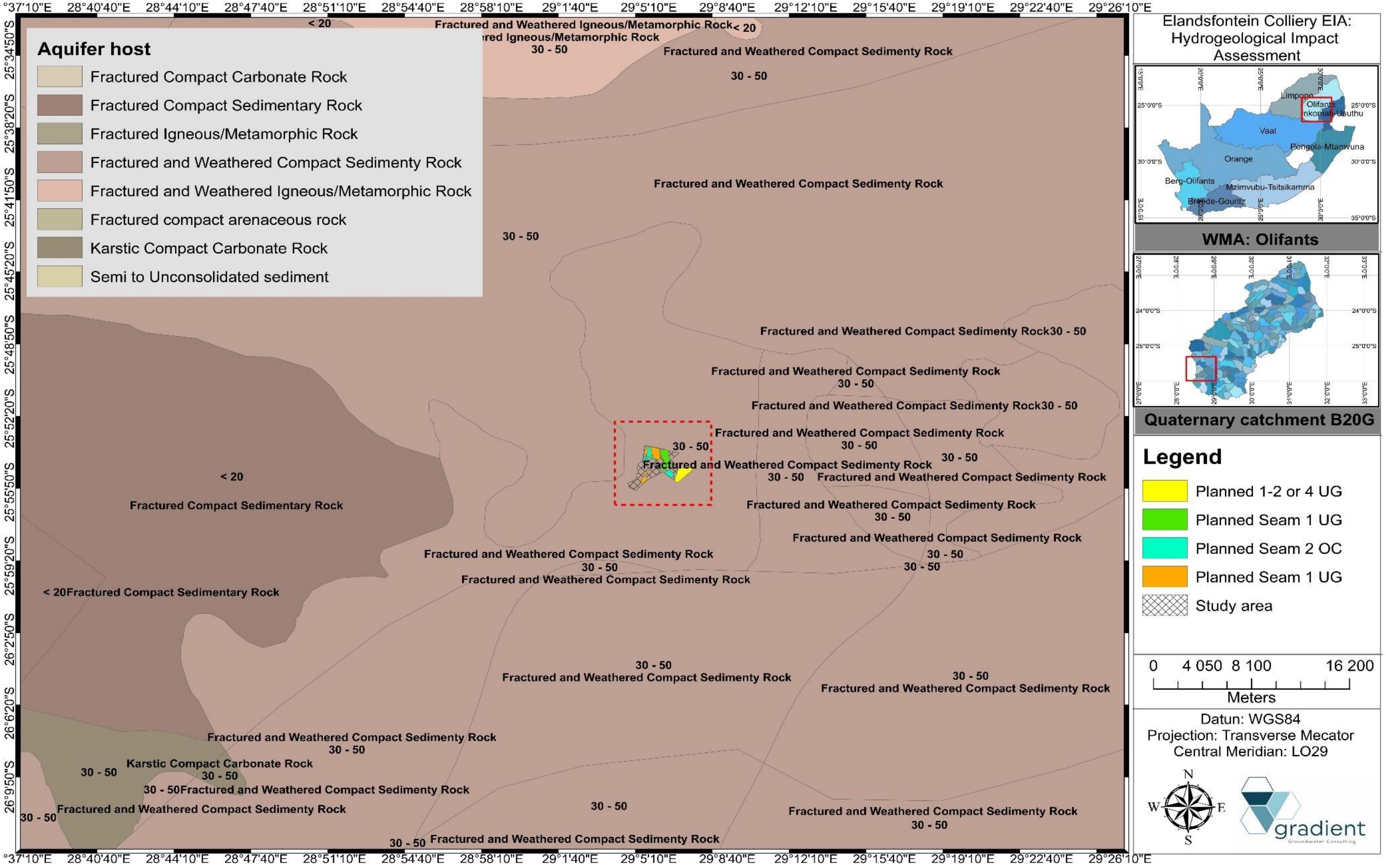


Figure 6-2 **Hydrostratigrpahical units.**

6.3. 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.

6.3.1. 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).

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

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 sandstone formations can range from $9e^{-05}$ – $9e^{-01}$ m/d whereas the hydraulic conductivity of denser shale formations is lower and estimated at $9e^{-09}$ – $9e^{-05}$ m/d. The conductivity of the weathered aquifer, including brittle coal seams, may be orders of magnitude higher and is estimated at $5e^{-02}$ m/d. It should also be noted that mined out and back-filled areas may have different hydraulic properties as the inherent values have been altered and modified (Freeze and Cherry, 1979).

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.

$$\boldsymbol{T = Kb}$$

where:

T = Transmissivity (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

The average transmissivity for the shallow, weathered aquifer is estimated at between 1.0 - 10.0 m^2/d, depending on the Hydrostratigraphic unit targeted.

6.3.2. Storativity

Storativity refers to the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. Typical storativity values for dense sedimentary formations is in the order of 10^{-5} – 10^{-3} while storativity values of the shallow, weathered aquifer can be slightly higher at 10^{-2} (Freeze and Cherry, 1979).

6.3.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. The porosity of sandstone formations ranges between 0.05 – 0.30, while porosity of shale formations varies from 0 – 0.10. Porosity of the weathered aquifer and unconsolidated formations can be as high as 0.25 – 0.40 depending on the nature and state of weathering as well as sorting (Freeze and Cherry, 1979).

6.3.4. Recharge

An approximation of recharge for the study area is estimated at ~6.21 % of MAP i.e. ~32.93 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 6-3) (iv) Harvest Potential Map; (v) Baseflow as a minimum recharge value (Figure 6-4) (vi) Literature and (vi) Qualified opinion. It should be noted that due to the modified mining environment, recharge values may differ at certain zones i.e. backfilled areas, discard dumps etc. Using the simplified CMB method as proposed by Bean (2003), the following equation applies to calculating recharge.

Equation 6-3 Chloride Mass Balance formula.

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

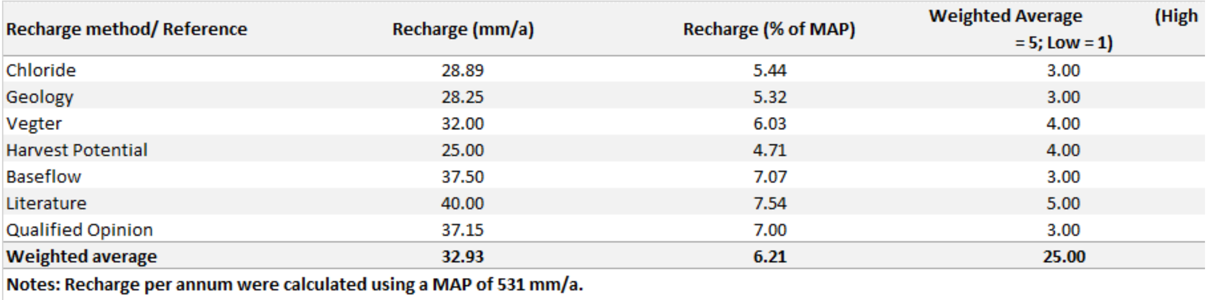
where:

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	28.89	5.44	3.00
Geology	28.25	5.32	3.00
Vegter	32.00	6.03	4.00
Harvest Potential	25.00	4.71	4.00
Baseflow	37.50	7.07	3.00
Literature	40.00	7.54	5.00
Qualified Opinion	37.15	7.00	3.00
Weighted average	**32.93**	**6.21**	**25.00**

Notes: Recharge per annum were calculated using a MAP of 531 mm/a.

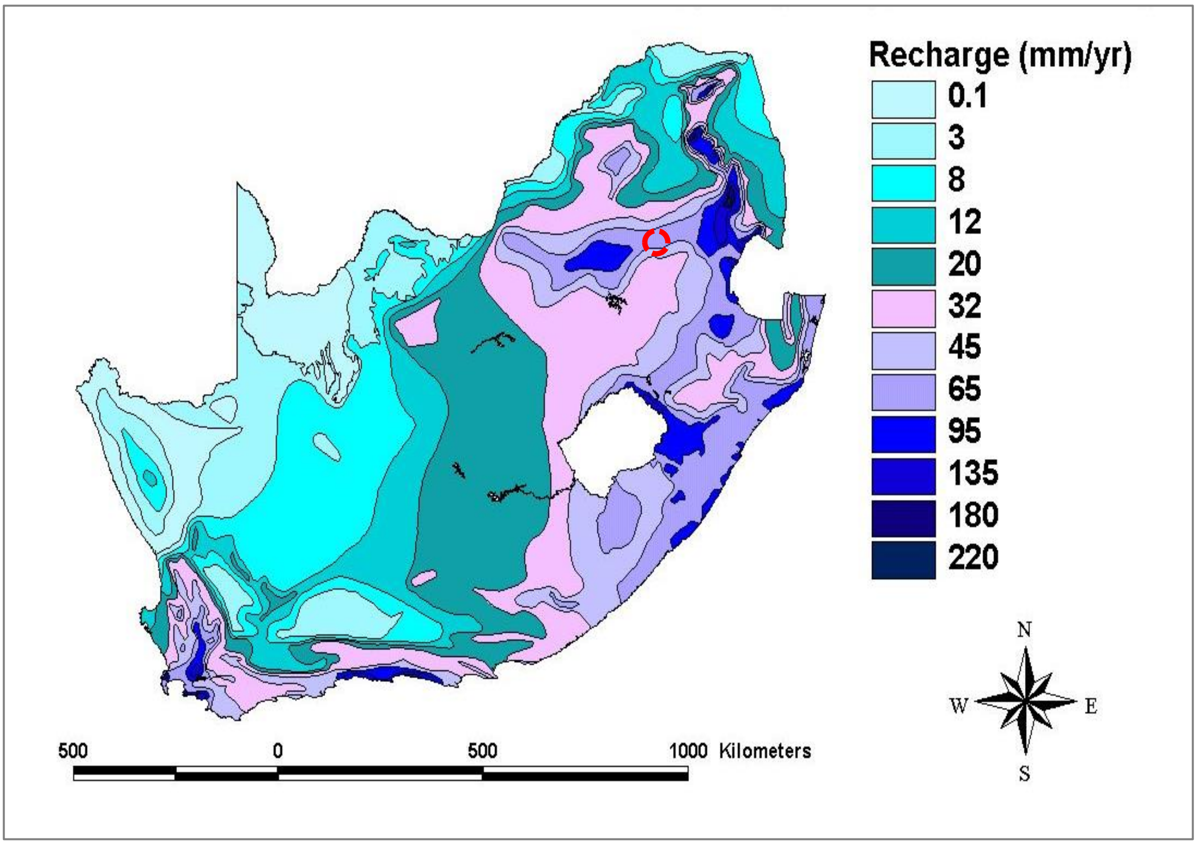


Figure 6-3 Groundwater recharge distribution in South Africa (After Vegter, 1995).

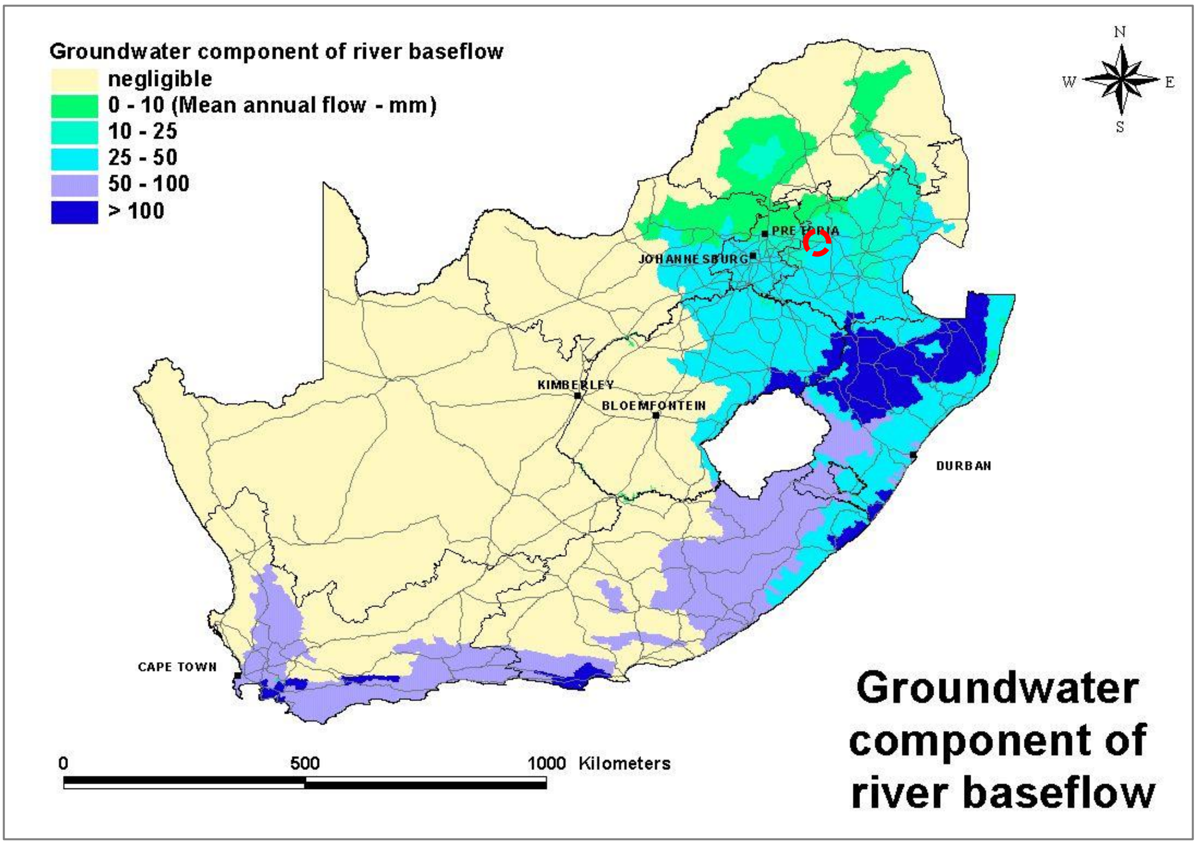


Figure 6-4 Groundwater component of river baseflow in South Africa (DWS, 2013).

6.4. Site investigation

A hydrocensus user survey within the greater study area was conducted during August 2019[5] 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 activities and to identify potential sensitive environmental receptors i.e. groundwater users in the direct vicinity of the operations. Geosites visited include 21 boreholes as well as two (2) surface water features i.e. drainages. Relevant hydrocensus information is summarised in Table 6-2 with a spatial distribution map shown in Figure 6-5.

6.4.1. Groundwater status

Of the boreholes recorded, the majority are in use (>73.0%) with only two boreholes are not currently utilised Refer to Figure 6-7.

6.4.2. Groundwater application

According to the Olifants Internal Strategic Perspective (ISP) (2004), the greater study area is charatcerised by agricultural activities, mostly stock farming, but with maize and other arable crops grown in flat areas. Most boreholes recorded are being applied for monitoring purposes (> 70.0 %) while groundwater application recorded for domestic and livestock purposes is ~17.0% and domestic and household purposes accounts for ~11.0% as summarised in Figure 6-8.

6.4.3. Borehole equipment

Most boreholes visited are not equipped (>70.0 %) while the remaining boreholes are equipped with submersible pumps (~28.0%) as indicated in Figure 6-9.

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[5] It should be noted that relevant site information gathered will be representative of dry season contribution.

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	Comments
ASW 01	-25.90871	29.06532	0.00		River	Not in use		Not in use		Witbank Anker Mine	
AHBH01	-25.91653	29.06203	4.85	Static	Borehole	Domestic	Submersible	Water supply	0724114242	Witbank Anker Mine	Pump 1x per week for 20 min
AHBH02	-25.91809	29.04529	10.29	Static	Borehole	Domestic & Livestock	Submersible	Water supply	0728984173	Witbank Anker Mine	Pump 4X per week for 1Hour
AHBH03	-25.92835	29.07116	8.18	Static	Borehole	Domestic	Submersible	Water supply	0715370381	Witbank Anker Mine	Pump 1x evey 2 weeks for 1,5 Hours
ELNBH1	-25.91337	29.10857	36.31	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ECBH05	-25.90390	29.09791	39.07	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ELNBH 07 S	-25.90810	29.09977	13.98	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ELNBH 06 D	-25.90823	29.09978	0.00		Borehole	Not in use	Not equipped	Not in use		Witbank Anker Mine	Ants closed borehole
ECBH 02	-25.90317	29.09656	7.56	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ECBH 03	-25.90300	29.09633	7.57	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ECBH 04	-25.90200	29.09721	9.55	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ELNBH 02	-25.91422	29.10172	49.69	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	Not allot of water to take sample
GW 02	-25.91337	29.09551	23.19	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ELNBH 03	-25.91994	29.08637	17.34	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ASW 02	-25.91884	29.07801	0.00		River	Not in use		Not in use		Witbank Anker Mine	
BH 173	-25.92416	29.07895	4.02	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
BH 172	-25.92389	29.07795	5.78	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
FFBH 11	-25.98498	29.08882	6.81	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
AHBH04	-25.91113	29.11185	7.18	Static	Borehole	Not in use	Not equipped	Not in use	0826263161	Witbank Anker Mine	
AHBH05	-25.90756	29.11130	38.68	Recovering	Borehole	Domestic & Livestock	Submersible	Water supply	0727833920	Witbank Anker Mine	Timer pump 1every hour foe 5min
AHBH06	-25.90661	29.11516	19.89	Recovering	Borehole	Domestic & Irrigation	Submersible	Water supply	0836607410	Witbank Anker Mine	Pump 1x pd for 9h
AHBH07	-25.90243	29.11997	7.54	Static	Borehole	Not in use	Not equipped	Not in use	0790532976	Witbank Anker Mine	
AHBH08	-25.90627	29.12654	4.28	Static	Borehole	Not in use	Submersible	Not in use	0790782209	Witbank Anker Mine	

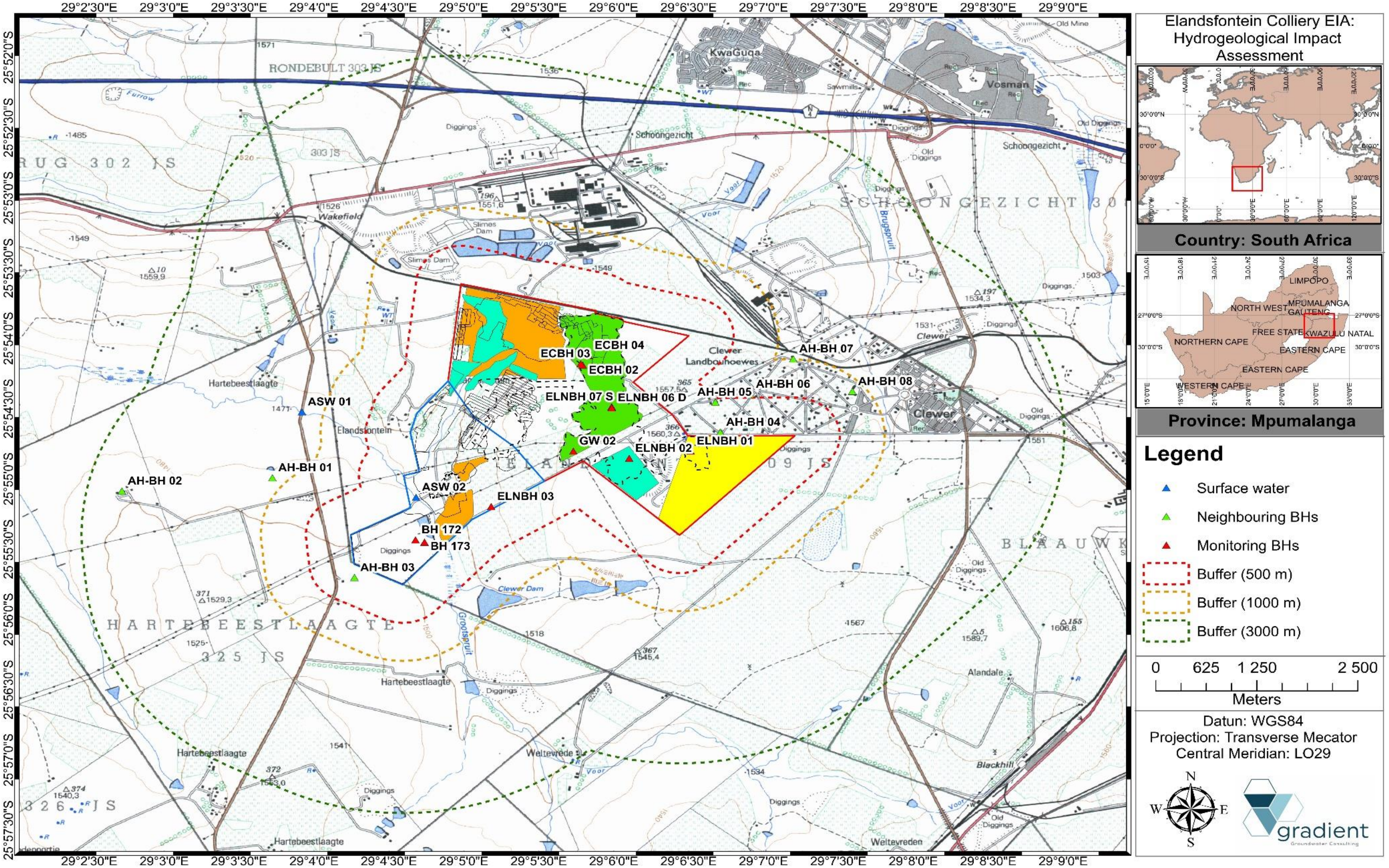

Figure 6-5 Spatial distribution of hydrocensus user survey geosites.

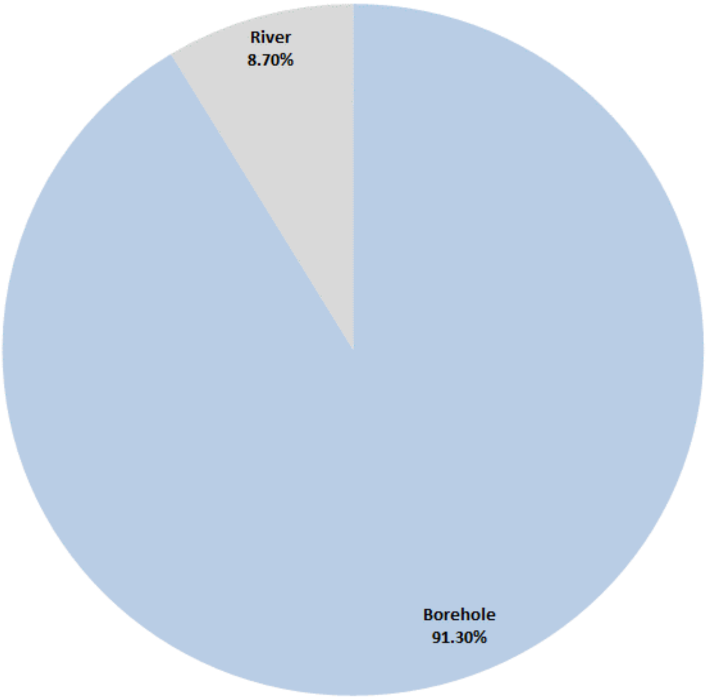

Figure 6-6 **Hydrocensus user survey: Geosite recorded.**

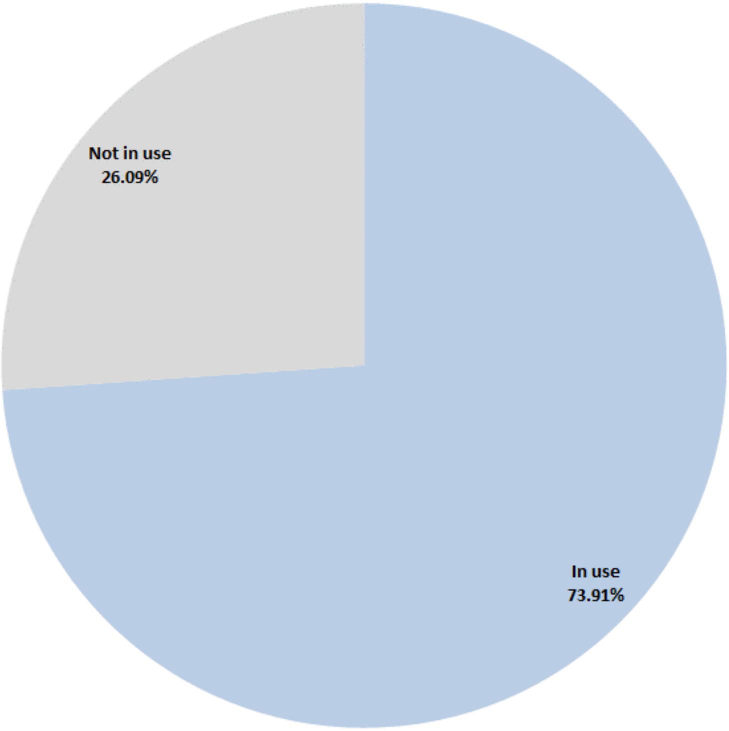

Figure 6-7 **Hydrocensus user survey: Groundwater status.**

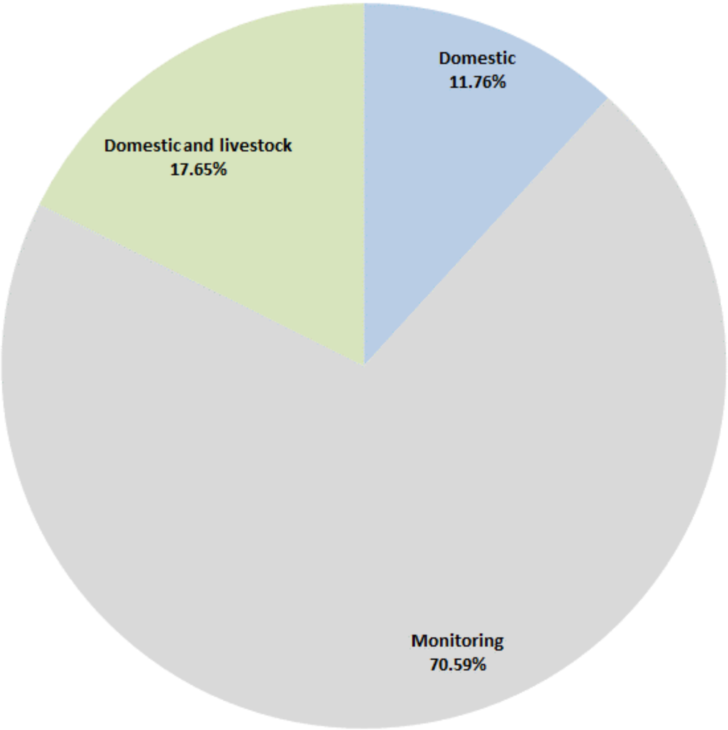

Figure 6-8 **Hydrocensus user survey: Groundwater application.**

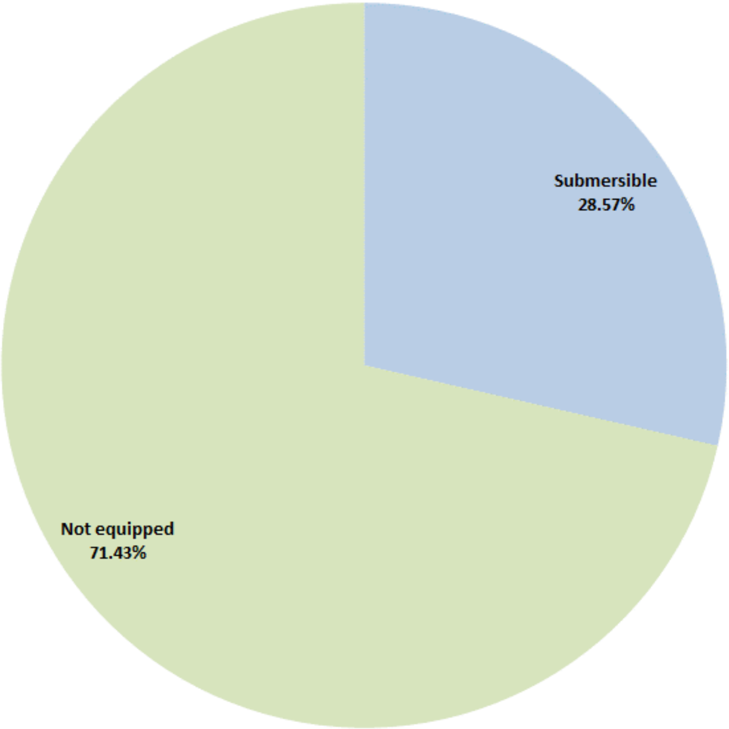

Figure 6-9 **Hydrocensus user survey: Equipment type.**

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[6] within the study area is in the order of ~2.85 to ~22.19 m with a mean thickness of approximately 8.50 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 was recorded at on-site borehole GW05 (2.85 mbgl), while the deepest water level measured was at borehole locality ELNBH02, 49.69 mbgl[7]. The average water level is 13.4 mbgl.

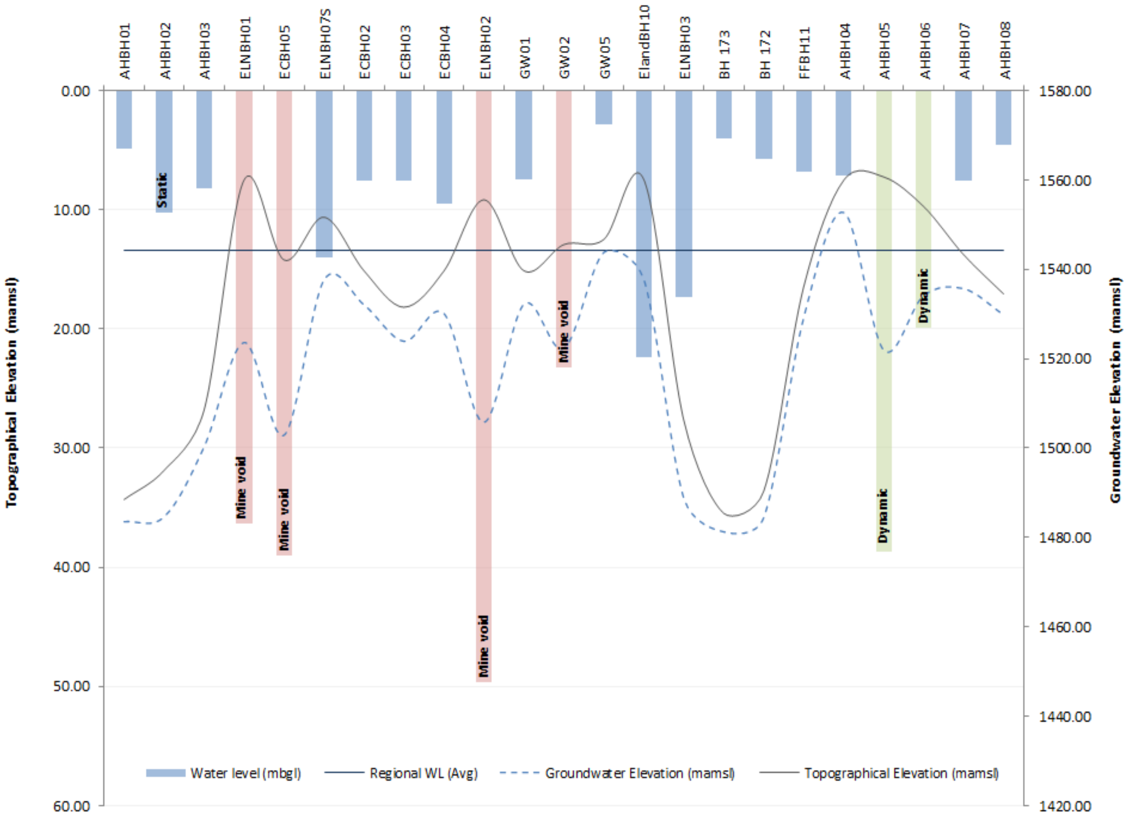

Figure 7-1 **Topographical elevation vs. groundwater elevation correlation graph.**

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[6] This is based on all static groundwater levels measured at surveyed boreholes.

[7] It should be noted that static water levels in excess of ~35.0 mbgl measured within the mining footprints are assumed to enter historical mine voids. Hydrochemistry analysis also confirm this assumption.

Table 7-1 Regional water level summary[8].

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)	Water level status
AHBH01	1488.41	4.85	1483.56	Static
AHBH02	1494.94	10.29	1484.65	Static
AHBH03	1508.46	8.18	1500.28	Static
ELNBH01	1559.92	36.31	1523.61	UG Void?
ECBH05	1541.99	39.07	1502.92	UG Void?
ELNBH07S	1551.57	13.98	1537.59	Static
ECBH02	1539.57	7.56	1532.01	Static
ECBH03	1531.45	7.57	1523.88	Static
ECBH04	1539.57	9.55	1530.02	Static
ELNBH02	1555.47	49.69	1505.78	Dynamic
GW01	1539.58	7.43	1532.15	Static
GW02	1545.46	23.19	1522.27	UG Void?
GW05	1546.62	2.85	1543.77	Static
ElandBH10	1559.99	22.33	1537.66	Static
ELNBH03	1506.10	17.34	1488.76	Static
BH 173	1485.29	4.02	1481.27	Static
BH 172	1490.29	5.78	1484.51	Static
FFBH11	1536.04	6.81	1529.23	Static
AHBH04	1559.84	7.18	1552.66	Static
AHBH05	1560.58	38.68	1521.90	Dynamic
AHBH06	1553.95	19.89	1534.06	Dynamic
AHBH07	1543.18	7.54	1535.64	Static
AHBH08	1534.39	4.58	1529.81	Static
Harmonic mean	**1533.20**	**8.50**	**1517.87**	
Minimum	**1485.29**	**2.85**	**1481.27**	
Maximum	**1560.58**	**49.69**	**1552.66**	
Standard deviation	**24.45**	**13.12**	**21.29**	
Correlation		**0.84**		

---

[8] Correlation factor calculated by accounting for all water levels measured on-site (static, dynamic and mine void water levels).

7.3. Groundwater flow direction and hydraulic gradients

Analysed data indicate that the regional groundwater elevation correlates moderately to the topographical elevation (R^2 ~ 0.84) suggesting a dynamic environment. However, water level data for the shallow aquifer indicate that the majority of levels correlate very well to the topographical elevation ($R^2 > 0.93$) (Figure 7-1). Accordingly, it can be assumed that the regional groundwater flow direction of the shallow aquifer is dictated by topography. Accordingly, the inferred groundwater flow direction of the shallow aquifer will be in a general southwestern direction towards the lower laying drainage system of the Grootspruit transecting the project area from where it will discharge as baseflow. On-site water levels of the underground mine void do not correlate well to topography and is a function of the coal seam floor contours historically mined.

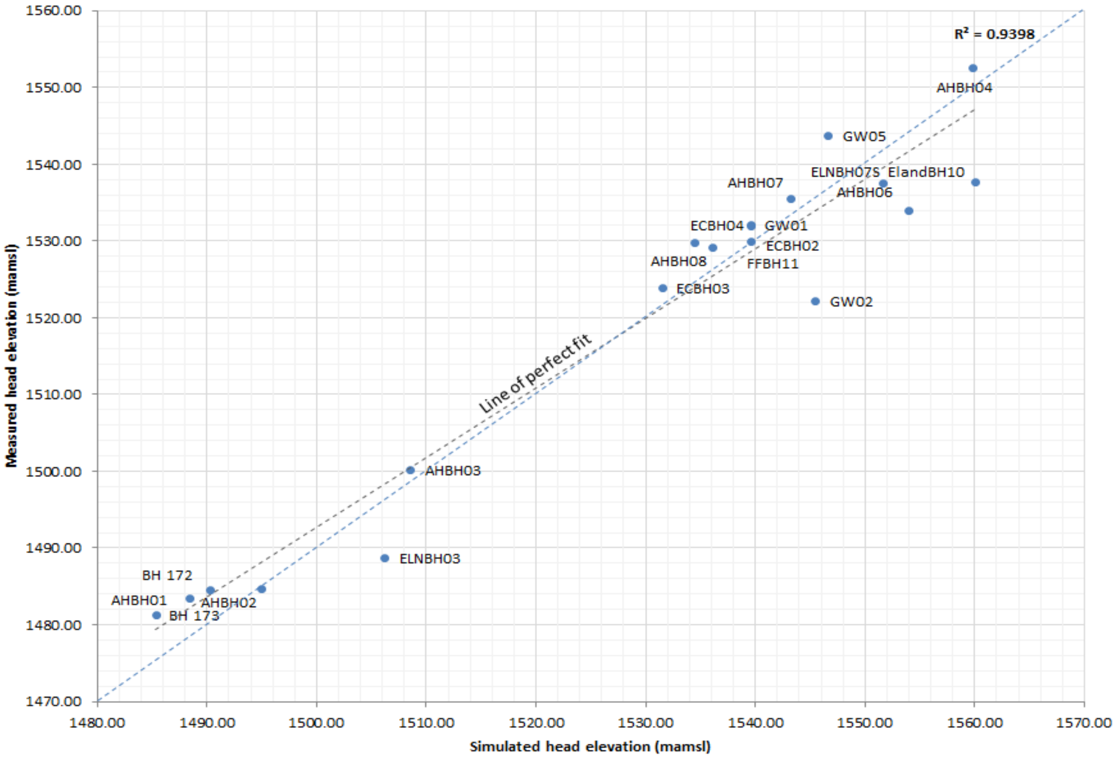

Figure 7-2 **Correlation between topography and groundwater elevation in the shallow aquifer (static WL).**

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 7-3.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.**

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

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points.

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas i.e. mine discard dump and/or slurry ponds is moderately flat and calculated at approximately 0.004, with a maximum of 0.013 towards the west and southwest while a gentler gradient of -0.003 exists to the north as summarised in Table 7-2.

Table 7-2 Inferred groundwater gradient and seepage direction.

Inferred seepage direction	Hydraulic gradient (i)
South	0.013
East	-0.005
West	0.011
North	-0.003
Minimum	**-0.005**
Maximum	**0.013**
Standard deviation	**0.008**
Geometric Mean	**0.004**

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[9] (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.

$$\boldsymbol{v} = \boldsymbol{Ki}$$

Equation 7-3 Seepage velocity.

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

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

$\emptyset$ = effective porosity.

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[9] It should be noted that effective porosity percentages have been assumed and in situ tests have not been conducted to confirm these ratios.

The expected seepage rate from contamination originating at the discard dump is estimated at an average of 0.48 m/a, with a maximum distance of 2.37 m/a in a southern to southwestern direction as summarized in Table 7-3[10].

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	0.013	0.050	0.001	0.100	0.007	2.373
East	0.005	0.050	0.000	0.100	0.002	0.890
West	0.011	0.050	0.001	0.100	0.005	1.986
North	0.003	0.050	0.000	0.100	0.001	0.476
Minimum	**0.003**	**0.050**	**0.000**	**0.100**	**0.001**	**0.476**
Maximum	**0.013**	**0.050**	**0.001**	**0.100**	**0.007**	**2.373**
Standard deviation	**0.004**	**0.000**	**0.000**	**0.000**	**0.002**	**0.774**
Harmonic Mean	**0.005**	**0.050**	**0.000**	**0.100**	**0.003**	**0.964**

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[10] 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.

Figure 7-3 Regional groundwater flow direction and depth to groundwater.

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 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^-.

8.2. Data validation

The laboratory precision was validated by employing the plausibility of the chemical analysis, electro neutrality (E.N.) which is determined according to Equation 8-1, below. An error of less than 5% is an indication that the analysis results are of suitable precision for further evaluation. All samples analysed indicate a good plausibility and data can be considered as accurate and correct (Table 8-3).

Equation 8-1 Electro-neutrality.

$$\boldsymbol{E.N.} = \frac{\sum cations\left[\frac{meq}{L}\right] + \sum anions\left[\frac{meq}{L}\right]}{\sum cations\left[\frac{meq}{L}\right] - \sum anions\left[\frac{meq}{L}\right]} \mathbf{.100\% < 5.0\%}$$

Table 8-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
ASW 01	32.70	32.96	-0.40%
AHBH 01	1.23	1.28	-2.02%
AHBH 02	4.71	4.79	-0.85%
AHBH 03	2.07	2.17	-2.52%
AHBH 04	2.00	2.00	0.09%
AHBH 05	0.84	0.84	-0.11%
AHBH 06	0.49	0.50	-0.96%
AHBH 07	0.84	0.86	-0.89%
ELN BH 01	1.03	1.09	-2.87%
ELN BH 03	28.68	29.05	-0.64%
ELN BH 07	0.46	0.48	-2.11%
ECBH 02	4.97	5.15	-1.75%
ECBH 03	30.38	32.47	-3.31%
ECBH 04	7.99	8.12	-0.80%
ECBH 05	1.52	1.61	-2.97%
BH172	16.09	15.97	0.36%
BH173	1.29	1.23	2.23%
ASW 02	7.40	7.46	-0.40%
FFBH 11	11.01	11.06	-0.20%

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

In order to assess future impacts of the proposed mining expansion activities on the groundwater regime, 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 for future reference. Table 8-4, Table 8-5 as well as Table 8-6 below classify water quality according to pH, Total Dissolved Solids (TDS) as well as total hardness.

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

8.3. Groundwater quality

The overall regional ambient groundwater quality of the shallow aquifer is good with the majority of macro and micro determinants below the SANS 241:2015 limits as summarised in Table 8-7 and Figure 8-1. Isolated sampling localities indicate above limits ammonium (NH4) concentrations which may suggest nearby anthropogenic activities. The local groundwater quality is indicative of an impacted groundwater system and suggest coal mine pollution and acid mine drainage (AMD) conditions present. The latter is characterised by a low pH environment increasing the solubility and concentrations of metals i.e. usually aluminum, iron and manganese. Leaching from mined out faces as well as other waste facilities i.e. discard dumps containing 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.

8.4. Surface water quality

The overall water quality of the surface water samples analysed is poor due to elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) and high salt loads, indicative of coal mine pollution (Table 8-8, Figure 8-2). There is a definite deterioration of water quality evident in a downstream direction and suggest contaminated water ingress from potentially mine decant and interflow zones. Figure 8-3 indicate a spatial distribution map of major anion and cation composition per sample. To follow is a brief description of the water quality for each sample analysed.

8.4.1. Surface water sampling locality ASW01

Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.16.
- TDS of 2150.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 1500.02 mg/l.

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

- EC of 239.0 mS/m.
- TDS of 2150.86 mg/l.
- SO_4 of 1529.17 mg/l.
- Al of 6.60 mg/l.
- Mn of 8.14 mg/l.

8.4.2. Surface water sampling locality ASW02

Water quality can be described as neutral, saline and very hard:

- pH of 7.09.
- TDS of 487.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 327.74 mg/l.

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

- SO_4 of 349.0 mg/l.
- Al of 1.52 mg/l.
- Fe of 0.80 mg/l.
- Mn of 4.52 mg/l.

8.4.3. Groundwater sampling locality ABHB01

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

- pH of 7.09.
- TDS of 487.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 327.74 mg/l.

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

8.4.4. Groundwater sampling locality ABHB02

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

- pH of 7.44.
- TDS of 248.46 mg/l.
- Total Hardness ($CaCO_3$/l) of 119.43 mg/l.

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

- F of 1.91 mg/l.

8.4.5. Groundwater sampling locality ABHB03

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

- pH of 5.71.
- TDS of 108.69 mg/l.
- Total Hardness ($CaCO_3$/l) of 73.95 mg/l.

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

8.4.6. Groundwater sampling locality ABHB04

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

- pH of 5.68.
- TDS of 137.83 mg/l.
- Total Hardness ($CaCO_3$/l) of 48.79 mg/l.

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

8.4.7. Groundwater sampling locality ABHB05

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

- pH of 5.45.
- TDS of 58.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 24.83 mg/l.

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

8.4.8. Groundwater sampling locality ABHB06

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

- pH of 5.90.
- TDS of 34.62 mg/l.
- Total Hardness ($CaCO_3$/l) of 14.66 mg/l.

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

8.4.9. Groundwater sampling locality AHBH07

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

- pH of 6.49.
- TDS of 48.94 mg/l.
- Total Hardness (CaCO3/l) of 17.94 mg/l.

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

- Mn of 0.14 mg/l.

8.4.10. Groundwater sampling locality ELNBH01

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

- pH of 2.90.
- TDS of 59.73 mg/l.
- Total Hardness (CaCO3/l) of 36.99 mg/l.

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

- pH of 2.90.

8.4.11. Groundwater sampling locality ELNBH03

Water quality can be described as acidic, very saline and extremely hard:

- pH of 5.17.
- TDS of 1832.71 mg/l.
- Total Hardness (CaCO3/l) of 899.00 mg/l.

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

- EC of 254.00 mS/m.

- TDS of 1832.71 mg/l.
- SO_4 of 1306.71 mg/l.
- F of 32.18 mg/l.
- Al of 31.20 mg/l.
- Fe of 8.11 mg/l.
- Mn of 105.00 mg/l.

8.4.12. Groundwater sampling locality ELNBH07

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

- pH of 6.50.
- TDS of 33.96 mg/l.
- Total Hardness ($CaCO_3$/l) of 17.56 mg/l.

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

8.4.13. Groundwater sampling locality ECBH02

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

- pH of 5.98.
- TDS of 333.37 mg/l.
- Total Hardness (CaCO3/l) of 174.80 mg/l.

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

- NH_4 of 44.40 mg/l.

8.4.14. Groundwater sampling locality ECBH03

Water quality can be described as acidic, very saline and extremely hard:

- pH of 4.83.
- TDS of 2091.54 mg/l.
- Total Hardness (CaCO3/l) of 1469.39 mg/l.

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

- pH 4.83.
- EC of 218.00 mS/m.
- TDS of 2091.54 mg/l.
- SO_4 of 1461.00 mg/l.
- Fe of 1.54 mg/l.
- Mn of 0.37 mg/l.

8.4.15. Groundwater sampling locality ECBH04

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

- pH of 5.06.
- TDS of 524.92 mg/l.
- Total Hardness (CaCO3/l) of 359.12 mg/l.

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

- SO_4 of 371.74 mg/l.
- Al of 1.07 mg/l.
- Fe of 1.16 mg/l.
- Mn of 2.02 mg/l.

8.4.16. Groundwater sampling locality ECBH05

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

- pH of 3.07
- TDS of 105.62 mg/l.
- Total Hardness (CaCO3/l) of 70.39 mg/l.

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

- pH of 3.07

8.4.17. Groundwater sampling locality BH172

Water quality can be described as neutral, very saline and very hard:

- pH of 6.39.
- TDS of 1023.88 mg/l.
- Total Hardness (CaCO3/l) of 529.39 mg/l.

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

- SO_4 of 733.86 mg/l.
- F of 12.31 mg/l.
- Al of 20.10 mg/l.
- Fe of 43.40 mg/l.
- Mn of 13.00 mg/l.

8.4.18. Groundwater sampling locality BH173

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

- pH of 3.25.
- TDS of 76.49 mg/l.
- Total Hardness (CaCO3/l) of 48.54 mg/l.

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

- pH of 3.25.
- F of 2.91 mg/l.

8.4.19. Groundwater sampling locality FFBH11

Water quality can be described as alkaline, saline and moderately hard:

- pH of 8.75.
- TDS of 741.57 mg/l.
- Total Hardness (CaCO3/l) of 152.19 mg/l.

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

- SO_4 of 362.00 mg/l.
- Mn of 0.15 mg/l.

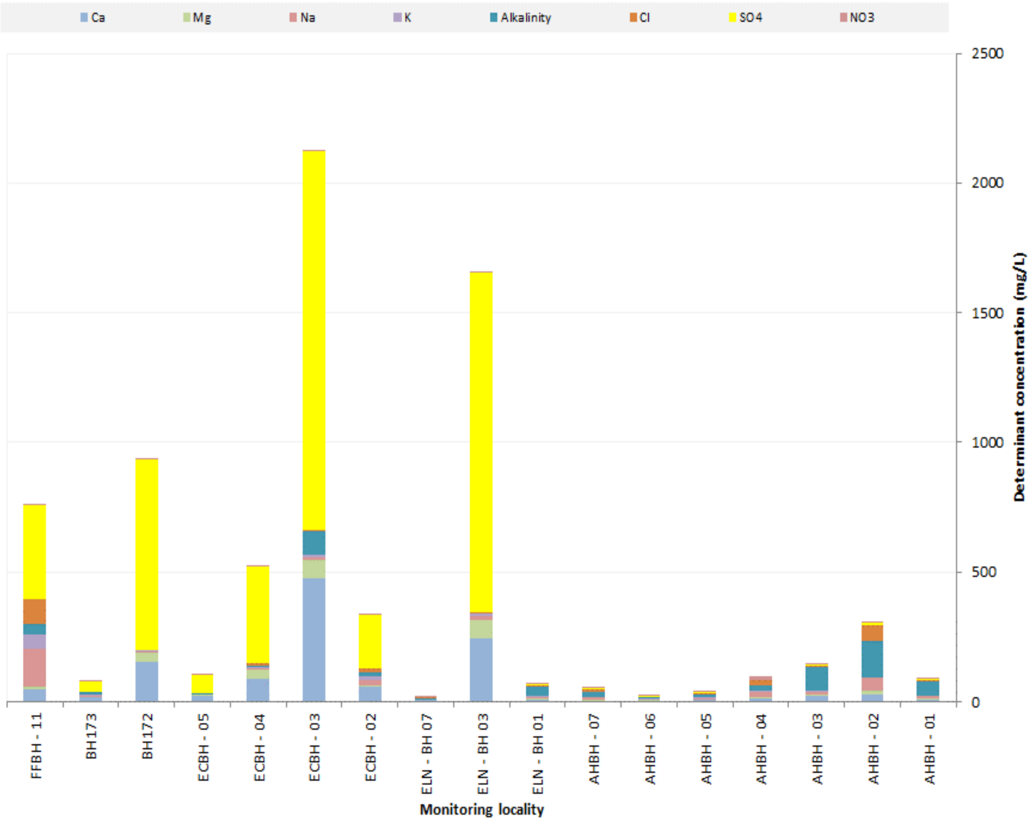

Figure 8-1 Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition.

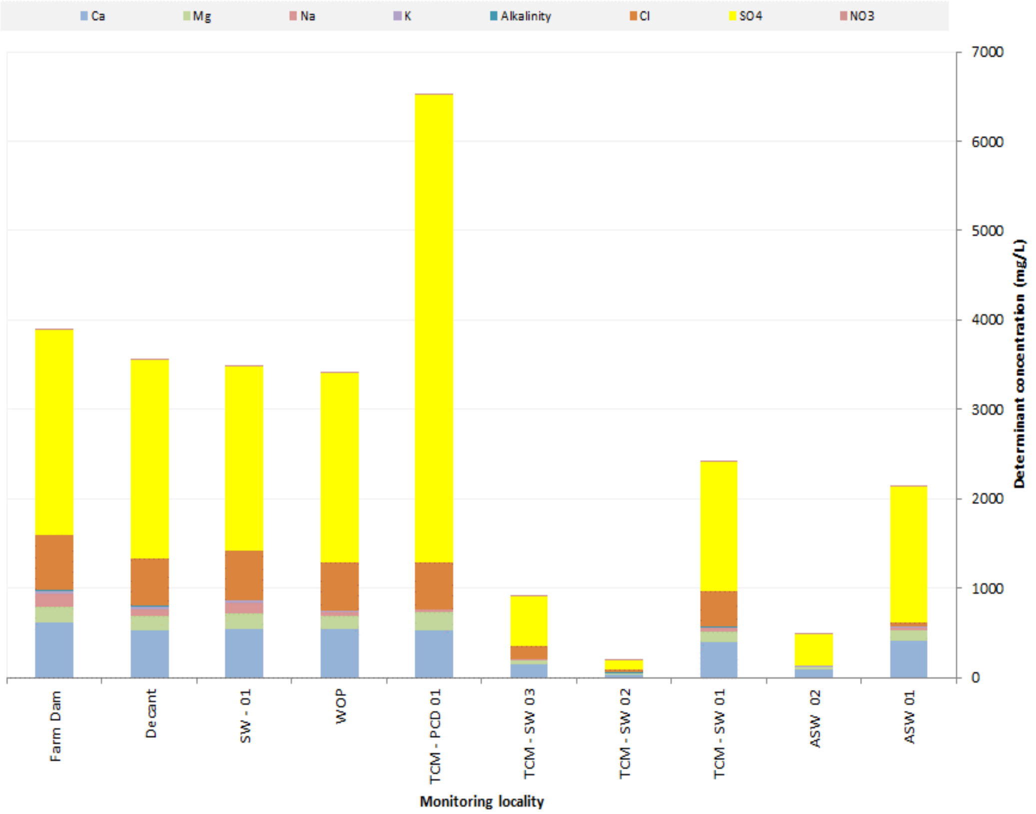

Figure 8-2 Hydrochemistry: Composite bar-chart indicating surface water major anion cation composition.

Table 8-7 Hydrochemistry: Groundwater quality evaluation (SANS 241:2015).

Determinant	Unit	Risk	SANS 241:2015 limits	AHBH 01	AHBH 02	AHBH 03	AHBH 04	AHBH 05	AHBH 06	AHBH 07	ELN BH01	ELN BH03	ELN BH07	ECBH 02	ECBH 03	ECBH 04	ECBH 05	BH172	BH173	FFBH 11
General parameters																				
pH	-	Operational	≥5.0 ≤ 9.5	7.57	7.44	5.71	5.68	5.45	5.90	6.49	2.90	5.17	6.50	5.98	4.83	5.06	3.07	6.39	3.25	8.75
EC	mS/m	Aesthetic	≤170.0	12.76	47.80	21.40	22.10	10.90	6.46	10.40	12.10	254.00	5.56	52.20	218.00	80.00	18.00	169.00	14.70	119.00
TDS		Aesthetic	≤ 1 200.0	63.01	248.46	108.69	137.83	58.86	34.62	48.94	59.73	1832.71	33.96	333.37	2091.54	524.92	105.62	1023.88	76.49	741.57
Total Alkalinity	CaCO3/l	-	-	55.60	141.00	91.80	18.00	7.60	5.80	20.60	38.00	0.00	3.20	19.80	90.20	2.60	2.80	0.00	11.20	38.20
Total Hardness	mg/l	-	-	36.71	119.43	73.95	48.79	24.83	14.66	17.94	36.99	899.00	17.56	174.80	1469.39	359.12	70.39	529.39	48.54	152.19
Anions																				
Cl	mg/l	Aesthetic	≤300.0	3.60	59.90	6.90	20.94	8.09	3.09	10.63	2.97	4.49	2.24	14.13	5.83	8.85	1.10	1.16	1.55	96.30
SO_4	mg/l	Acute health	≤250.0	2.49	7.63	2.78	1.85	2.43	0.68	1.16	5.95	1306.71	3.05	205.00	1461.00	371.74	68.10	733.86	38.90	362.00
F	mg/l	Acute health	≤1.50	0.21	1.91	1.03	0.09	<0.09	0.10	<0.09	0.18	32.18	0.11	1.47	0.52	0.51	0.09	12.31	2.91	<0.09
NO_3< N	mg/l	Acute health	≤11.0	<0.35	<0.35	0.40	13.91	5.65	3.80	1.59	1.51	<0.35	3.93	<0.35	0.46	0.66	1.44	<0.35	<0.35	<0.35
PO_4	mg/l	-	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cations and metals																				
NH_4	mg/l	Aesthetic	≤1.50	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	3.05	<0.45	4.44	0.82	<0.45	<0.45	0.63	<0.45	0.62
Na	mg/l	Aesthetic	≤200.0	10.41	51.60	10.60	19.92	3.83	2.92	9.93	3.17	17.07	1.58	20.04	11.30	8.92	1.50	6.06	5.30	150.00
K	mg/l	-	-	1.08	2.52	4.63	5.81	6.61	2.49	1.76	5.52	9.74	1.36	10.50	9.96	5.07	1.34	4.18	2.45	54.10
Ca	mg/l	-	-	7.13	28.70	20.10	12.40	5.77	3.71	3.59	8.73	243.78	5.12	56.10	475.00	86.10	20.90	153.54	16.76	46.60
Mg	mg/l	-	-	4.59	11.60	5.77	4.33	2.53	1.31	2.18	3.69	70.49	1.16	8.43	68.80	35.00	4.42	35.45	1.63	8.70
Al	mg/l	Operational	0.3	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	31.20	0.01	0.02	<0.01	1.07	0.05	20.10	0.14	<0.01
Fe	mg/l	Aesthetic	0.3	0.13	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.02	105.00	<0.01	<0.01	1.54	1.16	<0.01	43.40	0.06	<0.01
Mn	mg/l	Aesthetic	0.1	<0.01	<0.01	<0.01	0.09	0.01	0.01	0.14	<0.01	8.11	0.02	0.07	0.37	2.02	0.06	13.00	0.09	0.15

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.

Table 8-8 **Hydrochemistry: Surface water quality evaluation (SANS 241:2015).**

Determinant	Unit	Risk	SANS 241:2015 limits	ASW 01	ASW 02	TCM - SW 01	TCM - SW 02	TCM - SW 03	TCM - PCD 01	WOP	SW - 01	Decant	Farm Dam
General parameters													
pH	-	Operational	≥5.0 ≤ 9.5	7.16	7.09	4.74	6.31	3.45	2.43	3.33	5.58	6.00	6.36
EC	mS/m	Aesthetic	≤170.0	239.00	91.40	226.00	30.80	121.00	674.00	293.00	314.00	319.00	332.00
TDS		Aesthetic	≤ 1 200.0	2150.86	487.86	2072.68	172.02	773.92	7026.40	2952.55	3047.01	3135.03	3379.39
Total Alkalinity	CaCO3/l	-	-	0.00	0.00	2.60	15.20	0.00	0.00	0.00	5.20	13.80	12.20
Total Hardness	mg/l	-	-	1500.02	327.74	1436.93	119.69	548.64	2144.97	1952.85	2063.98	2007.70	2285.30
Anions													
Cl	mg/l	Aesthetic	≤300.0	38.65	5.42	399.00	26.00	146.00	528.72	538.00	546.70	525.17	607.63
SO_4	mg/l	Acute health	≤250.0	1529.17	349.00	1448.00	108.00	554.00	5230.92	2122.06	2070.00	2223.00	2301.00
F	mg/l	Acute health	≤1.50	<0.09	0.58	1.05	0.15	2.75	117.00	0.12	<0.09	2.93	<0.09
NO_3< N	mg/l	Acute health	≤11.0	<0.35	<0.35	0.40	<0.35	<0.35	<0.35	0.45	2.12	<0.35	0.64
Cations and metals													
NH_4	mg/l	Aesthetic	≤1.50	<0.45	<0.45	<0.45	<0.45	<0.45	4.09	1.74	1.33	5.50	<0.45
Na	mg/l	Aesthetic	≤200.0	28.00	8.13	43.40	6.78	7.11	28.66	41.90	115.00	70.81	136.90
K	mg/l	-	-	12.10	3.21	13.30	1.21	8.23	3.72	18.50	32.70	25.30	36.74
Ca	mg/l	-	-	416.26	89.15	399.00	26.00	146.00	528.72	538.00	546.70	525.17	607.63
Mg	mg/l	-	-	111.86	25.53	107.00	13.30	44.70	200.28	148.00	169.71	169.10	186.51
Al	mg/l	Operational	0.3	6.60	1.52	3.02	0.01	4.40	403.10	17.13	<0.01	<0.01	0.02
Fe	mg/l	Aesthetic	0.3	0.09	0.80	0.13	0.15	1.69	437.30	13.73	0.52	29.79	0.10
Mn	mg/l	Aesthetic	0.1	8.14	4.52	9.75	0.87	<0.01	68.25	14.47	12.55	11.15	5.13

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.

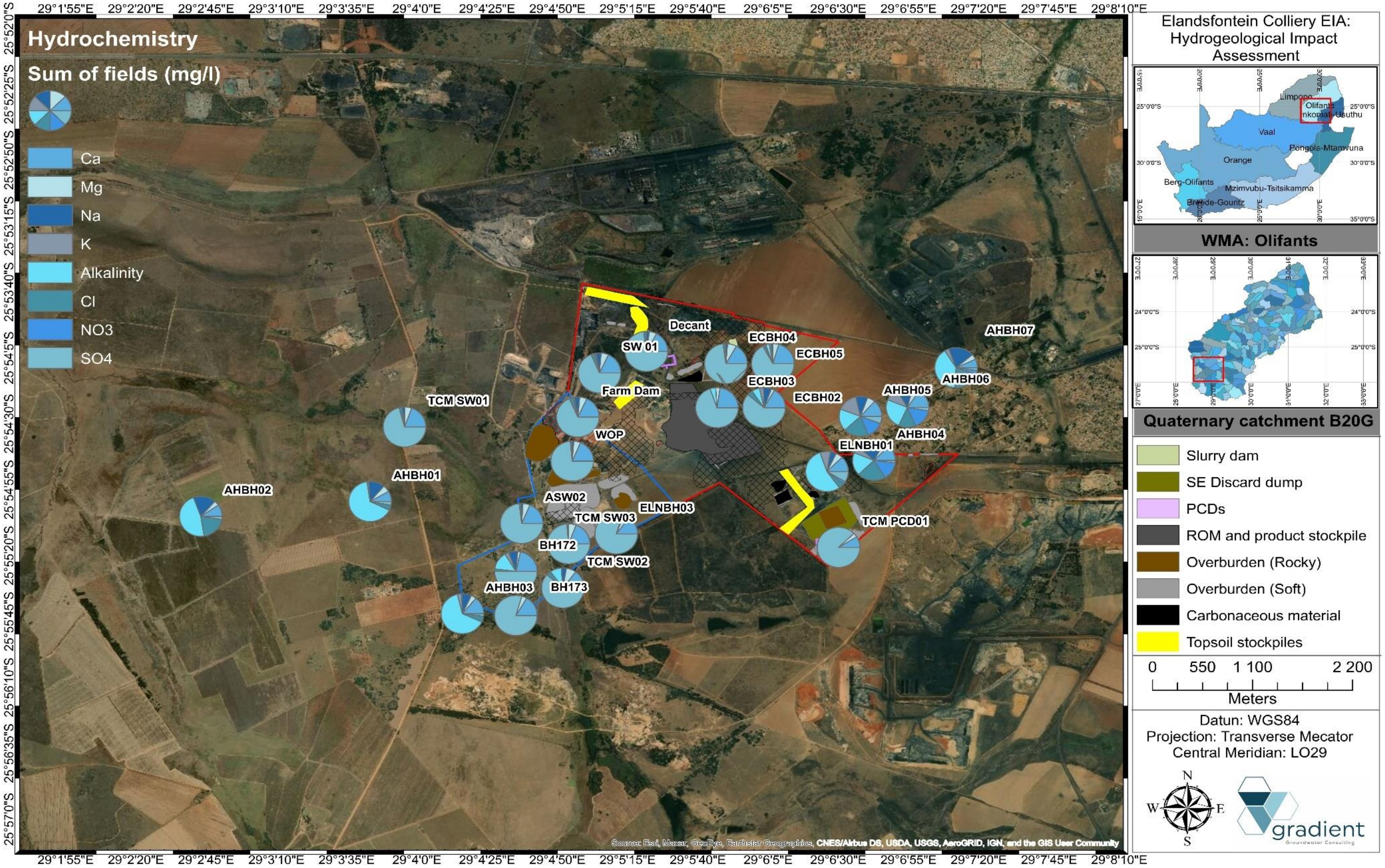

Figure 8-3 **Hydrochemical analysis spatial distribution (mg/l).**

8.5. Hydrochemical signature

The hydrochemical signature of the samples analysed were evaluated by means of diagnostic plots. The latter aid to get an understanding of various environments and sources from where groundwater and surface water originates. Three types of diagnostic plots were used to characterise analysed water samples based on hydrochemistry.

8.5.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 8-4). 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 8-5 depicts a piper diagram developed from the hydrocensus water quality analysis results. The majority of regional/ neighbouring boreholes suggest either a recently recharged and unimpacted water environment (Calcium-Bi-carbonate dominance), and/or area of dissolution and mixing, whereas current monitoring boreholes on site indicate a static and disordinate environment (Sulphate dominance suggesting impacts from coal mine pollution). Sampling locality FFBH11 indicate a Sodium-Chloride dominance suggesting brine waters.

8.5.2. 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 8-6 depicts Stiff diagrams compiled from the groundwater sampling analysis while Figure 8-7 indicate Stiff diagrams compiled from surface water sampling analysis. Groundwater sampling localities ECBH03, ELNBH03 correlate well to the hydrochemical signature of surface water sampling locality ASW01 and suggest similar water environments and potential origins.

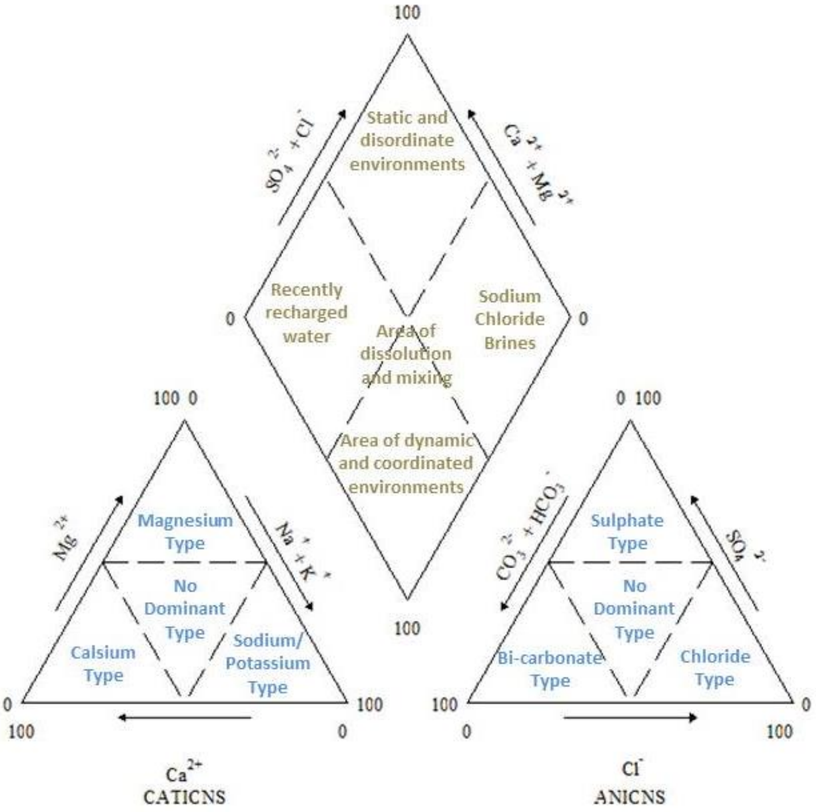

Figure 8-4 **Piper diagram indicating classification for anion and cation facies in terms of ion percentages.**

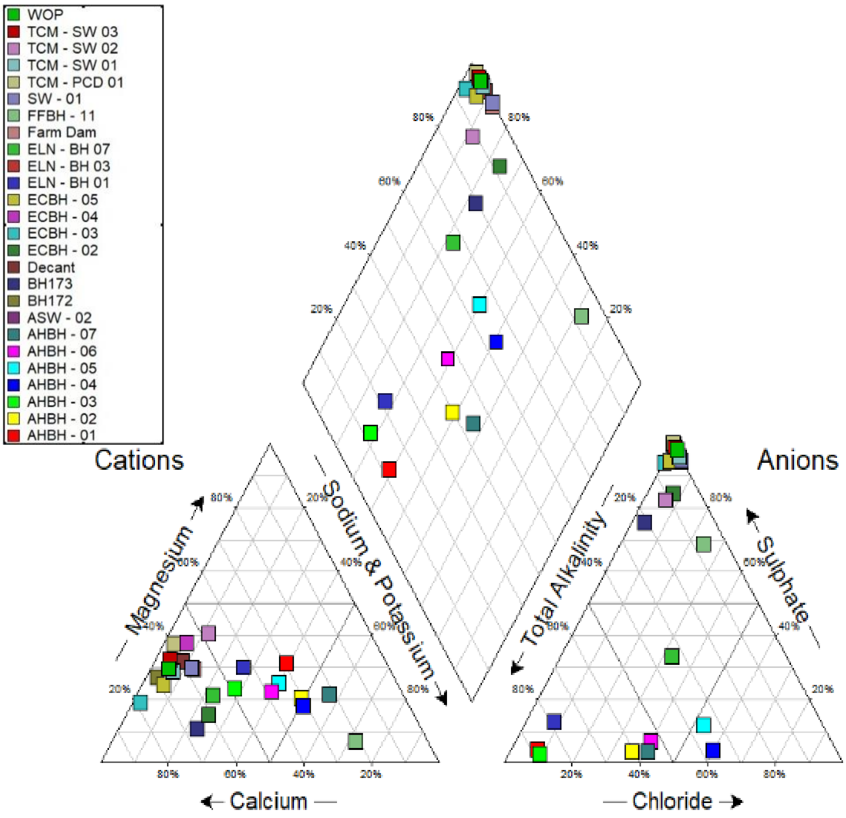

Figure 8-5 **Piper diagram indicating major anions and cations of hydrocnesus and monitoring water samples.**

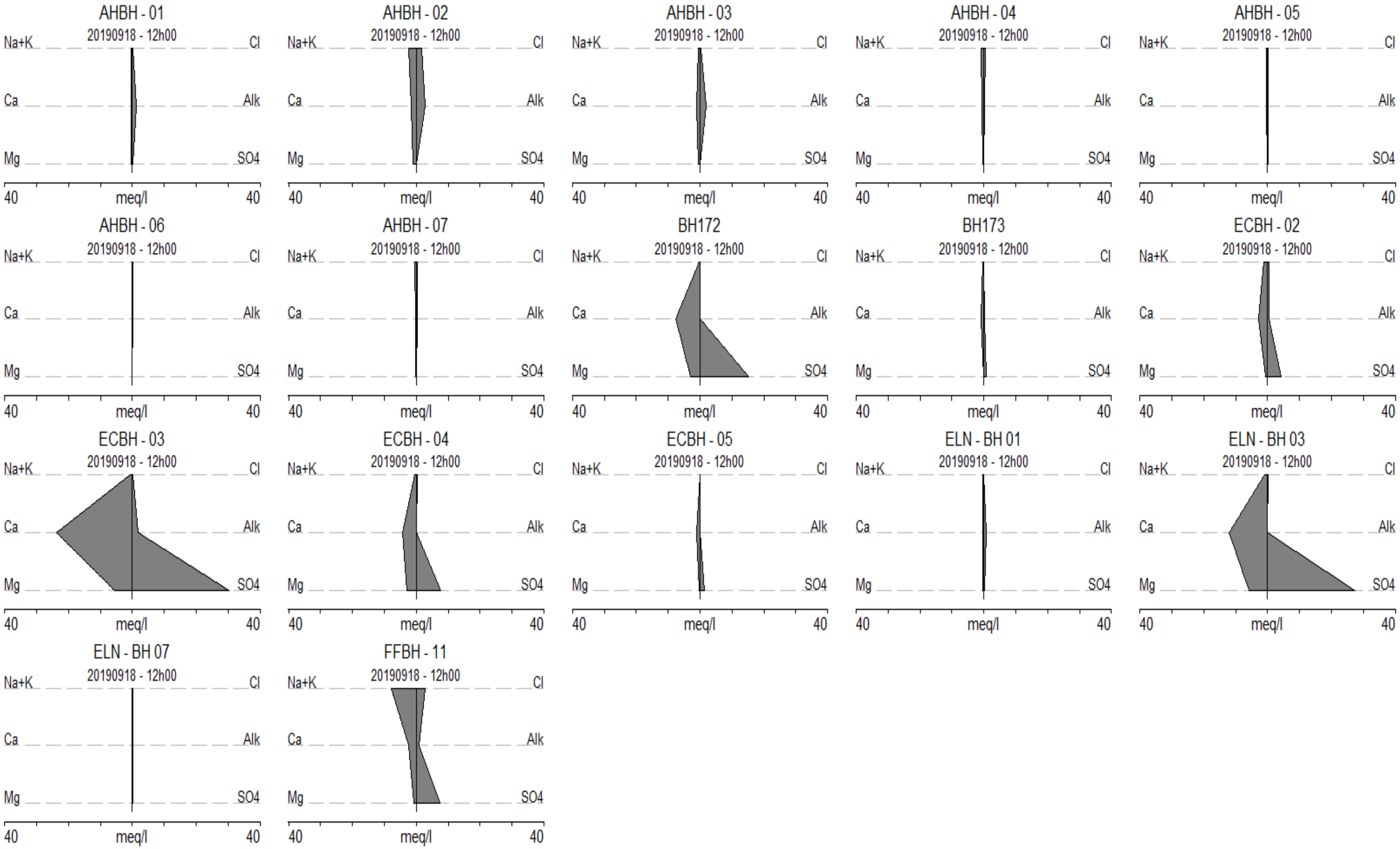

Figure 8-6 **Stiff diagrams representing groundwater sampling localities analysed.**

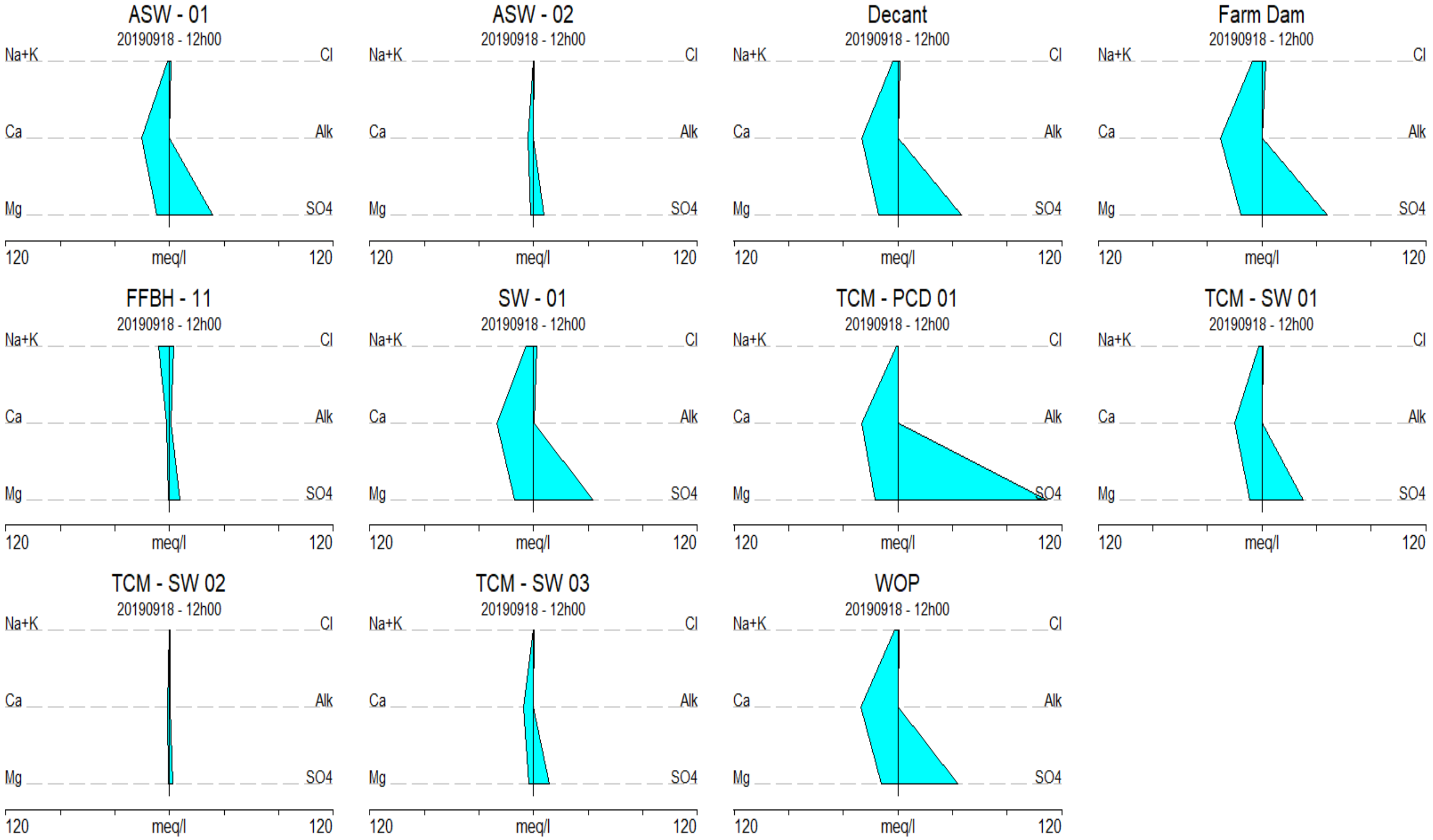

Figure 8-7 **Stiff diagrams representing surface water sampling localities analysed.**

8.6. 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 regional/ neighbouring groundwater samples can be classified as Field 02 i.e. mostly fresh, clean and relatively young with HCO_3- and CO_3 dominance evident, whereas most of the on-site monitoring boreholes can be classified as Field 04 which can often be associated with mining related SO_4 contamination.

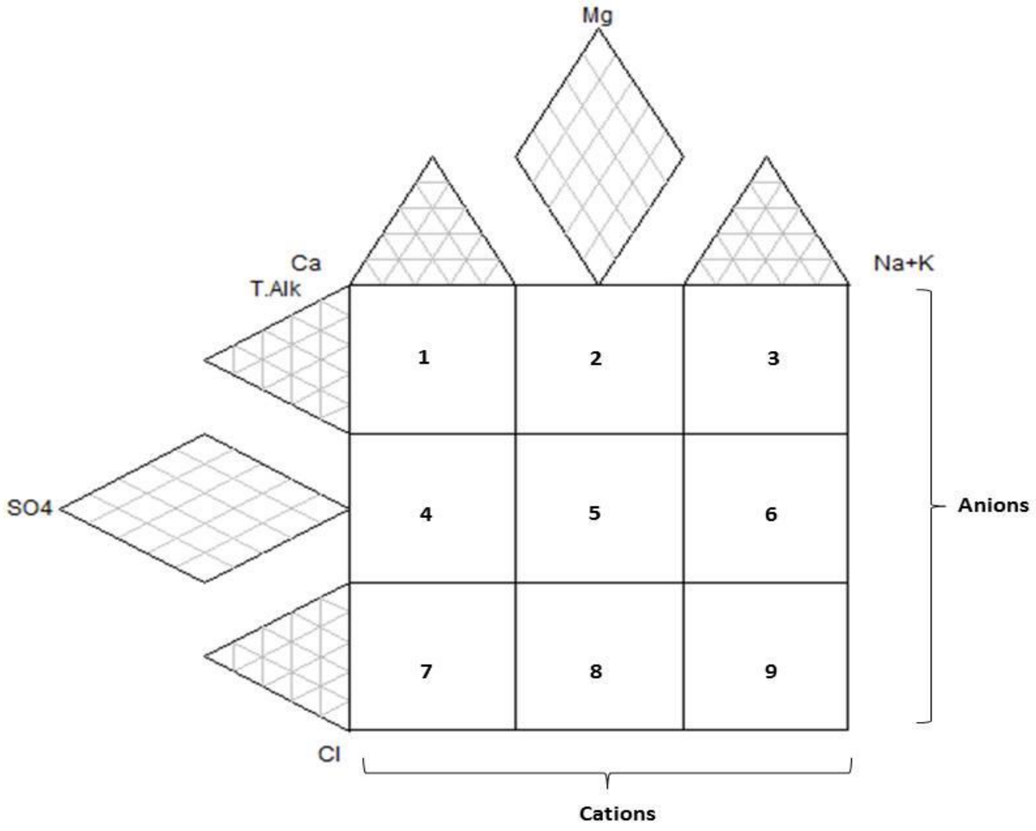

Figure 8-8 Extended Durov diagram indicating major anions and cations.

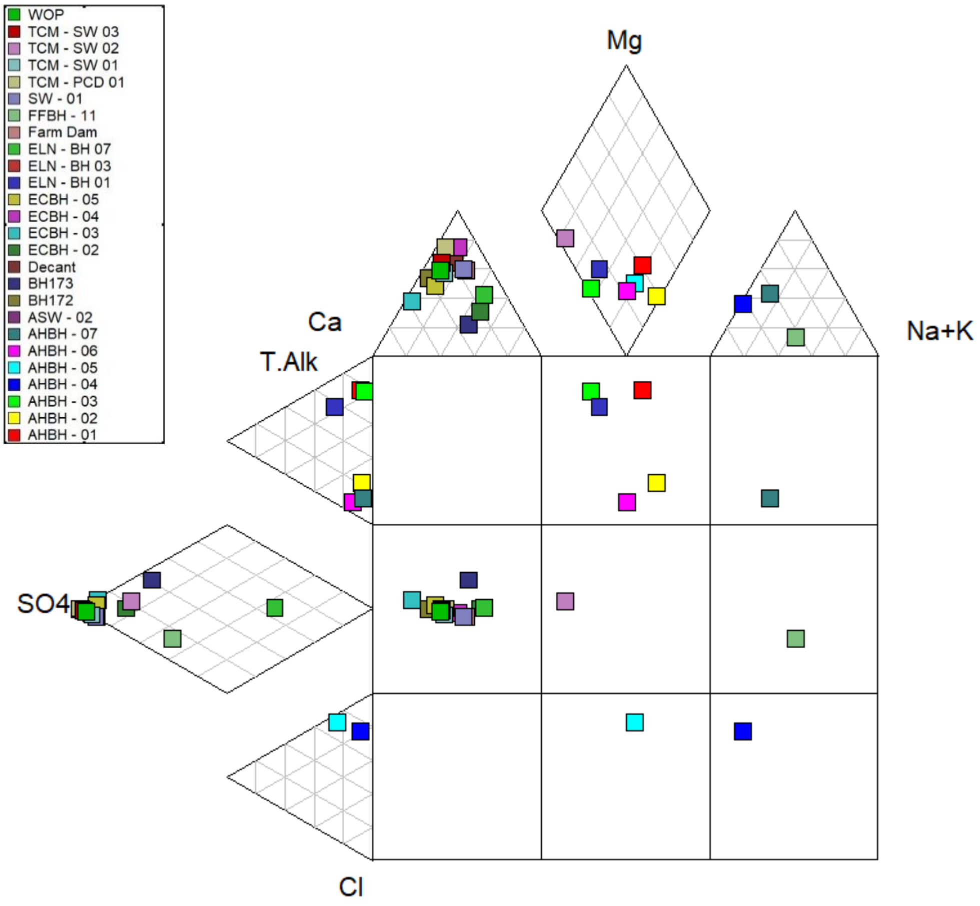

Figure 8-9 Extended Durov diagram of surface water monitoring points.

9. GEOCHEMISTRY

The primary objective of this geochemical assessment is to determine the chemical nature and character of the lithologies mined, evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for Acid Rock Drainage (ARD) occurring. Geochemical characterisation in the form of Acid Base Accounting (ABA), Net-Acid Generation (NAG), Sulphur speciation as well as static leach tests was performed on gathered samples. Geochemical test methodologies applied are summarised in Table 9-12. Refer to Appendix F for laboratory results and certificates.

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
Acid-base accounting (ABA) test	Determine the balance between the acid production and acid consumption properties of a mine waste material.	ASTM D3987
Sulphur Speciation	To determine the sulphide content of samples analysed.	ASTM E1915-11.
Nett Acid Generation (NAG Tests)	To indicate the net potential for ARD after oxidation with hydrogen peroxide.	ASTM E1915-13.
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.

9.1. Sampling

A total of four samples were collected for geochemical testing and analysis comprising various lithological units as well as coal stockpiles and discard material. Refer to Table 9-2 for a description of samples analysed as discussed below.

i. Sample ASS01 (Composite): Tailings sludge – sample collected at the existing slurry dam on site.

ii. Sample ASS13 (Composite): Coal product – representative of coal product and potential stockpile areas.

iii. Sample ASS15 (Composite): Sandstone, non-carbonaceous– representative of hanging wall, overburden and potential backfill material.

iv. Sample ASS16 (Composite)): Shale carbonaceous – representative of hanging wall, overburden and potential backfill material.

Table 9-2 Description of geochemical samples analysed.

Sample ID	Sample type	*	Test procedure	Description	Photo
ASS01	Composite	■	XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/ TCLP)	Tailings sludge	
ASS13	Composite	■	XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/ TCLP)	Coal	
ASS15	Composite	□	XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (TCLP)	Sandstone	
ASS16	Composite	▨	XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/TCLP)	Carbonaceous shale	

9.2. Minerology and total element analysis

The mineralogy and total element analysis of the samples was determined through X-Ray diffraction (XRD)[11]and X-Ray fluorescence (XRF) as discussed below.

9.2.1. 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 major mineral in the tailings sludge sample analysed (ASS01) is organic carbon (C) as well as kaolinite ($Al_2Si_2O_5(OH)_4$). Quartz ($Si0_2$) and gypsum ($CaSO_2$) is also present while trace amounts of microcline ($KAlSi_3O_8$) and muscovite ($KAl_2(AlSi_3O_{10})(OH,F)_2$ is observed.

ii. The coal product (ASS13) consist of relatively equal amounts of kaolinite ($Al_2Si_2O_5(OH)_4$) and organic carbon (C) Quartz ($Si0_2$) and pyrite (FeS_2) is also present with minor amounts of calcite, dolomite and muscovite observed.

iii. It should be noted that the presence of the sulphide mineral pyrite is observed in relatively small amounts in only the coal product, which may potentially form a main driver of acid rock drainage.

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[11] 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.

iv. As expected, the major mineral observed within the sandstone sample (ASS15) analysed is Quartz ($Si0_2$), followed by kaolinite ($Al_2Si_2O_5(OH)_4$) and microcline ($KAlSi_3O_8$). Trace amounts of dolomite and muscovite is also noted.

v. The carbonaceous shale sample (ASS16) analysed indicate that the major minerals present is kaolinite ($Al_2Si_2O_5(OH)_4$) and organic carbon. Microcline and quartz are also noted while trace amounts of dolomite, and muscovite is observed.

vi. It should be noted that the dolomite present in relatively small amounts in the sandstone as well as shale samples may contribute to the buffer capacity of the hanging wall/ overburden formations.

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

Mineral	*	Formula	Mineral type (Group)	Sub-group
Calcite	🟦	$CaCO_3$	Anhydrous Carbonates	Calcite group
Organic Carbon	⬛	C	Carbon	
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 %)			
		ASS01	ASS13	ASS15	ASS16
Calcite	$CaCO_3$	0.00	2.07	0.00	0.00
Dolomite	$CaMgCO_3$	0.00	0.46	0.15	0.19
Gypsum	$CaSO_4$	6.10	0.00	0.00	0.00
Kaolinite	$Al_2Si2O_5(OH)_4$	31.69	33.19	34.08	57.13
Microcline	$KAlSi_3O_8$	0.53	0.00	9.39	3.31
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_2$	1.21	1.60	1.65	1.03
Quartz	SiO_2	8.27	16.10	54.74	5.67
Organic Carbon	C	52.20	38.99	0.00	32.66
Pyrite	FeS_2	0.00	7.59	0.00	0.00

9.2.2. 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[12]. The following is noted:

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[12] 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.

i. Silicon, expressed as silica (SiO_2), is dominant in terms of the major elements in all the samples, followed by aluminium (III) oxide (Al_2O_3). Iron (III) oxide (Fe_2O_3) is also dominant in the tailings sludge and coal samples whereas potassium oxide (K_2O) and titanium (II) oxide (TiO_2) is dominant in the sandstone and carbonaceous shale samples respectively.

ii. The majority of samples analysed is slightly lower than the published ACU values with slightly elevated concentration for the following elements: aluminium (III) oxide (Al_2O_3) as well as phosphorus pentoxide (P_2O_5).

Table 9-5 **XRF analysis and Major Element Concentrations**

Element (%)	**Major element concentration (wt %) [s]**				****AUC**
	ASS01	**ASS13**	**ASS15**	**ASS16**	
Fe_2O_3	6.49353	**16.98403**	1.57476	0.4919	11.2
SiO_2	52.09781	47.16675	**77.74978**	57.86764	66.6
Al_2O_3	**28.31056**	**21.45632**	**16.99827**	**37.40786**	15.4
K_2O	1.02563	0.47236	2.42148	1.55633	2.8
P_2O_5	**0.49971**	**0.42908**	0.05626	**0.31796**	0.15
Mn_3O_4	0.15679	0.06306	0.03672	<0.008	
CaO	**5.36366**	**5.7997**	<0.009	0.28384	3.59
MgO	0.57678	0.53627	0.13301	0.131	2.48
TiO_2	**1.85551**	**1.27456**	**0.78493**	**1.68793**	0.64
Na_2O	<0.010	<0.010	<0.010	<0.010	3.27
V_2O_5	0.03423	0.02084	0.01383	0.03662	
BaO	0.11846	0.06271	0.08026	0.08404	
Cr_2O_3	0.05435	0.02121	0.01855	0.03211	
SrO	0.11567	0.09781	0.02013	0.05185	
ZrO_2	0.08516	0.05972	0.06871	0.12737	
MnO	**0.14582**	0.04542	0.03415	<0.007	0.1
SO_3	3.8927	6.16458	0.11763	0.07656	
CuO	<0.010	<0.010	<0.010	<0.010	
PbO	0.01128	0.00655	0.01279	0.01186	
ZnO	0.02496	0.00823	0.01937	0.04404	
NiO	0.01947	0.00603	0.00982	0.00645	
Total XRF	**100.88**	**100.68**	**100.15**	**100.22**	

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

Shaded cells exceed AUC values.

9.3. 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.

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

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 provides a schematic summary of the different fields for mine drainage as plotted on a sulphate vs pH diagram. Figure 9-3 indicates a site conceptual geochemical model summarising the dynamics of ARD within the greater hydrogeological regime.

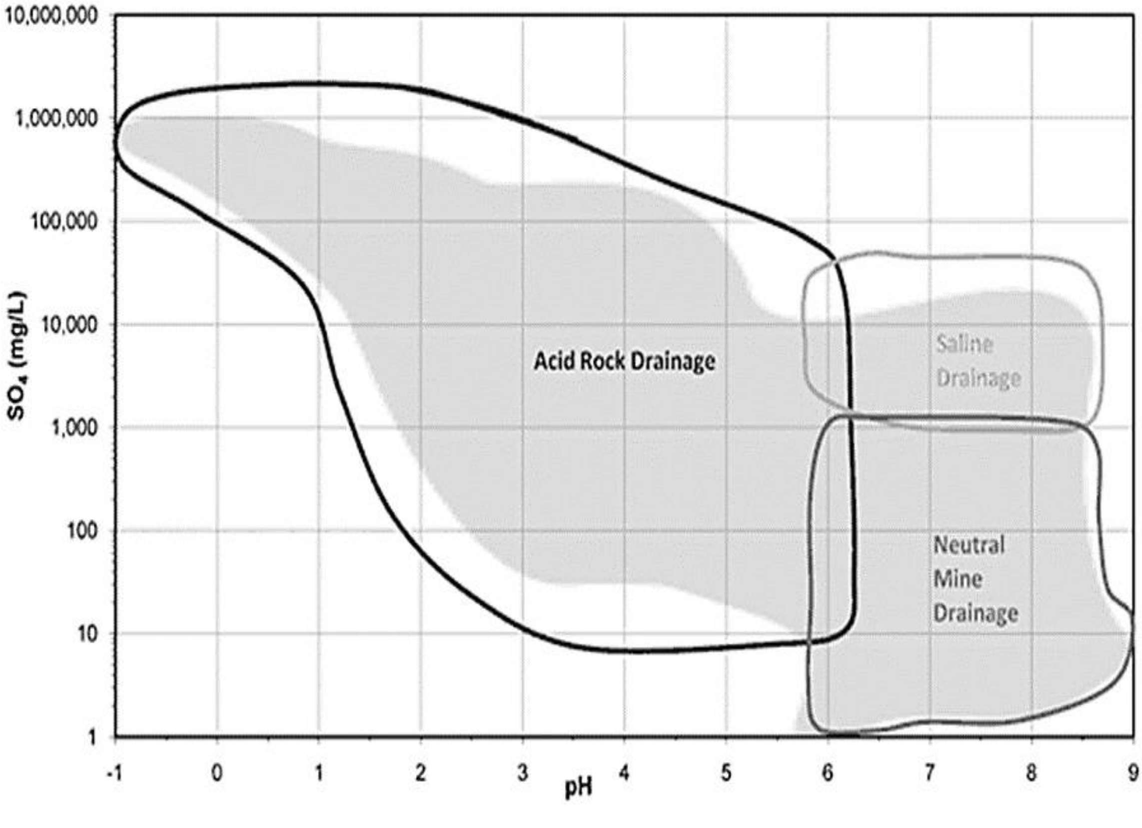

Figure 9-1 **Scematic diagram showing mine drainage as a function of pH and sulphate (Plumlee et al., 1999).**

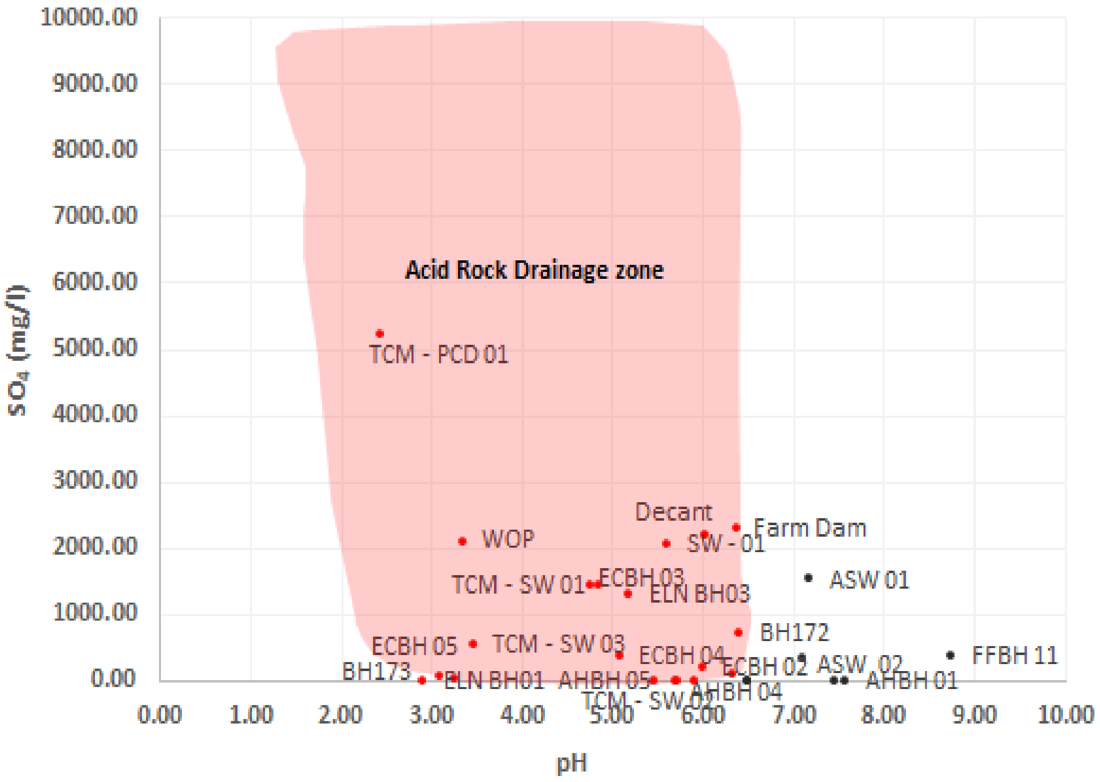

Figure 9-2 Diagram showing mine drainage as a function of pH and sulphate.

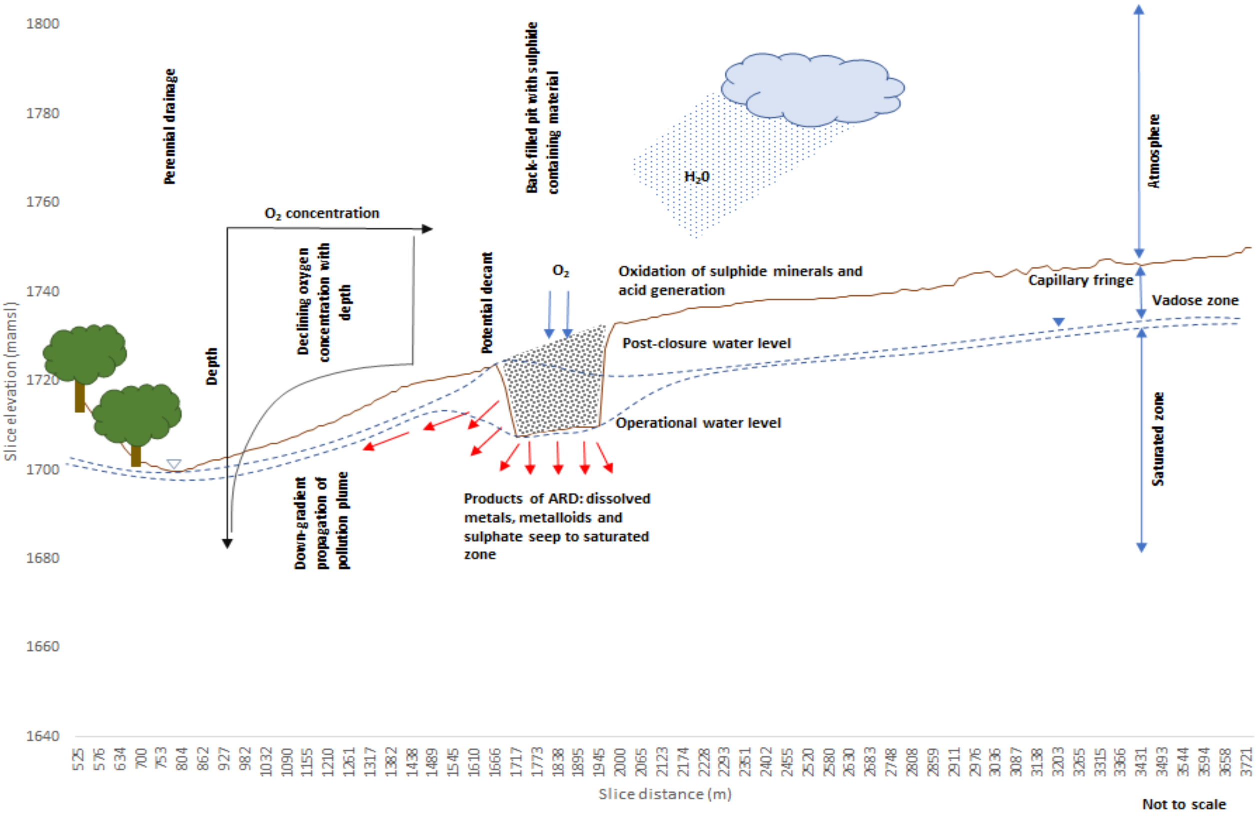

Figure 9-3 Conceptual geochemical model.

9.3.1. 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 %

9.3.2. 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.

9.3.3. 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 9-4 provide a comparison of sulphide percentage vs NPR while Figure 9-5 indicate NP:AP ratios of respective samples. Figure 9-6 summarises NAG pH vs NAG value per sample. 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.

ASS01 (Tailings sludge)

The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

ASS13 (Coal product)

The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

ASS15 (Sandstone non-carbonaceous)

The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.

ASS16 (Shale carbonaceous)

The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.

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)
ASS01	▓	4.90	1.44	0.14	45.00	0.00	-45.00	0.00
ASS13	■	3.29	3.19	1.89	99.69	0.00	-99.69	0.00
ASS15	□	8.30	0.013	0.01	0.41	12.70	12.29	30.98
ASS16	▒	6.79	0.22	0.15	6.94	5.51	-1.43	0.79

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)
ASS01	▓	1.53	88.00	108.00
ASS13	■	2.07	29.80	45.80
ASS15	□	9.67	<0.01	<0.01
ASS16	▒	3.74	1.17	5.96

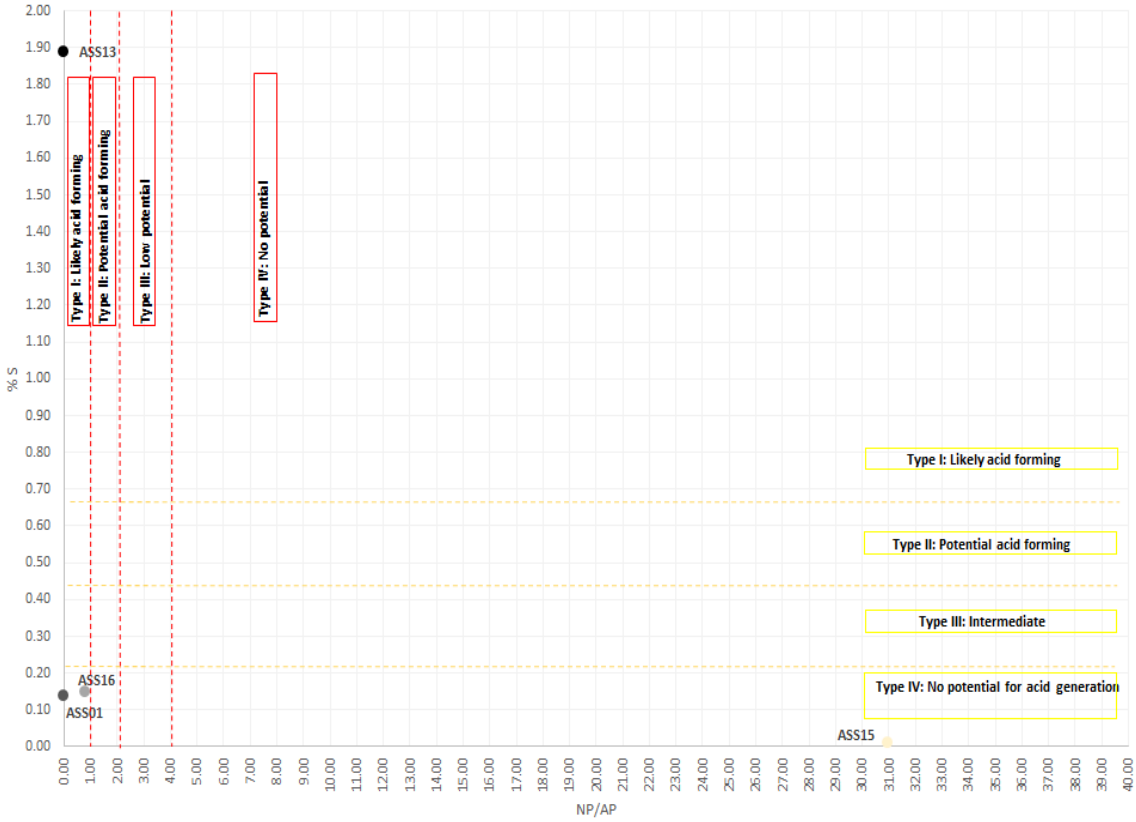

Figure 9-4 **Classification of samples in terms of %S (samples below 3%) and NP/AP.**

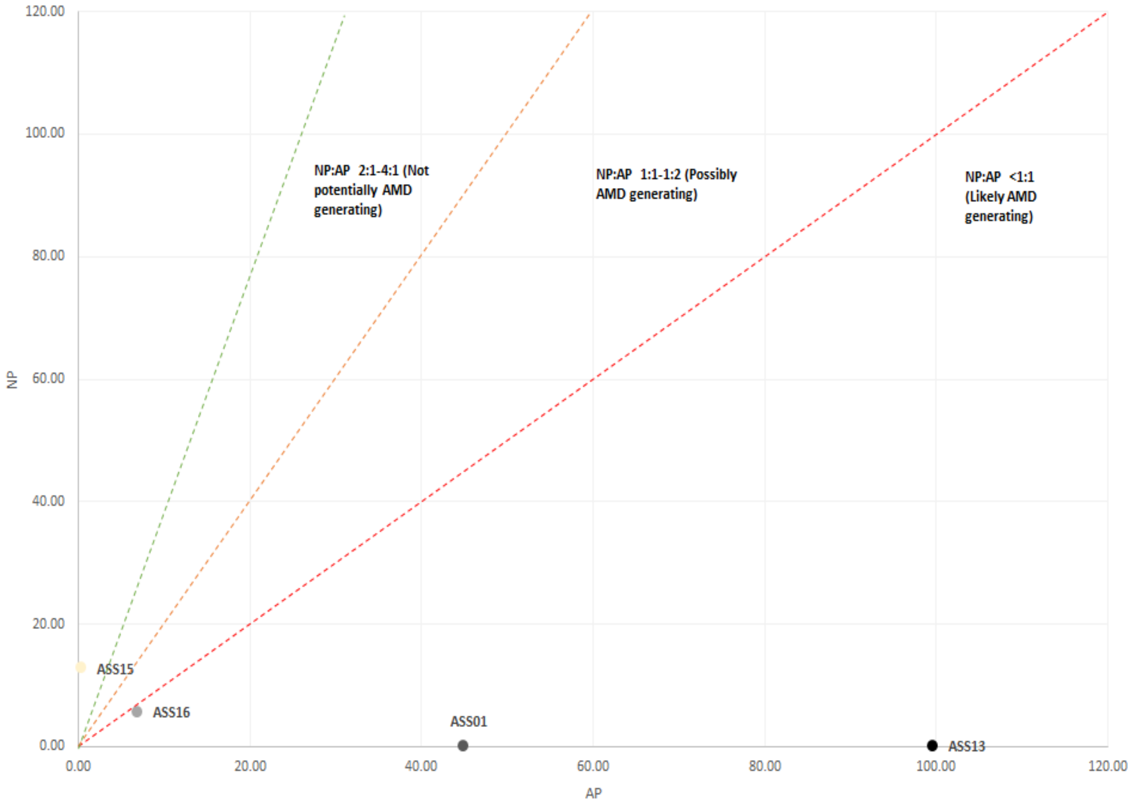

Figure 9-5 **Comparison graph: NP vs. AP.**

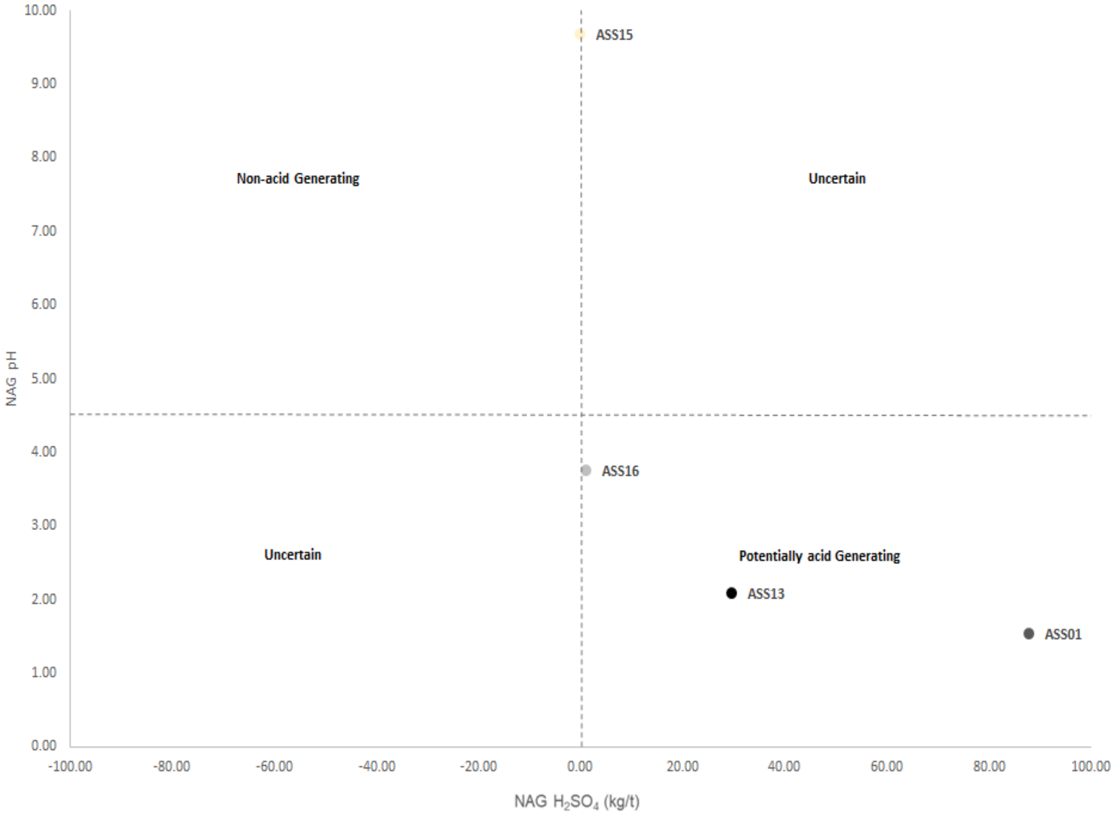

Figure 9-6 **Comparison graph: NAG pH vs NAG Value.**

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
ASS01			🟨			
ASS13	🟥					
ASS15						🟩
ASS16				🟩		
	🟥	🟧	🟨	🟩	🟩	🟩
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 salt load.**	**No potential for acidic drainage. Very low/no salt load.**

9.4. Static leach test: Toxicity characteristic leaching procedure

A toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material to identify water soluble chemicals that could potentially be leached from the waste material[13]. The sample was 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 9-13 for a summary of the leachate results. Elevated elements detected in the water leach include manganese (Mn) as well as sulphate ($S0_4$) for sample ASS01, manganese (Mn) for sample ASS13 and barium (Ba), manganese (Mn) as well as zinc (Zn) for sample ASS16. The remaining trace element concentrations detected were generally below detection limit.

Table 9-13 ICP-OES results of ditilled water leach.

Elements (mg/l)[ppm]	ASS01	ASS13	ASS16
As	< 0.5	< 0.5	< 0.5
B	< 5.0	< 5.0	< 5.0
Ba	< 0.5	< 0.5	**0.80**
Cd	< 0.5	< 0.5	< 0.5
Co	< 0.5	< 0.5	< 0.5
Cr	< 0.5	< 0.5	< 0.5
Cr^{6+}	< 0.05	< 0.05	< 0.05
Cu	< 0.5	< 0.5	0.65
Hg	< 0.005	< 0.005	< 0.005
Mn	**4.40**	**7.63**	**2.00**
Mo	< 1.0	< 1.0	< 1.0
Ni	< 0.5	< 0.5	< 0.5
Pb	< 1.0	< 1.0	< 1.0
Sb	< 0.5	< 0.5	< 0.5
Se	< 1.0	< 1.0	< 1.0
SO_4	**1420.00**	283.10	<20.0
V	< 0.5	< 0.5	< 0.5
Zn	< 0.5	< 0.5	**6.49**

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.

9.5. Waste assessment

All waste material collected were submitted for analyses in order to assess the waste type and class. 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 system is based on the Australian State of Victoria's waste classification system for disposal, which uses the Australian Standard Leaching Procedure (ASLP) to determine the leachable concentrations (LC) of pollutants in a particular waste (DEA, 2013a). The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations of samples taken. These results are compared to threshold limits i.e. leachable concentrations threshold (LCT) and total concentrations threshold (TCT) specified in R635

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[13] 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.

and the outcome is used to establish the type of waste and the most suitable disposal method for it[14]. The waste assessment was conducted in line with the following approach as summarised below:

i. Wastes with any element or chemical substance concentration above the LCT3 or TCT2 values (LC >LCT3 or TC>TCT2) are Type 0 Wastes. Type 0 wastes (extremely hazardous waste), require treatment/stabilisation before disposal.

ii. Wastes with any element or chemical substance concentration above the LCT2 but below LCT3 values, or above the TCT1 but below TCT2 values (LCT2<LC ≤ LCT3 or TCT1<TC ≤ TCT2), are Type 1 Wastes (highly hazardous waste).

iii. Wastes with any element or chemical substance concentration above the LCT1 but below the LCT2 values and all concentrations below the TCT1 values (LCT1 < LC ≤ LCT2 and TC ≤ TCT1) are Type 2 Wastes (moderate hazardous waste).

iv. Wastes with any element or chemical substance concentration above the LCT0 but below LCT1 values and all concentrations below the TCT1 values (LCT0 < LC ≤ LCT1 and TC ≤ TCT1) are Type 3 Wastes (low hazardous waste).

v. Wastes with all elements and chemical substance concentration levels for metal ions and inorganic anions below the LCT0 and TCT0 values (LC ≤ LCT0 and TC ≤ TCT0) are Type 4 Wastes (near inert wastes).

Waste types and categories are summarised in Table 9-14 while the TC and LC threshold limits, according to Section 6 of R635, are presented in Table 9-15 and Table 9-16 below.

Table 9-14 Waste types.

Criteria	Waste Type
LC > LC3; or TC > TC2 (extremely hazardous waste)	Type 0
LCT2 < LC ≤ LCT3; or TCT1 < TC ≤ TCT2 (highly hazardous waste)	Type 1
LCT1 < LC ≤ LCT2; and TC ≤ TCT1 (moderate hazardous waste)	Type 2
LCT0 < LC ≤ LCT1; and TC ≤ TCT1 (low hazardous waste)	Type 3
LC ≤ LCT0; and TC ≤ TCT0 (near inert wastes)	Type 4

Figure 9-7 indicate a bar-chart comparison of the Total Concentration analysis of elements per sample whereas Figure 9-8 show a bar-chart comparison of Leachable Concentrations analysis per sample. Dominant total concentrations include boron (B), barium (Ba), manganese (Mn) and lead (Pb) whereas dominant leachate concentrations include manganese (Mn) boron (B), barium (Ba), lead (Pb), chromium (VI) (Cr^{6+}) and zinc (Zn). The results of the De-Ionised Water Leach Test and Total Concentration analysis of the samples are shown in Table 9-18 and Table 9-19. The following is noted regarding the results:

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[14] 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.

9.5.1. Sample ASS01 (Tailings sludge)

The following elements fall above the prescribed thresholds in terms of the LC values: Mn (>LCT0), TDS (>LCT0) and $S0_4$ (>LCT0) while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), B (>TCT0), Ba (>TCT0), Cd (>TCT0), Co (>TCT0), Cu (>TCT0), Hg (>TCT0), Mo (>TCT0), Pb (>TCT0), Sb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.2. Sample ASS13 (Coal product)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), B (>TCT0), Ba (>TCT0), Cd (>TCT0), Co (>TCT0), Cu (>TCT0), Hg (>TCT0), Mo (>TCT0), Pb (>TCT0), Sb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.3. Sample ASS15 (Sandstone non- carbonaceous)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0), Cd (>TCT0), Cu (>TCT0), Pb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.4. Sample ASS16 (Shale carbonaceous)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0), Cu (>TCT0), Pb (>TCT0), Se (>TCT0), V (>TCT0) and Zn (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

Table 9-15 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.

Table 9-16 **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.

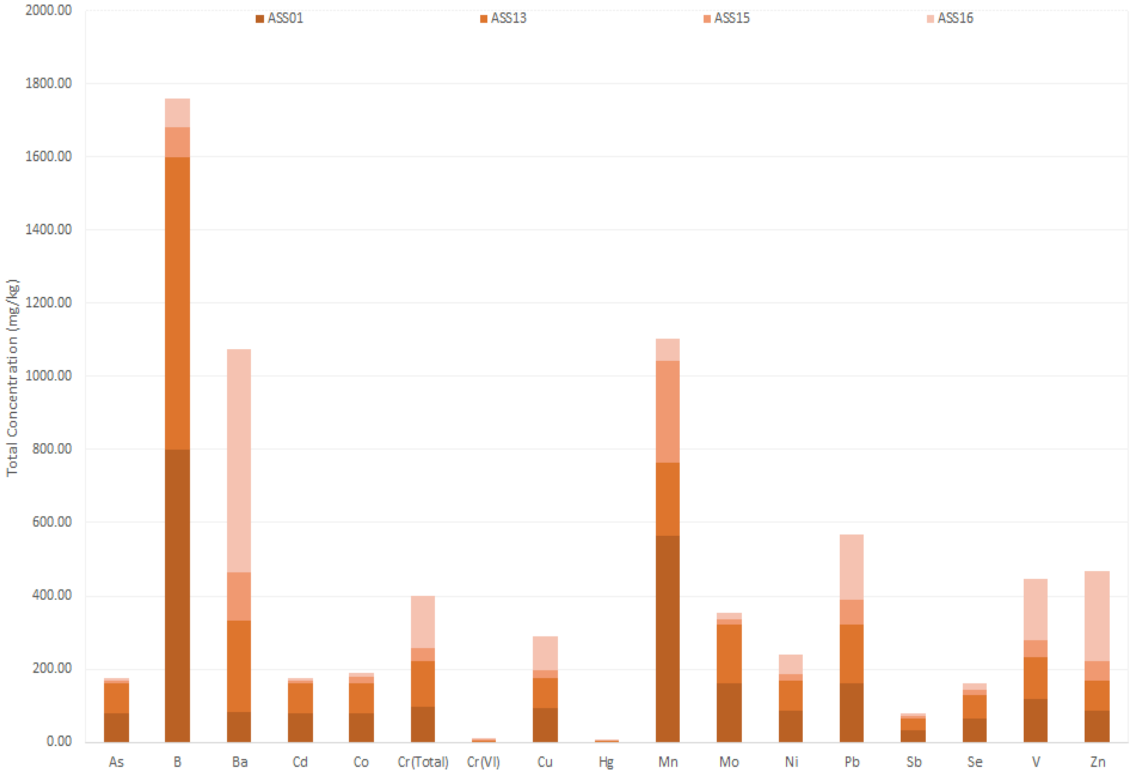


Figure 9-7 **Comparison of Total Concentration analysis of Elements.**

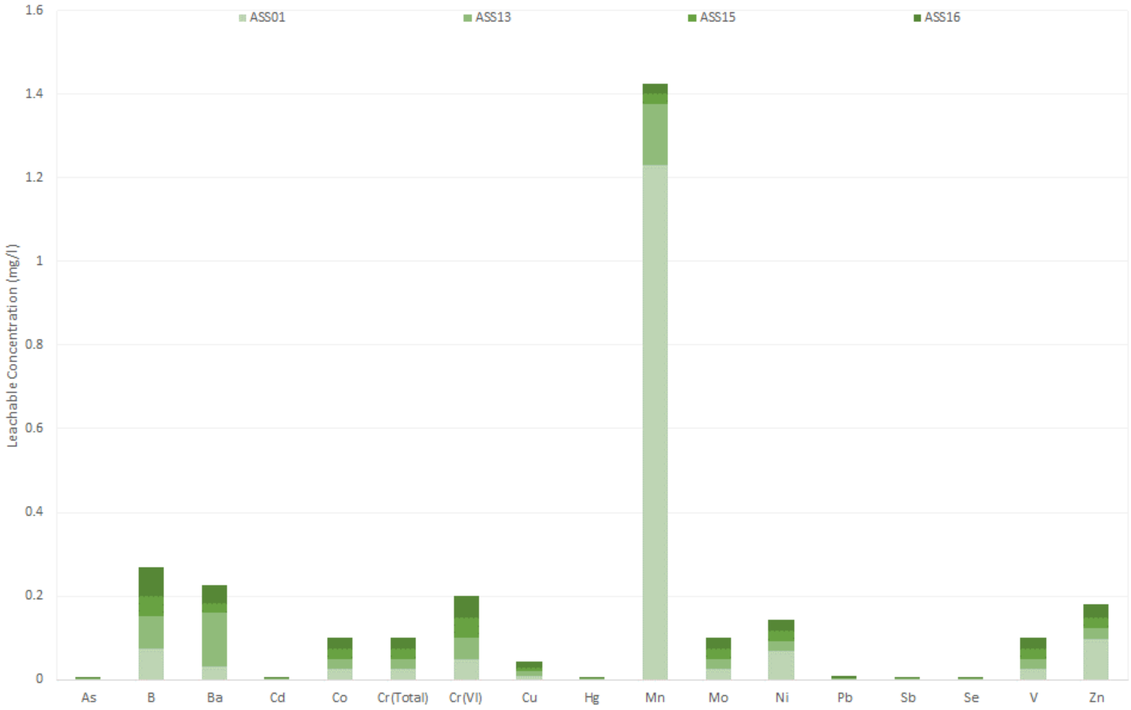


Figure 9-8 **Comparison of Leachable Concentrations analysis of samples.**

Table 9-17 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS01 (1:20 dilution).

Elements	TC (mg/kg)	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	**<80.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	**<800.0**	0.075		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**81.09**	0.032		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<80.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	**<80.0**	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	97.40	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**94.87**	<0.01		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**1.32**	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	563.20	**1.23**		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	**<160.0**	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	87.12	0.068		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**<160.0**	0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	**<32.0**	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<64.0**	<0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	117.30	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	86.52	0.098		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	3.87	4.56													
TDS		**2042.00**			1000.00			12500.00			25000.00			100000.00	
Chloride		<2.0			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		**1184.00**			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<2.22			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	<0.05		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	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-18 **Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS13 (1:20 dilution).**

Elements	TC (mg/kg)	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	**<80.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	**<800.0**	0.077		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**250.20**	0.127		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<80.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	**<80.0**	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	126.10	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**<80.0**	0.010		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**1.54**	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	202.00	0.146		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	**<160.0**	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	<80.0	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**<160.0**	<0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	**<32.0**	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<64.0**	0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	116.40	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	<80.0	<0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	7.90	8.00													
TDS		405.00			1000.00			12500.00			25000.00			100000.00	
Chloride		8.69			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		113.70			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.5			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	0.11		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	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-19 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS15 (1:20 dilution).

Elements	TC (mg/kg)	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	**<8.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	<80.0	0.048		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**132.70**	<0.025		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<8.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	18.10	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	34.82	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**20.40**	<0.01		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	<0.16	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	277.90	<0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<16.0	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	17.76	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**71.04**	<0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<8.0	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<16.0**	<0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	45.87	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	56.17	<0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	4.78	5.77													
TDS		28.00			1000.00			12500.00			25000.00			100000.00	
Chloride		2.07			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.75			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.5			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	<0.05		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	0.12	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-20 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS16 (1:20 dilution).

Elements	TC (mg/kg)	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	**<8.0**	0.003		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	<80.0	0.070		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**611.80**	0.041		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	<8.0	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	10.07	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	143.60	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**93.10**	0.012		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	<0.16	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	61.17	<0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<16.0	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	55.17	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**178.30**	0.006		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<8.0	0.004		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<16.0**	0.003		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	**166.40**	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	**245.70**	0.032		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	6.30	6.80													
TDS		30.00			1000.00			12500.00			25000.00			100000.00	
Chloride		3.31			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.87			250.00			12500.00			25000.00			100000.00	
NO_3 as N		0.51			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	0.18		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<0.1	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

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. Transitioning.

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 Management qualification		Aquifer vulnerability 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	**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.

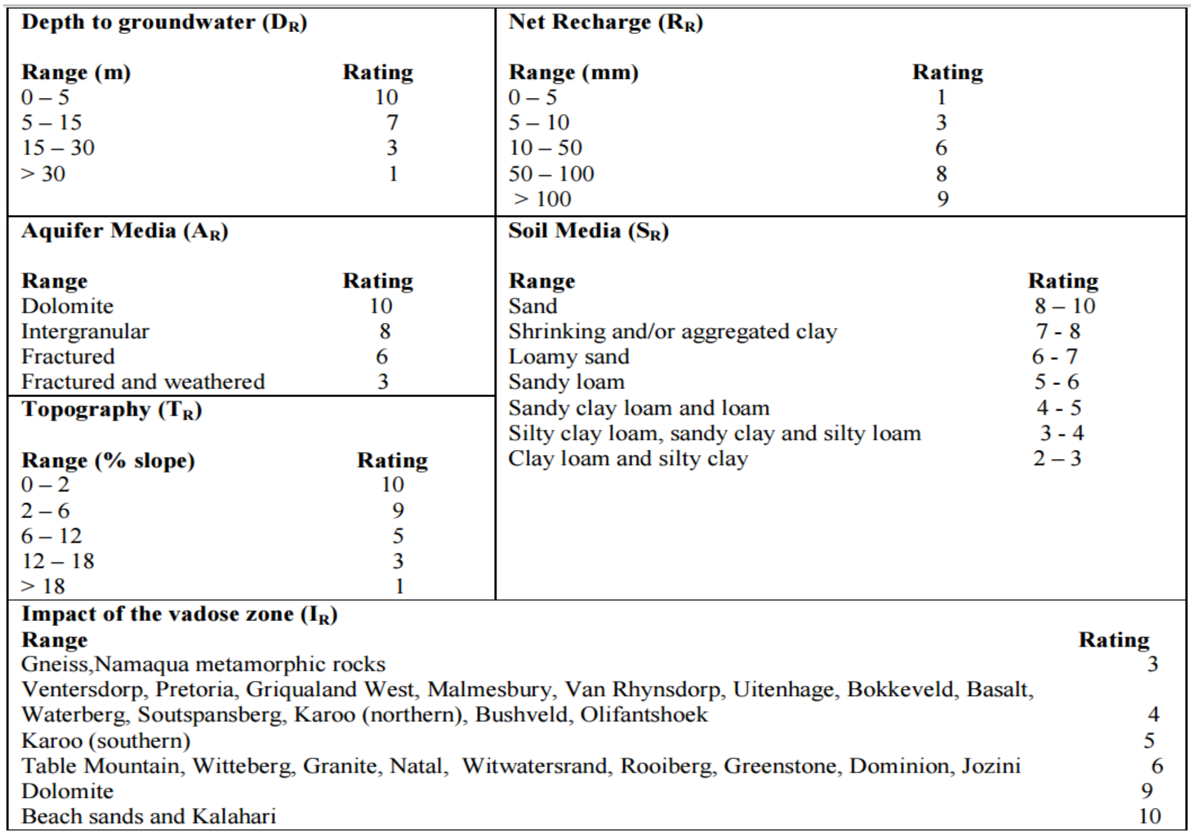
T = Topographic aspect.

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 "**Medium**", **Di** = 102 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) = 102				

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).

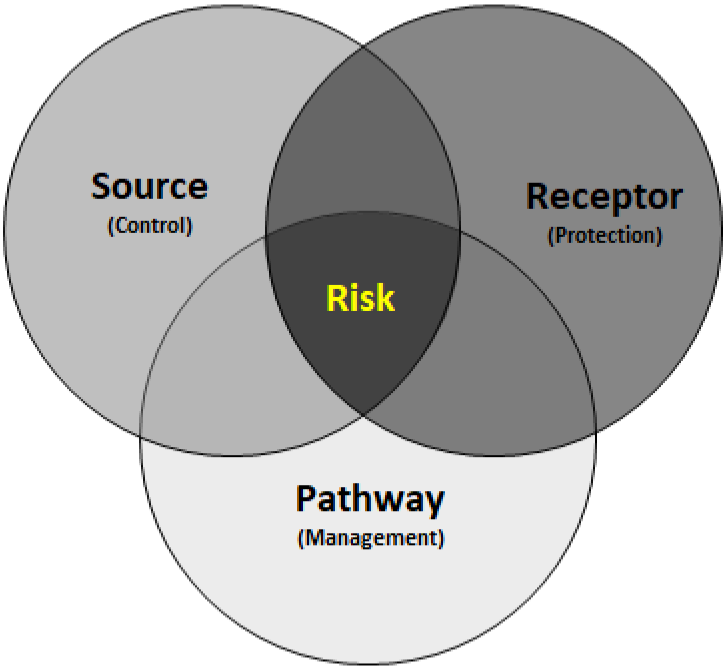


Figure 10-1 **Source pathway receptor principle.**

10.5.1. Potential sources

The following potential sources have been identified:

i. Leachate of poor-quality water from waste material i.e. carbonaceous material 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

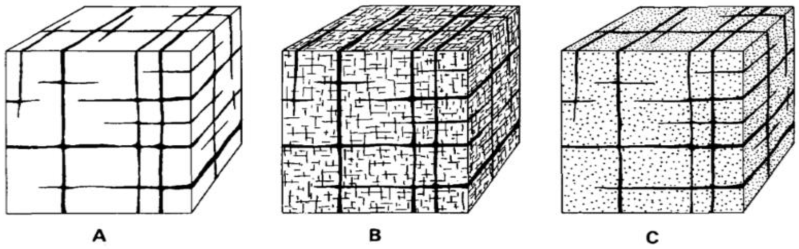
The following receptors were identified:

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

ii. Local rivers and streams, including on-site wetland system, 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. 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 5-2 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).

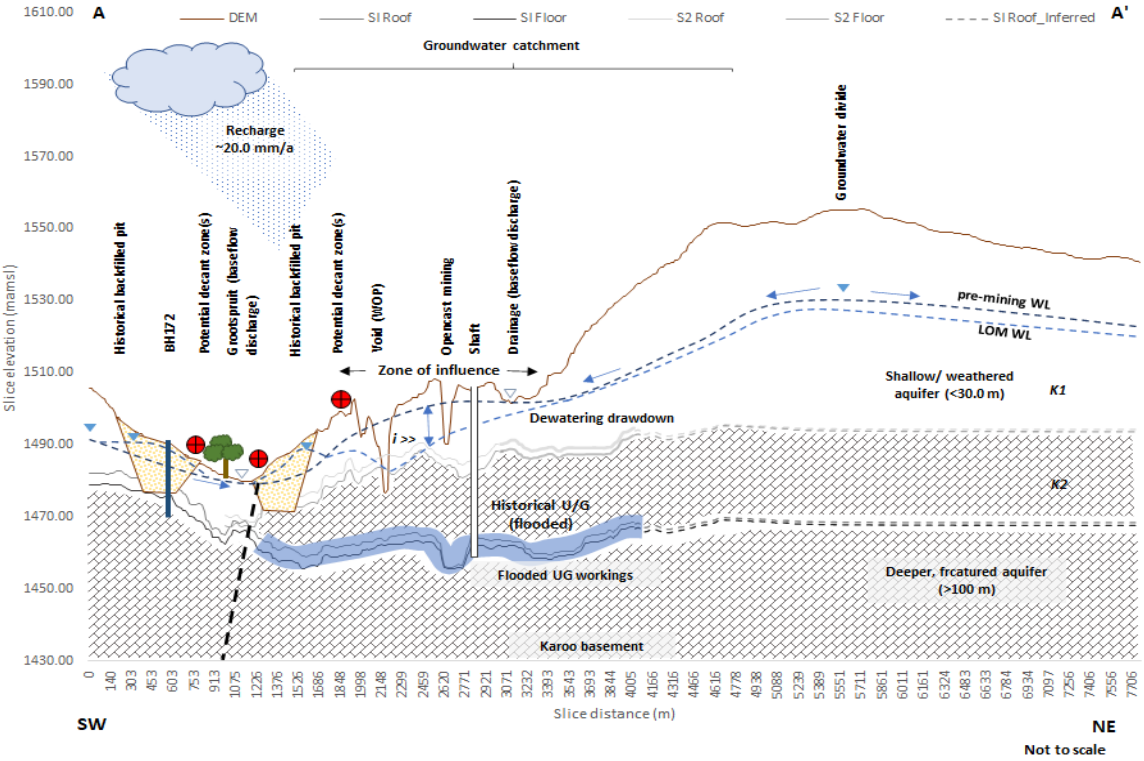


Figure 11-2 Hydrogeological conceptual model: Southwest-Northeast cross section (A-A') (Figure 12-2).

12. NUMERICAL GROUNDWATER FLOW AND CONTAMINANT TRANSPORT 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.

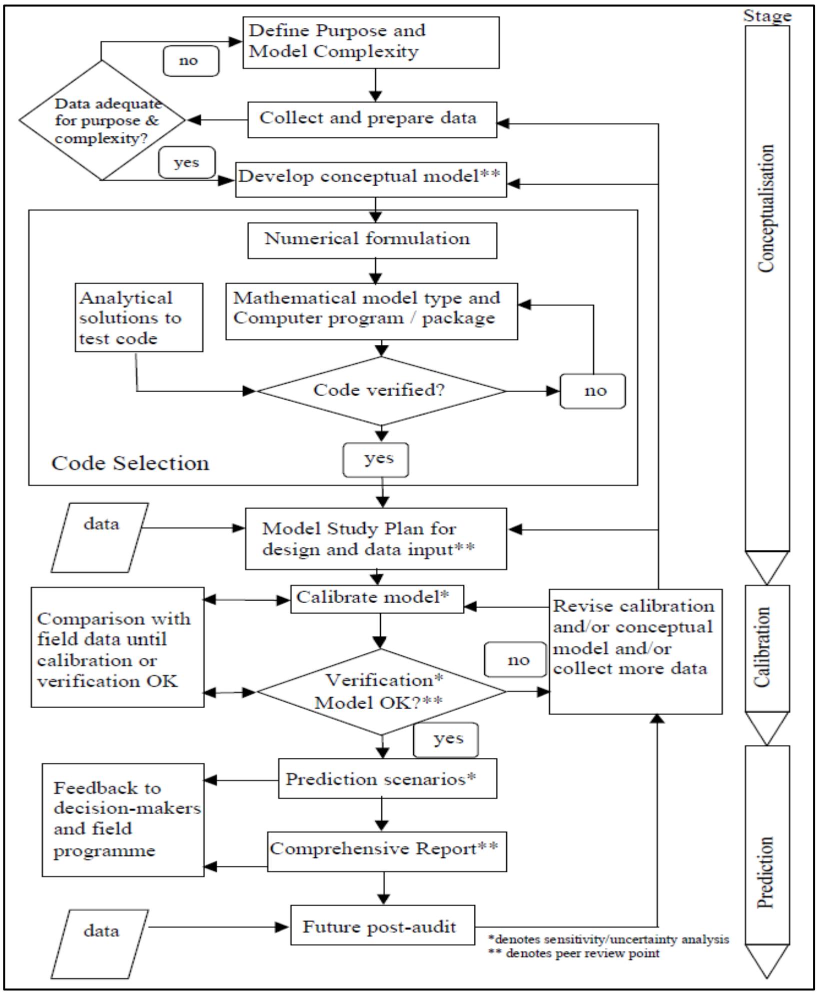


Figure 12-1 **Workflow numerical groundwater flow model development.**

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.

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

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: 9411.859 [m] and Y: -2866629.018 [m] using triangular prism type of elements. The model has a width of 13048.9 [m], height of 18000.2 [m], depth of 287.844 [m] and spans an area of $1.53e^{+8}$ m^2 with a volume of ~$1.99e^{+10}$. 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 W-E cross section.

12.3.2. Model construction

The model was constructed from FEM and consist of two layers i.e. three slices, 476 291 triangular prism elements per layer, a total of 952 582 elements for the model domain, with 239 472 nodes per slice. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 0.6%.
- Interior holes: 0.
- Obtuse angled triangles: 0.1% > 120°, 3.7% > 90°.

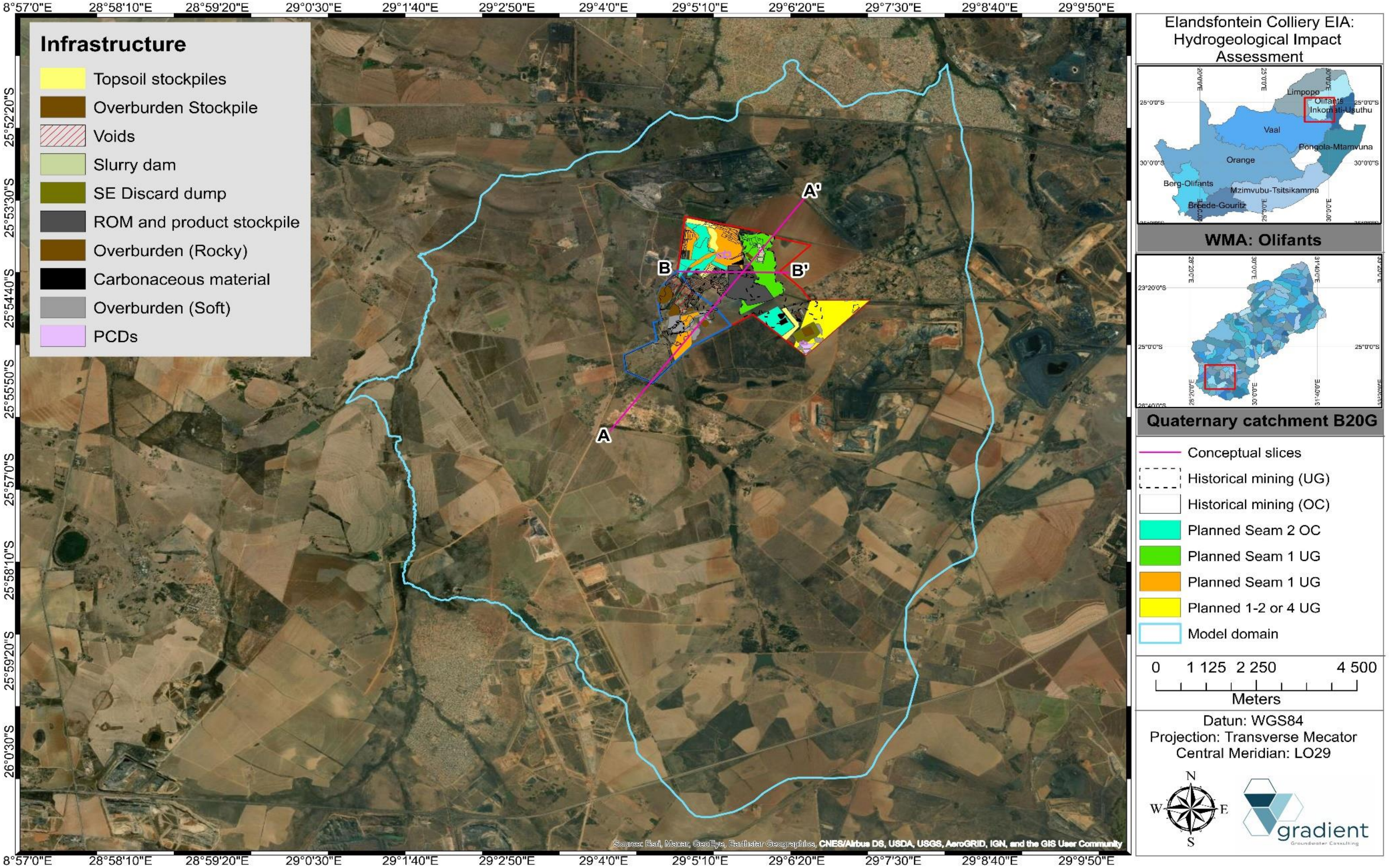


Figure 12-2 **Model domain: Aerial extent (Figure 11-2).**

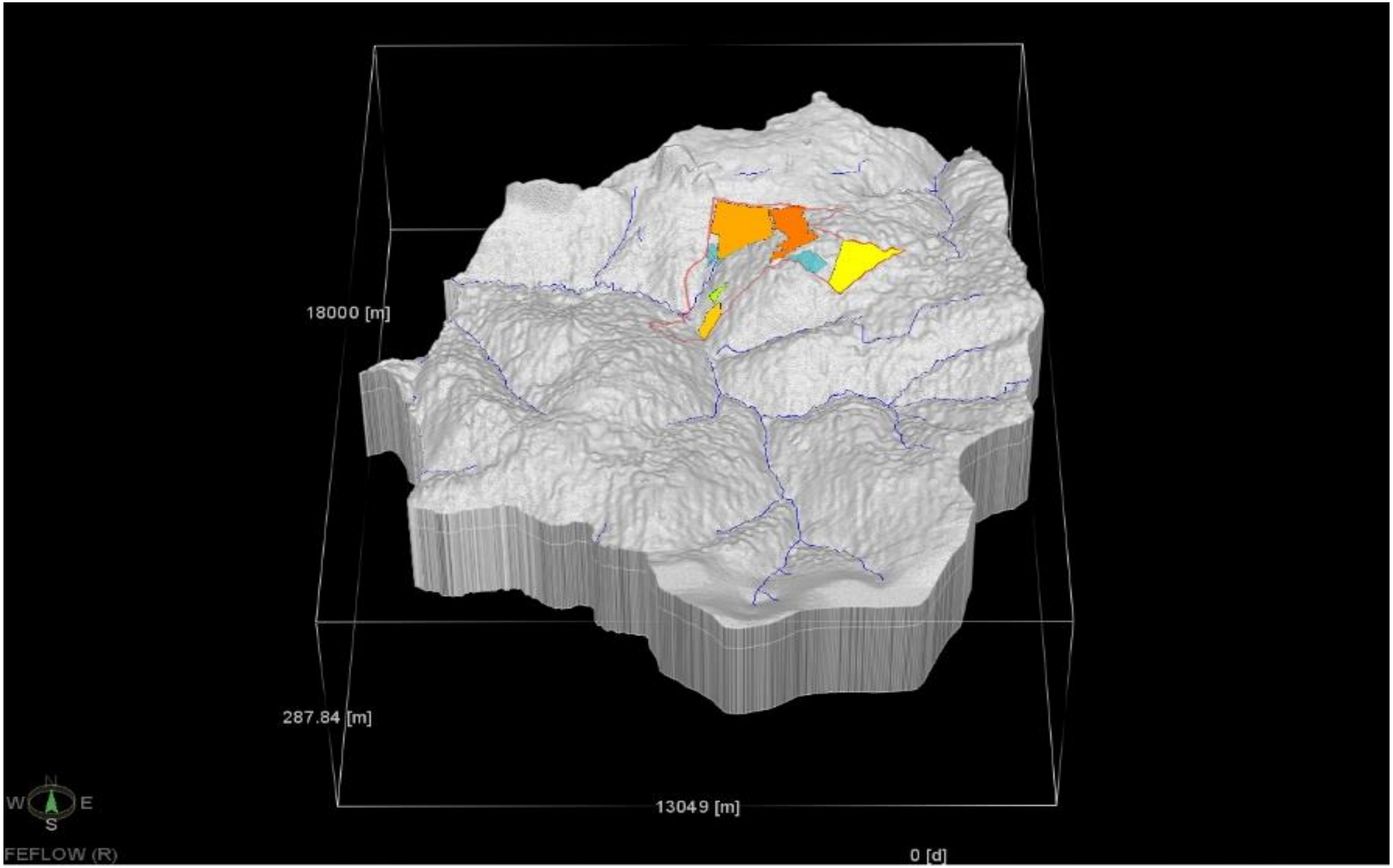


Figure 12-3 **Model domain 3-D FEM mesh view depicting a plan-view south-north orientation (Slice B-B').**

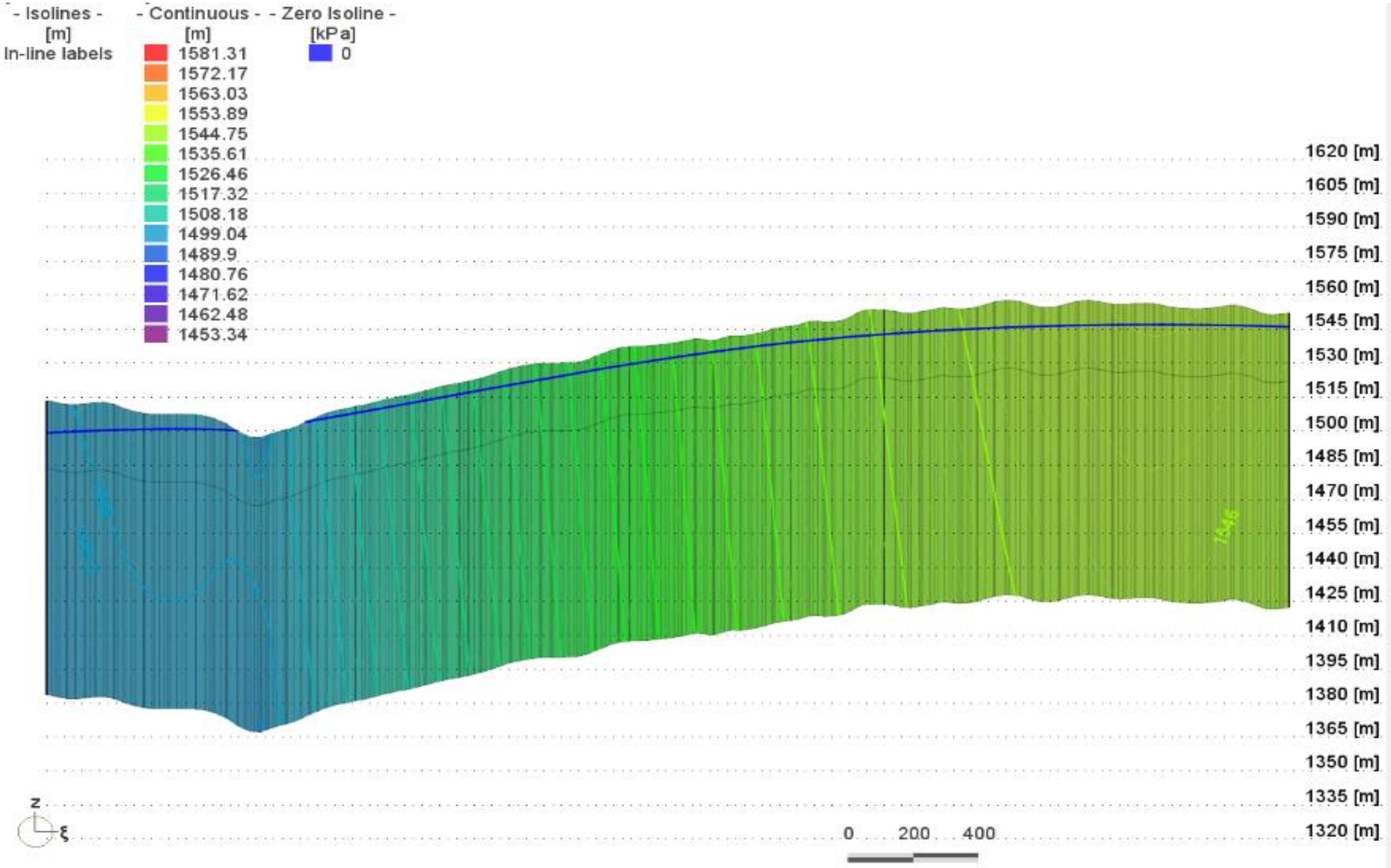


Figure 12-4 **Model domain 3-D FEM mesh view (cross sectional view west-east orientation B-B').**

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[15]. 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 = ~100.0 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 or Dwyka tillite/diamictite 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 regional drainages i.e. Grootboom traversing the site and Saalklapspruit to the west and Brugspruit to the east and northeast were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[16]. Neighbouring boreholes identified as part of the regional hydrocensus survey were assigned as pumping well boundary conditions[17]. 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[18]. Hydraulic conductivity values range from 0.01m/d for dolerite matrices, to 1.5m/d for regional geological lineament contact 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.

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

[16] Refer to "gaining stream" assumption.

[17] 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.

[18] 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. An approximation of recharge for the study area is estimated at ~3.85% of MAP i.e. ~20.58.0mm/a. Sinks in the model domain include groundwater abstraction from privately owned and community boreholes[19] as well as groundwater discharge to baseflow.

12.3.8. Storativity and specific storage

Specific storage values where assigned per layer (Layer01 = 3.00E^{-4}, Layer02 = 1.00E^{-5}) as listed in Table 12-1 below.

12.3.9. Porosity

A porosity value of 10.0% was assigned for the matrix of the weathered formations whereas fractured formations of layer 2 was assigned a porosity value of 1.0%. Backfilled and rehabilitated opencast areas were assigned a porosity value of 15.0%.

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)		Recharge (Re)	Specific storage (Sc)	Porosity (n)
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)	In/Outflow on top/bottom (mm/a)	Sc (1/m)	
Layer 01	Mw_Waterberg	30.00	0.040	0.004	20.6	3.00E-04	1.00E-01
	Dolerite		0.010	0.001			
	Diabase		0.060	0.006			
	Pd_Dwyka		0.070	0.007			
	Pe_Ecca		0.050	0.005			
	Vsi_Pretoria		0.050	0.005			
	Lineaments		1.500	0.150			
Layer 02	Mw_Waterberg	100.00	0.020	0.002	0.0	1.00E-05	1.00E-02
	Dolerite		0.005	0.001			
	Diabase		0.030	0.003			
	Pd_Dwyka		0.035	0.004			
	Pe_Ecca		0.025	0.003			
	Vsi_Pretoria		0.025	0.003			
	Lineaments		0.750	0.075			

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[19] 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.

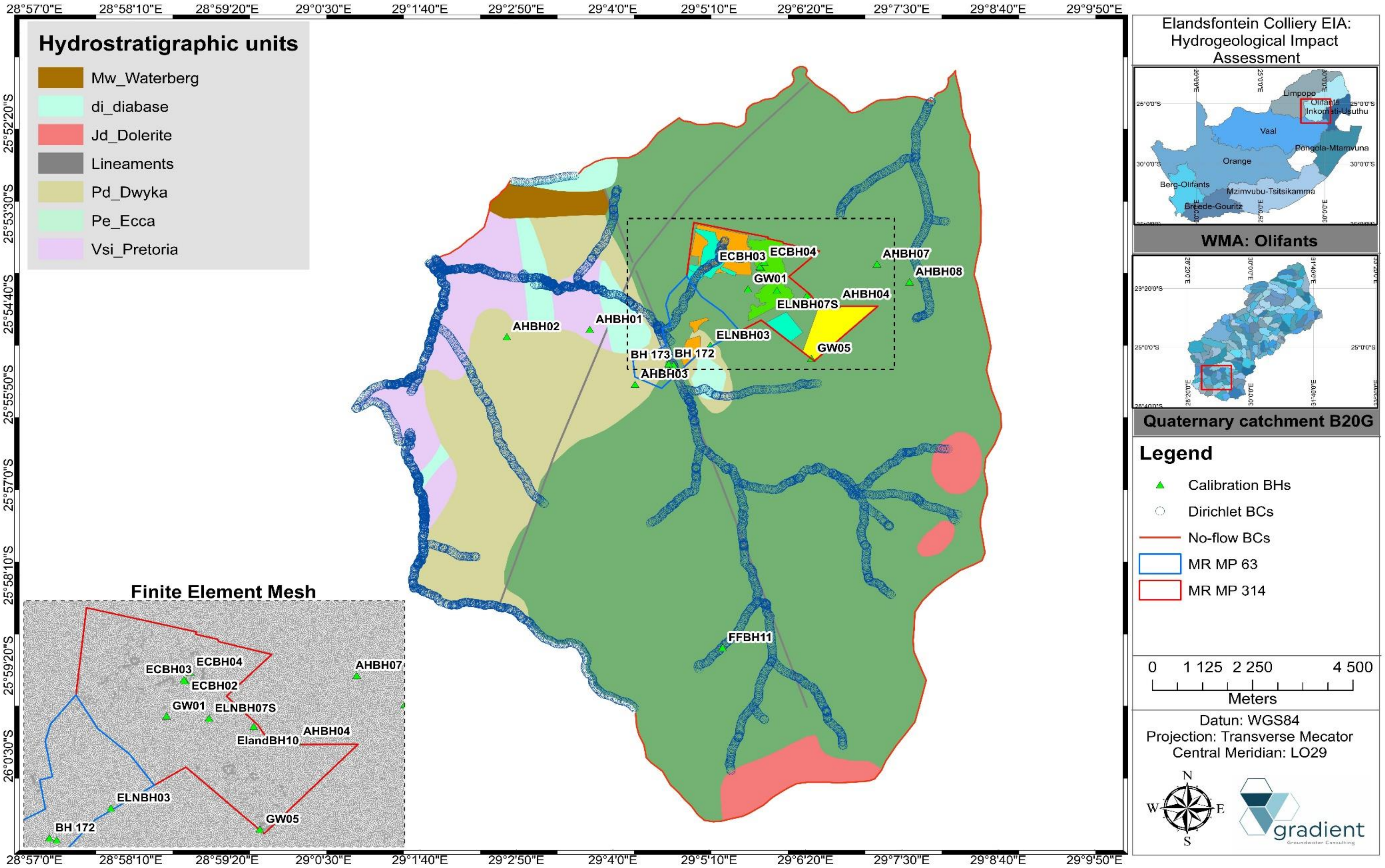

Figure 12-5 **Hydrostratigraphic units and model boundary conditions.**

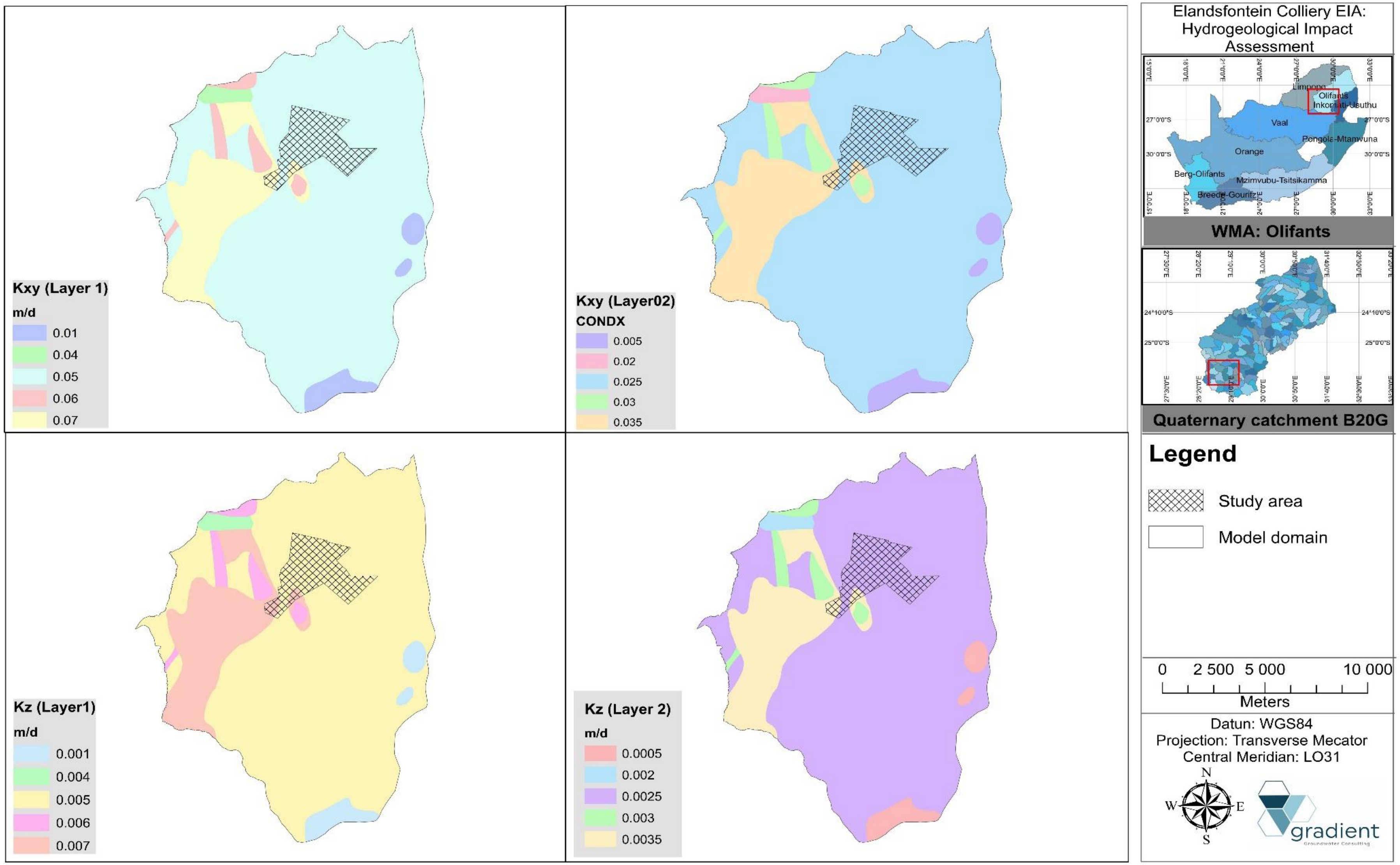

Figure 12-6 **Numerical groundwater flow model: Hydraulic properties.**

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 12-10 depicts steady state hydraulic head contours and groundwater flow directions. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.98 was obtained (Figure 12-7 and Figure 12-8) while Figure 12-9 indicate calibration error margin per borehole observation locality. 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): -2.36 m.

ii. Mean Absolute Error (MAE): 3.93 m.

iii. Normalised Root Mean Square Deviation (NRMSD): 6.85 % i.e. represents the deviation between observed and calibration water levels across the model domain.

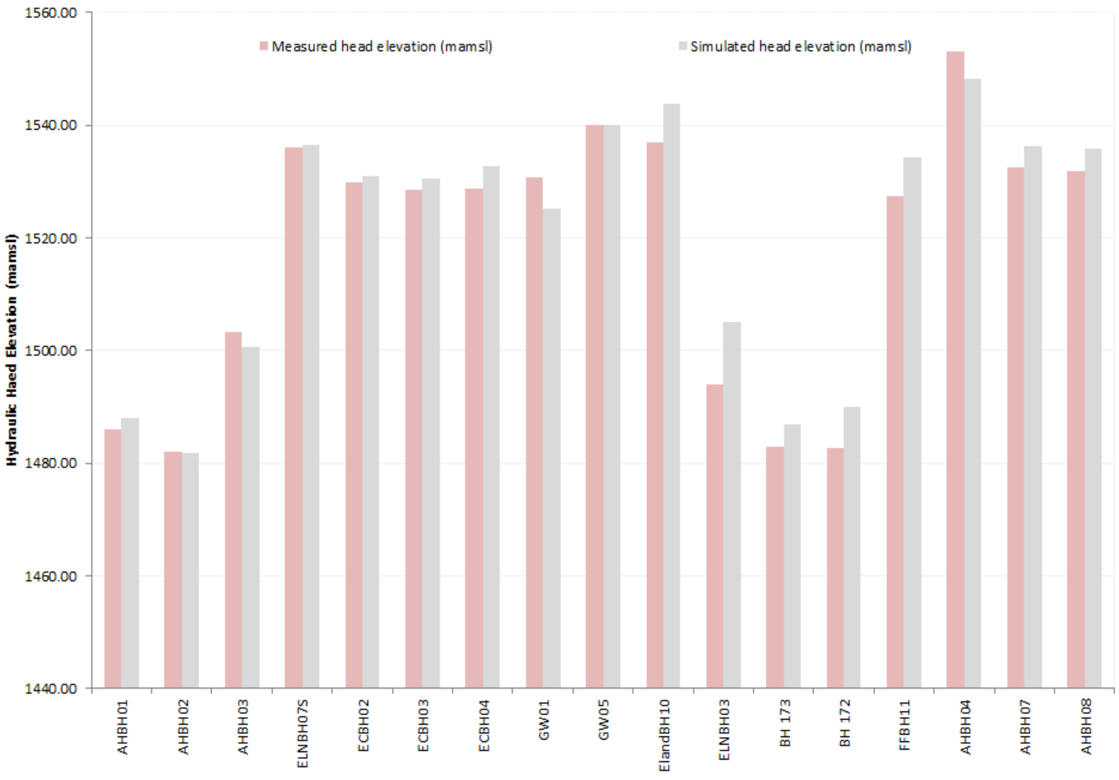

Table 12-2 Steady State Model Calibration – Statistical Summary.

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)
AHBH01	1490.87	4.85	1486.02	1488.05	-2.03	2.03	4.13
AHBH02	1492.27	10.29	1481.98	1481.84	0.15	0.15	0.02
AHBH03	1511.54	8.18	1503.36	1500.53	2.83	2.83	8.01
ELNBH07S	1549.96	13.98	1535.98	1536.44	-0.46	0.46	0.21
ECBH02	1537.32	7.56	1529.76	1531.04	-1.27	1.27	1.62
ECBH03	1536.13	7.57	1528.56	1530.55	-1.99	1.99	3.96
ECBH04	1538.36	9.55	1528.81	1532.75	-3.94	3.94	15.52
GW01	1538.26	7.43	1530.83	1525.26	5.57	5.57	30.99
GW05	1542.94	2.85	1540.09	1540.04	0.05	0.05	0.00
ElandBH10	1559.20	22.33	1536.87	1543.86	-6.99	6.99	48.88
ELNBH03	1511.36	17.34	1494.02	1504.92	-10.90	10.90	118.79
BH 173	1486.91	4.02	1482.89	1486.91	-4.02	4.02	16.16
BH 172	1488.44	5.78	1482.66	1489.95	-7.30	7.30	53.26
FFBH11	1534.12	6.81	1527.31	1534.27	-6.96	6.96	48.39
AHBH04	1560.17	7.18	1552.99	1548.21	4.78	4.78	22.80
AHBH07	1539.99	7.54	1532.45	1536.15	-3.70	3.70	13.72
AHBH08	1536.52	4.58	1531.94	1535.86	-3.92	3.92	15.38
Average	**1526.73**	**8.70**	**1518.03**	**1520.39**	**-2.36**	**3.93**	**23.64**
Minimum	**1486.91**	**2.85**	**1481.98**	**1481.84**	**-10.90**	**0.05**	**0.00**
Maximum	**1560.17**	**22.33**	**1552.99**	**1548.21**	**5.57**	**10.90**	**118.79**
Correlation			**0.983**				
∑					**-40.12**	**66.85**	**401.85**
1/n					**-2.36**	**3.93**	**23.64**
Root Mean Square Deviation (RMSD)					**1.54**	**1.98**	**4.86**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**6.85**

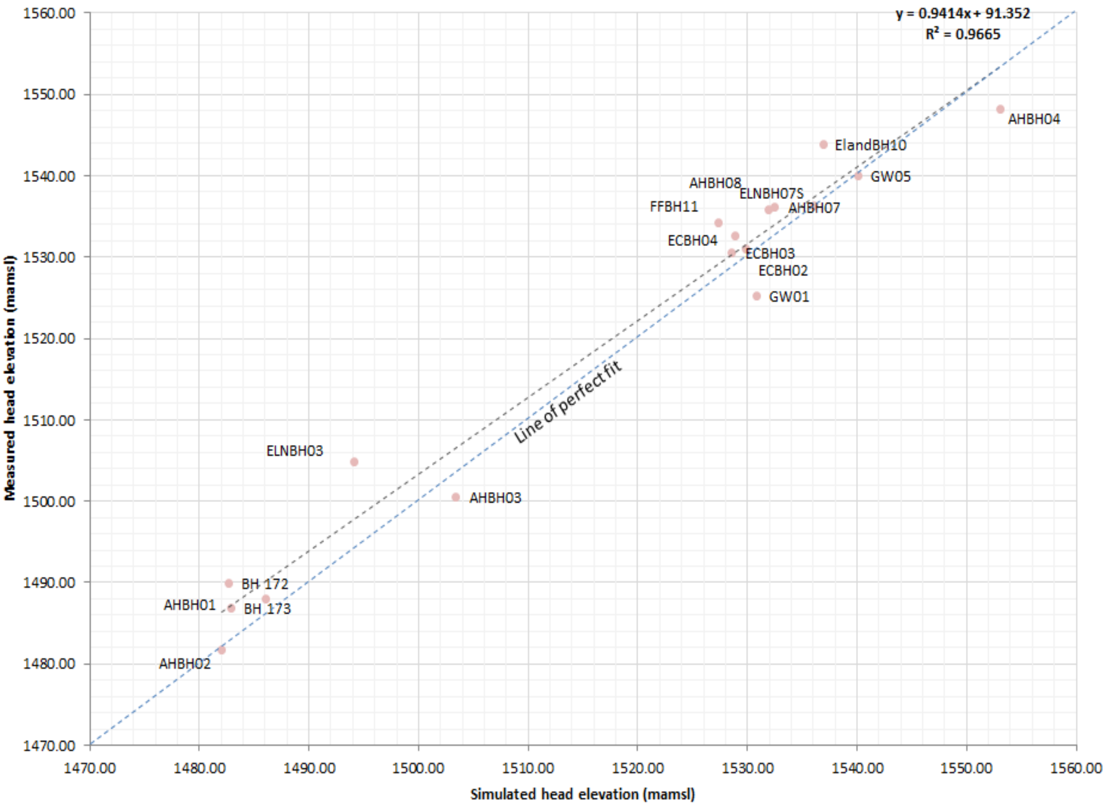

Figure 12-7 Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.

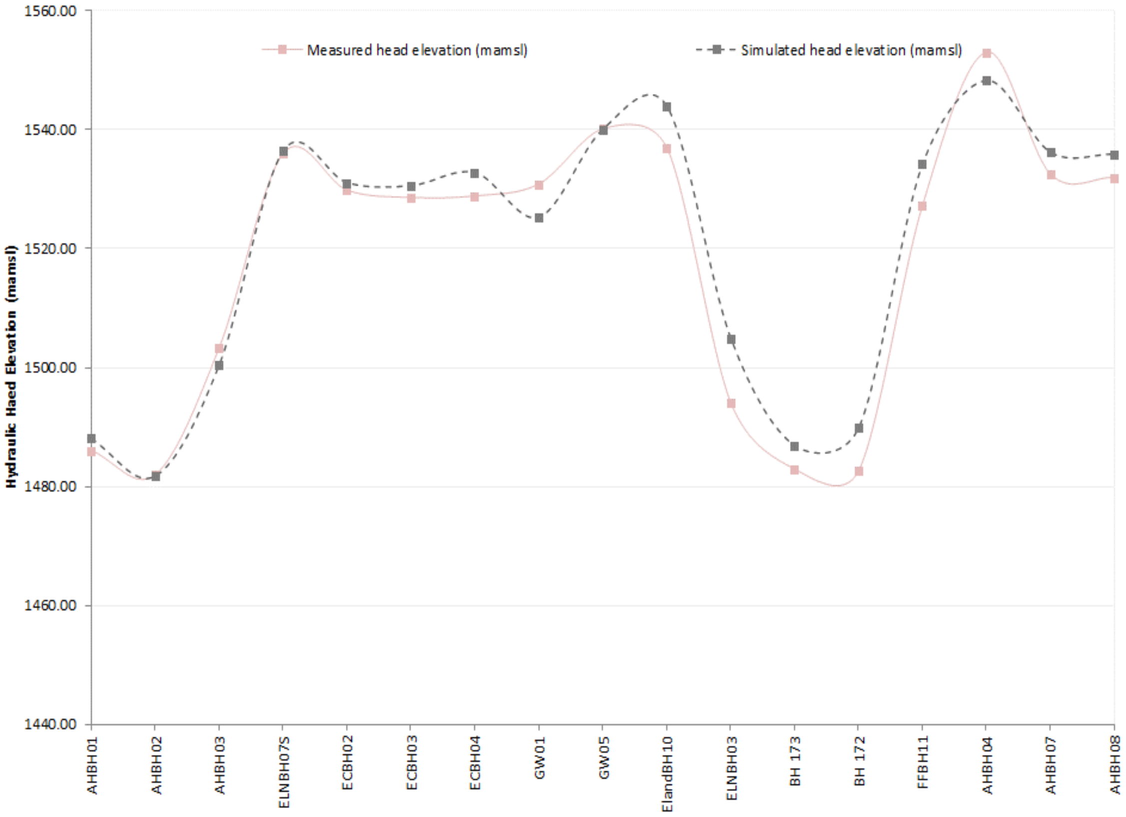

Figure 12-8 Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.

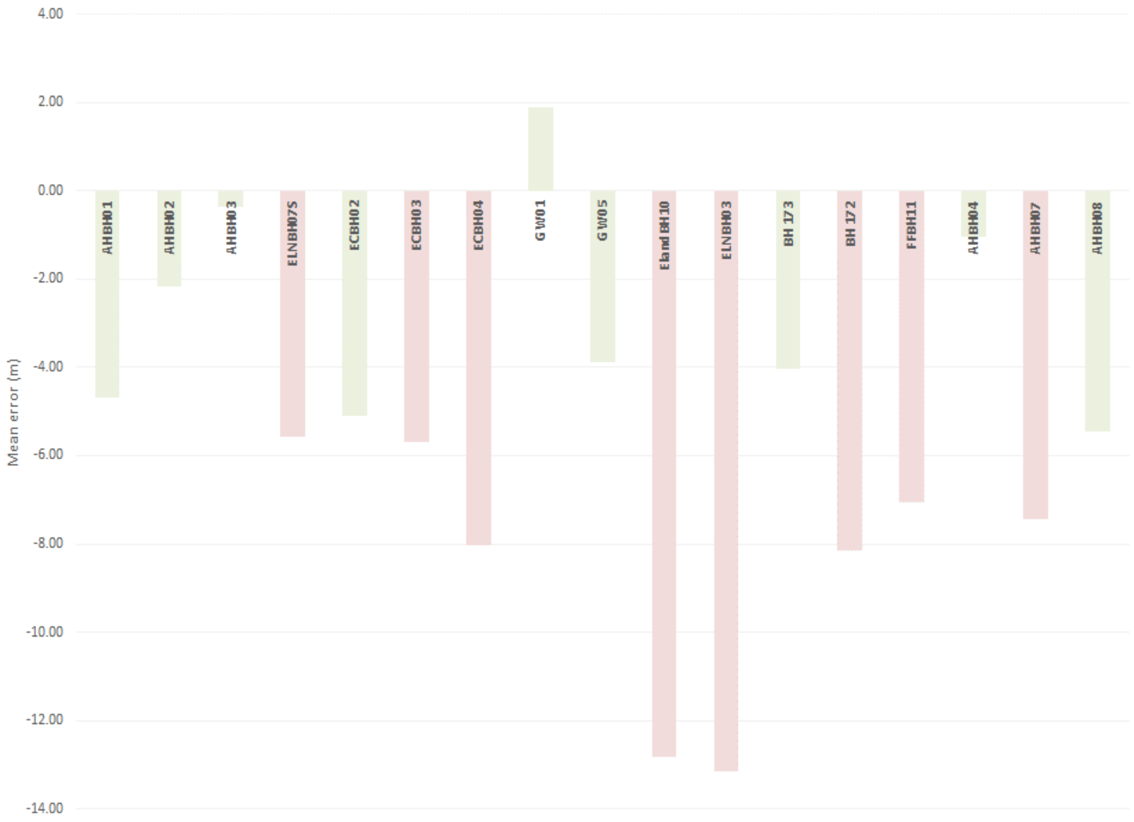

Figure 12-9 **Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.**

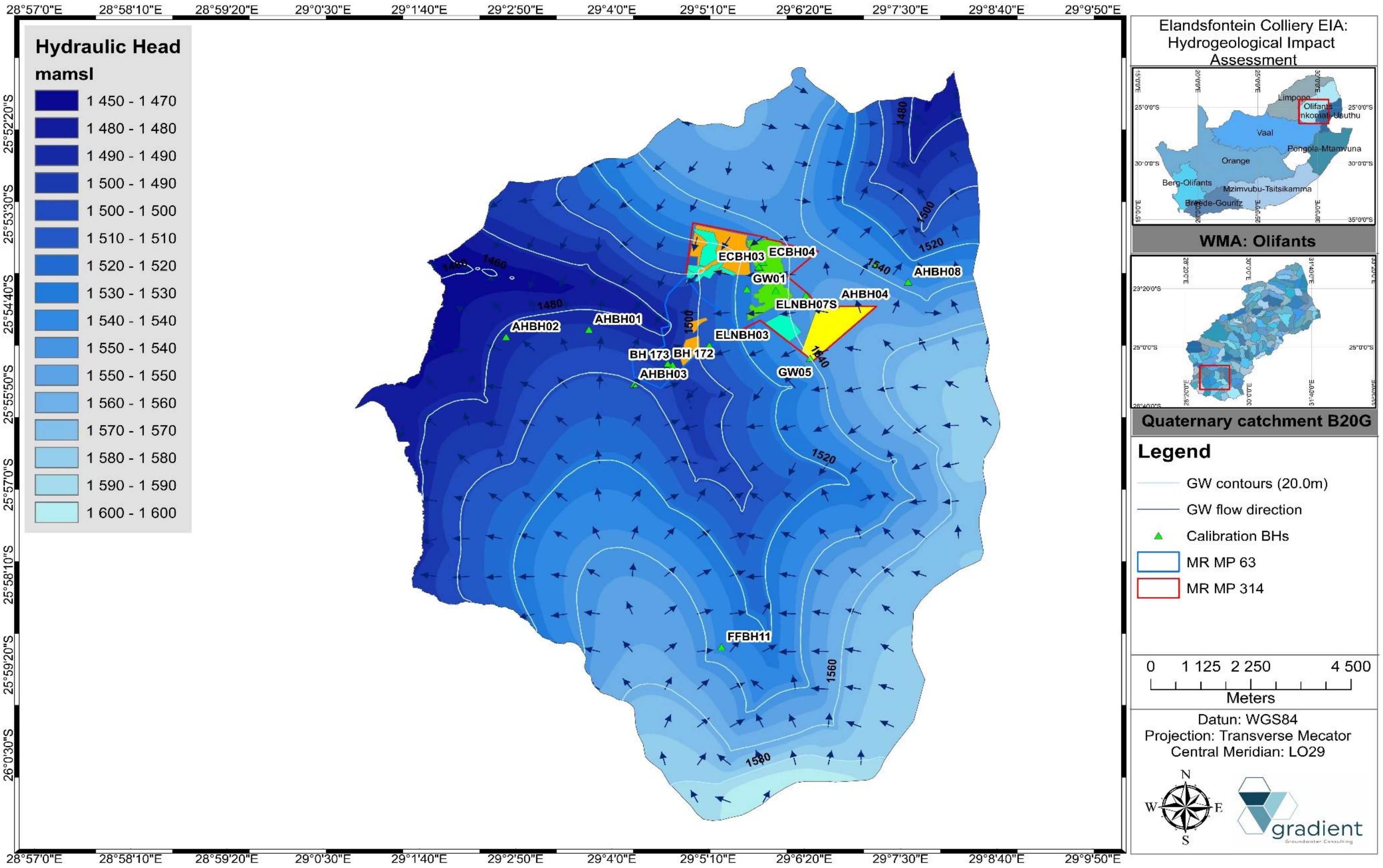

Figure 12-10 **Model calibration: steady state hydraulic heads and groundwater flow direction.**

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 (Figure 12-11, Figure 12-12 and Figure 12-13)[20].

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

Parameter	Scenario: Base Case	Scenario: 90% of calibrated K-value	Scenario: 110% of calibrated K-value	Scenario: 90% of calibrated recharge	Scenario: 110% of calibrated recharge
Correlation	0.98	0.99	0.98	0.98	0.99
Mean Error	-2.36	-4.63	-1.45	-0.79	-5.46
Mean Abs Error	3.93	5.21	3.75	3.81	5.68
RMSD	4.86	6.07	4.88	4.75	6.67
NRMSD	6.85%	8.55%	6.87%	6.96%	9.39%

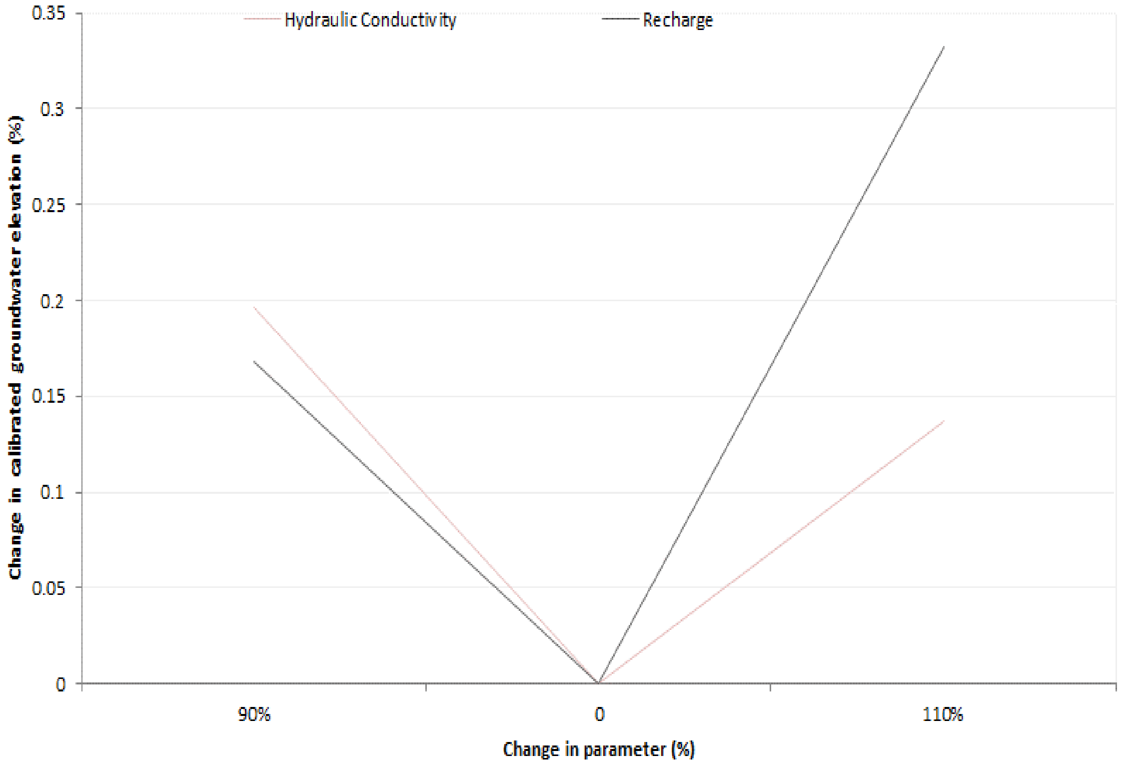

Figure 12-11 Model steady state calibration: sensitivity analysis for monitoring locality ELNBH07S.

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[20] 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.

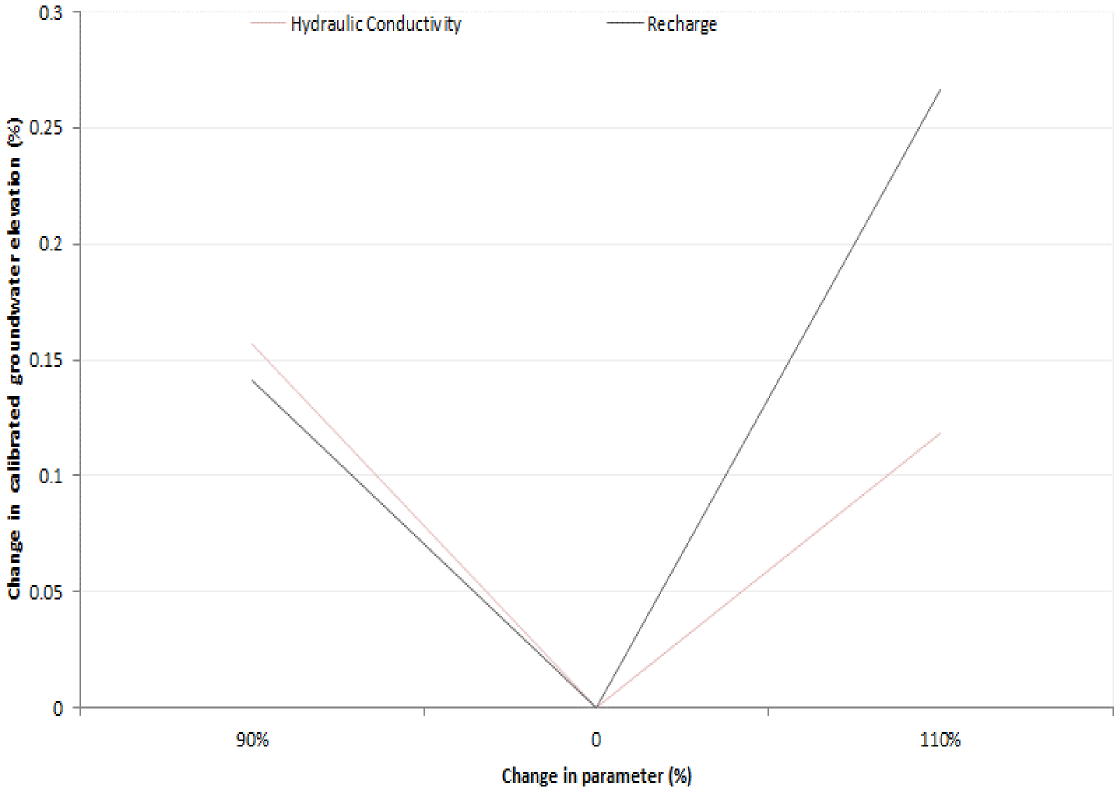

Figure 12-12 Model steady state calibration: sensitivity analysis for monitoring locality ECBH04.

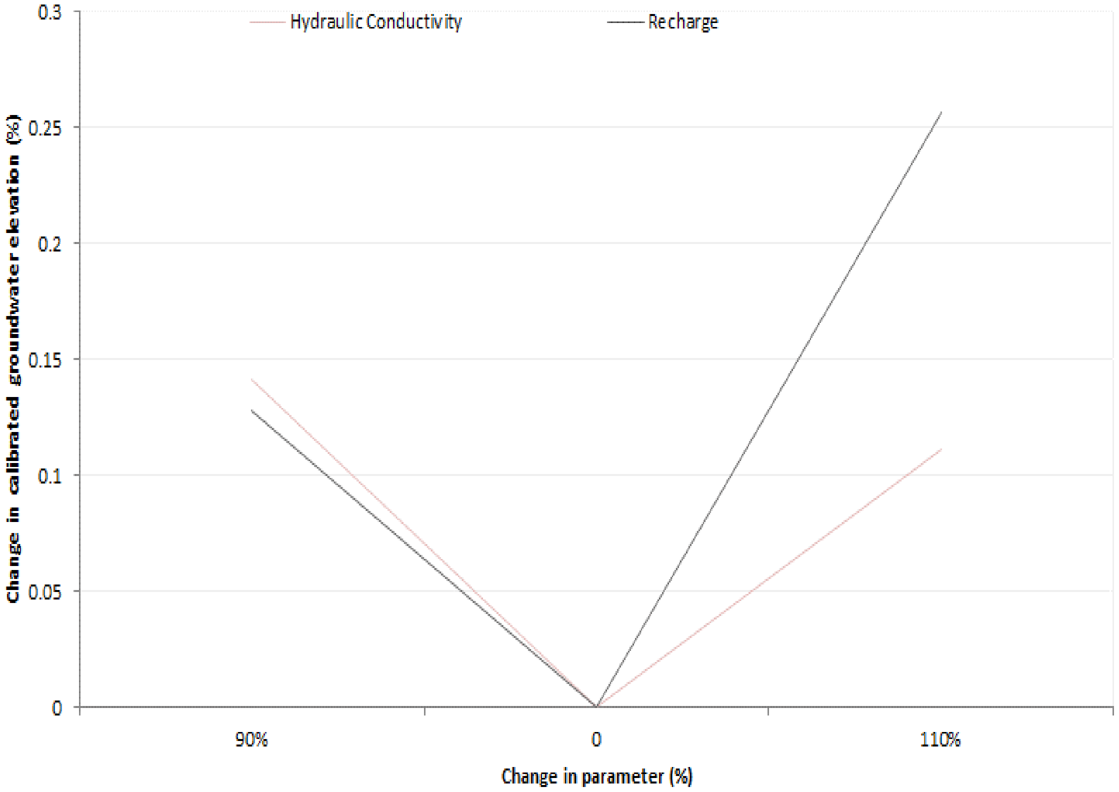

Figure 12-13 Model steady state calibration: sensitivity analysis for monitoring locality GW05.

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:** Proposed LOM opencast dewatering operational phase(s).

iii. **Scenario 02b:** Proposed LOM underground dewatering operational phase(s).

iv. **Scenario 03a:** Post-closure opencast pits re-watering, hydraulic head recovery and decant potential.

v. **Scenario 03b:** Post-closure underground void re-watering, hydraulic head recovery and decant potential.

vi. **Scenario 04:** Proposed LOM sulphate pollution plume migration.

vii. **Scenario 05a:** Post-closure sulphate pollution plume migration (50-years).

viii. **Scenario 05b:** Post-closure sulphate pollution plume migration (100-years).

ix. **Scenario 06a (mitigation and management):** Seepage capturing/ scavenger boreholes down-gradient of waste facilities and backfilled opencasts.

x. **Scenario 06b (mitigation and management):** Cut-off seepage capturing trench down-gradient of waste facilities and backfilled opencasts.

xi. **Scenario 06c (mitigation and management):** Maintaining a minimum in-pit water level below decant elevation by establishment of in-pit abstraction facilities.

xii. **Scenario 06d (mitigation and management):** Scavenger boreholes down-gradient of waste facilities and implementation of a lined facility for disposal of carbonaceous waste material.

xiii. **Scenario 06e (mitigation and management):** Active water management by establishment of scavenger boreholes down-gradient of waste facilities in combination with disposal of carbonaceous waste material in the northern discard pit.

xiv. **Scenario 06f (mitigation and management):** Active water management by establishment of scavenger boreholes down-gradient of waste facilities in combination with rehabilitation of the south-eastern discard dump.

Table 12-4 Summary of model stress-periods.

Stress period	Description
Year01 - Year04	EMP 2017 LOM operational opencast and underground [21]
Year05 - Year10	LOM operational opencast and underground
Year 60	50-years post closure
Year 110	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 3.06E^{+03} m^3/d, while the largest loss to the groundwater system is via baseflow, 1.81E^{+03} m^3/d. An assumption has been made for the total volume of groundwater abstraction from privately owned water supply boreholes account to 8.64E^{+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)	3.06E+03	0.00E+00	3.06E+03
Abstraction (m^3/d)	0.00E+00	8.64E+02	-8.64E+02
Baseflow (m^3/d)	0.00E+00	1.81E+03	-1.81E+03
Imbalance ignoring internal transfer (m^3/d)	0.00E+00	3.83E+02	-3.83E+02
Total (m^3/d)	**3.06E+03**	**3.06E+03**	**0.00E+00**

12.5.3. Scenario 02a: Proposed future LOM opencast dewatering operational phase(s).

Table 12-6 summarises the groundwater catchment water balance for stress periods representing the proposed opencast LOM phases. Model simulations suggest the average open pit dewatering is approximately 2.57E^{+02} m^3/d with a maximum pit water ingress of approximately 5.09E^{+02} m^3/d for the duration of the simulation period. It is noted that the opencast groundwater ingress volumes expected is much lower due to the existing groundwater drawdown caused by current dewatering activities. Figure 12-14 depicts the time-series dewatering curve for the opencast LOM period, while Figure 12-15 shows the simulated groundwater drawdown observed at observation borehole localities.

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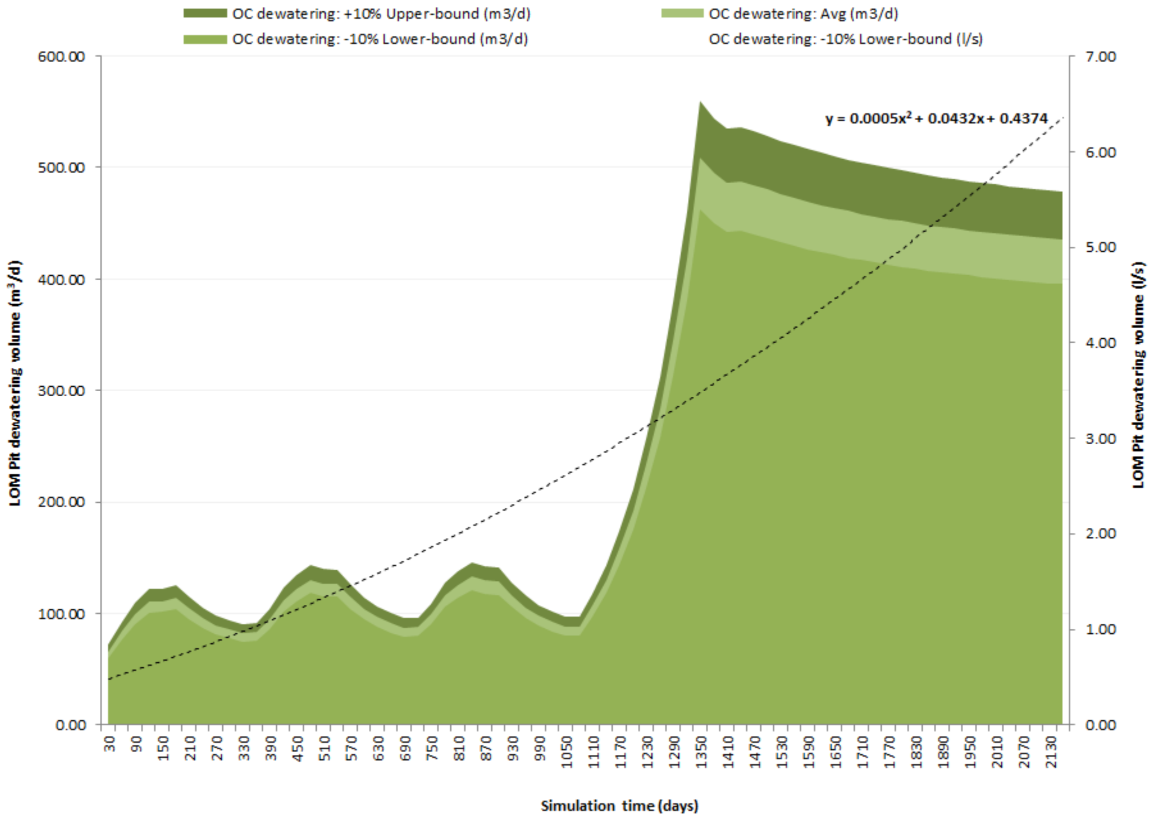
[21] It should be noted that, although this stress period is not reported on and does not form part of this investigation SOW, it has been simulated in order to obtain a background from where the future LOM simulations have been based on.

It is expected that the groundwater drawdown will range from 4.0m to ~ 24.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 211.0ha as indicated in Figure 12-17[22]. It should be noted that the simulated impact zone extends slightly beyond the eastern perimeter of the mining right area, however, falls mainly within the mining properties. The expected groundwater zone of influence stretches and overlap with the wetland system traversing the site. Baseflow discharges[23] to the model catchment drainages, accounts to approximately 1800.0 m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1750.0 m^3/d. This accounts for an average loss of ~3.0% with a maximum of >10.0% during the simulation period (refer to Figure 12-16 below).

Table 12-6 Catchment water balance: Scenario 02a - Proposed LOM opencast dewatering operational phase(s).

Scenario 02a: Proposed LOM opencast dewatering operational phase(s)			
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	3.06E+03	0.00E+00	3.06E+03
Abstraction (m^3/d)	0.00E+00	8.64E+02	-8.64E+02
Baseflow (m^3/d)	0.00E+00	1.76E+03	-1.76E+03
Opencast dewatering (m^3/d)	0.00E+00	2.57E+02	-2.57E+02
Storage Capture(-)/Release(+)(m^3/d)	0.00E+00	1.81E+02	-1.81E+02
Total (m^3/d)	**3.06E+03**	**3.06E+03**	**0.00E+00**



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[22] It should be noted be noted that no groundwater drawdown is simulated for the proposed south-eastern pit (Area H) due to excavation taking place in an already influenced groundwater system (historical groundwater drawdown).

[23] It should be noted that baseflow calculations is expressed as a total observed loss based on all drainages within the delineated model domain/catchment, including the wetland and associated drainage system of the Grootspruit segments.

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

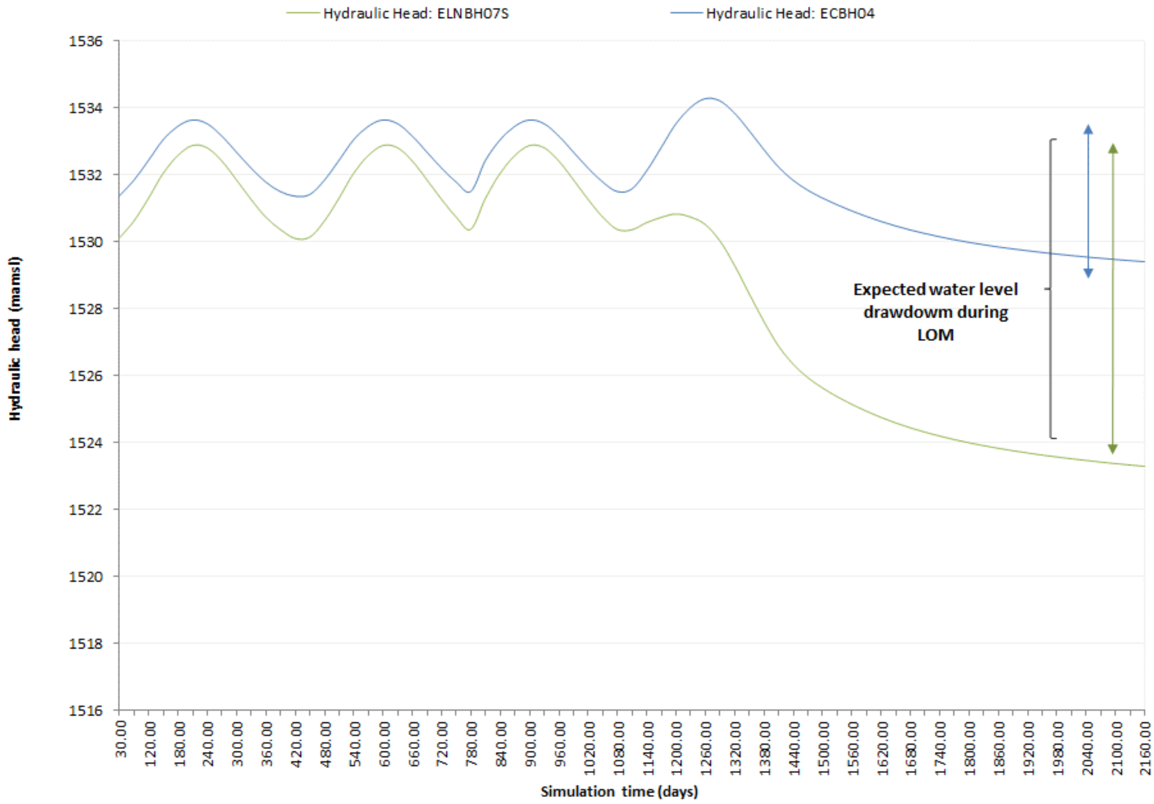

Figure 12-15 **Scenario 02a: time-series water level drawdown for on-site monitoring boreholes.**

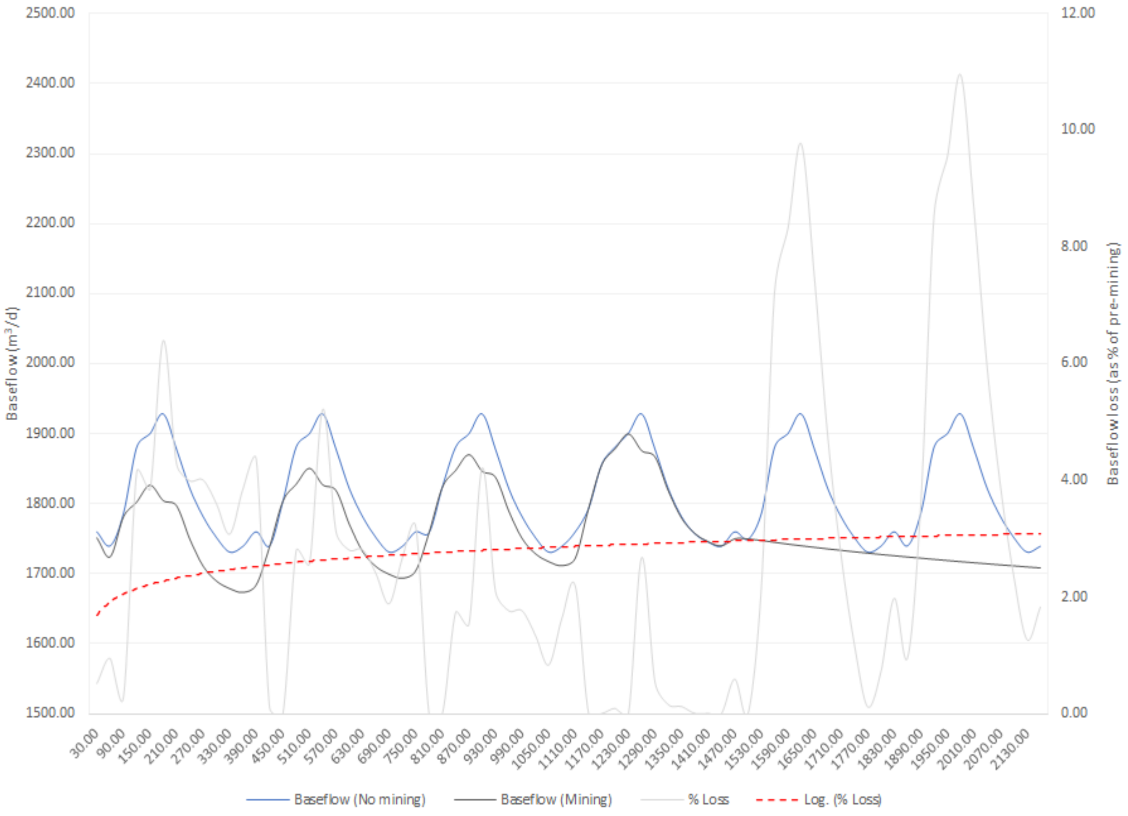

Figure 12-16 **Scenario 02a: Baseflow comparison curve: Pre-mining vs opencast dewatering.**

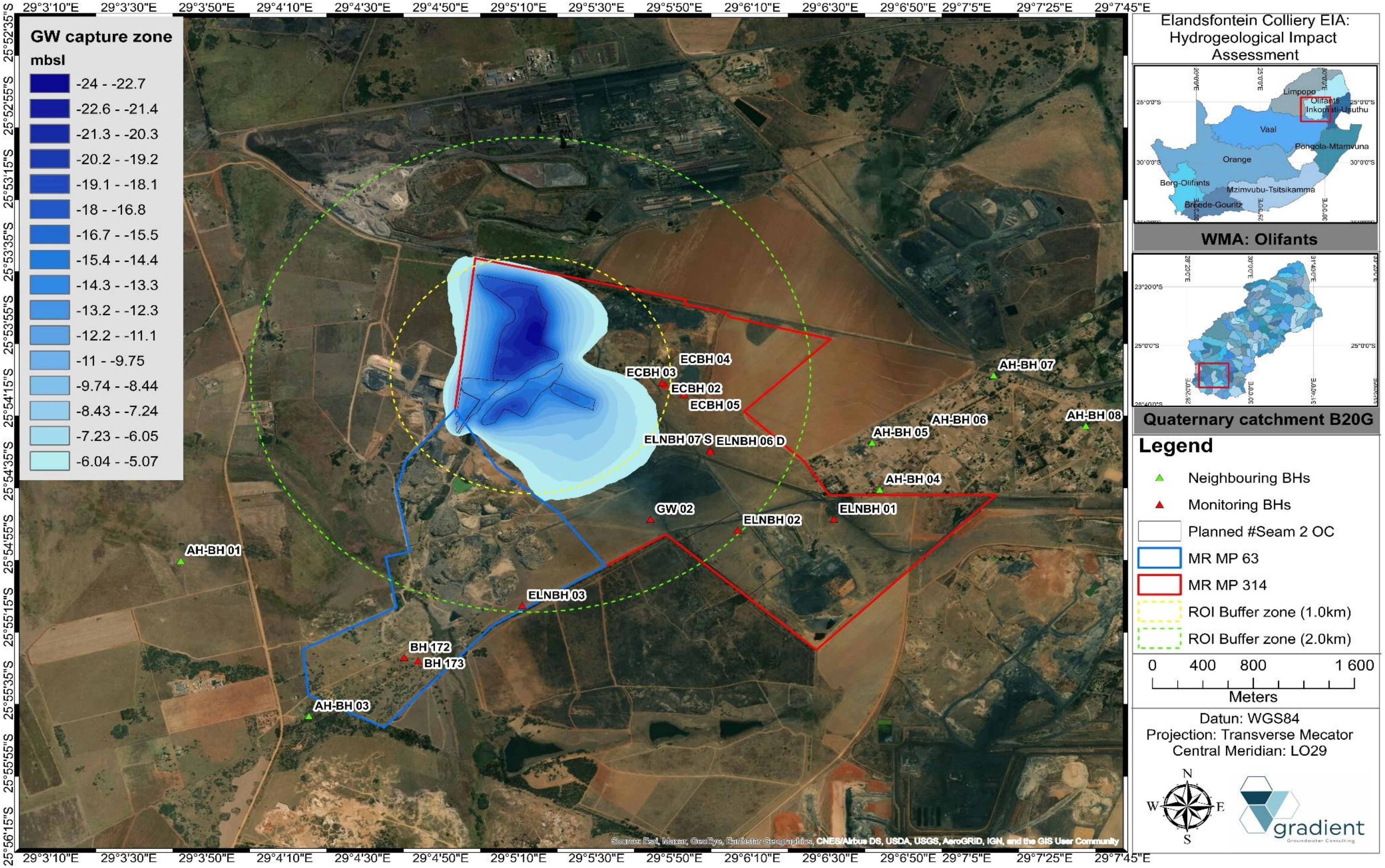

Figure 12-17 **Scenario 02a: Water level drawdown and groundwater capture zone of the shallow, weathered aquifer.**

12.5.4. Scenario 02b: Proposed LOM underground dewatering operational phase(s).

Table 12-7 summarises the groundwater catchment water balance for stress periods representing the proposed underground LOM phases. Model simulations suggest the average underground void dewatering is approximately 1.44E^{+03} m^3/d with a maximum underground water ingress of approximately 2.03E^{+03} m^3/d for the duration of the simulation period. Figure 12-18 depicts the time-series dewatering curve for the underground LOM period, while Figure 12-19 shows the simulated groundwater drawdown observed at observation borehole localities. It is expected that the groundwater drawdown will range from 4.0m to ~ 30.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 720.90ha as indicated in Figure 12-17. It should be noted that the simulated impact zone extends slightly beyond the eastern and south-eastern perimeters of the mining right area, however, falls mainly within the mining properties. It is not expected that the underground operations will have a significant effect on the baseflow discharge to local drainages.

Table 12-7 Catchment water balance: Scenario 02b - Proposed LOM underground dewatering operational phase(s).

Scenario 02b: Proposed LOM underground dewatering operational phase(s)			
Parameter	**Inflow (m³/d)**	**Outflow (m³/d)**	**Balance (m³/d)**
Recharge (m³/d)	3.06E+03	0.00E+00	3.06E+03
Abstraction (m³/d)	0.00E+00	8.64E+02	-8.64E+02
Baseflow (m³/d)	0.00E+00	2.54E+02	-2.54E+02
Underground dewatering (m³/d)	0.00E+00	1.44E+03	-1.44E+03
Storage Capture(-)/Release(+)(m³/d)	0.00E+00	5.02E+02	-5.02E+02
Total (m³/d)	**3.06E+03**	**3.06E+03**	**0.00E+00**

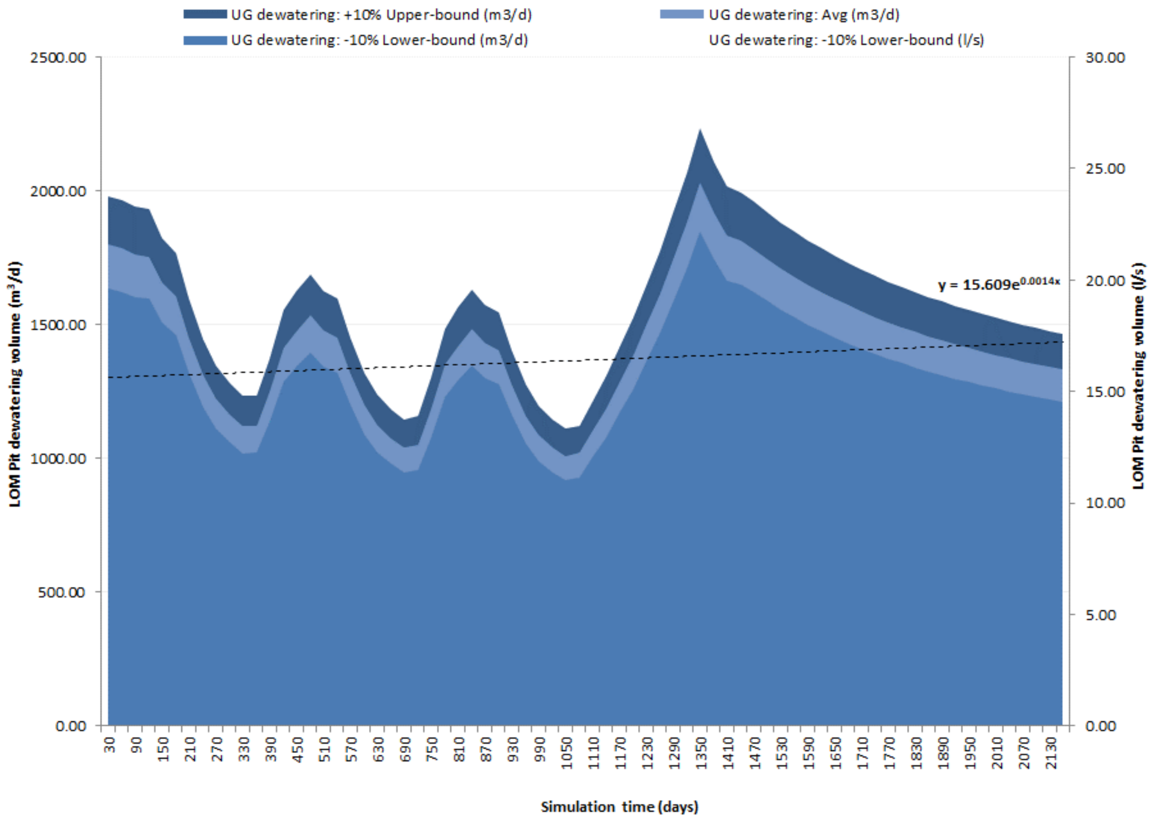

Figure 12-18 Scenario 02b: Underground time-series dewatering/ groundwater ingress curve.

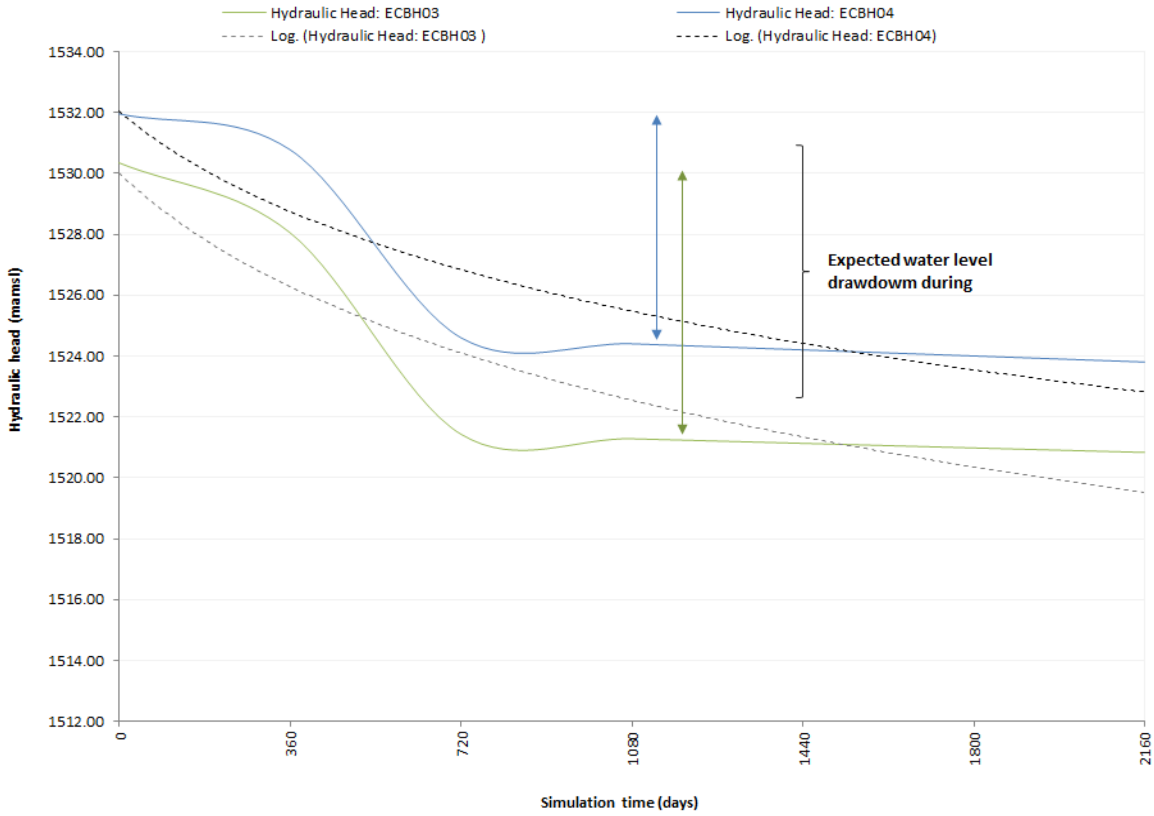

Figure 12-19 Scenario 02b: time-series water level drawdown for on-site monitoring boreholes.

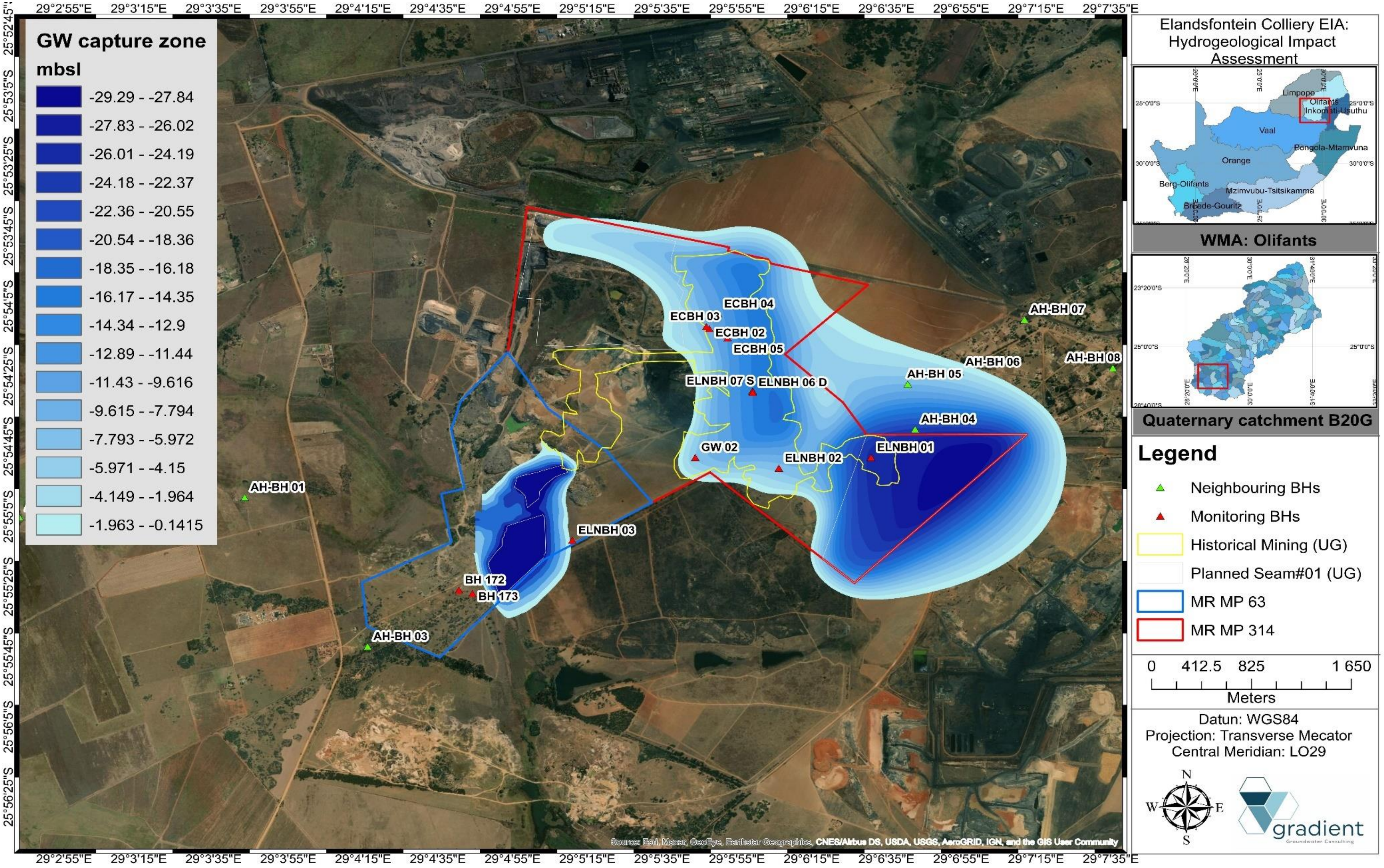

Figure 12-20 **Scenario 02b: Water level drawdown and groundwater capture zone of the deeper, fractured aquifer.**

12.5.5. Scenario 03a: Post-closure opencast pits re-watering, hydraulic head recovery and decant potential.

In order to determine the timeframe that the backfilled pits will take to fill up and decant, the void space must be calculated. Various backfilled porosity scenarios as well as effective pit infiltration rates were applied to determine the range of expected decant volumes and timeframes. Simulated average groundwater ingress for the LOM opencast operation was combined with the expected groundwater recharge i.e. effective pit infiltration reporting to the backfilled opencast (variable depending on the rainfall scenario applied) in order to calculate the expected time to fill and decant. Figure 12-21 shows a bar-chart summary of decant timeframes per opencast pit. Pit flooding and associated decant periods ranges between ~5.0years to >20years depending on the geometry of the backfilled pit.

Generally, the decant point/zone is the lowest topographical point of the existing mining footprint which is in direct connection with surface topography. A mine post-closure scenario was simulated wherein hydraulic head recovery within the proposed opencast areas was evaluated. It is calculated that the newly proposed backfilled opencast pit flooding and associated decant periods ranges between ~5.0years to >20years depending on the geometry of the backfilled pit. Expected decant volumes for the backfilled opencast pits varies from 8.0m^3/d to > 70.0m^3/d depending on the pit effective infiltration volumes. The combined decant volume is approximately ~150.0m^3/d as summarised in Table 12-8, Table 12-9 as well as Table 12-10. It should be noted that decant volumes for the opencast operation is expected to be much higher due to the increased effective pit infiltration and rainfall recharge of the backfilled and modified zones. It is calculated that the existing/historical backfilled opencast pits decant volumes varies from 40.0m^3/d to > 190.0m^3/d with a combined decant volume of approximately ~626.0m^3/d. It should be noted that there are various decant points potentially discharging into the wetland drainage system traversing the site. Potential decant zones are depicted in Figure 12-22, it is noted that there are various decant points potentially discharging into the wetland drainage system traversing the site. Figure 12-23 indicate a map of alternative final void positions to be established post-closure should it be necessary.

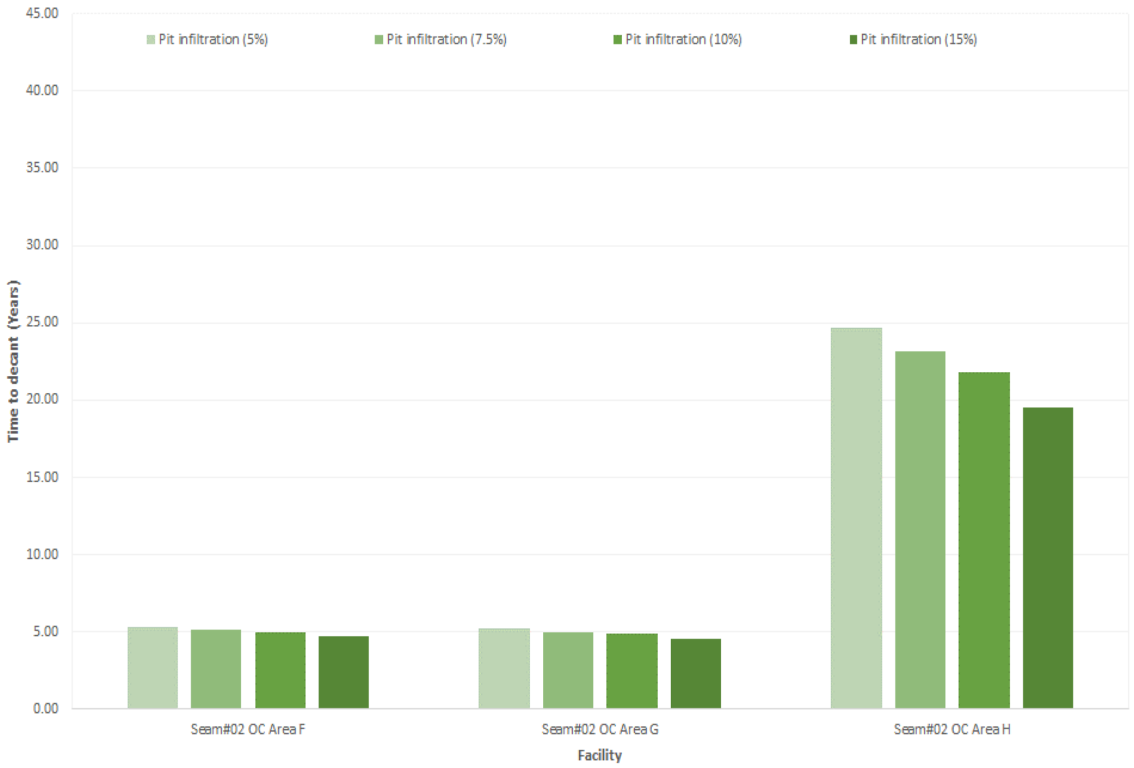

Figure 12-21 Scenario 03a: Bar chart summarsining expected decant timeframes curve for back-filled pits.

Table 12-8 Scenario 03a: Proposed mining of Seam#02 - Area F.

DECANT SCENARIOS: Future mining Seam#02 OC Area F	
Decant elevation (mamsl)	1 498.00
Mined area (m^2)	118 301.23
Mined volume (m^3)	1 183 012.27
Backfill porosity (10%)	118 301.23
Backfill porosity (20%)	236 602.45
Backfill porosity (30%)	354 903.68
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
Average simulated pit inflow (m^3/d)	114.00

Time to decant (Years):

Backfill porosity scenarios	**Effective pit infiltration**			
%	**5.00%**	**7.50%**	**10.00%**	**15.00%**
10.00%	2.68	2.59	2.50	2.34
20.00%	5.36	5.17	5.00	4.69
30.00%	7.93	7.66	7.41	6.96

Effective steady state decant volume (m^3/d)

Rainfall scenarios	**Effective pit infiltration**			
	5.00%	**7.50%**	**10.00%**	**15.00%**
Dry cycle (5th Percentile)	5.63	8.45	11.26	16.89
Average rainfall (MAP)	8.72	13.08	17.44	26.16
Wet cycle (95th Percentile)	11.79	17.69	23.59	35.38

Table 12-9 Scenario 03a: Proposed mining of Seam#02- Area G.

DECANT SCENARIOS: Future mining Seam#02 OC Area G	
Decant elevation (mamsl)	1 498.00
Mined area (m^2)	320 997.85
Mined volume (m^3)	3 209 978.48
Backfill porosity (10%)	320 997.85
Backfill porosity (20%)	641 995.70
Backfill porosity (30%)	962 993.55
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
Average simulated pit inflow (m^3/d)	320.00

Time to decant (Years):

Backfill porosity scenarios	**Effective pit infiltration**			
%	**5.00%**	**7.50%**	**10.00%**	**15.00%**
10.00%	2.59	2.51	2.43	2.28
20.00%	5.19	5.02	4.85	4.56
30.00%	7.68	7.43	7.20	6.76

Effective steady state decant volume (m^3/d)

Rainfall scenarios	**Effective pit infiltration**			
	5.00%	**7.50%**	**10.00%**	**15.00%**
Dry cycle (5th Percentile)	15.28	22.92	30.56	45.84
Average rainfall (MAP)	23.66	35.49	47.33	70.99
Wet cycle (95th Percentile)	32.00	48.01	64.01	96.01

Table 12-10 Scenario 03a: Proposed mining of Seam#02- Area H.

DECANT SCENARIOS: Future mining Seam#02 OC Area H	
Decant elevation (mamsl)	1 552.00
Mined area (m^2)	255 696.15
Mined volume (m^3)	6 392 403.65
Backfill porosity (10%)	639 240.37
Backfill porosity (20%)	1 278 480.73
Backfill porosity (30%)	1 917 721.10
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
Average simulated pit inflow (m^3/d)	125.00

Time to decant (Years):

Backfill porosity scenarios	**Effective pit infiltration**			
%	**5.00%**	**7.50%**	**10.00%**	**15.00%**
10.00%	12.34	11.58	10.91	9.78
20.00%	24.69	23.17	21.83	19.56
30.00%	36.59	34.37	32.40	29.06

Effective steady state decant volume (m^3/d)

Rainfall scenarios	**Effective pit infiltration**			
	5.00%	**7.50%**	**10.00%**	**15.00%**
Dry cycle (5th Percentile)	12.17	18.26	24.34	36.52
Average rainfall (MAP)	18.85	28.27	37.70	56.55
Wet cycle (95th Percentile)	25.49	38.24	50.99	76.48

Figure 12-22 Scenario 03a: Potential decant zones for the backfilled opencast pits.

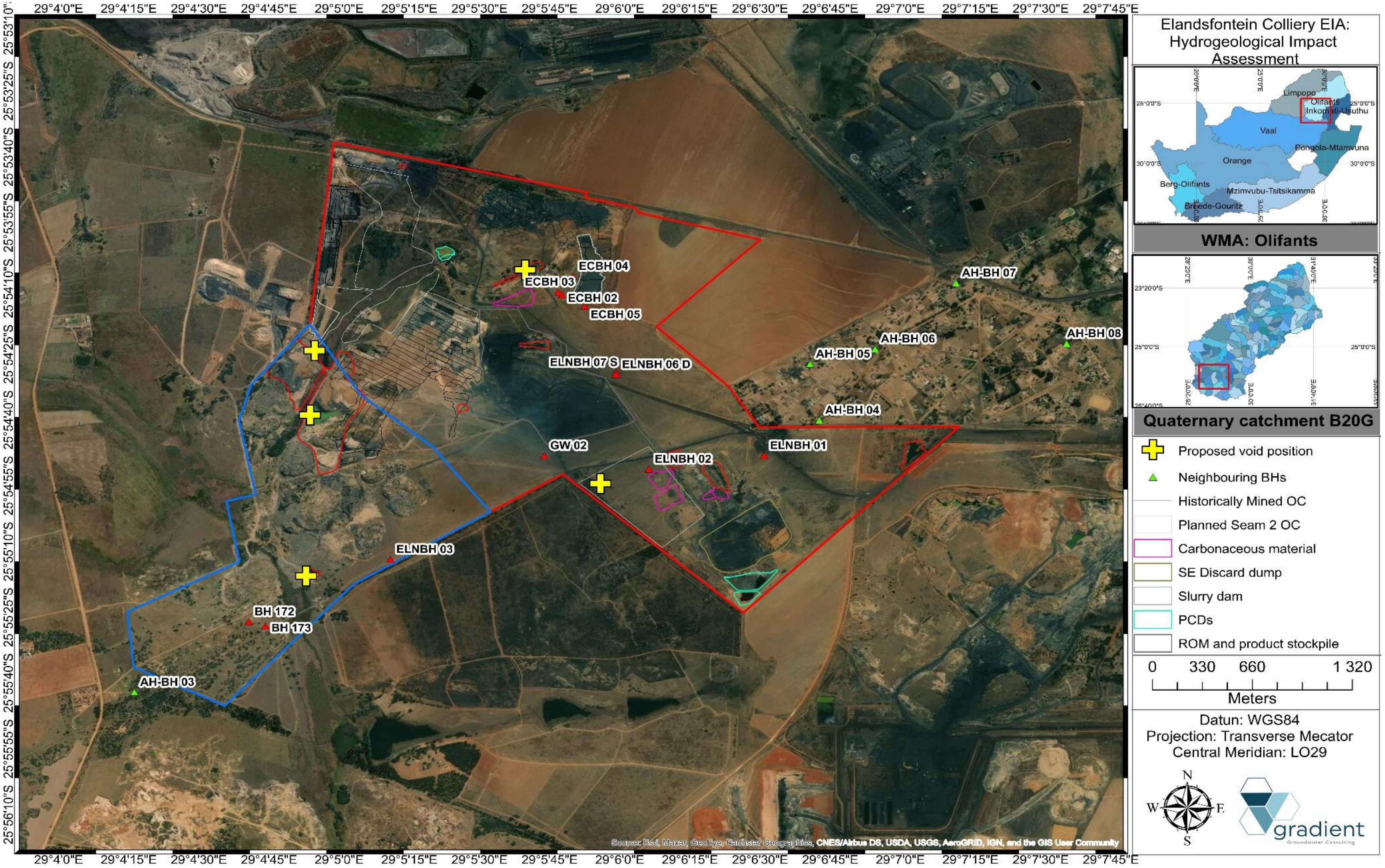

Figure 12-23 **Scenario 03a: Map indicating alternative final void positions.**

12.5.6. Scenario 03b: Post-closure underground void re-watering, hydraulic head recovery and decant potential.

A mine post-closure scenario was simulated wherein hydraulic head recovery within the existing underground voids as well proposed mining areas was evaluated. In order to determine the period the underground voids will take to be flooded, and potentially decant, the mine void space must be calculated for the underground operations as summarised in Figure 12-24. It is calculated that the existing underground void as well as newly proposed mine footprints, will occupy an approximate total volume of $8.56e^{+6}m^3$ of void space. Simulated average groundwater ingress[24] for the LOM underground operation was combined with the expected groundwater recharge reporting to the underground void in order to calculate the expected time to flooding of these voids. The flooding curves for the underground operation are depicted in Figure 12-25. From these volumes it is estimated that under average rainfall conditions, the underground will be flooded in approximately 35 to 40 years after ceasing of mining activities. The proposed depth and geometry of the underground operations allows for the majority of footprint to be flooded except where coal floor contour elevation >1530.0mamsl.

Generally, the decant point/zone is the lowest topographical point of the existing mining footprint which is in direct connection with surface topography. The latter usually occur via a preferred groundwater flow pathway such as shafts (as in this case) or unrehabilitated exploration boreholes as well as geological lineaments such as fault zones or weathered contact zones of dykes.

The proposed depth and geometry of the underground operations allows for the entire footprint to be flooded without any decant expected, however as indicated in Figure 12-26, a potentially higher decant risk area i.e. coal floor contour <10.0mbgl is earmarked accordingly.

Expected decant volumes for the underground voids are relatively low due to the presence of confining shale and mudstone layers restricting the downward filtration of rainwater recharge into the underground mine void(s) and ranges between $0.85m^3/d$ to ~$17m^3/d$ with a combined volume of approximately $50.0m^3/d$ as summarised in Table 12-11, Table 12-12, Table 12-13, Table 12-14, Table 12-15 and Table 12-16.

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[24] It should be noted that the dewatering volumes applied is representative of the maximum operational dewatering rates i.e. coal floor contours. Recovering of hydraulic gradient will lead to a decrease in groundwater ingress over time. Once a new equilibrium i.e. quasi steady state has been reached, mine outflow volumes (decant) will be equal to effective rainfall recharge infiltration volumes.

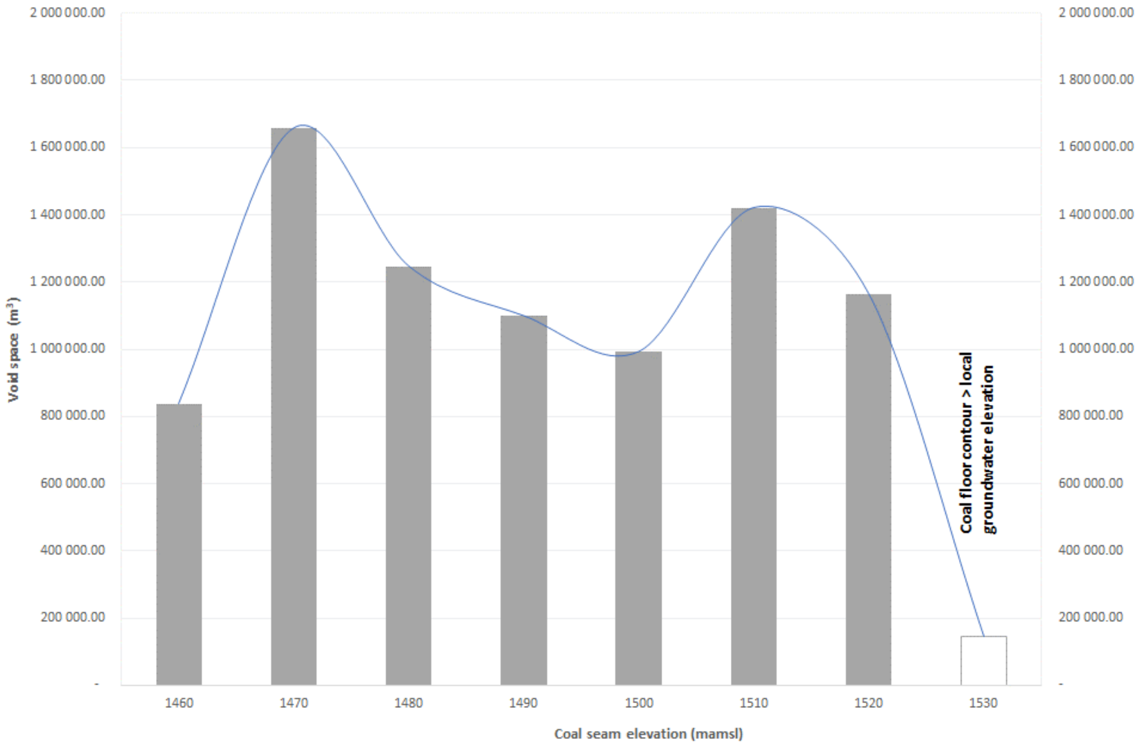

Figure 12-24 Scenario 03b: Mine void space for the underground operartions.

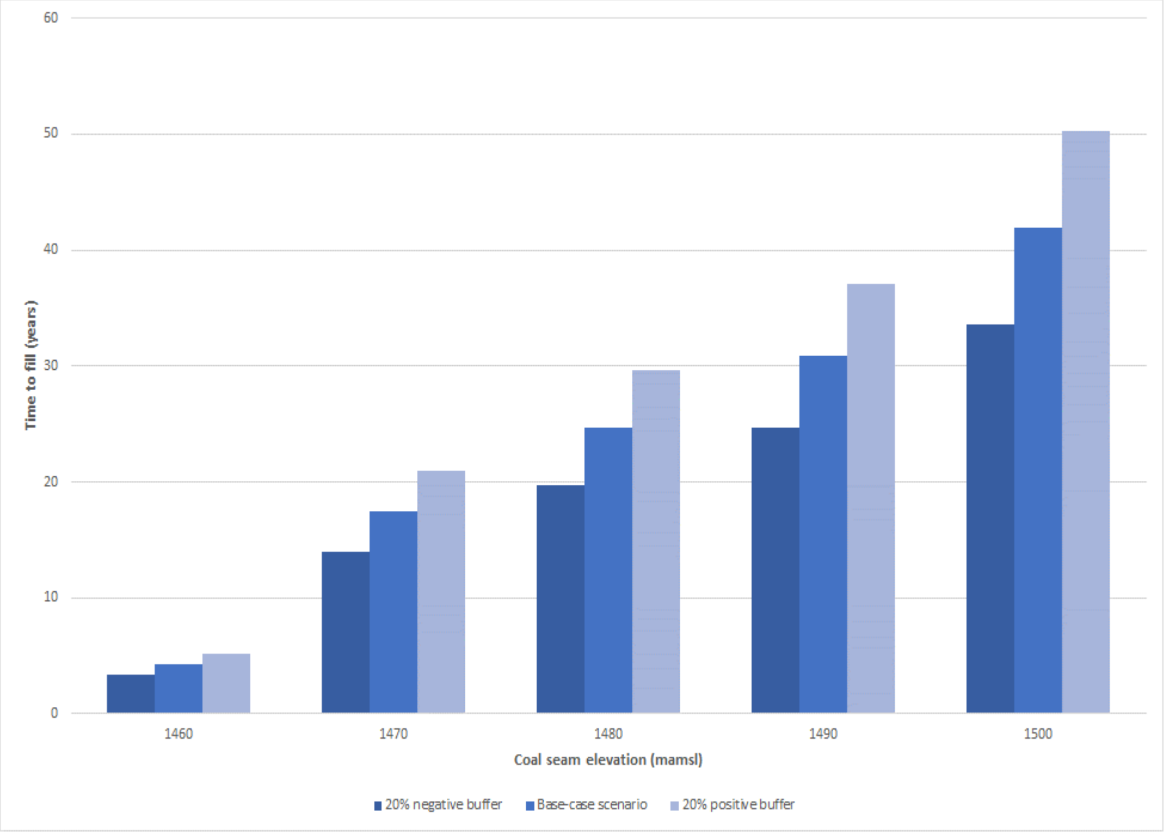

Figure 12-25 Scenario 03b: Flooding curve for the underground operartions.

Table 12-11 Scenario 03b: Existing mining of Seam#01.

DECANT SCENARIOS: Seam#01 UG EMP 2017	
Mined area (m²)	326 874.19
Average seam thickness	2.60
Mined volume (m³)	594 911.02
Average simulated void inflow (m³/d)	232.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	7.03
Average rainfall (MAP)	6.98
Wet cycle (95th Percentile)	6.93
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	3.11
Average rainfall (MAP)	4.82
Wet cycle (95th Percentile)	6.52

Table 12-12 Scenario 03b: Proposed re-mining of Seam#01.

DECANT SCENARIOS: Future mining Seam#01 _Re-mining historical UG	
Mined area (m²)	967 277.63
Average seam thickness	2.60
Mined volume (m³)	2 514 921.85
Average simulated void inflow (m³/d)	260.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	25.95
Average rainfall (MAP)	25.47
Wet cycle (95th Percentile)	25.01
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	9.21
Average rainfall (MAP)	14.26
Wet cycle (95th Percentile)	19.29

Table 12-13 Scenario 03b: Proposed mining of Seam#01- Area A.

DECANT SCENARIOS: Future mining Seam#01 UG Area A	
Mined area (m²)	940 473.82
Average seam thickness	2.60
Mined volume (m³)	1 711 662.35
Average simulated void inflow (m³/d)	297.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	15.54
Average rainfall (MAP)	15.29
Wet cycle (95th Percentile)	15.06
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	8.95
Average rainfall (MAP)	13.87
Wet cycle (95th Percentile)	18.75

Table 12-14 Scenario 03b: Proposed mining of Seam#01- Area B.

DECANT SCENARIOS: Future mining Seam#01 UG Area B	
Mined area (m²)	179 187.47
Average seam thickness	2.60
Mined volume (m³)	326 121.20
Average simulated void inflow (m³/d)	190.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	4.73
Average rainfall (MAP)	4.70
Wet cycle (95th Percentile)	4.68
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	1.71
Average rainfall (MAP)	2.64
Wet cycle (95th Percentile)	3.57

Table 12-15 Scenario 03b: Proposed mining of Seam#01- Area C.

DECANT SCENARIOS: Future mining Seam#01 UG Area C	
Mined area (m^2)	57 454.02
Average seam thickness	2.60
Mined volume (m^3)	104 566.32
Average simulated void inflow (m^3/d)	95.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	3.04
Average rainfall (MAP)	3.03
Wet cycle (95th Percentile)	3.02
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	0.55
Average rainfall (MAP)	0.85
Wet cycle (95th Percentile)	1.15

Table 12-16 Scenario 03b: Proposed mining of Seam#01- Area D+E.

DECANT SCENARIOS: Future mining Seam#01 UG Area D+E	
Mined area (m^2)	1 149 124.81
Average seam thickness	2.60
Mined volume (m^3)	2 091 407.15
Average simulated void inflow (m^3/d)	306.00
Dry cycle: 5th Percentile (mm/a)	342.74
Average rainfall: MAP (mm/a)	530.76
Wet cycle: 95th Percentile (mm/a)	717.84
-	
Time to decant (Years):	
Dry cycle (5th Percentile)	18.33
Average rainfall (MAP)	17.99
Wet cycle (95th Percentile)	17.66
Effective steady state decant volume (m3/d)	
Dry cycle (5th Percentile)	10.94
Average rainfall (MAP)	16.94
Wet cycle (95th Percentile)	22.91

Figure 12-26 **Scenario 03b: Potential high-risk decant zone for the underground mine void.**

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[25];

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.

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

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[25] 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.

characterisation (refer to Section 10.5) and assigned as 2200.0mg/l for all surface waste facilities i.e. discard dump, slurry dam, ROM and stockpile areas, pollution control dams, existing voids (WOP) as well as carbonaceous material storage dumps. Furthermore, a sulphate source term of 2200.0mg/l was also assigned to existing and proposed opencast areas i.e. mining faces as well as underground mining footprints. The contaminant transport model was calibrated based on hydrochemistry observed at down-gradient observation and monitoring boreholes as well as published literature for coal mine operations. Model domain background values were interpreted from the hydrochemical data analysis as gathered during the hydrocensus user survey and assigned as ~ 35.0mg/l.

12.6.1. Scenario 04: LOM sulphate pollution plume migration

Scenario 04 simulated a sulphate pollution plume for the newly proposed mining footprints for LOM. Figure 12-28 depicts the expected sulphate pollution plume migration within the weathered aquifer, emanating from the existing waste and proposed opencast footprints. The pollution plume extent covers a total area of approximately 447.0ha, reaching a maximum distance of ~350.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that no neighbouring boreholes, except on-site monitoring boreholes is impacted on during the operational LOM while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on.

Figure 12-27 depicts the sulphate pollution plume from newly proposed opencast footprints in conjunction with potential impacts from historical, backfilled mining areas. The simulated pollution plume extent covers a total area of approximately 665.0ha, also reaching lower laying drainage and wetland systems observed on-site. Figure 12-29 shows the simulated sulphate pollution plume within the fractured aquifer, emanating from the underground mining faces. The simulated pollution plume extent covers a total area of approximately 618.0ha, however is limited to the mining right areas.

Figure 12-30 summarises a time-series graph of mass load contribution to existing monitoring boreholes. It is evident that sulphate concentrations for all monitoring boreholes is above the SANS threshold for the duration of the LOM, reaching maximum concentrations of between ~1200.0 to ~1 600.0mg/l respectively. It is noted that sulphate concentrations for all monitoring boreholes (ECBH02, ECBH03 and ECBH04) rises above the SANS threshold reaching the LOM, where borehole ECBH03 reaches a maximum concentration of ~1 370 mg/l, correlating well to on-site monitoring results.

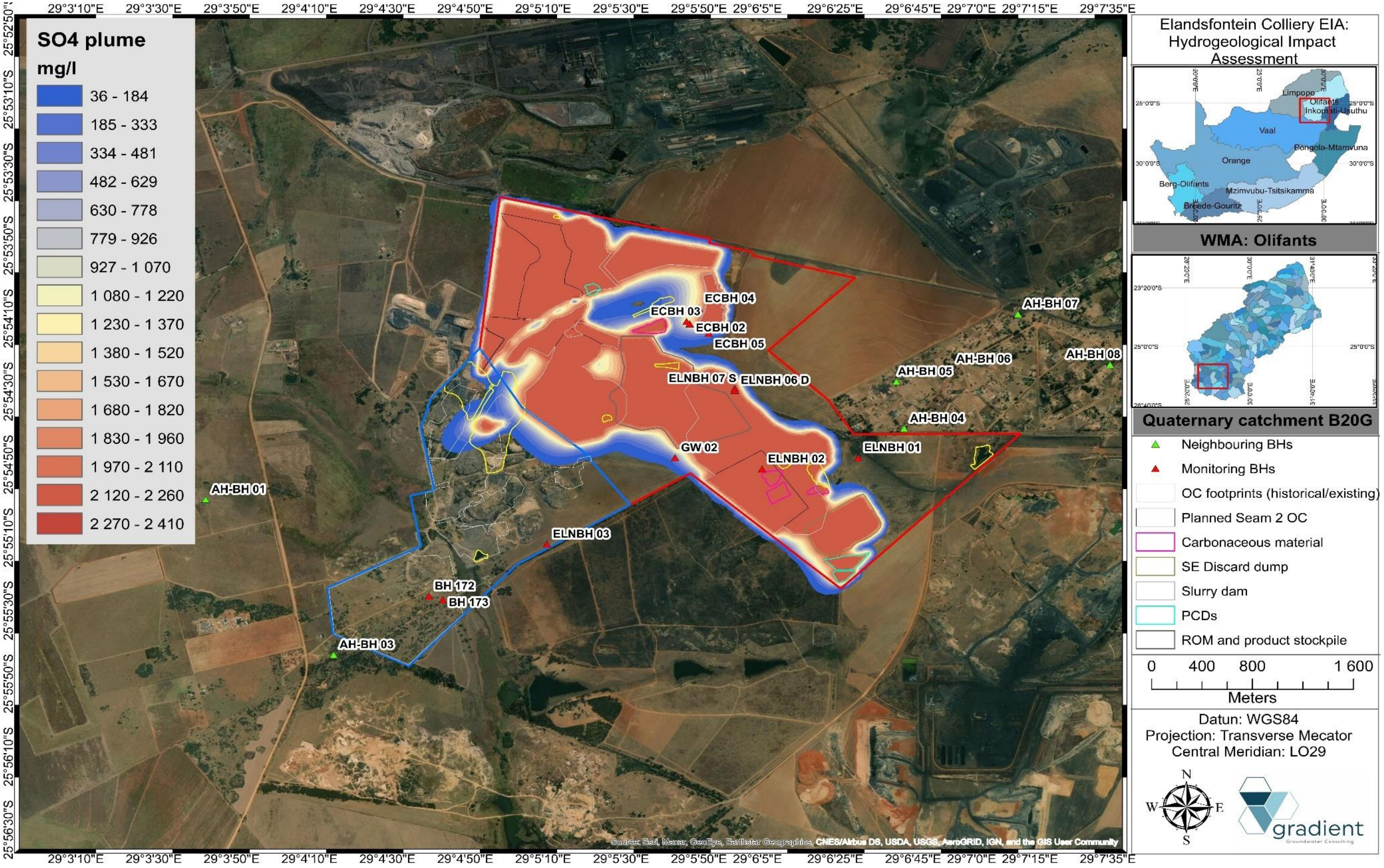

Figure 12-27 **Scenario 04: LOM sulphate pollution plume of the weathered aquifer (plume migration of proposed pit footprints only).**

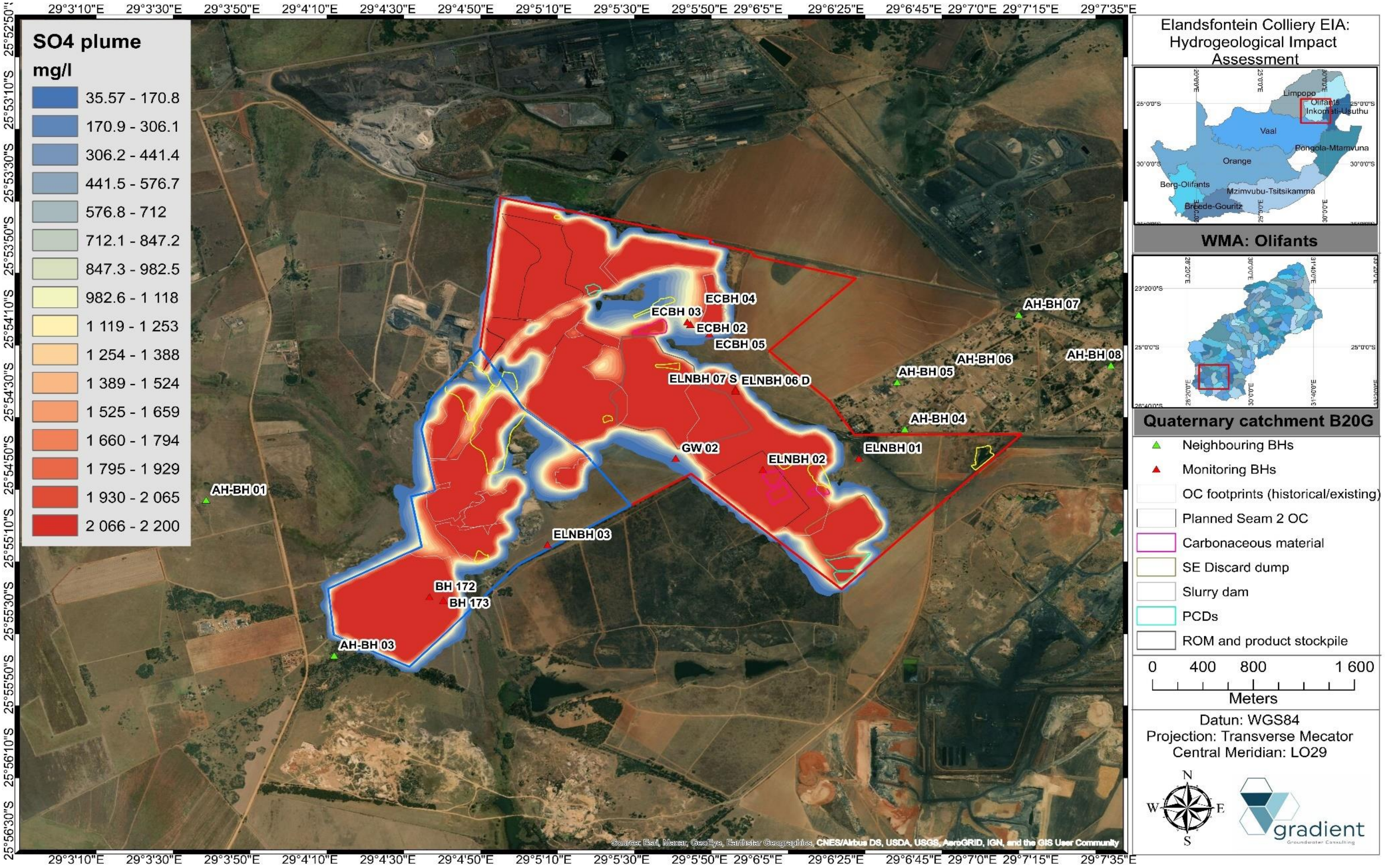

Figure 12-28 Scenario 04: LOM sulphate pollution plume of the weathered aquifer (plume migration from proposed and historical, backfilled pit footprints).

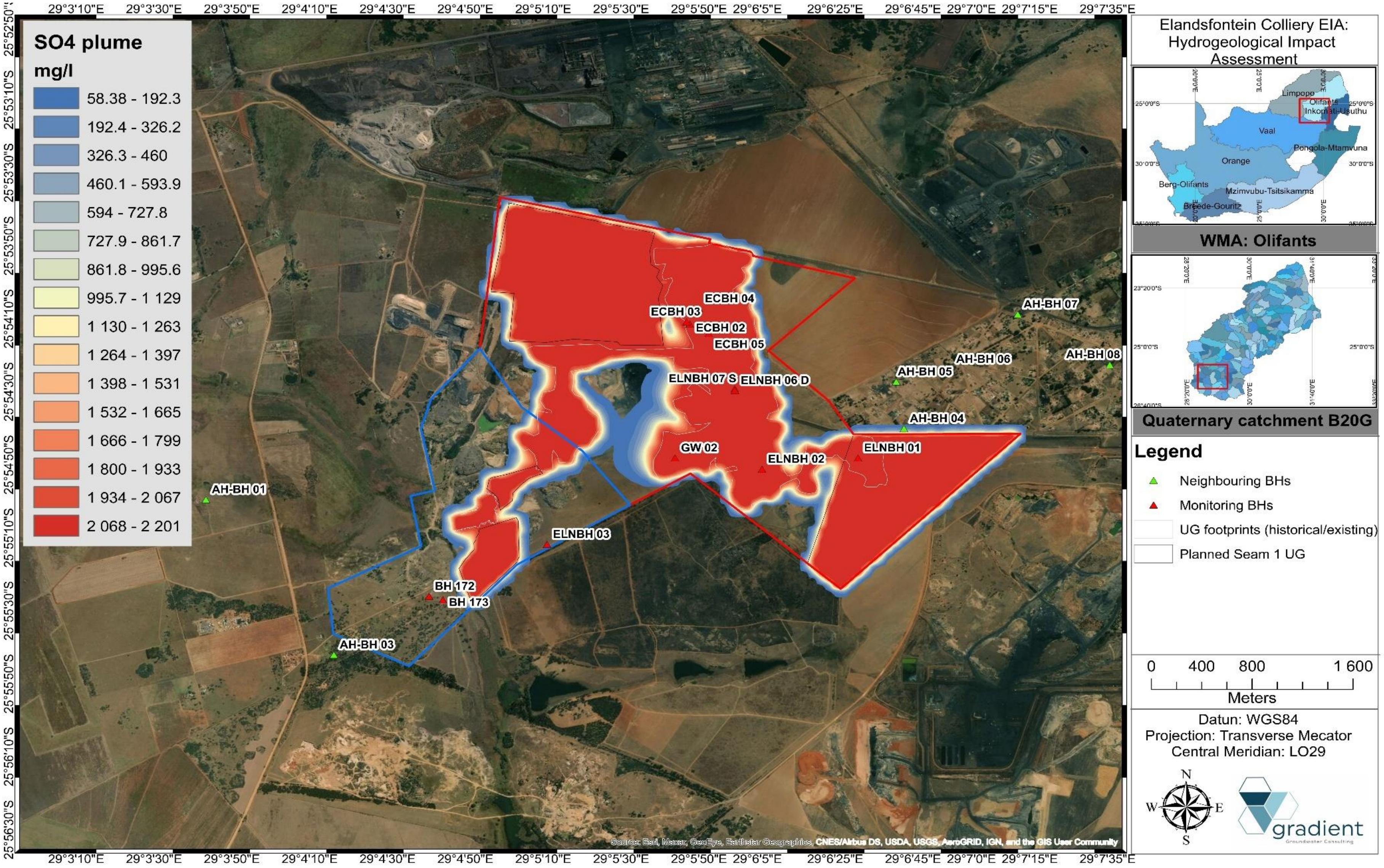

Figure 12-29 **Scenario 04: LOM sulphate pollution plume of the underground mining operations (fractured aquifer).**

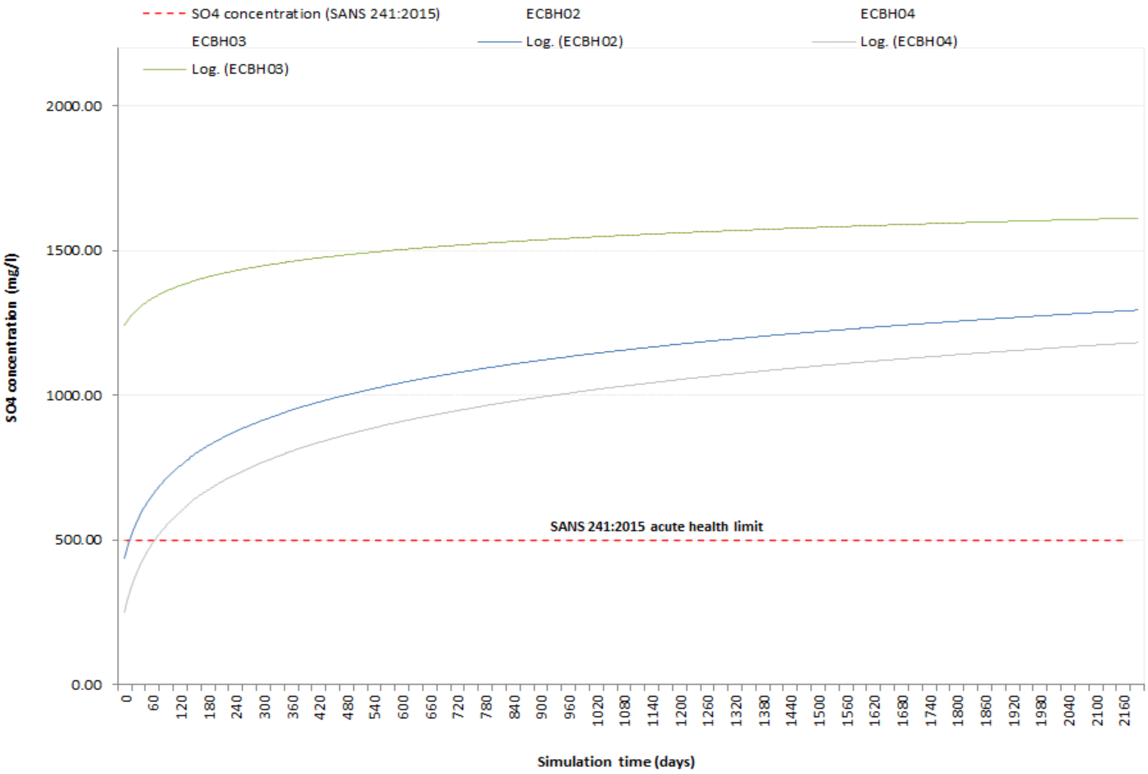

Figure 12-30 **Scenario 04: Time-series graph indicating mass load contribution of waste facilities on down-gradient receptors.**

12.6.2. Scenario 05a: Post-closure sulphate pollution plume migration (50-years).

A 50-year post-closure scenario was simulated to evaluate the pollution plume migration after discontinuing of mining activities. Figure 12-31 depicts the simulated sulphate pollution plume migration within the weathered aquifer after a period of 50-years. The pollution plume extent covers a total area of approximately 875.0ha, reaching a maximum distance of ~600.0 to 700.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on.

12.6.3. Scenario 05b: Post-closure sulphate pollution plume migration (100-years).

A 100-year post-closure scenario was simulated in order to evaluate the pollution plume migration after discontinuing of mining activities. Figure 12-32 depicts the simulated sulphate pollution plume migration within the weathered aquifer after a period of 100-years. The pollution plume extent covers a total area of approximately 1030.0ha, reaching a maximum distance of 1100.0 to 1300.0m in a general south-western direction. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on. Figure 12-33 indicate a time-series graph of mass load contribution to existing monitoring boreholes. It is evident that sulphate concentrations for all monitoring boreholes stabilises to a maximum sulphate contribution load of between 1600.0 to 1800.0mg/l, which is above the SANS threshold.

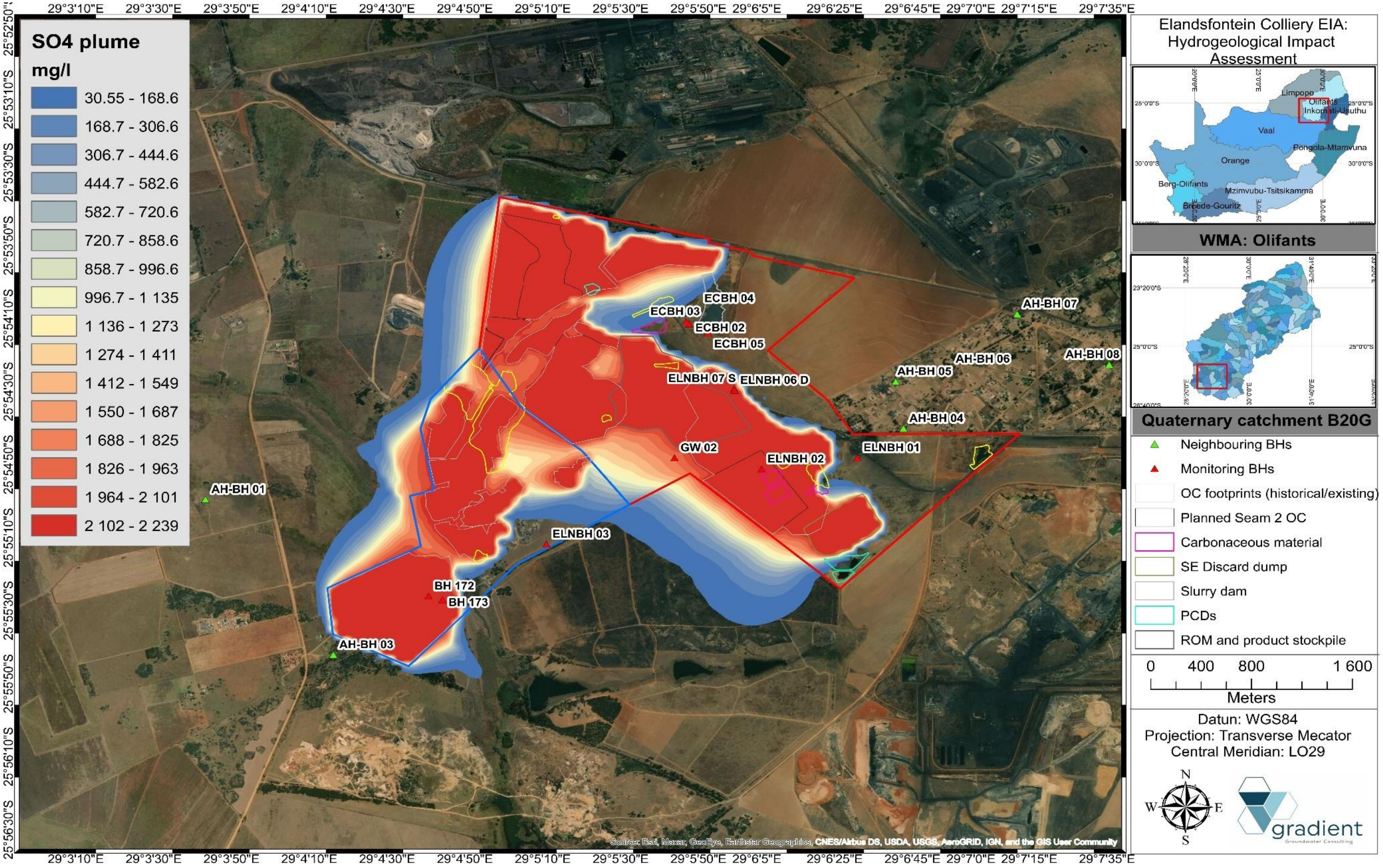

Figure 12-31 Scenario 05a: Post-closure sulphate pollution plume (50 years).

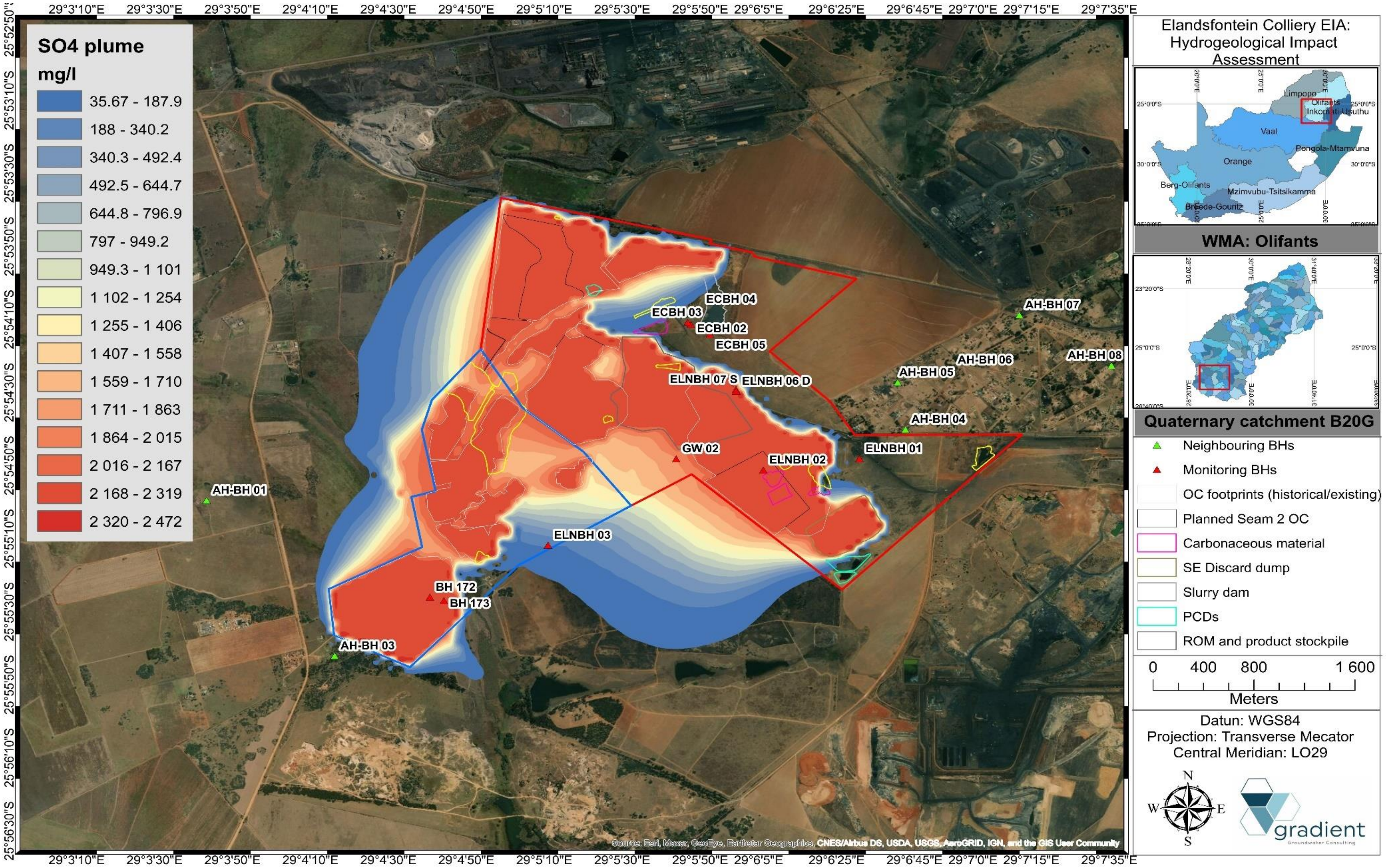

Figure 12-32 **Scenario 05b: Post-closure sulphate pollution plume (100 years).**

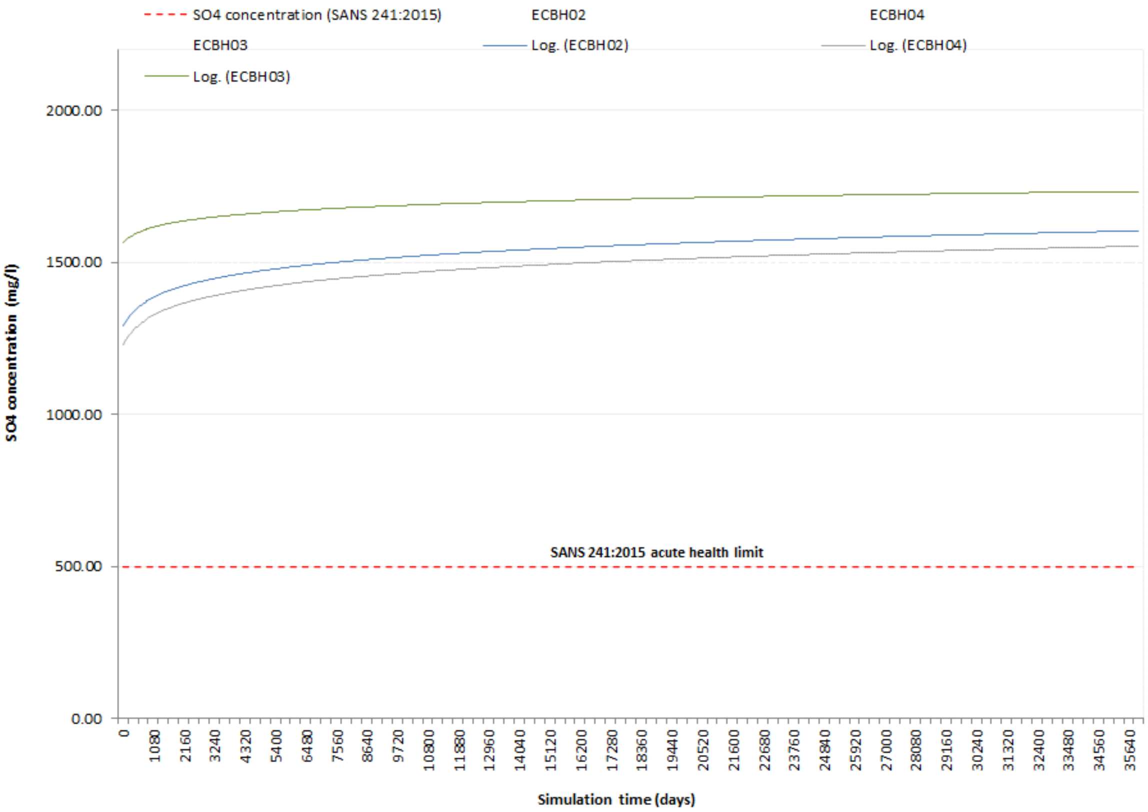

Figure 12-33 **Time-series graph indicating mass load contribution of waste facilities on down-gradient receptors (Pre-mitigation).**

12.6.4. Scenario 06: Mitigation and management

Various alternative management and mitigation scenarios which include active as well as passive water management strategies were simulated to evaluate the remedial options available. Table 12-17 provides a summary of the mitigatory effect and effectiveness of proposed management alternatives on the pollution plume migration and extent as well as intercepted water volumes to be treated before discharge.

12.6.5. Scenario 06a: Active (or passive) water management by establishment of scavenger boreholes down-gradient of waste facilities and backfilled opencasts

An active (or passive) management scenario evaluating the mitigating effect of seepage capturing boreholes i.e. scavenger boreholes on the plume migration via active pumping or passive abstraction via windmills were simulated. A series of seepage capturing boreholes were established down-gradient of mine waste facilities as indicated in Figure 12-35. Due to the negative groundwater gradient created, the pollution plume footprint is reduced by approximately ~25.0% to ~842.0ha with an abstraction volume of ~0.15l/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. Abstracted groundwater volumes expected accounts to approximately 421.0m^3/d, which should be treated before discharge and re-established into the local groundwater catchment balance. Due to no additional management measures proposed to mitigate the impact of carbonaceous waste material to be disposed, leachate of various chemical constituents may continue indefinitely (depending on its geochemical character) and the treatment duration for intercepted contact water may be infinite[26].

12.6.6. Scenario 06b: Passive water management by implementation of a cut-off seepage capturing trench down-gradient of waste facilities and backfilled opencasts

A passive management scenario evaluating the mitigating effect of a sub-surface cut-off trench/fracturing curtain[27] on the plume migration were simulated as depicted in Figure 12-36. Due to deeper groundwater levels i.e. increased vadose zone experienced towards the northwest as well as southeast, this mitigation alternative is not intercepting adequate water to create a negative gradient within these zones and accordingly, the pollution plume footprint is reduced by only ~7.0% to ~1054.0ha. Intercepted groundwater volumes expected is approximately 969.0m^3/d, however this will be dependable on the depth of the proposed cut-off trench. Due to no additional management measures proposed to mitigate the impact of carbonaceous waste material to be disposed, leachate of various chemical constituents may continue indefinitely (depending on its geochemical character) and the treatment duration for intercepted contact water may be infinite.

12.6.7. Scenario 06c: Active water management by maintaining a minimum in-pit water level below decant elevation by establishment of in-pit abstraction facilities

An active management scenario evaluating the mitigating effect of maintaining a minimum in-pit water level approximately 3.0 to 5.0m below relevant decant elevation of backfilled pits by establishment of in-pit abstraction boreholes which should be actively pumped. Due to the negative groundwater gradient created, the pollution plume footprint is reduced by approximately 21.0% to 894.0ha as shown in Figure 12-37. Abstracted in-pit water volumes expected accounts to approximately 1491.0m^3/d, which should be treated before discharge and re-established into the local groundwater catchment balance. Due to no additional management measures proposed to mitigate the impact of carbonaceous waste material to be disposed, leachate of various chemical constituents may continue indefinitely (depending on its geochemical character) and the treatment duration for intercepted contact water may be infinite. This mitigation alternative is not considered as best-practise as it creates a negative groundwater gradient within the backfilled pit area and, as such, will draw-in clean water to contaminated zones.

12.6.8. Scenario 06d: Active water management by establishment of scavenger boreholes down-gradient of waste facilities and implementation of a lined facility for disposal of carbonaceous waste material

An active management scenario evaluating the mitigating effect of seepage capturing boreholes in combination with implementation of a lined facility (Class C or GLB+ containment barrier design i.e. Type 3: Low-risk waste) for disposal all carbonaceous waste material on the plume migration were simulated. A series of seepage capturing boreholes were established down-gradient of mine waste facilities as indicated in Figure 12-38. The combination of the mitigation effect of the negative groundwater gradient created as well as the reduction in waste footprints due to implementation of a lined facility, reduces the pollution plume footprint by approximately ~35.0% to ~738.0ha. Abstracted groundwater volumes expected accounts to approximately 421.0m^3/d[28], which should be treated before

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[26] Additional geochemical characterisation will be required in order to accurately determine duration of buffer reactions and source depletion timeframes. For the purposes of this investigation, a timeframe of >100 years have been applied.

[27] It should be noted that a trench depth of >6.0-8.0mbgl becomes impractical to implement, and as such, simulations are based on these designs.

[28] It should be noted that dirty surface water runoff is excluded from the intercepted water volume reported here and is not accounted for.

discharge and re-established into the local groundwater catchment balance. Due to separation of carbonaceous waste material to be disposed, leachate of various chemical constituents from proposed backfilled zones will be limited to a period not exceeding a 50-year duration[29].

12.6.9. Scenario 06e: Active water management by establishment of scavenger boreholes down-gradient of waste facilities in combination with disposal of carbonaceous waste material in the northern discard pit

An active management scenario evaluating the mitigating effect on the establishment of scavenger boreholes down-gradient of waste facilities and backfilled opencasts in combination with disposal of carbonaceous waste material in the northern discard pit on the plume migration were simulated as depicted in Figure 12-39. The combination of the mitigation effect of the negative groundwater gradient created reduces the pollution plume footprint approximately ~35.0% to ~738.0ha. Accordingly, this mitigation scenario is the most likely case and preferred scenario. It is recommended that the northern discard pit footprint be compacted and a barrier system (capping) and/or evapotranspiration cover be established in order to minimise water and oxygen ingress which is the drivers of acid rock drainage conditions.

Abstracted groundwater volumes expected accounts to approximately 421.0m^3/d, which should be treated before discharge and re-established into the local groundwater catchment balance. Due to separation of carbonaceous waste material to be disposed and post-closure rehabilitation of the disposal facility, leachate of various chemical constituents from proposed backfilled zones will be limited to a period not exceeding a 50-year duration.

Figure 12-34 indicate the simulated post-closure decant volumes for backfilled voids as well as the decant contribution of the northern discard pit when it is not rehabilitated vs. a capping and rehabilitation scenario. It is noted that the facility contributes a total volume of approximately 40.0 m^3/d if not rehabilitated while the decant volume is reduced to ~ 12m^3/d when applying a barrier system (capping) and/or an evapotranspiration cover.

12.6.10. Scenario 06f: Active water management by establishment of scavenger boreholes down-gradient of waste facilities in combination with rehabilitation of the south-eastern discard dump

An active management scenario evaluating the mitigating effect on the establishment of scavenger boreholes down-gradient of waste facilities and backfilled opencasts in combination with rehabilitation of the south-eastern discard dump on the plume migration were simulated as depicted in Figure 12-40. The combination of the mitigation effect of the negative groundwater gradient created as well as the reduction in waste footprints due to removal and rehabilitation of the existing south-eastern discard damp, reduces the pollution plume footprint by >35.0% to ~717.0ha. Abstracted groundwater volumes expected accounts to approximately 408.0m^3/d, which should be treated before discharge and re-established into the local groundwater catchment balance.

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[29] Additional geochemical characterisation will be required in order to accurately determine duration of buffer reactions and source depletion timeframes. For the purposes of this investigation, a timeframe of 50 years has been assumed.

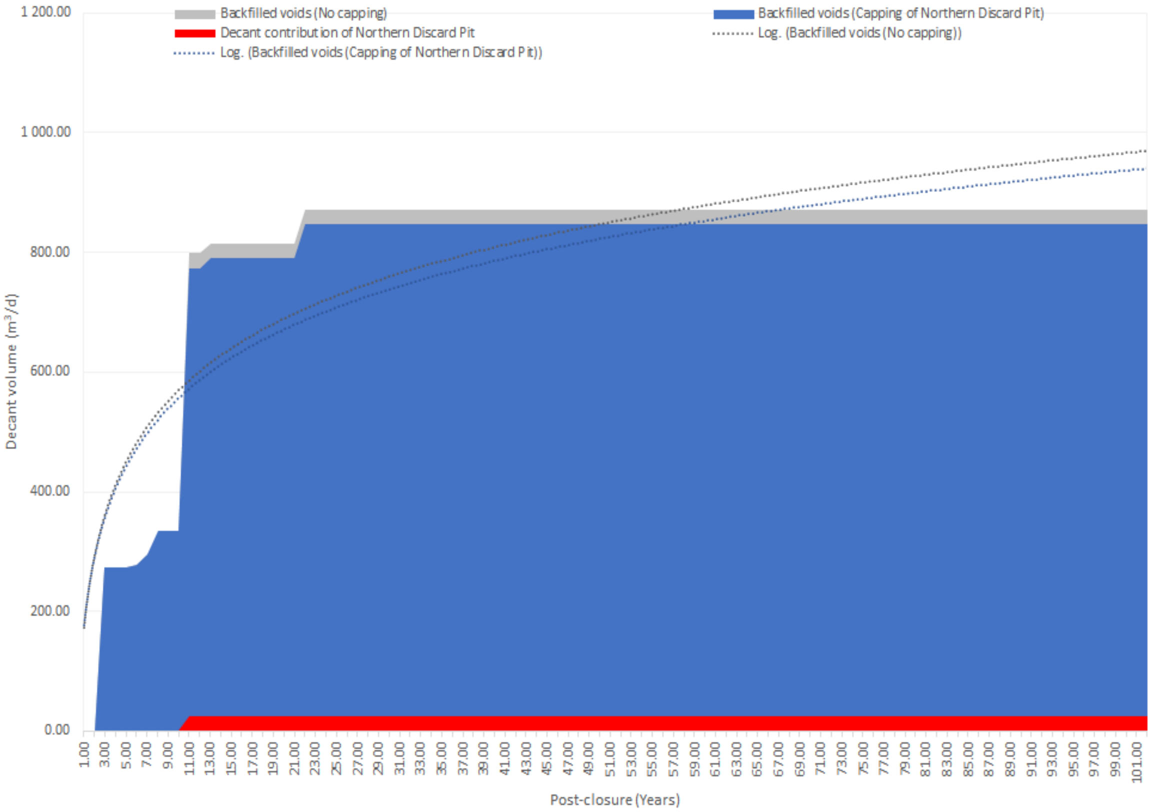


Figure 12-34 Time-series graph indicating expected decant contribution of backfilled zones (Pre-mitigation vs. mitigation).

Table 12-17 Mitigation alternatives pollution plume areas and effectiveness.

Mitigation and management scenarios	Plume area (pre-mitigation) (ha)	Plume area (post-mitigation) (ha)	Improvement (%)	Intercepted contact water volume (m³/d)	Potential treatment duration (years)
Scenario 06a: Establishment of scavenger boreholes@0.15l/s	1133.00	842.00	25.68	421.00	>100.00
Scenario 06b: Implementation of a cut-off trench/ fracturing curtain	1133.00	1054.00	6.97	696.00	>100.00
Scenario 06c: Maintaining a minimum in-pit water level below decant elevation	1133.00	894.00	21.09	1491.00	>100.00
Scenario 06d: Establishment of scavenger boreholes and lined facility for carbonaceous waste material	1133.00	738.00	34.86	421.00**	50-100
Scenario 06e: Establishment of scavenger BHs, disposal of carbonaceous material in the northern discard pit including rehabilitation and capping	1133.00	738.00	34.86	421.00	50-100
Scenario 06f: Establishment of scavenger boreholes and rehabilitation of SE discard dump	1133.00	717.00	36.72	408.00	>100.00

****It should be noted that dirty surface water runoff is excluded from this volume.**

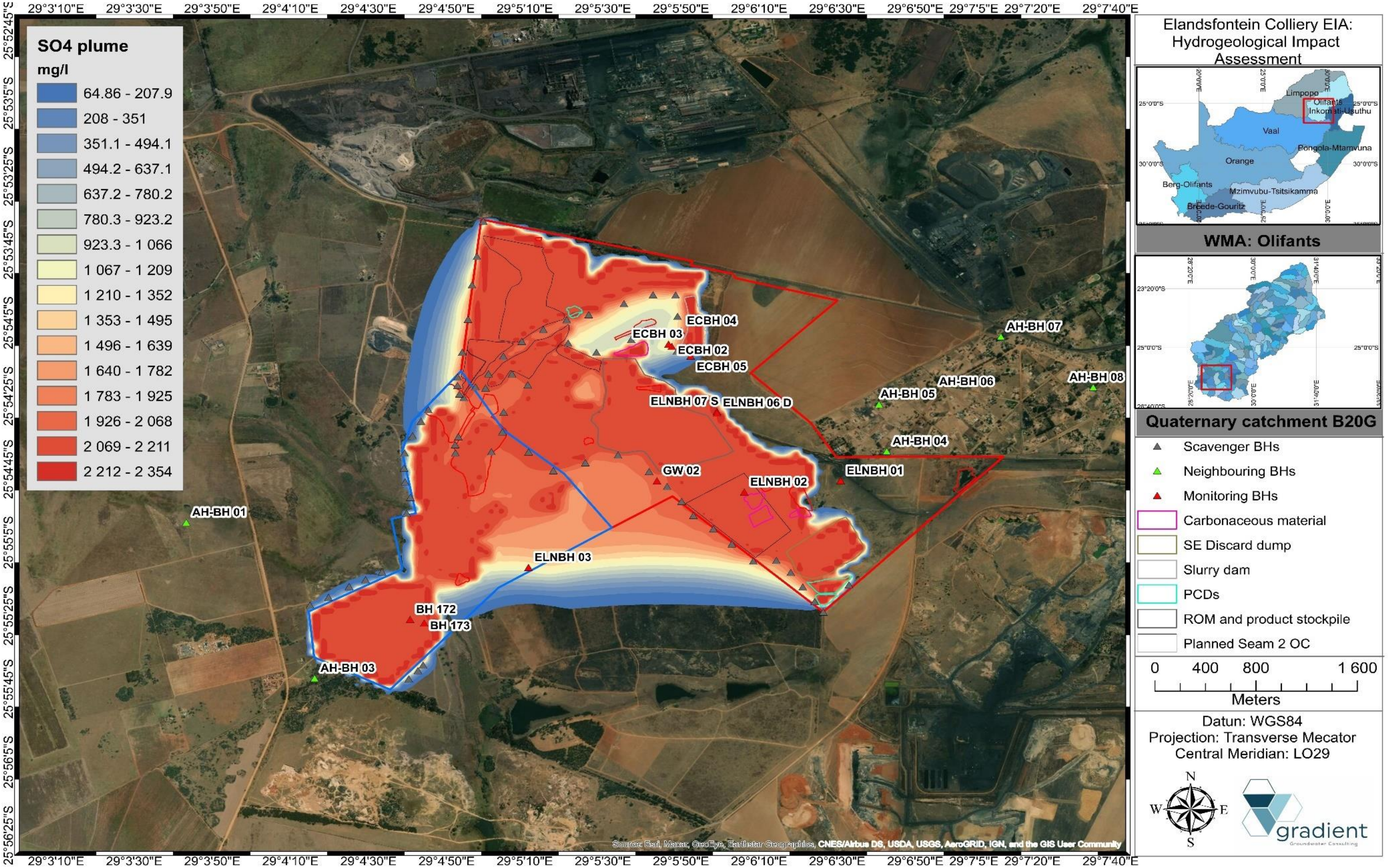


Figure 12-35 Scenario 06a: Mitigation alternative 01: Establishment of seepage capturing boreholes down-gradient of pollution sources.

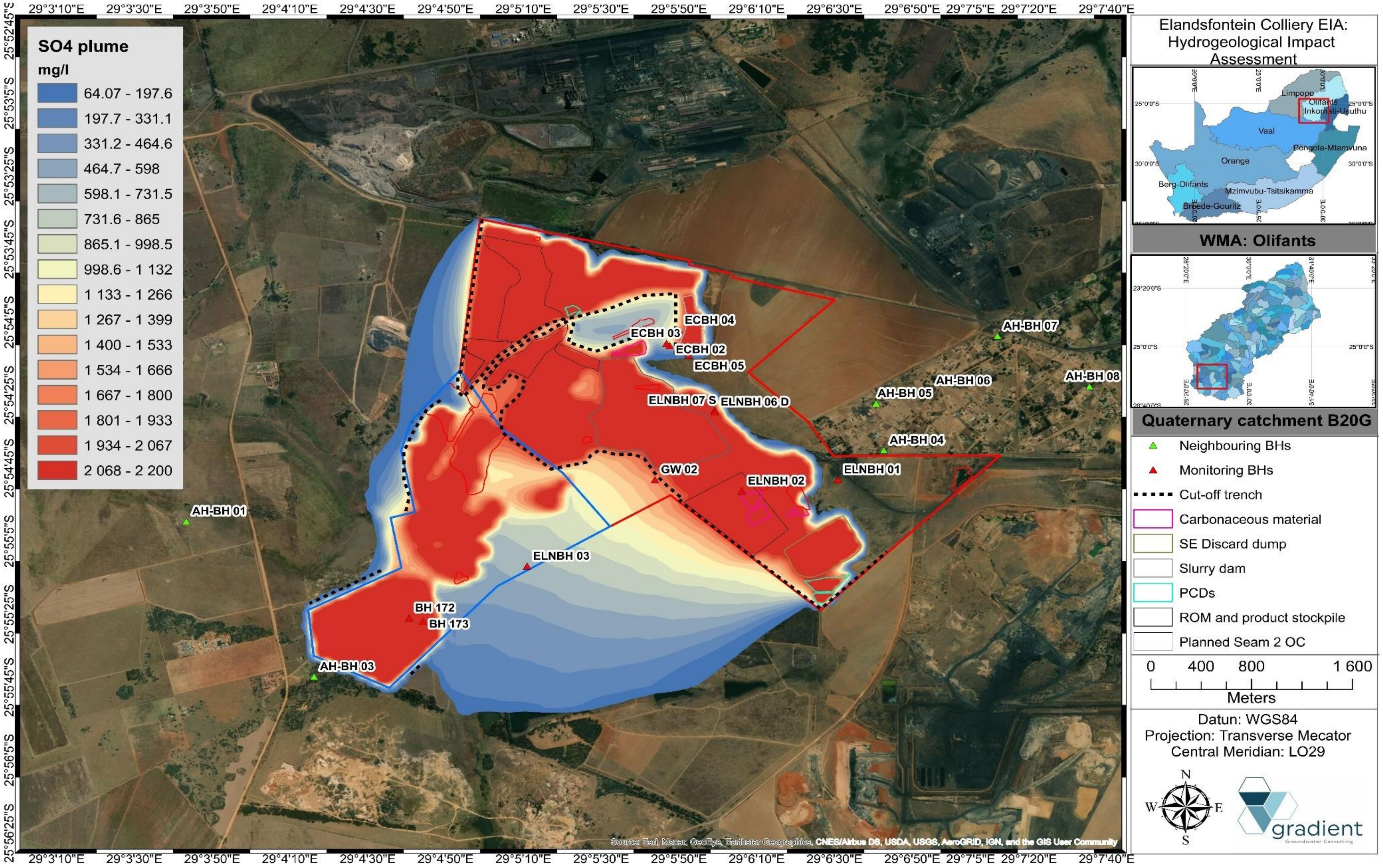


Figure 12-36 Scenario 06b: Mitigation alternative 02: Implementation of a seepage cut-off trench.

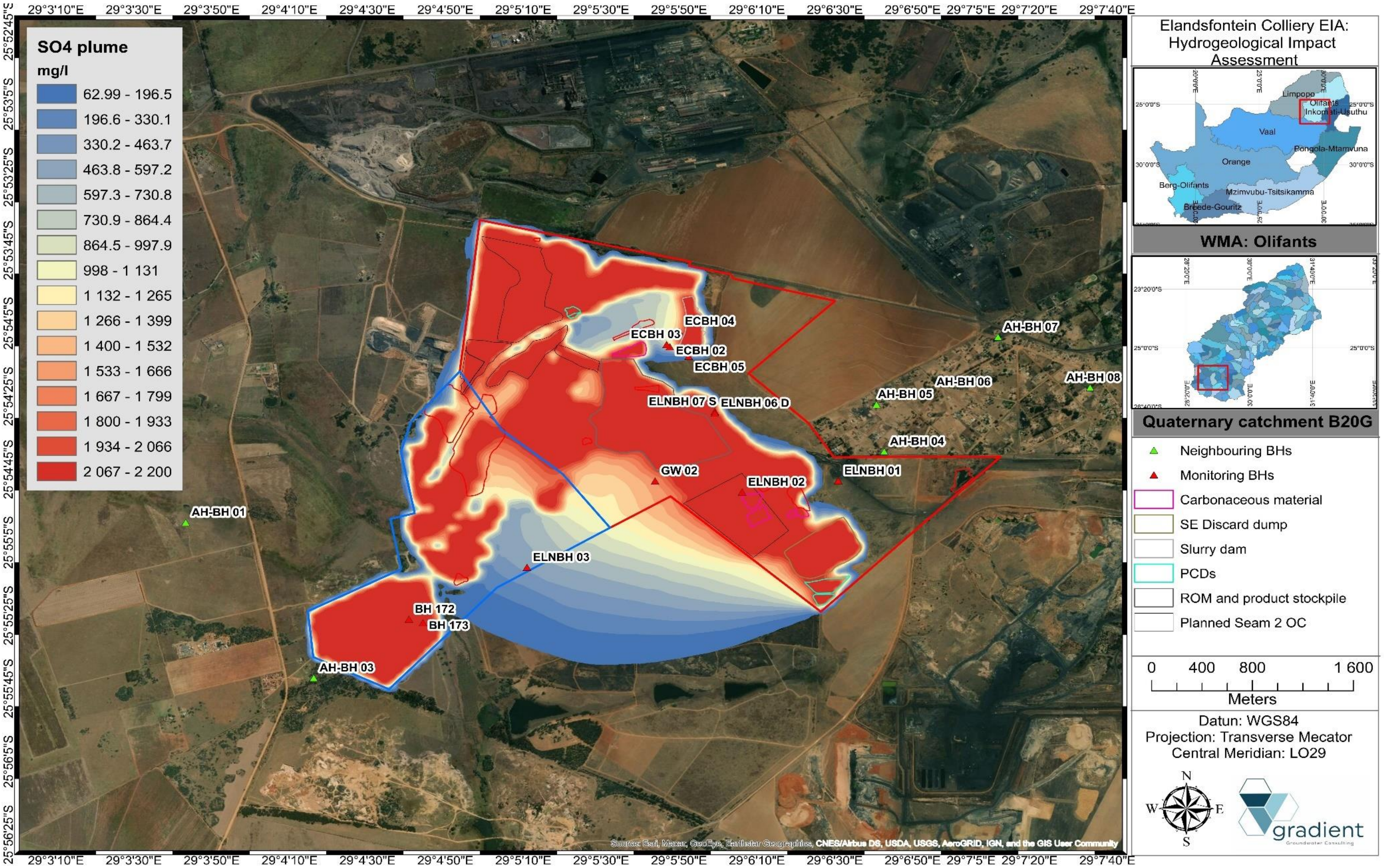


Figure 12-37 **Scenario 06c: Mitigation alternative 03: Maintaining a minimum in-pit water level below decant elevation.**

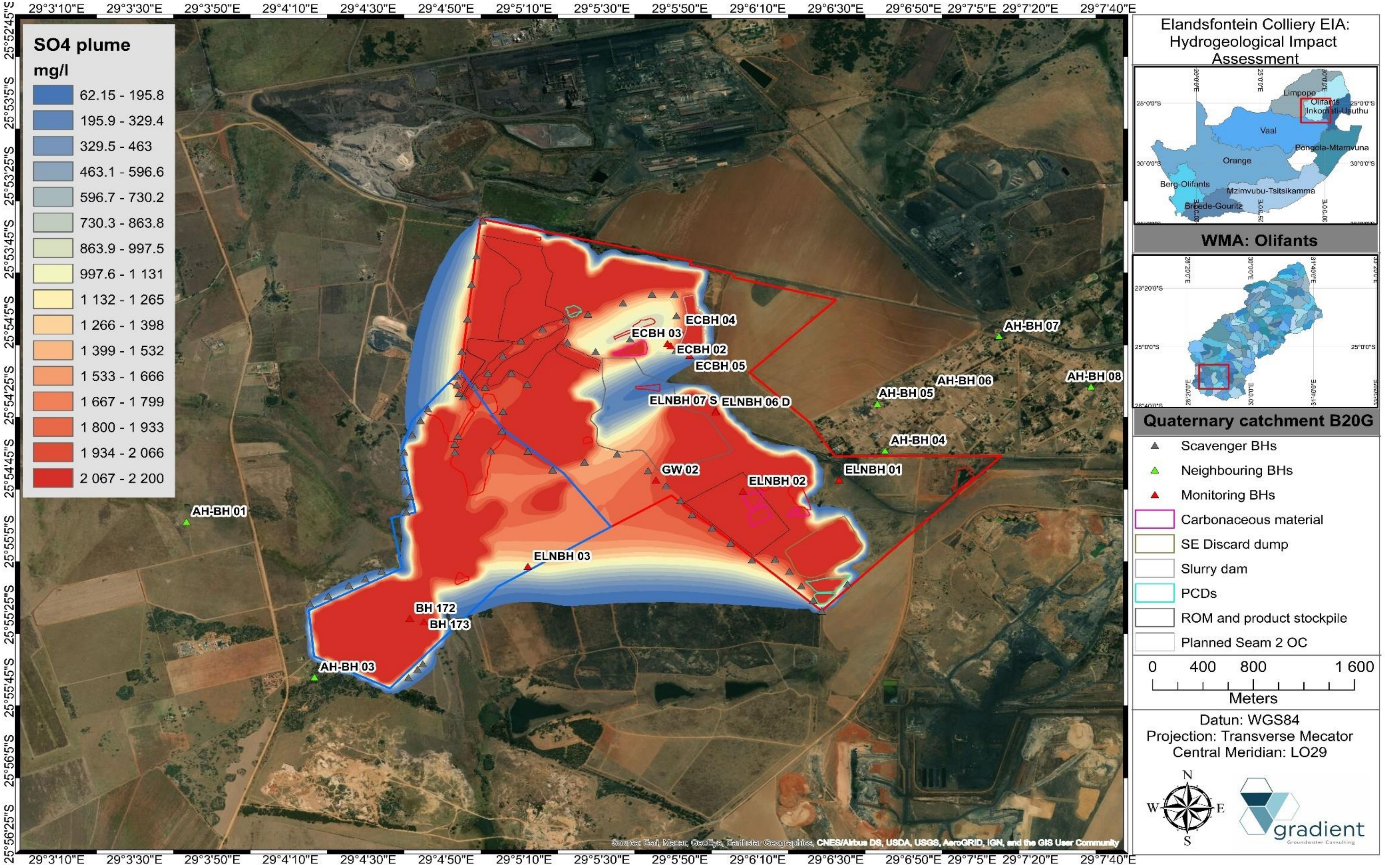


Figure 12-38 Scenario 06d: Mitigation alternative 04: Establishment of scavenger boreholes and lined facility for carbonaceous waste material.

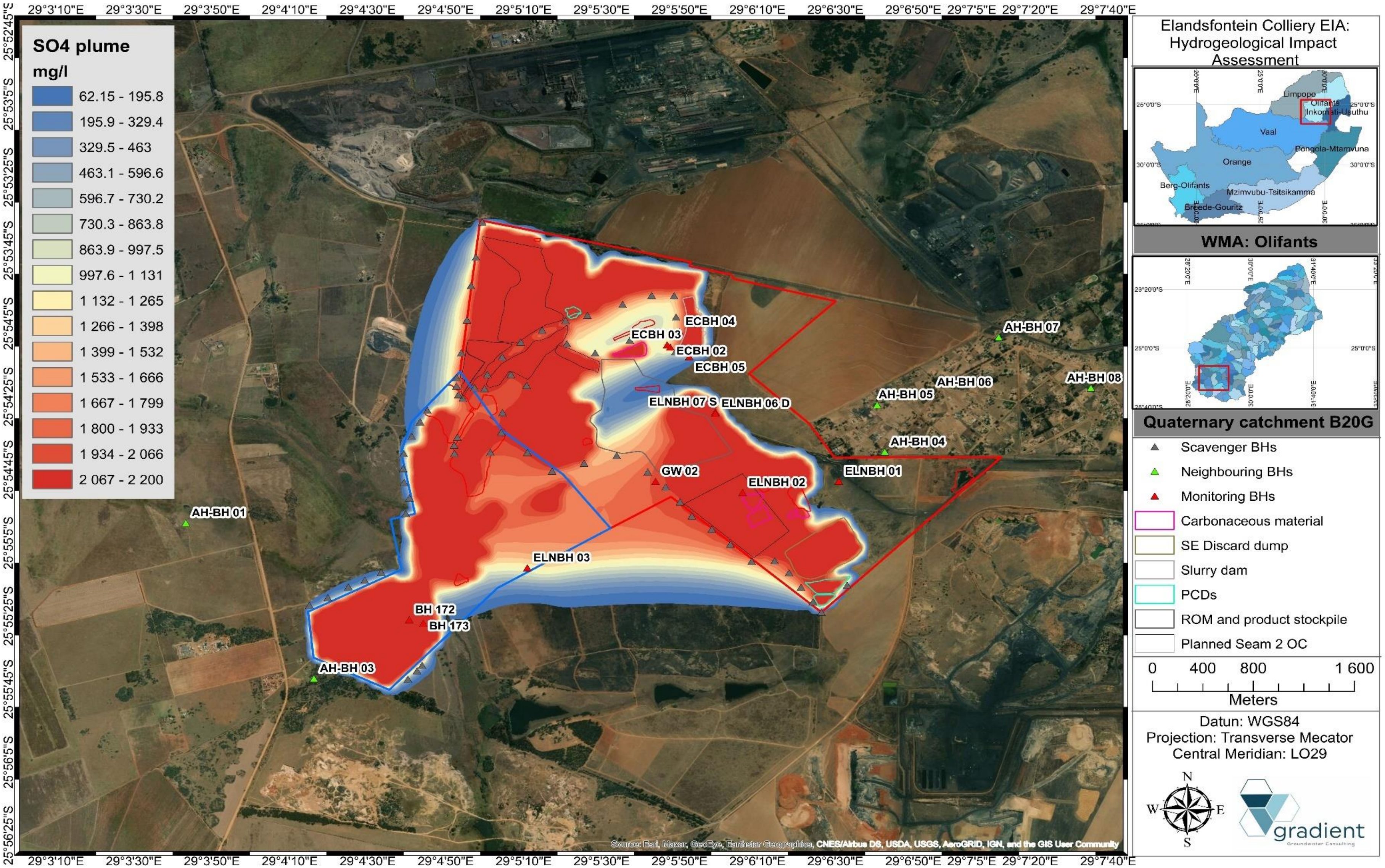


Figure 12-39 Scenario 06e: Mitigation alternative 05: Establishment of scavenger boreholes in combination with disposal of carbonaceous waste material in the northern discard pit.

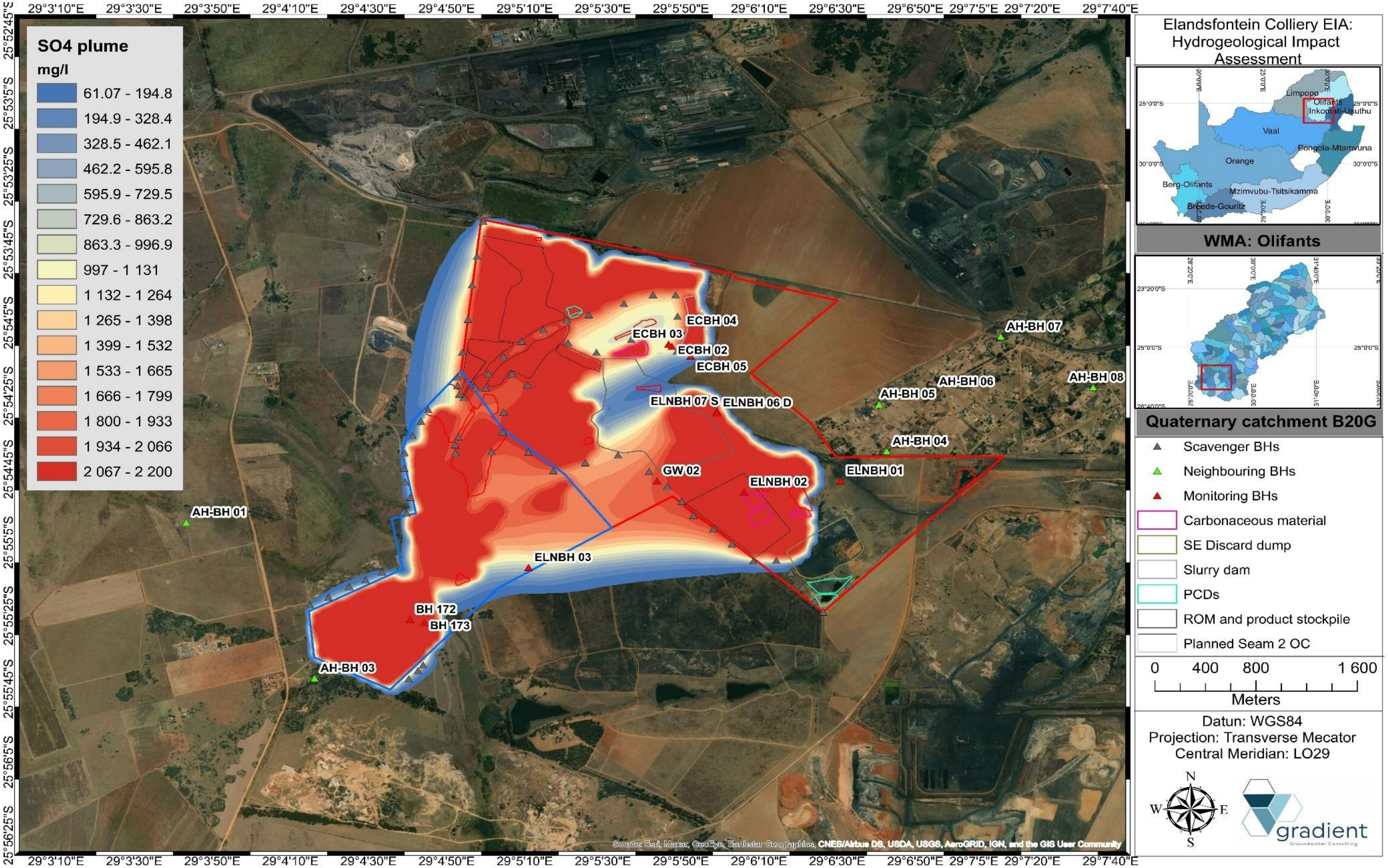


Figure 12-40 Scenario 06f: Mitigation alternative 06: Establishment of scavenger boreholes in combination with rahabilitation of SE discard dump.

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 **N**ature, **E**xtent, **D**uration, **M**agnitude, and **R**eversibility) 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.

$$\mathbf{C} = (\boldsymbol{E} + \boldsymbol{D} + \boldsymbol{M} + +\boldsymbol{R})(\boldsymbol{N}\mathbf{4})$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 13-1 below with Table 13-2 summarising the probability scorings.

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.**

$$\text{ER} = \boldsymbol{C} \,.\, \boldsymbol{P}$$

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

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

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. 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.

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 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 (Table 13-7), 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.

13.4.1. Construction phase: Associated activities and impacts

As Elandsfontein 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

During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as medium negative without implementation of remedial measure and low negative with implementation of proposed mitigation measures. Groundwater quality impacts from the discard dump, coal stockpile areas, PCD's and related waste facilities are rated as medium negative without implementation of remedial measures and medium/low negative with implementation of mitigation measures. 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 as well as groundwater supported wetlands may occur.
3. Poor quality leachate may emanate from underground mined out faces as well as backfilled opencast pits which will have a negative impact on groundwater and surface water quality.
4. Poor quality leachate may emanate from various source areas and waste generated, e.g. coal

stockpiles, discard dumps, pollution control dams, slurry ponds, dirty roads, etc. which will have a negative impact on water quality.

5. Dust suppression with poor quality water, obtained from mine dirty water containment facilities, will have a detrimental impact on groundwater and surface water quality.
6. Mobilisation and maintenance of mine heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.
7. Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.
8. 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, hence the formation of a zone of depression, is inevitable. 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 as well as water levels will serve as early warning mechanism to implement mitigation measures such as seepage capturing boreholes down-gradient of the waste facilities in order to constrain the contamination plume migration as well as manage the groundwater cone of depression.

iii. The geochemical character of the non-carbonaceous spoils material i.e. sandstone and mudstone/shale are non-acid forming and will not impact on water quality. This material can thus be utilised as backfill substance as part of the rehabilitation.

iv. The geochemical character of the carbonaceous spoils material i.e. carbonaceous shale suggests a likely capacity for acid formation. However relatively low oxidisable sulphides deem the material insufficient to sustain long term acid generation. Thus, any material of carbonaceous character can also be used as backfill substance, however it is recommended that additional geochemical characterisation be conducted to confirm this.

v. All material analysed can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly.

vi. All preferred groundwater flow pathways which are in direct connection with surface topography i.e. adits, ventilation shafts and/or unrehabilitated exploration boreholes should be sealed off and rehabilitated.

vii. It is expected that post-closure the generated pollution plume and local groundwater contamination footprint will decay and be diluted by rainfall recharge, however the lasting effect and subsequent impact on neighbouring borehole qualities should be monitored with alternative water supply sources or compensation measures available for nearby users if impacted on.

viii. The existing groundwater flow model should be recalibrated with time-series monitoring data on a biannual basis in order to be applied as water management tool. Scenario predictions and model simulations should be conducted and interpreted by an external and independent specialist.

ix. 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.

x. 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.

xi. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, 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.

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

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

xiv. 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.

xv. Monitoring results should be evaluated and reviewed on a biannual basis by a registered hydrogeologist for interpretation and trend analysis for submission to the Regional Head of Department. Based on the water quality results, the monitoring network should be refined and updated every three to five years based on hydrochemical results obtained to ensure optimisation and adequacy of the proposed localities.

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

13.4.4. Post-operational phase: Associated activities and impacts

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. 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 voids and potential flooding of backfilled opencast pits may occur.
2. Poor quality leachate and decant may emanate from backfilled opencast pits as well as underground mined out faces which will have a negative impact on groundwater and surface water quality.
3. Seepage of poor water quality caused by leachate of sulphide bearing minerals from mine waste facilities i.e. discard dumps, slurry dams as well as pollution control dams.

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 of backfilled opencast and mine waste facility footprints areas is properly conducted and in accordance with best practise guidelines as well as approved mine closure and rehabilitation plans. Rehabilitation should allow for free draining of runoff in order to prevent any surface water ponding.

iii. The geochemical character of the non-carbonaceous spoils material i.e. sandstone and mudstone/shale are non-acid forming and will not impact on water quality. This material can thus be utilised as backfill substance as part of the rehabilitation.

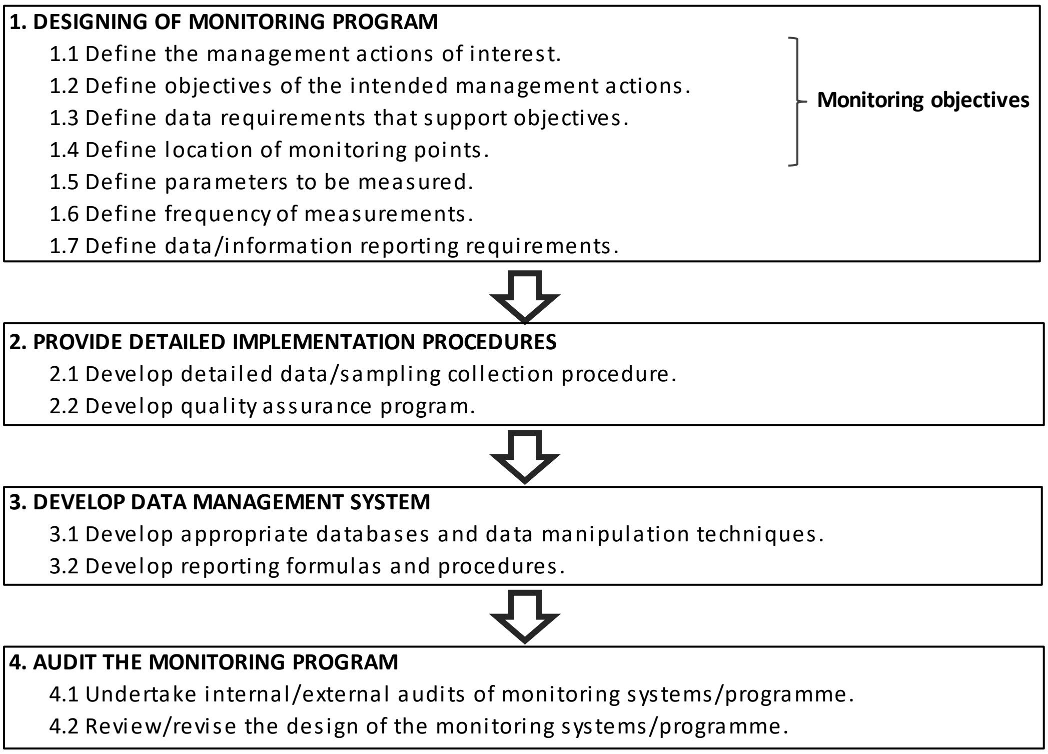
iv. The geochemical character of the carbonaceous spoils material i.e. carbonaceous shale suggests a likely capacity for acid formation. However relatively low oxidisable sulphides deem the material insufficient to sustain long term acid generation. Thus, any material of carbonaceous character can also be used as backfill substance, however it is recommended that additional geochemical characterisation be conducted to confirm this.

v. Alternative remedial options such as introducing lime within the backfilling material, thus increasing the material buffering capacity, should form part of the mine closure and rehabilitation strategy.

vi. 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.

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 revised monitoring network and program along with relevant information and are depicted in Figure 14-2. Newly suggested monitoring localities are conceptual only and it is suggested that a geophysical survey be conducted in order to target sub-surface lineaments/weathered zones acting as groundwater flow and contaminant transport pathways. Furthermore, existing monitoring boreholes which are blocked and/or inaccessible should be revisited in order to confirm adequacy for inclusion into the updated monitoring protocol.

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[30]. Chemical variables to form part of the sampling run are listed below.

14.3.1. Groundwater

Groundwater monitoring boreholes 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), Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Cobalt (Co) 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 of the Department within timeframes as stipulated in the WUL conditions.

14.5. Underground dewatering volumes

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

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[30] 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.

14.6. 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.

Table 14-1 **Monitoring network and programme.**

Site ID	Latitude	Longitude	Locality description	Monitoring frequency Water quality	 Water level	Parameters
Existing monitoring boreholes						
ELNBH 01	-25.913370	29.108570	Existing Elandsfontein monitoring network	Quarterly	Monthly	As in Chapter 14.3
ELNBH 02	-25.914220	29.101720	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ELNBH 03	-25.919940	29.086370	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ELNBH 07 S	-25.908100	29.099770	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ELNBH 06 D	-25.908230	29.099780	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ECBH 01	-25.913399	29.095491	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ECBH 02	-25.903170	29.096560	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ECBH 03	-25.903000	29.096330	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ECBH 04	-25.902000	29.097210	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ECBH 05	-25.903900	29.097910	Existing Elandsfontein monitoring network	Quarterly	Monthly	
GW 05	-25.922730	29.106740	Existing Elandsfontein monitoring network	Quarterly	Monthly	
BH 172	-25.923890	29.077950	Existing Elandsfontein monitoring network	Quarterly	Monthly	
BH 173	-25.924160	29.078950	Existing Elandsfontein monitoring network	Quarterly	Monthly	
FFBH 11	-25.984980	29.088820	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ELAND 3	-25.911966	29.086386	Existing Elandsfontein monitoring network	Quarterly	Monthly	
ELAND 10	-25.909180	29.105893	Existing Elandsfontein monitoring network	Quarterly	Monthly	
GRBH 01	-25.918850	29.100870	Existing Elandsfontein monitoring network	Quarterly	Monthly	
GRBH 02	-25.928180	29.098130	Existing Elandsfontein monitoring network	Quarterly	Monthly	
GRBH 03	-25.925730	29.103740	Existing Elandsfontein monitoring network	Quarterly	Monthly	
Newly proposed monitoring boreholes						
AH-BH 01	-25.916530	29.062030	Neighbouring borehole - down-gradient	Quarterly	Monthly	As in Chapter 14.3
AH-BH 03	-25.928350	29.071160	Neighbouring borehole - down-gradient	Quarterly	Monthly	
AH-BH 04	-25.911130	29.111850	Neighbouring borehole - up-gradient	Quarterly	Monthly	
AH-BH 05	-25.907560	29.111300	Neighbouring borehole - up-gradient	Quarterly	Monthly	
Newly proposed monitoring boreholes						
EBH01	-25.895463	29.089447	Additional monitoring borehole up-gradient of opencast pits.	Quarterly	Monthly	As in Chapter 14.3
EBH02	-25.894391	29.083373	Additional monitoring borehole up-gradient of opencast pits.	Quarterly	Monthly	
EBH03	-25.899036	29.082896	Additional monitoring borehole down-gradient of opencast pits.	Quarterly	Monthly	
EBH04	-25.905111	29.079085	Additional monitoring borehole down-gradient of opencast pits.	Quarterly	Monthly	
EBH05	-25.912852	29.079919	Additional monitoring borehole located down-gradient of WOP.	Quarterly	Monthly	

Site ID	**Latitude**	**Longitude**	**Locality description**	**Monitoring frequency**		**Parameters**
				Water quality	**Water level**	
EBH06	-25.906897	29.088494	Additional monitoring borehole located down-gradient of ROM stockpile area.	Quarterly	Monthly	
EBH07	-25.923334	29.105526	Additional monitoring borehole located down-gradient of PCD area.	Quarterly	Monthly	
EBH08	-25.917974	29.098737	Additional monitoring borehole down-gradient of opencast pits.	Quarterly	Monthly	
EBH09	-25.916614	29.077298	Wetland monitoring borehole.	Quarterly	Monthly	
EBH10	-25.910801	29.089691	Additional monitoring borehole located down-gradient of ROM stockpile area.	Quarterly	Monthly	
EBH11	-25.901200	29.089069	Additional monitoring borehole located down-gradient of PCD area.	Quarterly	Monthly	
Surface water monitoring localities						
ELAN	-25.928507	29.106382	Most upstream point in game farm tributary	Monthly	Monthly	As in Chapter 14.3
FARM DAM	-25.907626	29.082571	Downstream from SW01	Monthly	Monthly	
GSHL 02	-25.929664	29.101439	Second point in game farm tributary	Monthly	Monthly	
GSHL 03	-25.929526	29.095632	Third point in game farm tributary	Monthly	Monthly	
SW01	-25.903008	29.085863	Most upstream point in northern tributary	Monthly	Monthly	
TCMPCD 01	-25.921360	29.108347	Rehabilitated Coal-disposal seepage PCD	Monthly	Monthly	
TCMPCD 03	-25.900712	29.089354	PCD containing decant	Monthly	Monthly	
TCMSW 01	-25.908673	29.065435	Most downstream point after confluence of two tributaries	Monthly	Monthly	
TCMSW 02	-25.923392	29.081096	Upstream point - tributary coming from game farm	Monthly	Monthly	
TCMSW 03	-25.920989	29.081663	Open void, receiving water from cut-off trench	Monthly	Monthly	
TCMSW 04	-25.918894	29.078099	Downstream from TCMSW 02	Monthly	Monthly	
TCMSW 05	-25.915604	29.078239	Downstream of Farm Dam	Monthly	Monthly	
WOP	-25.911403	29.082017	Western Open Pit	Monthly	Monthly	

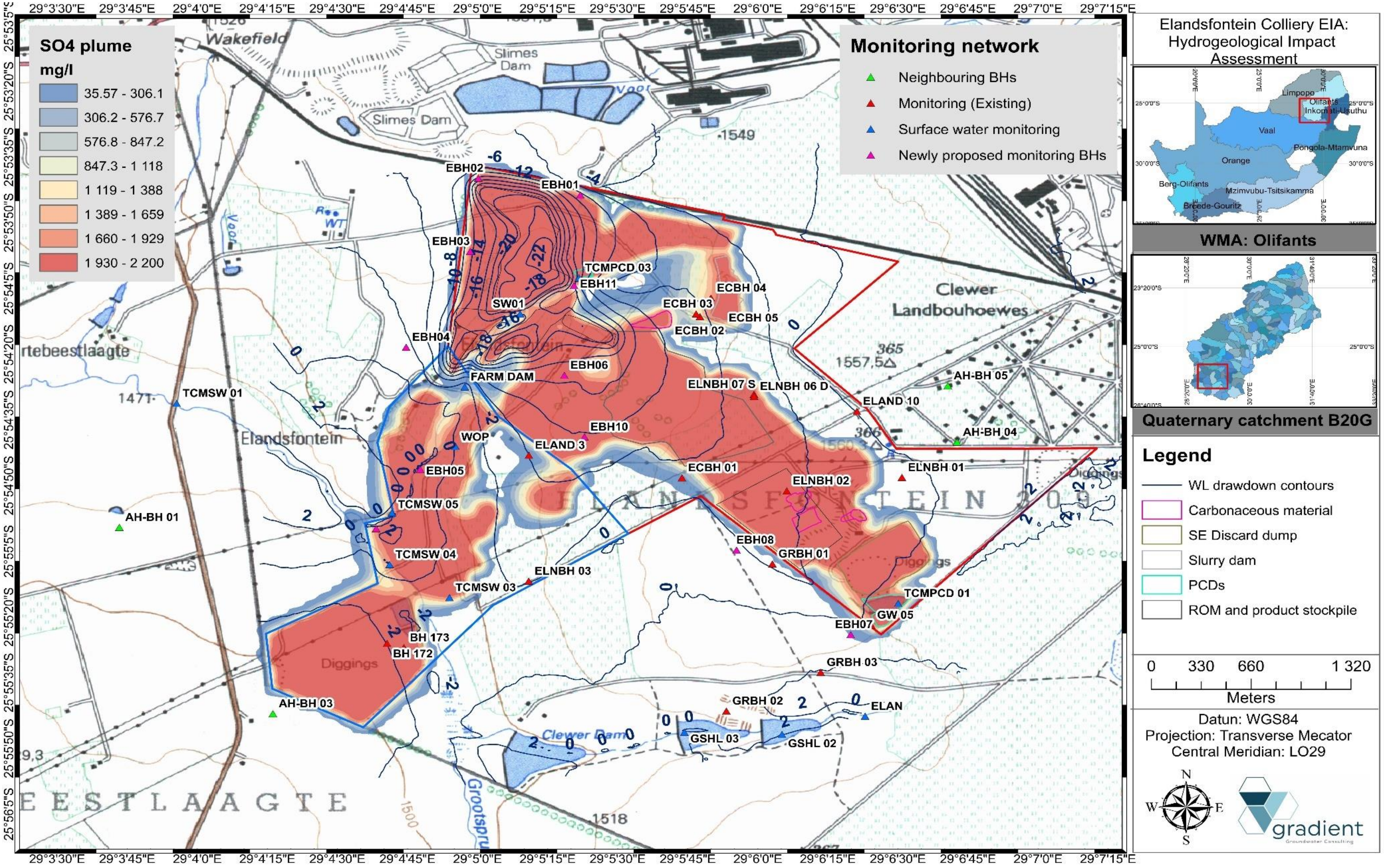

Figure 14-2 Updated groundwater and surface water monitoring network.

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 shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices.
2. On a local scale, two 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.
3. Various neighbouring boreholes in close proximity (< 1.0 km) to the mining operations are utilized for domestic and livestock watering.
4. The unsaturated/ vadose zone within the study area is limited (~ 8.0 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 moderately to the topographical elevation suggesting a dynamic environment. The inferred groundwater flow direction of the shallow aquifer mimics topography and is expected to be in a general southwestern direction towards the lower laying drainage system of the Grootspruit from where it will discharge as baseflow.
6. The groundwater gradient increases towards the west and southwest while a gentler gradient exists to the north. The latter will influence seepage rates from mine waste facilities and should be noted.
7. The regional ambient groundwater quality of the shallow aquifer is good and suggest an unimpacted groundwater system, however isolated monitoring localities within site boundary is indicative of an impacted groundwater system and shows signs of coal mine pollution and acid mine drainage (AMD).
8. The mine void water quality is acidic and extremely saline with pH < 3.0 and sulphate concentration > 1400 mg/l.
9. The hydrochemical signature of surface water locality ASW01, downstream sampling locality of the Grootspruit, suggest similar water environments to the mine void water which is potentially decanting as either interflow or baseflow at the lower laying zones or seepage from unrehabilitated discard dumps and other waste facilities.
10. The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although

the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

11. The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.
12. The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.
13. The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.
14. A Toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material suggest elevated concentrations of manganese (Mn) as well as sulphate ($S0_4$) for the tailings slurry sample, manganese (Mn) for the coal product sample and barium (Ba), manganese (Mn) as well as zinc (Zn) for the carbonaceous shale sample.
15. All waste samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly.
16. The numerical groundwater flow model simulations for the proposed opencast operation suggest the average open pit dewatering is approximately $2.57E^{+02}$ m^3/d with a maximum pit water ingress of approximately $5.09E^{+02}$ m^3/d for the duration of the simulation period. It is noted that the opencast groundwater ingress volumes expected is much lower due to the existing groundwater drawdown caused by current dewatering activities. It is expected that the groundwater drawdown will range from 4.0m to ~ 24.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 211.0ha. It should be noted that the simulated impact zone extends slightly beyond the eastern perimeter of the mining right area, however, falls mainly within the mining properties. Baseflow discharges to the model catchment drainages, accounts to approximately 1800.0 m^3/d during pre-mining conditions, whereas baseflow discharge during the operational life of mine period decreases to ~ 1750.0 m^3/d. This accounts for an average loss of ~3.0% with a maximum of >10.0% during the simulation period.
17. Model simulations for the proposed underground development suggest the average underground void

dewatering is approximately $1.44E^{+03}$ m^3/d with a maximum underground water ingress of approximately $2.03E^{+03}$ m^3/d for the duration of the simulation period. It is expected that the groundwater drawdown will range from 4.0m to ~ 30.0m below the static water level (mbsl) and the groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of 720.90ha. It should be noted that the simulated impact zone extends slightly beyond the eastern and south-eastern perimeters of the mining right area, however, falls mainly within the mining properties. It is not expected that the underground operations will have a significant effect on the baseflow discharge to local drainages.

18. A mine post-closure scenario was simulated wherein hydraulic head recovery within the proposed opencast areas was evaluated. It is calculated that the newly proposed backfilled opencast pit flooding and associated decant periods ranges between ~5.0years to >20years depending on the geometry of the backfilled pit. Expected decant volumes for the backfilled opencast pits varies from 8.0m^3/d to > 70.0m^3/d depending on the pit effective infiltration volumes. The combined decant volume is approximately ~150.0m^3/d.
19. It is calculated that the existing/historical backfilled opencast pits decant volumes varies from 40.0m^3/d to > 190.0m^3/d with a combined decant volume of approximately ~626.0m^3/d. It should be noted that there are various decant points potentially discharging into the wetland drainage system traversing the site.
20. A mine post-closure scenario was simulated wherein hydraulic head recovery within the existing underground voids as well proposed mining areas was evaluated. Simulated average groundwater ingress for the LOM underground operation was combined with the expected groundwater recharge reporting to the underground void and from these volumes it is estimated that under average rainfall conditions, the underground will be flooded in approximately 35 to 40 years after ceasing of mining activities. The proposed depth and geometry of the underground operations allows for the majority of the footprint to be flooded with a low risk of decant occurring. Expected decant volumes for the underground voids are relatively low due to the presence of confining shale and mudstone layers restricting the downward filtration of rainwater recharge into the underground mine void(s) and ranges between 0.85m^3/d to ~17m^3/d with a combined volume of approximately 50.0m^3/d.
21. The combined expected decant volume expected post-closure is approximately 870.0 m^3/d.
22. It is noted that sulphate concentrations for all monitoring boreholes (ECBH02, ECBH03 and ECBH04) rises above the SANS threshold reaching the LOM, where borehole ECBH03 reaches a maximum concentration of ~1 370 mg/l, correlating well to on-site monitoring results.
23. The simulated sulphate pollution plume extent for the newly proposed mining footprints for LOM covers a total area of approximately 447.0ha (inclusive of existing opencast footprints), reaching a maximum distance of ~350.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that no neighbouring boreholes, except on-site monitoring boreholes is impacted on during the operational LOM while the unknown tributary of the

Grootspuit and associated wetland are affected.

24. It is evident that sulphate concentrations for all monitoring boreholes is above the SANS threshold for the duration of the LOM, reaching maximum concentrations of between ~1200.0 to ~1 600.0mg/l respectively.
25. A 50-year post-closure scenario was simulated and covers a total area of approximately 875.0ha, reaching a maximum distance of ~600.0 to 700.0m in a general south-western direction towards the lower laying drainage and wetland systems. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on.
26. A 100-year post-closure scenario was simulated and covers a total area of approximately 1030.0ha, reaching a maximum distance of 1100.0 to 1300.0m in a general south-western direction. The simulation indicates that, although the pollution plume extends beyond the mining properties, no neighbouring boreholes will potentially be impacted post-closure while the unknown tributary of the Grootspuit and associated wetland might potentially be impacted on. It is evident that sulphate concentrations for all monitoring boreholes stabilises to a maximum sulphate contribution load of between 1600.0 to 1800.0mg/l, which is above the SANS threshold.
27. Various alternative management and mitigation scenarios were simulated to evaluate the remedial options available. The preferred mitigation scenario entails establishment of scavenger boreholes down-gradient of waste facilities and backfilled opencasts in combination with disposal of carbonaceous waste material in the northern discard pit. The combination of the mitigation effect of the negative groundwater gradient created reduces the pollution plume footprint to ~35.0% to ~738.0ha. Accordingly, this mitigation scenario is the most likely case and preferred scenario.
28. It is evident that if mitigation and management measures evaluated can be implemented successfully, mass load contributions by source terms can be limited.
29. During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as medium negative without implementation of remedial measure and low negative with implementation of proposed mitigation measures. Groundwater quality impacts from the discard dump, coal stockpile areas, PCD’s and related waste facilities are rated as medium negative without implementation of remedial measures and medium/low negative with implementation of mitigation measures.
30. 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 revised monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. 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 Human Settlements, Water and Sanitation.
3. It is recommended that additional monitoring boreholes, as indicated in this report, be established down-gradient of potential decant zones in order to evaluate the mass load contribution of decant water to environmental receptors. Proposed monitoring boreholes should be drilled in pairs to target shallow, weathered as well as deeper, fractured aquifer units. Drilling localities should be determined by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.
4. Due to the impact and reduction of baseflow reporting to the on-site wetland, it is recommended that a monitoring borehole(s) be drilled in order to evaluate perched water level recovery of the wetland following rehabilitation.
5. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a bi-annual basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.
6. It is recommended that supplementary geochemical characterisation i.e. kinetic leach test should be performed on carbonaceous waste material to be used as backfill material i.e. northern discard pit, with a dynamic geochemical model developed to aid in calculation of source term depletion timeframes.
7. It is imperative that the water level recovery of the underground voids as well as backfilled opencast pits 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 in terms of decanting.
8. Alternative remedial options to reduce rainfall recharge and effective infiltration, which will lead to an increase in leachate volumes, should form part of the mine closure and rehabilitation strategy. It is recommended that the northern discard pit footprint be compacted and a barrier system (capping) and/or evapotranspiration cover be established in order to minimise water and oxygen ingress which is the drivers of acid rock drainage conditions.
9. All preferred groundwater flow pathways which are in direct connection with surface topography i.e. adits, ventilation shafts and/or unrehabilitated exploration boreholes should be sealed off and rehabilitated.

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18. APPENDIX A: RAINFALL DATA (RAINFALL ZONE B2C)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	125.2	61.1	76.2	74.0	91.2	138.9	17.4	11.6	0.0	0.0	0.0	17.5	613.1
1921	58.0	107.9	74.1	51.5	69.1	90.7	0.6	29.0	13.7	0.0	44.6	15.0	554.3
1922	58.9	109.7	80.8	135.2	46.1	20.9	18.7	0.1	2.2	1.1	0.0	4.4	478.3
1923	18.0	84.7	78.4	56.9	60.4	124.3	30.7	23.4	0.0	0.0	2.2	18.7	497.7
1924	39.3	98.9	106.0	50.9	90.7	127.9	58.2	48.9	21.6	0.3	0.3	60.3	703.3
1925	20.6	69.2	63.5	50.0	40.8	27.9	5.6	35.1	1.8	12.9	0.0	13.4	340.8
1926	16.0	74.1	45.9	83.2	77.0	64.3	21.1	0.8	0.0	52.5	9.7	9.6	454.0
1927	100.2	32.9	55.7	110.0	45.5	40.5	15.4	0.9	0.0	0.0	20.1	8.0	429.1
1928	15.9	85.9	85.9	57.0	50.4	95.5	20.1	14.7	11.1	0.0	0.1	57.7	494.2
1929	116.3	98.3	113.0	96.8	95.3	64.4	24.0	1.9	0.0	21.2	10.7	0.2	642.1
1930	12.0	31.9	59.8	70.4	41.9	46.5	38.6	0.0	0.3	42.9	0.0	0.0	344.2
1931	39.3	61.5	57.7	135.4	60.4	52.5	7.7	11.9	0.1	0.0	0.0	23.5	450.0
1932	42.3	96.5	66.5	50.7	62.5	37.8	13.4	0.1	3.0	3.9	0.0	13.3	390.0
1933	4.6	169.0	116.6	151.8	100.9	56.5	38.5	19.7	8.6	14.1	18.4	24.1	722.9
1934	22.7	106.3	103.8	51.6	74.1	73.2	5.0	1.1	0.0	0.0	3.9	1.6	443.3
1935	17.4	32.9	75.2	122.9	99.7	96.3	41.4	87.9	0.0	0.1	0.0	22.9	596.8
1936	51.6	127.6	53.9	153.2	98.4	26.9	15.3	1.4	0.0	0.1	0.0	12.6	541.1
1937	59.8	17.0	127.9	114.9	39.8	42.8	81.5	3.2	5.9	9.6	7.0	11.7	521.1
1938	42.4	46.0	114.4	94.0	183.8	73.5	15.0	42.1	0.0	46.0	3.7	19.4	680.4
1939	47.5	147.8	123.3	60.3	63.1	58.9	22.8	26.3	58.2	0.0	1.4	57.1	666.6
1940	13.8	122.4	92.4	75.8	61.3	70.5	76.3	0.0	0.0	0.2	0.2	18.0	530.9
1941	36.7	20.1	87.9	107.4	64.5	67.0	17.7	29.9	17.7	0.0	12.1	25.0	485.9
1942	73.1	84.7	144.0	85.7	49.2	58.2	95.2	35.4	0.2	30.8	32.4	22.8	711.6
1943	55.6	84.2	92.2	107.4	148.2	51.9	5.0	3.7	30.2	0.0	0.0	23.8	602.2
1944	76.4	118.4	30.4	94.4	66.8	56.9	20.2	10.0	0.0	0.0	0.0	0.6	474.1
1945	32.7	48.9	72.6	136.7	128.8	71.5	12.0	5.8	0.0	0.0	0.0	0.2	509.2
1946	19.7	76.9	83.6	70.9	57.7	49.8	25.4	0.1	7.8	1.7	0.0	4.6	398.2
1947	26.5	101.6	127.6	128.2	31.7	75.3	14.5	8.5	0.0	0.1	0.0	11.8	525.7
1948	67.8	111.5	32.6	143.8	35.1	33.1	36.7	12.1	2.6	0.0	0.0	12.8	488.2
1949	51.2	113.4	101.8	74.1	51.1	48.5	71.6	14.3	0.6	0.4	0.0	4.9	531.9
1950	15.8	52.9	91.6	73.9	59.4	47.3	41.0	37.5	1.3	0.8	19.9	3.5	444.8
1951	96.5	10.1	83.3	53.5	76.6	23.0	17.4	6.3	2.5	16.2	0.2	0.6	386.1
1952	26.7	83.1	114.0	66.0	96.5	94.3	40.2	8.1	0.2	0.0	0.3	6.1	535.3
1953	34.1	154.5	73.2	95.1	76.8	45.7	35.4	9.0	0.0	0.0	0.3	12.0	536.0
1954	26.2	99.2	68.6	139.3	139.4	50.3	50.3	17.5	5.8	0.2	0.6	0.0	597.3
1955	52.0	84.8	147.2	55.2	111.9	60.6	0.1	81.3	9.9	2.8	0.0	45.8	651.5
1956	85.8	71.6	81.5	68.7	107.2	72.9	20.3	15.7	27.2	39.6	20.5	51.5	662.6
1957	52.9	31.6	34.8	117.1	34.5	42.2	98.4	3.8	0.1	0.0	0.0	46.1	461.5
1958	69.5	60.1	118.2	90.0	56.2	28.5	31.1	13.7	0.7	4.6	0.0	2.6	475.2
1959	20.4	138.7	95.7	59.9	49.3	54.5	77.3	7.3	2.1	0.5	8.1	5.1	518.9
1960	41.3	86.5	87.6	68.0	64.3	84.6	72.9	22.3	7.8	1.7	0.1	16.1	553.3
1961	51.8	63.9	88.6	73.8	56.3	44.7	38.0	0.7	2.8	0.0	6.2	9.8	436.5
1962	43.2	117.3	76.7	103.6	24.2	24.3	39.6	9.8	73.2	13.4	0.0	1.7	527.0
1963	50.3	78.0	40.5	148.3	43.3	24.6	12.7	3.0	5.2	0.0	4.3	2.3	412.6
1964	136.2	38.3	113.6	81.4	40.4	8.2	31.8	9.2	0.0	3.8	2.7	3.1	468.8
1965	10.5	76.1	65.5	55.2	46.9	5.8	13.7	6.3	3.5	0.0	0.4	7.3	291.4
1966	83.9	86.8	107.9	151.3	91.7	46.8	94.1	6.8	1.2	3.9	14.3	6.3	695.0
1967	75.3	97.4	79.4	84.4	50.7	97.5	37.2	13.8	0.2	2.2	7.0	1.6	546.7
1968	29.9	89.8	80.0	65.2	74.6	144.4	36.9	37.7	0.0	0.1	0.9	12.8	572.3
1969	103.5	98.1	115.4	75.7	57.3	33.0	31.9	6.7	0.7	3.1	11.6	8.4	545.5
1970	72.5	72.5	84.9	131.2	33.3	41.6	75.8	14.8	1.9	0.0	0.1	36.8	565.3
1971	35.7	121.1	100.8	126.1	37.8	82.8	12.2	6.8	0.4	0.0	4.2	23.1	551.0
1972	33.4	102.7	48.8	98.8	43.2	66.6	54.2	0.0	0.0	0.0	2.9	41.8	492.4
1973	55.4	61.1	130.2	95.1	47.5	20.0	45.0	2.1	0.9	9.0	0.8	10.9	478.0
1974	19.3	94.0	81.3	189.8	123.8	34.0	82.5	6.7	6.4	0.2	0.1	1.1	639.2
1975	30.8	123.8	90.4	95.8	72.7	73.2	28.9	31.2	0.0	0.0	0.0	8.5	555.4
1976	71.5	83.9	75.6	96.5	8.8	83.1	30.1	1.4	0.0	0.0	3.2	33.0	487.2
1977	40.4	76.8	49.3	150.8	90.0	60.2	16.3	1.1	0.0	0.5	11.1	24.4	521.0
1978	51.3	49.0	39.1	49.6	28.2	32.7	28.3	3.4	1.7	7.6	12.7	10.1	313.7
1979	67.7	116.4	58.6	115.9	119.1	52.9	11.1	0.8	0.0	0.0	0.1	31.4	573.9
1980	12.6	129.8	68.1	110.3	71.7	58.4	15.8	0.0	8.3	0.0	9.2	26.2	510.3
1981	56.6	54.9	62.2	116.7	38.3	62.7	9.1	0.6	0.7	16.3	0.0	3.6	421.8
1982	58.7	24.6	57.9	112.6	31.1	53.3	21.0	13.7	13.3	12.1	25.8	5.8	430.0
1983	76.5	135.5	89.1	70.1	29.9	93.0	3.5	0.1	12.9	9.3	5.8	4.0	529.7
1984	92.7	60.9	51.5	83.4	101.3	67.3	0.5	14.4	0.0	0.2	4.9	28.0	505.0
1985	65.9	31.5	102.8	70.0	43.6	42.4	25.9	0.0	9.2	0.0	0.5	1.5	393.4
1986	85.8	116.8	135.7	82.5	49.1	131.1	9.7	1.2	0.0	0.0	19.2	78.5	709.4
1987	48.3	145.1	109.5	68.4	32.0	69.4	16.0	3.2	9.6	0.5	6.4	21.1	529.6
1988	79.4	39.1	65.3	71.6	102.9	31.5	32.9	1.3	48.0	0.0	5.8	0.8	478.7
1989	33.0	118.0	112.0	45.4	92.4	94.1	87.2	2.0	0.0	1.0	0.9	2.9	588.9
1990	32.9	49.7	121.1	102.2	120.6	121.4	0.8	2.4	7.7	0.0	0.0	3.8	562.6
1991	37.5	48.8	102.3	74.6	62.2	35.6	9.5	0.0	0.5	0.0	15.8	6.3	393.1
1992	66.3	79.9	93.1	47.0	95.8	85.3	22.6	1.6	0.0	0.0	5.6	39.0	536.3
1993	125.5	103.6	68.1	69.6	93.1	50.4	6.8	0.0	0.0	0.0	0.0	12.3	529.4
1994	46.6	61.9	62.4	62.2	36.2	113.9	56.8	6.8	0.0	0.0	6.7	9.6	463.3
1995	66.7	140.9	174.1	166.2	238.9	84.8	54.8	6.8	0.0	0.3	5.8	1.6	940.9
1996	78.6	35.3	67.1	68.3	4.2	172.7	33.5	58.0	2.3	2.7	3.0	21.7	547.4
1997	57.6	111.0	49.9	80.9	43.8	42.2	4.6	0.0	0.0	0.0	0.0	48.9	438.7
1998	41.2	133.3	101.7	68.3	8.7	23.2	14.7	13.9	5.8	0.0	0.0	13.9	424.8
1999	34.7	144.9	161.0	174.2	140.1	129.1	51.5	14.1	1.7	0.4	0.0	14.9	866.5
2000	99.1	78.7	103.6	29.9	61.9	22.2	8.4	40.4	14.6	0.0	0.0	10.6	469.2
2001	72.2	109.4	61.1	39.9	47.1	13.4	23.5	14.2	7.8	0.0	6.5	12.1	407.3
2002	38.4	32.1	92.2	52.6	71.4	44.1	6.0	0.0	1.2	0.0	0.7	3.0	341.5
2003	61.6	51.1	93.2	80.1	153.6	189.5	21.9	4.4	4.5	12.2	0.7	0.0	672.9
2004	0.0	119.2	115.2	161.0	45.2	62.5	78.1	0.0	0.0	0.0	0.0	0.0	581.1
2005	24.1	85.0	59.3	191.0	135.1	55.0	0.0	0.0	0.0	0.0	0.0	0.0	549.6
2006	0.0	96.5	115.5	36.3	7.2	12.9	18.7	0.0	20.5	0.0	0.0	29.2	336.7
2007	162.3	95.8	131.7	215.5	22.8	195.3	0.0	30.9	0.0	0.0	0.0	0.0	854.3
2008	45.5	130.3	85.9	118.3	80.8	83.2	5.8	13.0	39.7	0.0	14.9	25.1	642.6
2009	89.7	149.2	117.4	134.0	102.2	73.7	130.1	0.0	0.0	0.0	0.0	0.0	796.3
Geometric mean	**52.6**	**86.4**	**87.7**	**94.1**	**70.1**	**64.9**	**31.6**	**12.3**	**6.1**	**4.5**	**4.9**	**15.6**	**530.8**
Minimum	**0.0**	**10.1**	**30.4**	**29.9**	**4.2**	**5.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**291.4**
Maximum	**162.3**	**169.0**	**174.1**	**215.5**	**238.9**	**195.3**	**130.1**	**87.9**	**73.2**	**52.5**	**44.6**	**78.5**	**940.9**
Standard deviation	**31.5**	**36.1**	**29.3**	**38.9**	**39.7**	**37.9**	**27.1**	**16.7**	**12.4**	**10.4**	**7.9**	**16.3**	**119.5**

19. APPENDIX B: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

21. APPENDIX C: GEOCHEMICAL ANALYSIS LABORATORY CERTIFICATES

22. APPENDIX D: SPECIALIST CURICULUM VITAE