**Document Number**
HG-R-24-014-V2

# MOOIPLAATS COLLIERY WUL AMENDMENT HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

November 2024

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

**Compiled by:**
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## INDEMNITY AND SPECIALIST DECLARATION

The findings, results, observations, conclusions and recommendations given in this report are based on the author's best scientific and professional knowledge as well as available information. The report is based on assessment techniques, which are limited by information available, time and budgetary constraints relevant to the type and level of investigation undertaken and Gradient Consulting (Pty) Ltd reserve the right to modify aspects of the report including the recommendations if and when new information may become available from ongoing research, monitoring, further work in this field, or pertaining to the investigation. Although Gradient Consulting (Pty) Ltd exercises due care and diligence in rendering services and preparing documents, Gradient Consulting (Pty) Ltd accepts no liability, and the client, by receiving this document, indemnified Gradient Consulting (Pty) Ltd against all actions, claims, demands, losses, liabilities, costs, damages and expenses arising from or in connection with the services rendered, directly or indirectly by Gradient Consulting (Pty) Ltd and by the use of the information contained in this document. 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). We realise that a false declaration is an offence in terms of regulation 48 of the Environmental Impact Assessment Regulations, 2014 (as amended) promulgated in terms of the National Environmental Management Act, 107 of 1998 (NEMA) and is punishable in terms of section 49B of the NEMA.

I, JFW Mostert, hereby declare that:

- I act as the independent specialist in this investigation.
- I will perform the work relating to the study 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 study, including knowledge of the Act, Regulations and any guidelines that have relevance to the 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 project 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.

Respectfully submitted.

JFW Mostert (Hydrogeologist)

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

# List of Abbreviations

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

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

# Executive summary

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment to support a water use licence (WUL) amendment process to be followed for the Mooiplaats Colliery.

Mooiplaats Colliery (Pty) Ltd is an existing underground mining operation operates and has an approved Mining Right MP 30/5/1/2/2/68 MP, 2007 (MR) and Integrated Water Use Licence No. 08/C11B/AGJ/2141, 02 May 2013. Active mining is no longer taking place and the existing coal beneficiation plant and associated infrastructure is intended to be repurposed for Toll Washing (the processing of third-party supplier coal). The applicant would like to amend their existing Water Use Licence to align the water uses with existing infrastructure and the proposed future activities on site.

This investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts of existing as well as proposed activities and infrastructure on the receiving groundwater environment.

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

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

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

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

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

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock.
ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones.
iii. Shallow quaternary and recent types of sediments (perched, unconfined) are characteristically a primary porosity aquifer.

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

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

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

In order to determine the sustainable yield at which the proposed production boreholes can be abstracted, boreholes were subjected to constant discharge aquifer tests to obtain site representative aquifer parameters and hydraulic properties. A sustainable abstraction rate of 1692.0m$^3$/d (0.47l/s) is recommended for a 12-hour duty cycle while an abstraction rate of 1188.0m$^3$/d (0.33l/s) is recommended for a 24-hour duty cycle for the Potable Water Borehole whereas a sustainable abstraction rate of 19 673.63m$^3$/d (4.46l/s) is recommended for a 12-hour duty cycle while an abstraction rate of 11 358.57m$^3$/d (3.16l/s) is recommended for a 24-hour duty cycle for the Usuthu borehole.

The unsaturated zone within the study area is in the order of ~0.50m to ~13.0m with a mean thickness of approximately 4.0m.

The minimum water level recorded is at monitoring borehole GKL-1, 0.82mbgl, with the deepest water level measured IS at the potable water borehole, 58.77 mbgl. The average water level recorded, with inclusion of potential dynamic water levels is 13.32mbgl, while the average water level, only considering the static water levels is calculated at 4.79mbgl. The relatively low standard deviation compared to the mean depth to groundwater i.e., Coefficient of Variation (CV) < 100%, suggests a relatively steady state groundwater environment.

Analysed data indicate that the surveyed static water levels correlate very well to the topographical elevation with the correlation calculated at $R^2$ >0.99. It should be noted that when static water levels as well as dynamic water levels are considered, the correlation is not good and the $R^2$ ~0.81. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography, however localised deviation in groundwater flow direction can be observed and is attributed to abstraction causing negative hydraulic gradients towards respective boreholes, altering flow directions. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system of the Vaal River traversing the study area. The groundwater flow in the northern segment of the mining right area will be in a general south to southeastern direction whereas the groundwater flow in the southern section of the mining right area will be in a general north to northwestern direction.

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the study area is relatively flat and calculated at a mean of 0.004, with a maximum of 0.007 in a southwestern to northeastern orientation.

The expected seepage rate from contamination originating at surface pollution sources is estimated at an average of approximately 3.63 metres per annum (m/a), with a maximum distance of ~8.39m/a in a southwestern to northeastern orientation.

Regional drainages can be generally classified as influent or gaining stream systems. Groundwater head elevation compared to topographical elevation confirms that there exists groundwater discharge as baseflow to local drainages.

The overall water quality of groundwater samples analysed is poor with the majority of monitoring points analysed indicating elevated sulphate concentrations. Water quality can be described as neutral to acidic, saline to very saline as well as moderately soft to slightly hard. Isolated sampling localities indicate above limit total dissolved solids (TDS), WT-S05 and WT-S06, with sulphate and sodium the main drivers of the high salt loads observed. Monitoring locality WT-S05 also indicates elevated concentrations of manganese. It can be observed that the overall salt load (TDS) is much higher if compared to the groundwater monitoring localities with sulphate the main driver of the higher mass load.

The overall water quality of groundwater samples analysed is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Water quality can be described as neutral, non-saline and slightly to moderately hard. Isolated sampling localities indicate a high salt load i.e., GKL-4D and the Usuthu borehole. It should be noted that monitoring locality GKL-4D suggests elevated fluoride, sodium as well as aluminum and iron concentration while monitoring locality Usuthu BH suggest a very high TDS (very saline) with elevated sulphate and sodium concentrations. The latter can be attributed to the defunct underground workings targeted.

All the surface water monitoring localities can be distinguished as being of a Magnesium- Sulphate dominance suggestive of a dynamic and coordinated environment which have potentially been impacted by mining related activities. It is evident that the majority of groundwater monitoring localities can be characterized as being recently recharged groundwater and unimpacted groundwater environment (Magnesium-Bi-carbonate dominance) while isolated boreholes suggest Sodium-Chloride dominance (GKL-4D) and the Usuthu borehole and GKL-5S indicating an area of a dynamic and coordinated environment (Sodium-Bi-carbonate dominance).

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

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

Abstraction of water from the study area's host-aquifer, expressed as a percentage of recharge on the mining properties, is classified as **Category A** (Proposed abstraction = ~43.56% of rainfall recharge) while abstraction of water from the study area's host-aquifer, expressed as a percentage of recharge reporting to the delineated sub-catchment, is also classified as **Category A** (Proposed abstraction = ~19.35% of rainfall recharge). The latter indicates a small scale of abstraction (<60% recharge on property) and consequently low levels of stress in terms of the abstraction recharge ratio.

For the purposes of this investigation, it can be assumed that groundwater abstraction will be limited to the meso-catchment (resource management unit (RMU)) i.e., sub-catchment for the simulated groundwater capture zone which has a total area of $27.68km^2$. If current abstraction and ecological water requirement (Reserve) is accounted for there exists a surplus volume/allocable groundwater volume of $0.78M/m^3/a$ (25.14l/s) within the RMU. Accordingly, it can be concluded that the proposed volume of groundwater to be abstracted from the production boreholes, falls within the calculated groundwater available for allocation, which also accounts for the Reserve.

Data and information gathered during the site investigation was incorporated to develop a conceptual understanding of the regional hydrogeological system on which the numerical groundwater flow model was based on. The latter was calibrated to an acceptable error margin by using site specific hydrogeological data to serve as a tool to evaluate various water management options and scenarios.

Scenario 02 simulated the water level drawdown caused by abstraction from proposed production boreholes for the operational phase(s). It is evident that the abstraction activities change the hydraulic gradient as groundwater is removed from storage. It should be noted that the simulated groundwater drawdown zone intercepts various monitoring boreholes and stretches to the drainage systems or associated wetlands in the proximity of the site. The groundwater drawdown during the simulated abstraction period will range from <1.0mbsl (meter below static level), i.e., relatively little drawdown expected within the Usuthu boreholes to >21.0mbsl simulated within the Potable water borehole. The groundwater capture zone i.e. drawdown zone of influence extent will cover an estimated footprint of approximately $3.36km^2$ propagating radially reaching a maximum distance of approximately 1.40km in a general south to southeastern direction. As there exist a pronounced interaction between surface and groundwater it can be assumed that the two regimes are well-linked. Groundwater contribution to baseflow discharge[1] accounts to approximately $1.33E^{+04}m^3/d$ during baseline conditions, whereas groundwater contribution to baseflow discharge during the operational period decreases to ~$1.29E^{+04}m^3/d$. The latter accounts for an average loss of $3.68E^{+02}m^3/d$, ~2.84% with a maximum reduction of 4.21% for the operational phase(s).

Scenario 03 simulated the pollution plume migration within the intergranular aquifer originating from the waste infrastructure footprints for the duration of the operational period without any mitigation or management measures applied i.e., worst-case scenario. It can be observed that the pollution plume migration is generally in a northeastern to eastern direction towards the lower lying drainage system. The pollution plume extent covers a total area of approximately $0.95km^2$, reaching a maximum distance of ~330.0m in a general northeastern to eastern direction. The simulation indicates that the pollution plume generated is mostly confined to the mining right area, however, does intercept various monitoring boreholes and reach to the local drainage system and associated wetlands. It can be observed that the sulphate mass load contribution to local observation boreholes increases to a maximum of between 950.0mg/l to 1500.0mg/l and is a function of the distance towards the

1 Baseflow calculations is expressed as the observed loss based on the drainage system traversing the project area.

waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure is above the SANS 241:2015 acute health threshold concentration after a simulation period of approximately 20 years. It can be observed that the mass load contribution to the local drainage system increases to a maximum of 130.0mg/l however remain below the SANS 241:2015 acute health threshold concentration for the duration of the simulation period.

A post-closure scenario was simulated to evaluate the pollution plume migration within the intergranular aquifer host after discontinuing of current activities. It can be observed that the post-closure pollution plume migration remains in a general northeastern to eastern direction towards the lower lying drainage system. The 50-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.25km$^2$, reaching a maximum distance of ~500.0m in a general northeastern to eastern direction towards the lower laying drainage systems. The 100-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.47km$^2$, reaching a maximum distance of ~570.0m in a general northeastern to eastern direction towards the lower laying drainage systems. The simulation indicates that the pollution plume generated slightly extends beyond the mining right area and intercepts various monitoring boreholes situated towards the north and northeast. Furthermore, it is noted that the simulated pollution plume reaches the local drainage system and associated wetlands. It can be observed that the sulphate mass load contribution to local observation boreholes continues to increase during the post-closure phase, reaching a maximum concentration of between 1950.0mg/l to 2150.0mg/l and is a function of the distance towards the waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure remains above the SANS 241:2015 acute health threshold concentration for the duration of the post-closure period. It can be observed that the mass load contribution to the local drainage system increases to a maximum of >1400.0mg/l, breaking through the SANS 241:2015 acute health threshold concentration after a simulation period of approximately 15 years post-closure. It can be noted that the mass load contribution during the post-closure phase for all borehole receptors have not reached a quasi-state conditions and remains in an upward

Various alternative management and mitigation scenarios were simulated to evaluate the remedial options available. An active management scenario evaluating the mitigating effect of seepage capturing boreholes i.e. scavenger boreholes on the plume migration via active pumping were simulated. Based on the constraining effect of this mitigation scenario on both the pollution plume migration as well as reduced mass load contribution, this alternative can be viewed as the best remedial option for implementation

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

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

**The following recommendations are proposed following this investigation:**

i. It is recommended that the management and mitigation measures be implemented as part of the integrated groundwater management plan (Section 16 of this Report). The Licensee shall appoint a suitably qualified and responsible person and make all of the necessary and reasonable financial, human and equipment resources available to him/her" to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.

ii. It is recommended that the monitoring network and 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 on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

iii. Additional monitoring boreholes as recommended should be established down-gradient of the existing waste infrastructure footprints in order to evaluate the groundwater drawdown as well as mass load contribution to environmental and sensitive groundwater receptors. 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.

iv. Newly established monitoring boreholes should be subjected to aquifer hydraulic parameters to supplement and verify existing hydraulic parameters interpreted as part of the first phase drilling and testing run.

v. Groundwater abstraction from proposed production boreholes should not exceed recommended sustainable or safe yields and pump duty cycles.

vi. All waste material analysed can be classed as Type 3 waste (low hazardous waste) and should be handled and stored/ disposed as such.

vii. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.

viii. Alternative remedial options, as suggested in this report, should form part of the mine closure and rehabilitation strategy.

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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 baseline investigation and groundwater impact assessment to support a water use licence (WUL) amendment process to be followed for the Mooiplaats Colliery.

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This investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts of existing as well as proposed activities and infrastructure on the receiving groundwater environment.

## 1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors by evaluation and interpretation of existing time-series monitoring data.

ii. Determine the current status quo of the regional groundwater system including aquifer classification, aquifer unit delineation and vulnerability.

iii. Perform constant discharge aquifer tests to determine aquifer sustainable borehole yields and borehole duty cycles.

iv. Data analysis and interpretation of water level drawdown and recovery curves for estimations of borehole sustainable yields, duty cycles as well as pump specifications.

v. Geochemical characterisation, waste assessment and first order evaluation on the long-term potential for the occurrence of acid rock drainage.

vi. Rapid Reserve determination and groundwater catchment water balance.

vii. Utilising the existing numerical groundwater flow and mass transport model to perform updated abstraction scenarios.

viii. Hydrogeological impact assessment and risk matrix.

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

x. Review and evaluation on the adequacy of the existing 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 proposals ref.no. HG-P-23-051-V2, submitted in September 2023 as well as ref.no. HG-P-24-009-V2, submitted in May 2024. This project plan and scope of work (SoW) was compiled based on Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications as published by the Department of Water Affairs and Sanitation (DWS, 2017) as well as Government Notice NO. R. 982: Environmental Impact Assessment (EIA) Regulations controlling environmental authorization applications (NEMA, 2014). The scope of work is listed below.

### 1.3.1. Phase A: Desktop review and data evaluation

Phase A will entail the following activities:

i. Information gathering and data acquisition.

ii. Desk study and review of historical groundwater baseline information and existing specialist reports.

iii. Fatal flaw and gap-analysis.

### 1.3.2. Phase B: Hydrogeological baseline assessment – Review of existing monitoring data, hydrochemical analysis and aquifer classification

Phase B will entail the following activities:

i. Review of existing time-series monitoring data in order to evaluate possible trends in water levels and water quality as well as identification of potential sensitive groundwater receptors in close proximity to the amended activities and infrastructure.

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

iii. 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: Aquifer testing – Constant discharge pump tests

Phase C will entail the following activities:

i. Constant discharge pump tests i.e. 24-hour constant discharge and recovery measurements to determine sustainable yields on two (2) boreholes. All pump-tests will be conducted under test supervision and according to SANS 10299-4:2003 standards.

ii. Sampling of newly established boreholes according to best practice guidelines and analyses of two (2) water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

iii. Data analysis and interpretation of water level drawdown and recovery curves for estimations of borehole sustainable yields, duty cycles as well as pump specifications.

iv. Rapid Reserve determination and groundwater catchment water balance.

#### 1.3.4. Phase D: Geochemical characterisation and waste assessment

Phase D will entail the following activities:

i. Desk study and review of historical geochemical baseline information including existing specialist reports.

ii. Formulation of an opinion on the expected geochemical character of the coal sourced from regional collieries.

#### 1.3.5. Phase E: Update the existing numerical groundwater flow and mass transport model

Phase E will entail the following activities:

iii. 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. Impact of dewatering of the underground Usutu workings as well as associated cone of depression zone.

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

   d. Mine post-closure pollution plume migration with time.

   e. Water management alternatives and best practice mitigation measures.

#### 1.3.6. Phase F: Hydrogeological impact assessment and reporting

Phase F 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. Local groundwater exploitation potential and groundwater availability.

   f. Safe sustainable groundwater abstraction rates on successful boreholes.

   g. Geochemical characterisation and waste assessment opinion.

   h. Update of the existing numerical groundwater flow and mass transport model, recalibration and management simulations.

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

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

ii. Review and evaluation on the adequacy of the existing groundwater monitoring network and protocol.

### 1.4. Details and expertise of the author

The details of the author(s) who prepared this report are summarised in Table 1-1 below. The specialist Curriculum Vitae is included as Appendix E.

**Table 1-1 Details of the authors.**

| **Author** | Joseph Ferdinand Willem Mostert |
|---|---|
| **Highest qualification** | M.Sc. Hydrogeology |
| **Years' experience** | 17+ |
| **Professional registration** | SACNASP Member (Reg. No 40057/14 – Water Resource Science).<br>Member of the Groundwater Division of the Geological Society of South Africa (MGSSA). |

### 1.5. Available information

The following information was available and used as part of the desktop review phase of this investigation:


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

ii. Barnard, H. C., 2000. An explanation of the 1:500 000 general Hydrogeological Map. Nelspruit 2530.

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xix. van Tonder and Xu, 2000. Program to estimate groundwater recharge and the Groundwater Reserve.

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### 1.6. Project assumptions and limitations

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

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

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

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

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

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

vi. 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.

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

viii. 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.

ix. 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.

x. 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.

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

xii. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly[2].

## 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. Review and evaluation of monitoring data

Review of existing time-series monitoring data in order to evaluate possible trends in water levels and water quality as well as identification of potential sensitive groundwater receptors in close proximity to the amended activities and infrastructure.

### 2.3. Hydrochemical analysis

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

### 2.4. Aquifer tests

Production boreholes were subjected to aquifer tests i.e. pump tests to determine hydraulic parameters and borehole sustainability or safe-yields. Pump tests comprised the following phases:

i. Stepped discharge test: Also referred to as step drawdown test and is performed to determine optimal discharge yield at which the perspective borehole will be subjected to during the constant discharge test. This involves pumping of the borehole at consecutive pumping rates, measuring the magnitude of drawdown against time. Calibration steps may vary from 60 to 120 minutes.
ii. Constant discharge test: Performed to assess the aquifer response to borehole stressing, determining safe yield at which groundwater can be abstracted and defining hydraulic properties. This entails pumping the borehole at a discharge rate which is kept constant over period of time. Test should be utilized approximately 70 % of available drawdown (borehole depth – static water level). Drawdown in water level is continuously measuring.
iii. Recovery test: Provides an indication of ability of borehole to recover from stress of abstraction. Recovery rate is again analysed to determine hydraulic properties of local aquifer. After

[2] 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.

pump has been switched off, the test encompasses a period of monitoring, with duration of test governed by the period of constant discharge test.

### 2.5. Rapid Reserve Determination

The Department of Water Affairs and Sanitation is required to determine the Reserve for all or part of any significant water resource before any water use can be allocated and/or licensed. A groundwater balance is calculated on the targeted catchment in order to determine allocable volumes for licencing purposes.

### 2.6. Geochemical assessment and waste classification

The potential risk of mine waste to generate acid i.e. acid rock drainage (ARD) was evaluated by review of available acid base accounting tests conducted on coal sourced from regional collieries. 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, existing waste classification results of waste was reviewed in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010).

### 2.7. Numerical groundwater flow and mass transport model update

The existing numerical groundwater flow and mass transport model was updated and recalibrated based on the site characterisation data gathered as well as the redefined 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.

### 2.8. 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. Mooiplaats Colliery operates under an approved Water Use Licence (WUL Ref.No. 08/C11B/AGJ/2141, issued 02 May 2013). This investigation will serve as supporting documentation to amend this existing licence to cater for newly identified water uses as listed below:

### 3.1.1. Section 21 water use activities

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

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

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

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

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

**Section 4: Restriction of Locality**

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

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

**Section 6: Capacity requirements of clean and dirty water systems**

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

i. Confine any unpolluted water to a clean water system, away from any dirty area;
ii. Design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;
iii. Collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity, into a dirty water system;
iv. Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and
v. Design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act.
vi. Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years."

**Section 7: Protection of water resources**

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

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

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

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

i. Residue stockpiles and residue deposits must be managed in the prescribed manner on any site demarcated for that purpose in the environmental management plan or environmental management programme in question.

ii. No person may temporarily or permanently deposit any residue stockpile or residue deposit on any site other than on a site contemplated in subsection.

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

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

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

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

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

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

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

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

# 4. STUDY AREA AND INFRASTRUCTURE

## 4.1. Regional setting and site locality

The project extent and greater mine lease area is located on Portions 1, 2, 8, 9 and Remaining Extent of Portion 1 as well as 9 of the Farm Mooiplaats 290 in the Msukaligwa Local Municipality, Mpumalanga Province, South Africa. Mooiplaats Colliery is located approximately 15km south-east of the town of Ermelo and is accessible from the N2 national route and is situated approximately 1.7 km from the Camden Power Station. General site coordinates are listed in Table 4-1 with the site locality and project boundary depicted in Figure 4-1. Refer to Figure 4-2 for an aerial extent of the project area.

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

| | |
|---|---|
| **Latitude** | 26°38'39.99"S |
| **Longitude** | 30° 05'50.74"E |

## 4.2. Mining infrastructure and schedule

Mooiplaats Colliery is an existing coal mining operation. The applicant would like to amend their existing Water Use Licence to align the water uses with existing infrastructure and the proposed future activities on site. As a main objective, Mooiplaats Colliery is no longer undertaking underground coal mining and the existing coal beneficiation plant and associated infrastructure is intended to be repurposed for Toll Washing (the processing of third-party supplier coal). Existing and new water uses will be necessary for the intended repurposing of the plant to take effect (Figure 4-3).

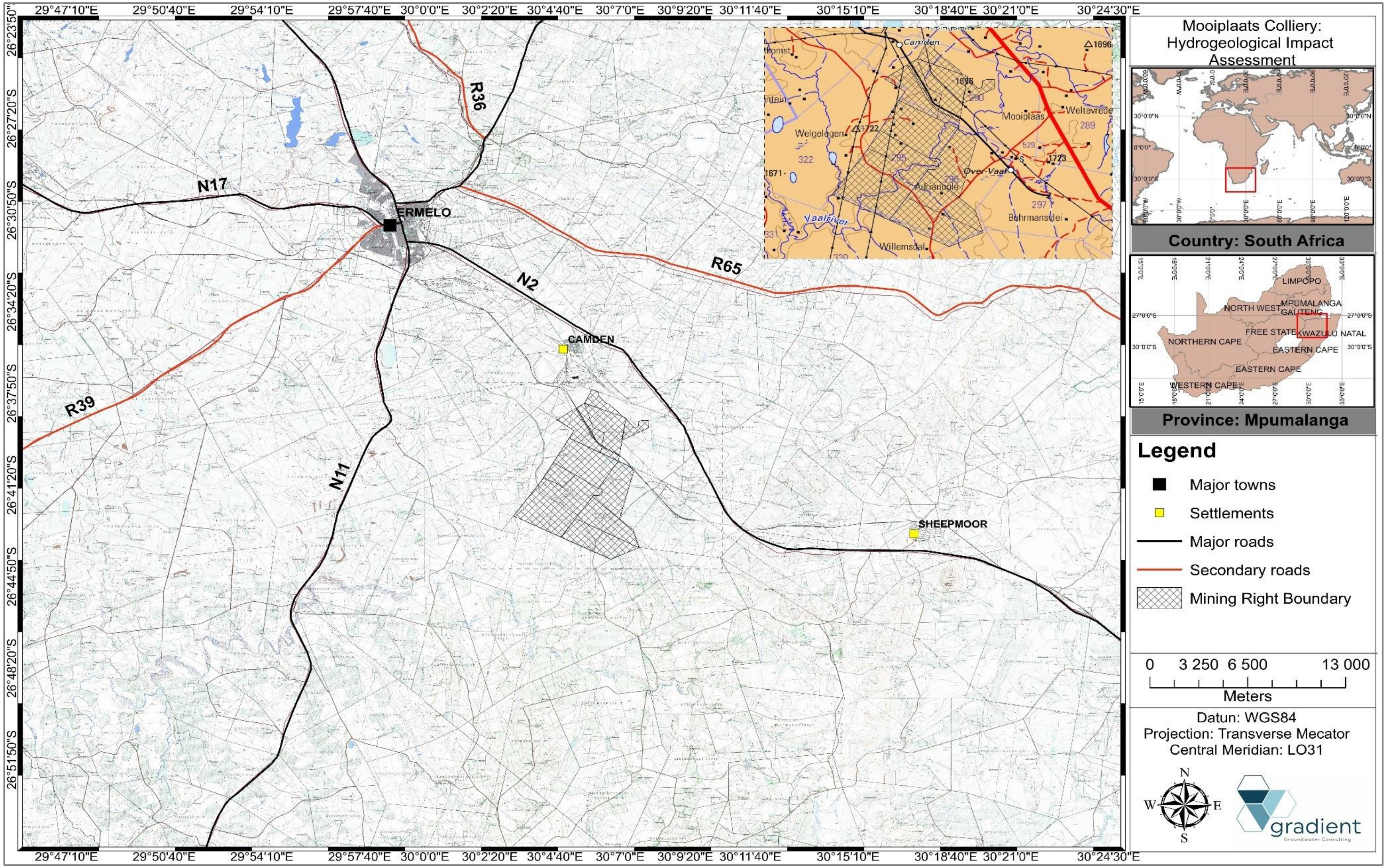



**Figure 4-1 Greater study area and project boundary (topographical mapsheet 2630CA).**

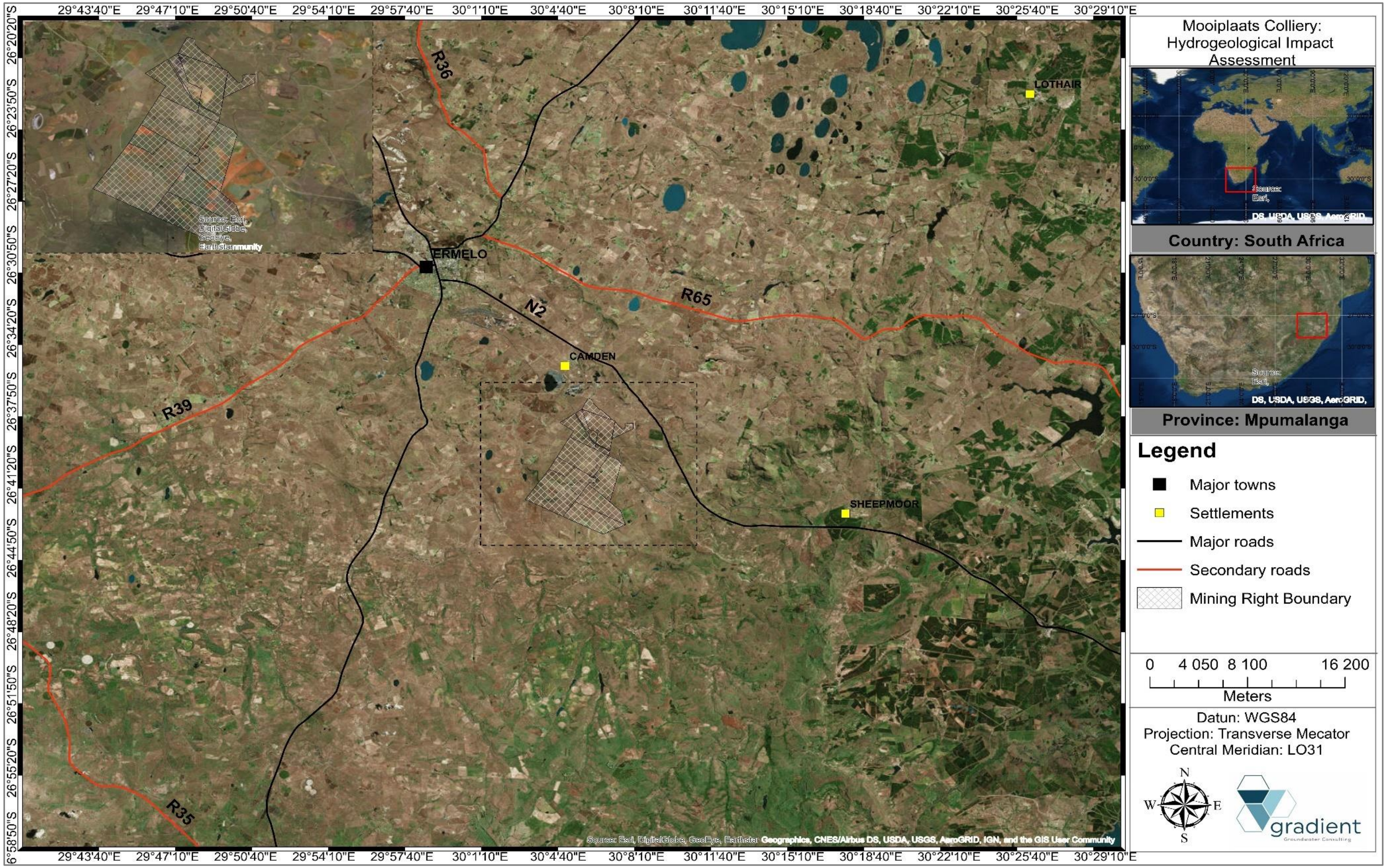



**Figure 4-2** **Aerial extent and mining right boundary.**

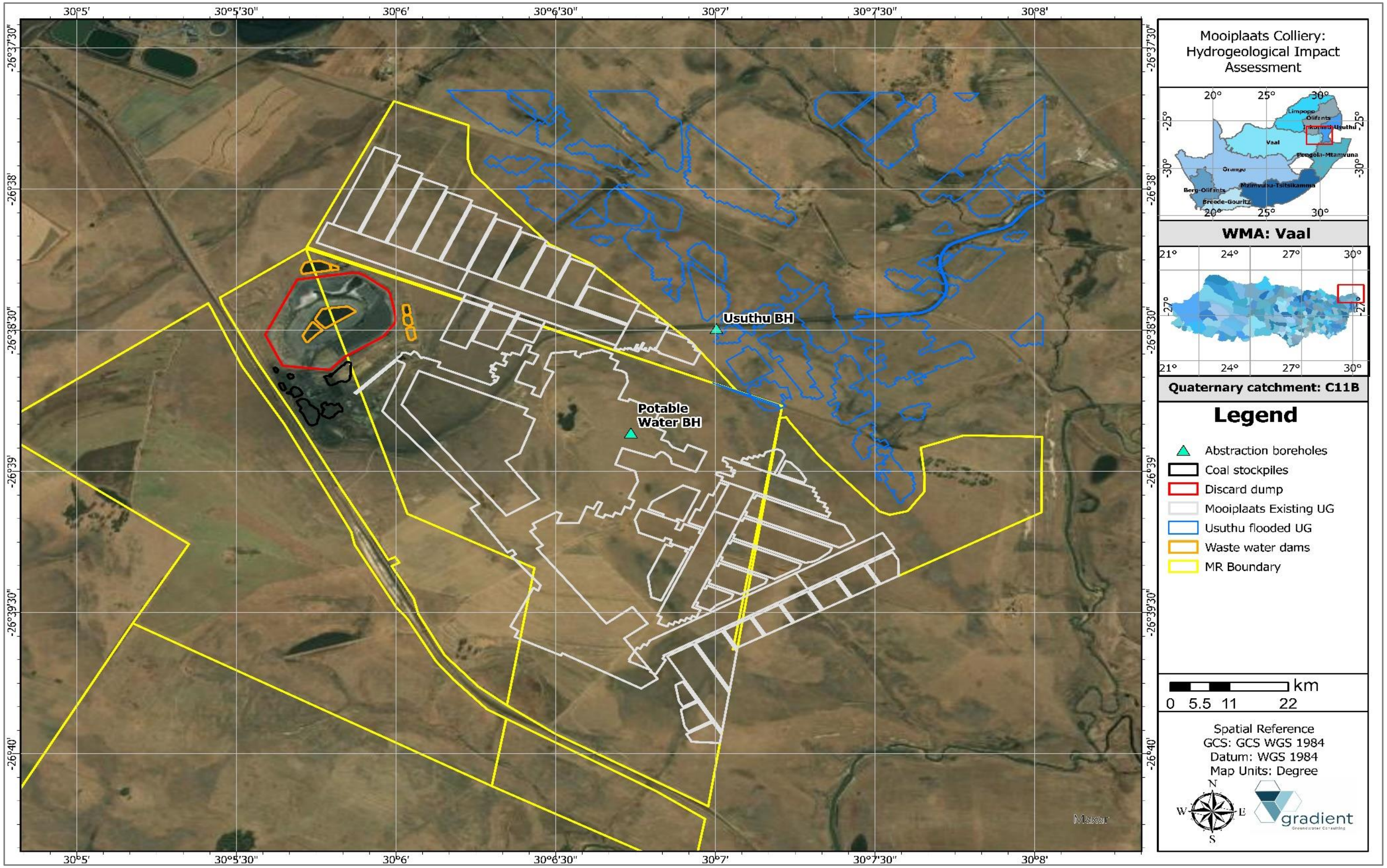



**Figure 4-3** **Mine layout and infrastructure.**

# 5. PHYSIOGRAPHY

## 5.1. Topography

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

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

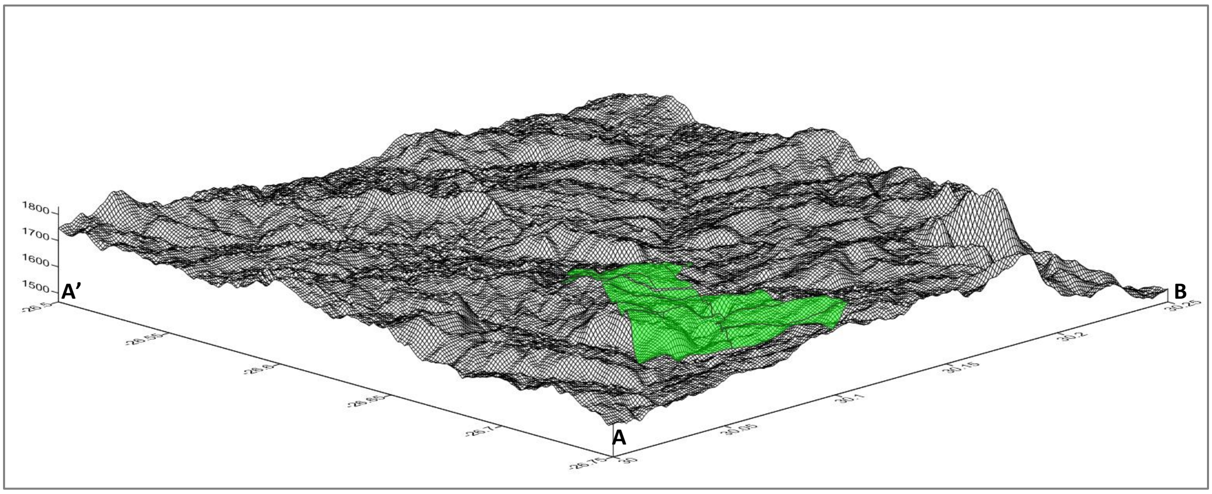



**Figure 5-1 Topographical cross-sections of the greater study area.**

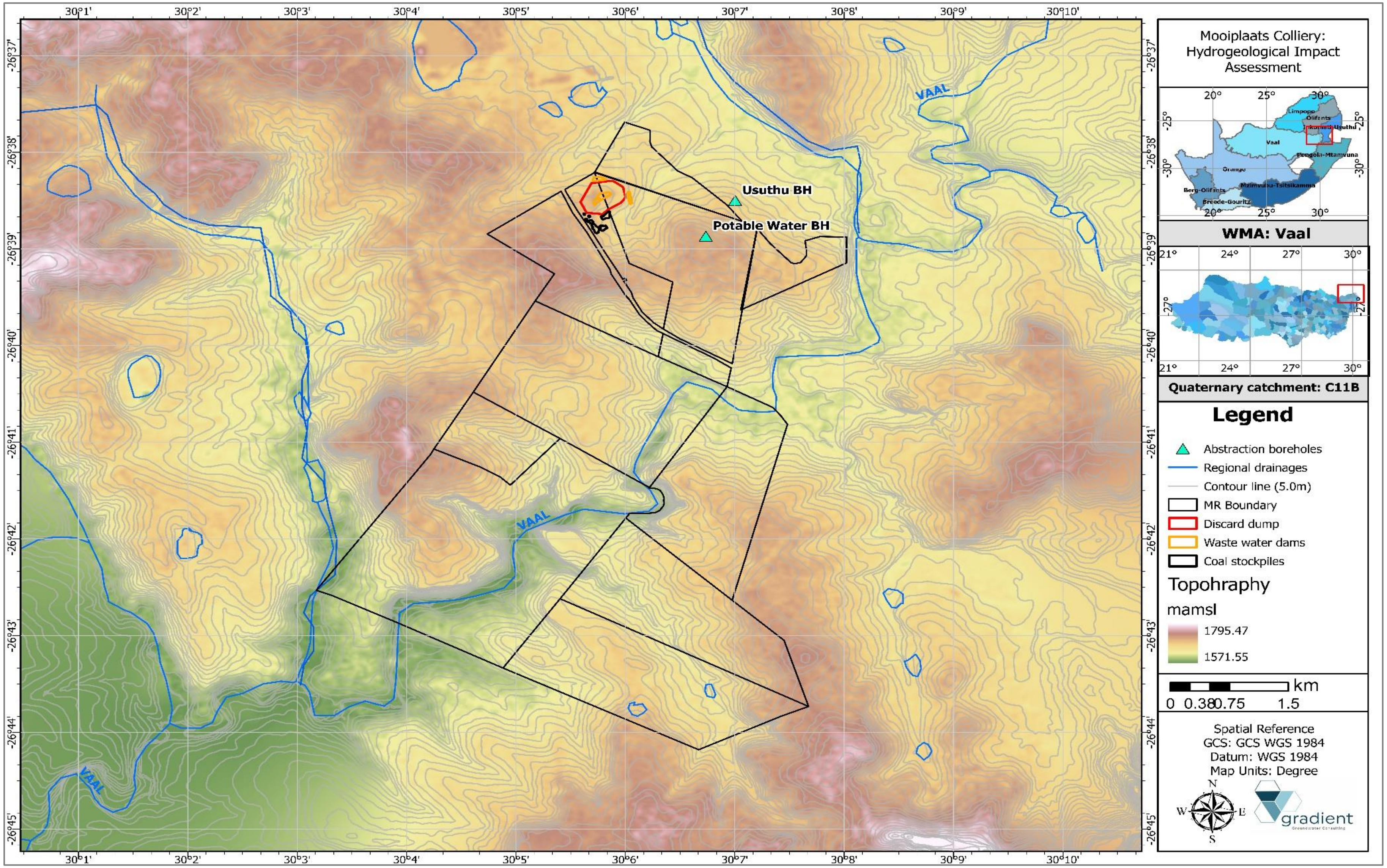



**Figure 5-2** **Regional topography.**

## 5.2. Drainage and catchment

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

**Table 5-1 Quaternary catchment information: C11B.**

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

**Note: Catchment based information sourced from Aquiworx 2014.**

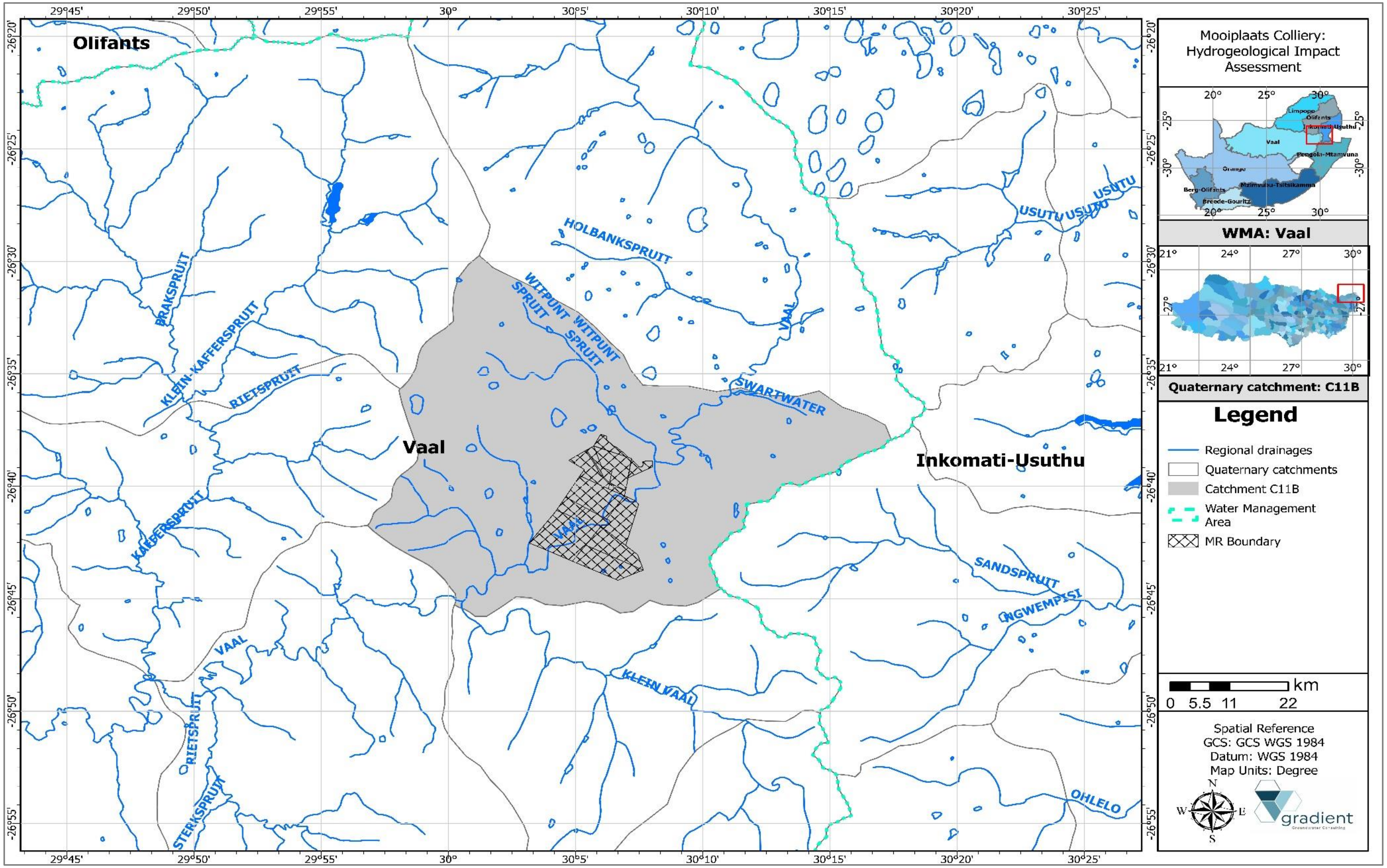



**Figure 5-3** **Quaternary catchments and water management area.**

## 5.3. Climate

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

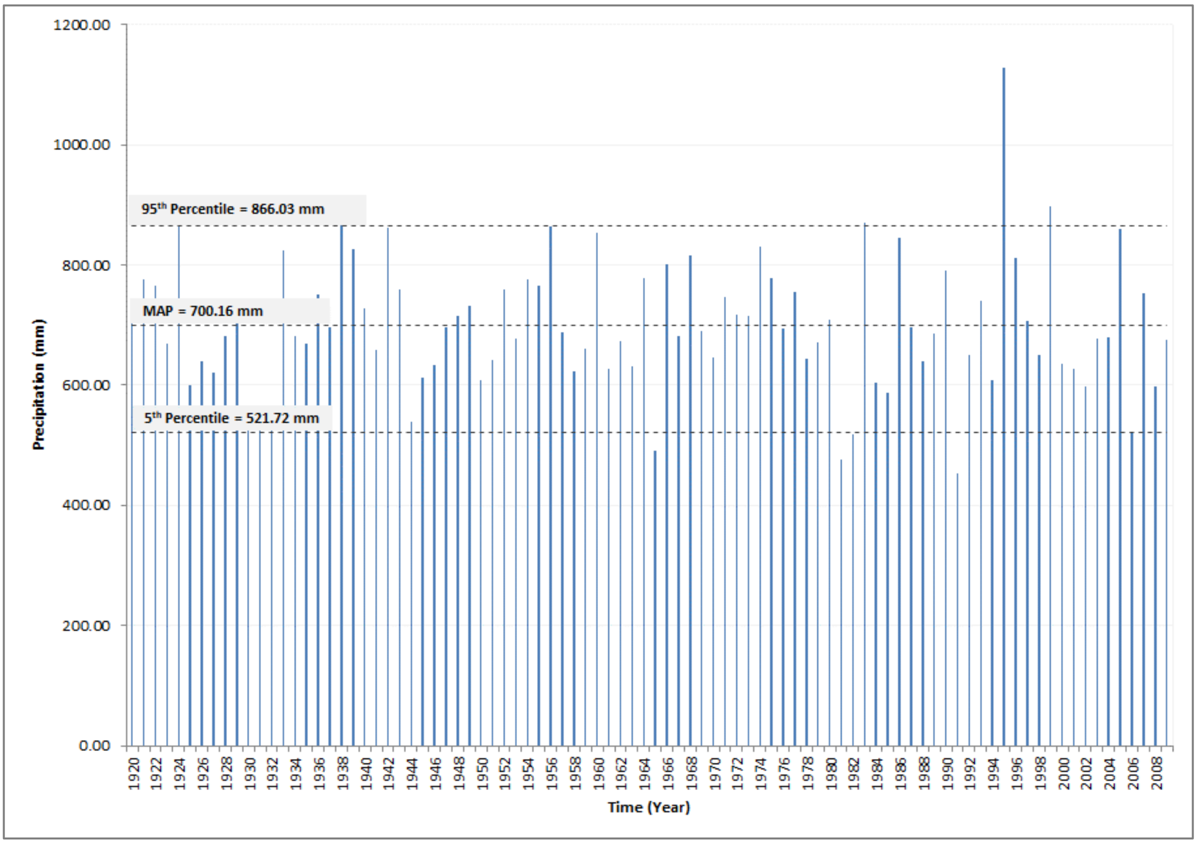



**Figure 5-4 Bar chart indicating yearly rainfall distribution for rainfall zone C1A (WR2012).**

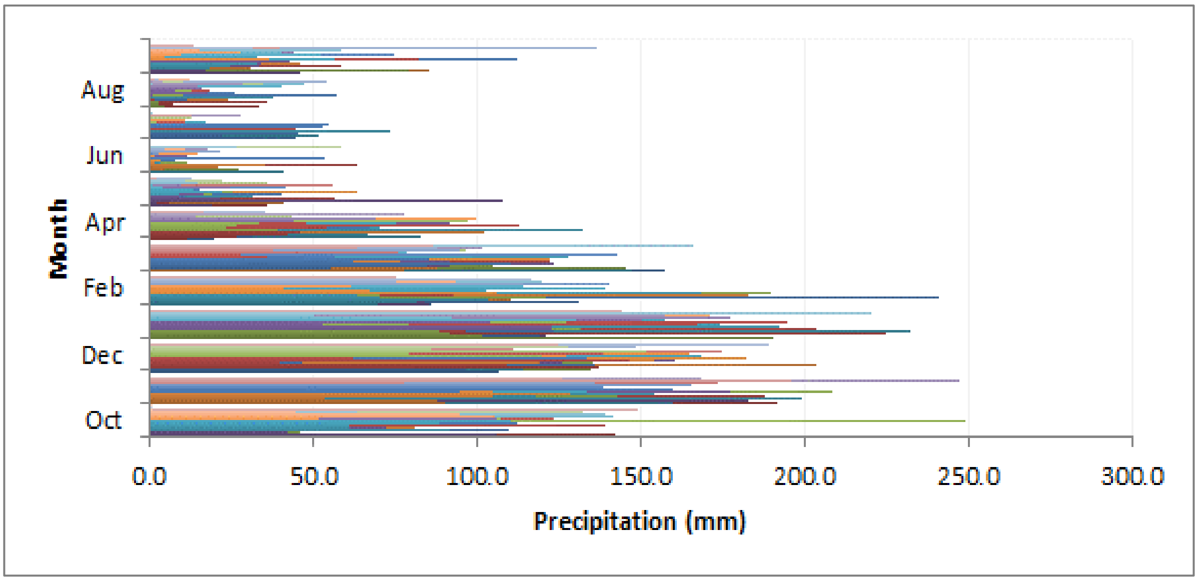



**Figure 5-5** **Bar chart indicating monthly rainfall distribution for rainfall zone C1A (WR2012).**

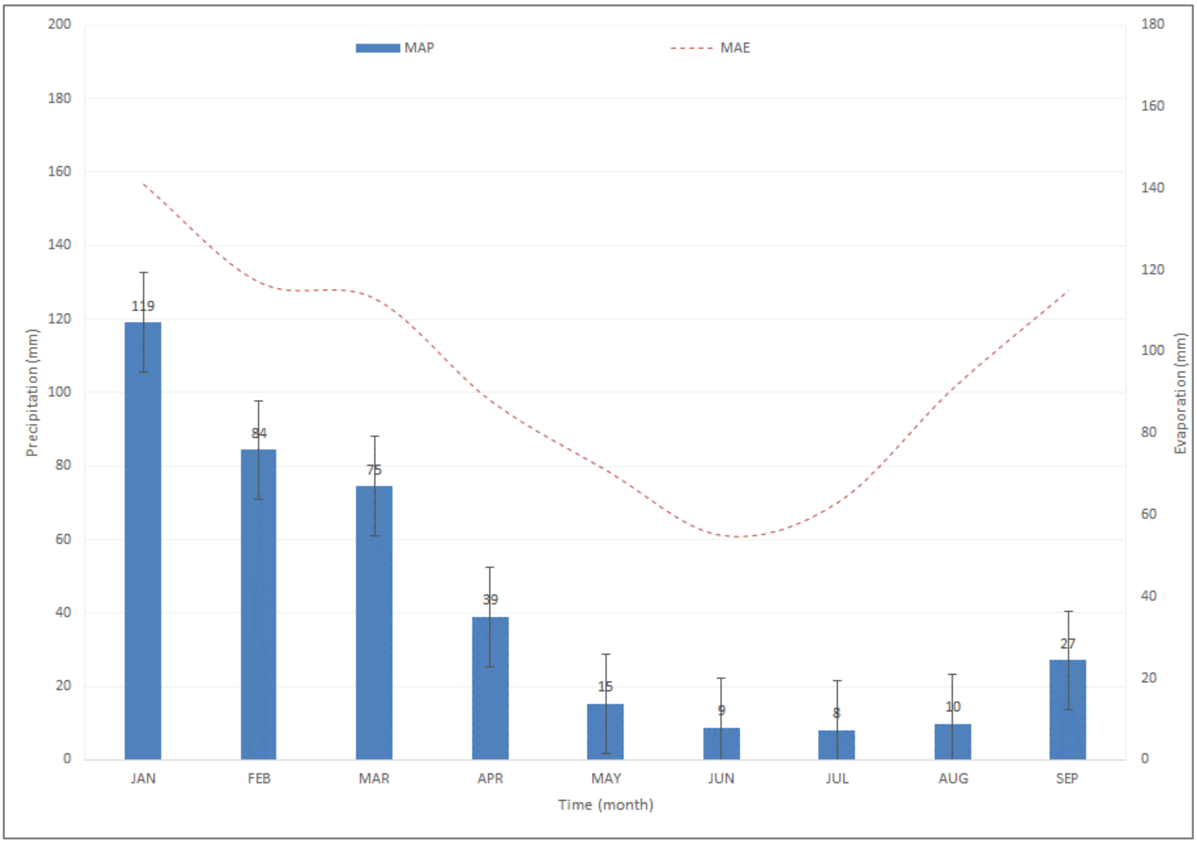



**Figure 5-6** **Bar chart and curve comparing monthly rainfall and evaporation distribution (WR2012).**

## 5.4. Geological setting

### 5.4.1. Regional geology

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

### 5.4.2. Local geology

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

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

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

### 5.4.3. Structural geology

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

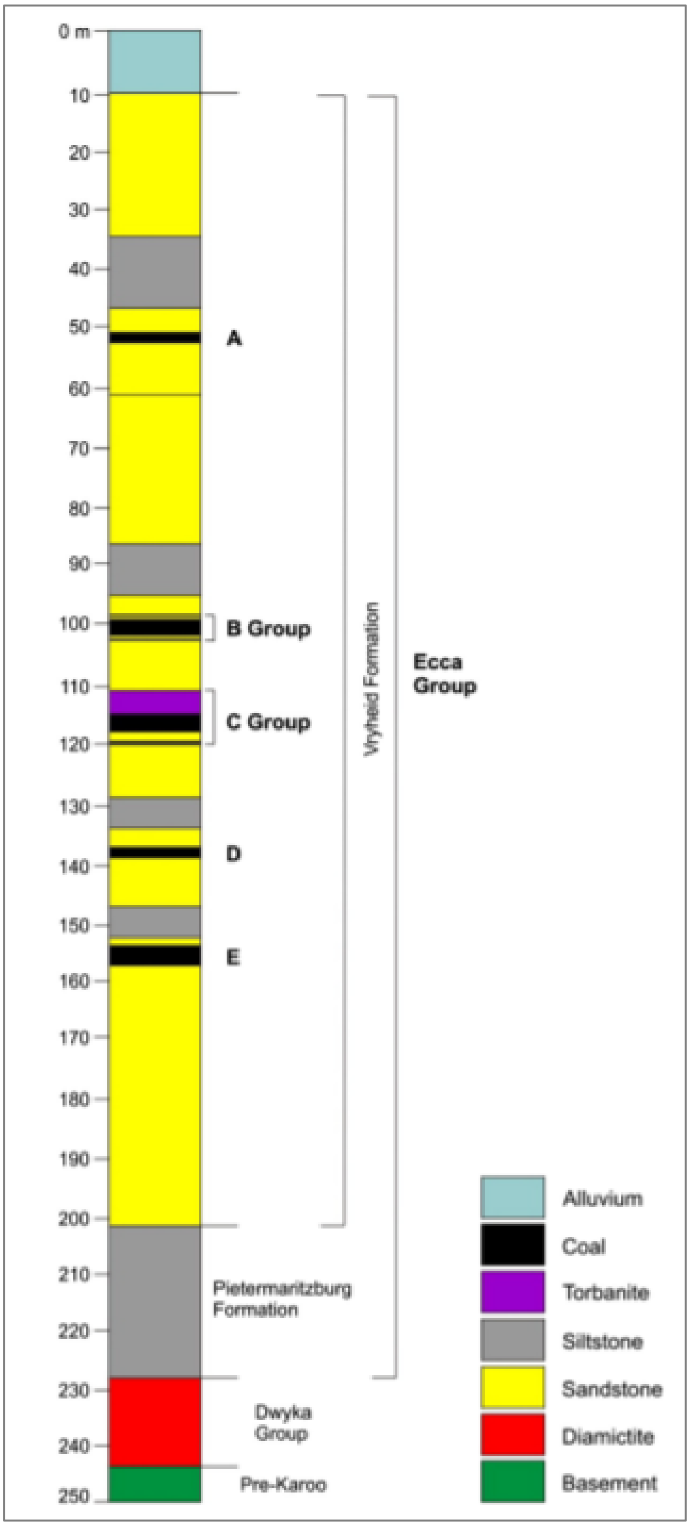



**Figure 5-7** **Stratigraphic column of the Karoo Supergroup in the Ermelo Coalfield (after Greenshields, 1986).**

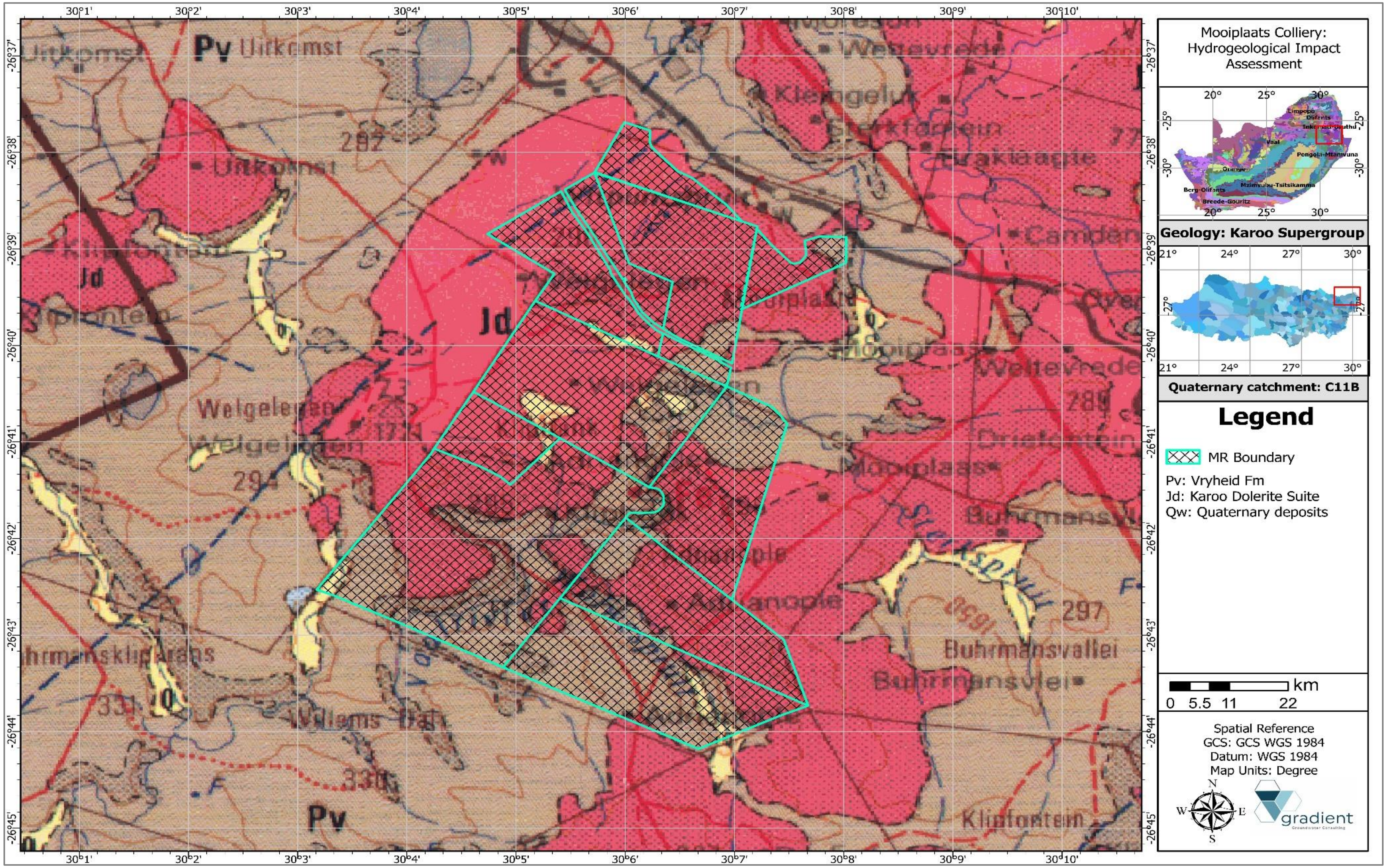



**Figure 5-8** **Regional geology and stratigraphy (Geological mapsheets 2630).**

# 6. HYDROGEOLOGICAL BASELINE ASSESSMENT

## 6.1. Desktop study

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

a. **Class A:** Intergranular o Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.
b. **Class B:** Fractured o Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.
c. **Class C:** Karst o Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.
d. **Class D:** Intergranular and fractured o Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water are stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into it. Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields (Figure 6-1).

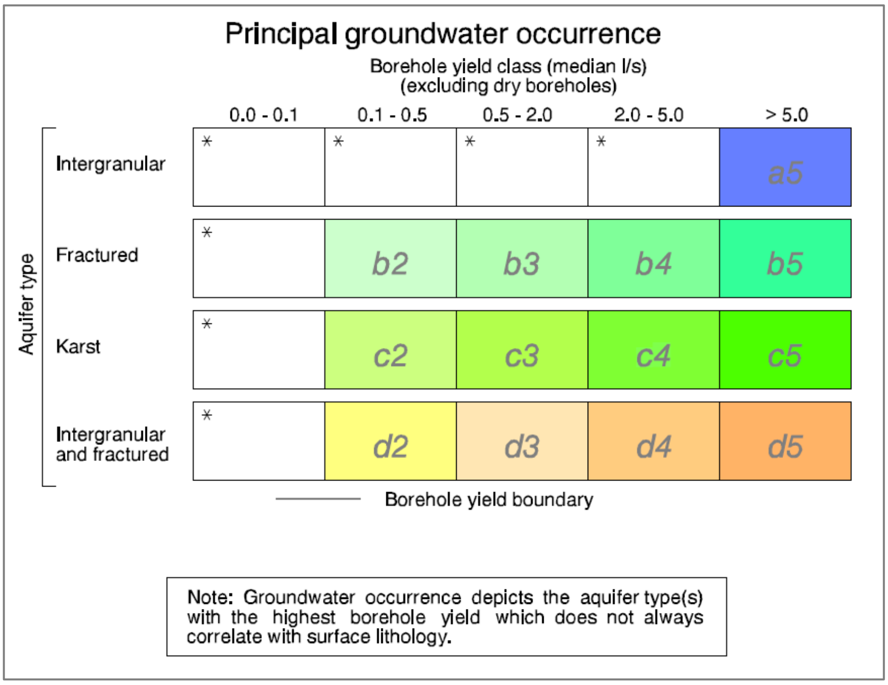



**Figure 6-1** **Principal groundwater occurrences in South Africa.**

### 6.1.1. Regional hydrogeology

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

The maximum aquifer depth (i.e. shallow/weathered aquifer system) ranges between 30.0 – 50.0 mbgl with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level. Refer to Figure 6-3 for a regional hydrogeological map illustrating the typical groundwater occurrence for the study region.

### 6.1.2. Hydrostratigraphic units

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

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

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

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

[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.

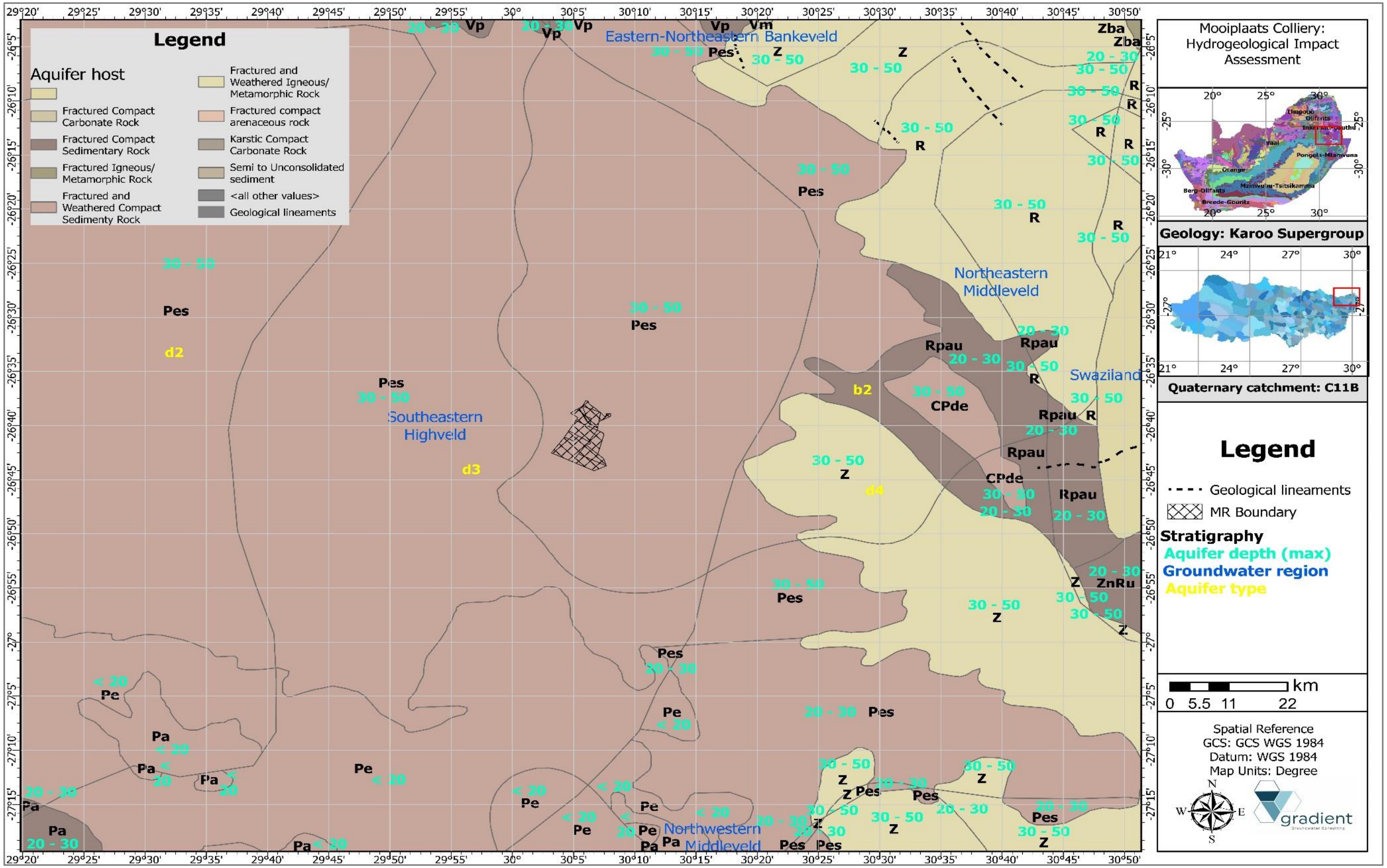



**Figure 6-2** **Hydrostratigrpahical units.**

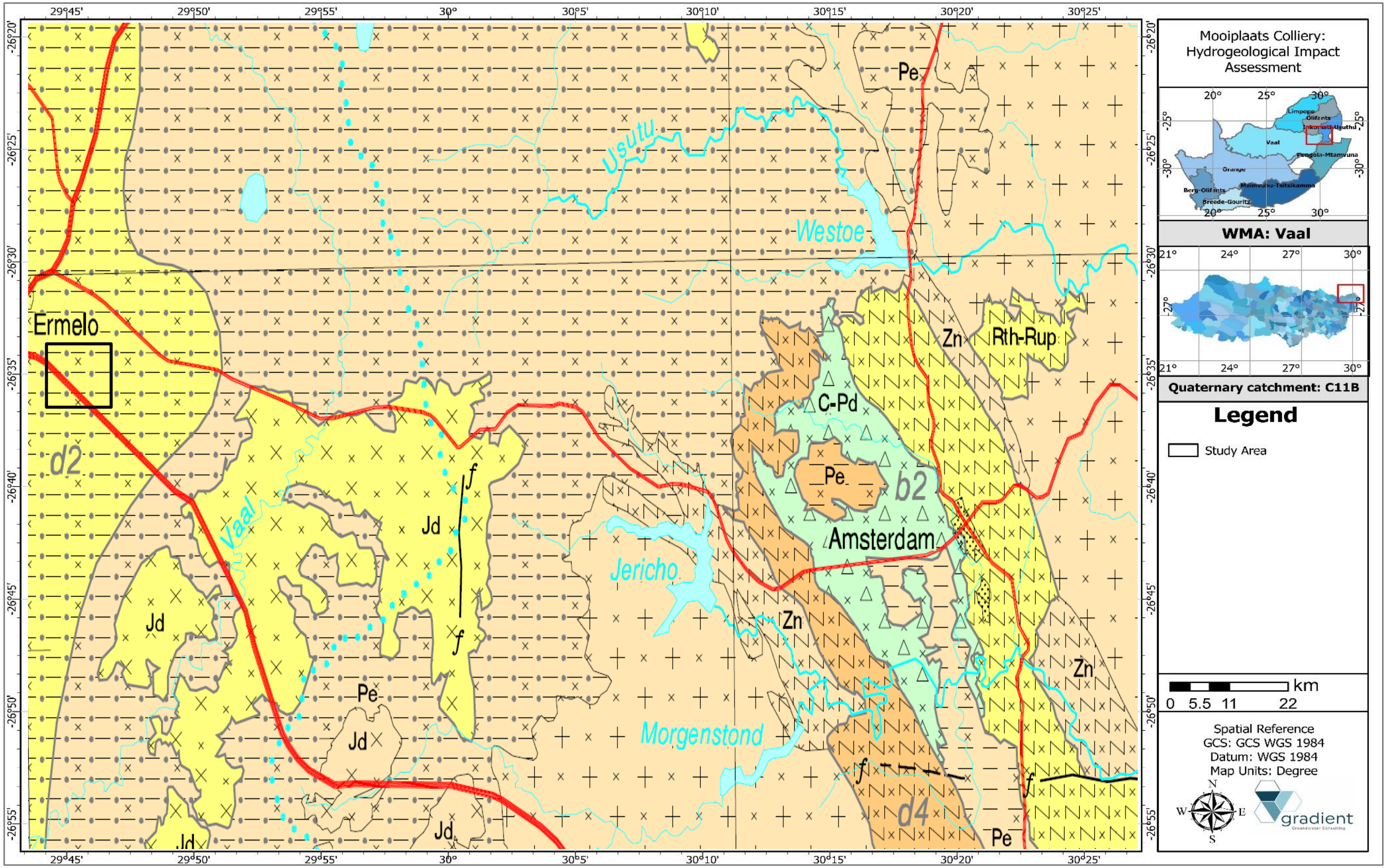



**Figure 6-3** **Hydrogeological map illustrating the typical groundwater occurrence for the study region (Nelspuit, 2530).**

## 6.2. Hydraulic parameters

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

### 6.2.1. Hydraulic conductivity and Transmissivity

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

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

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

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

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

**Equation 6-2 Transmissivity.**

$$T = Kb$$

**where:**

T = Transmissivity ($m^2$/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

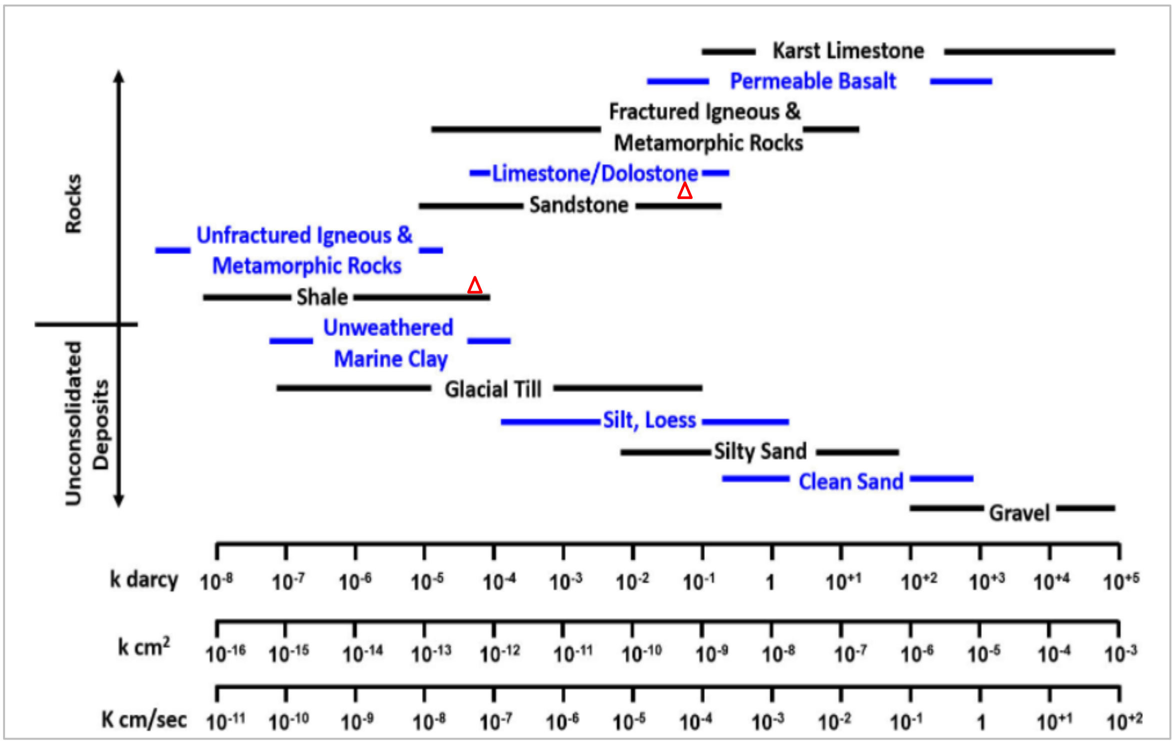



**Figure 6-4** **Typical hydraulic conductivity values for on-site hydrostratigraphical units.**

### 6.2.2. Storativity

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

### 6.2.3. Porosity

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

### 6.2.4. Recharge

An approximation of recharge for the study area is estimated at ~6.0 % of MAP i.e. ~42.0 mm/a as summarised in Table 6-1. Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride Mass Balance (CMB) method (Figure 6-5) (ii) Geology (iii) Vegter Groundwater Recharge Map (Figure 6-6) (iv) Harvest Potential Map (v) Baseflow Map (Figure 6-7) (vi) Literature review ; and (vii) Qualified opinion. Using the simplified CMB method as proposed by Bean (2003), the following equation applies to calculating recharge.

**Equation 6-3 Chloride Mass Balance formula.**

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

**where:**

R = Recharge (mm/a)

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

$Cl_g$ = Chloride concentration in groundwater resulting from diffuse recharge

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

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

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

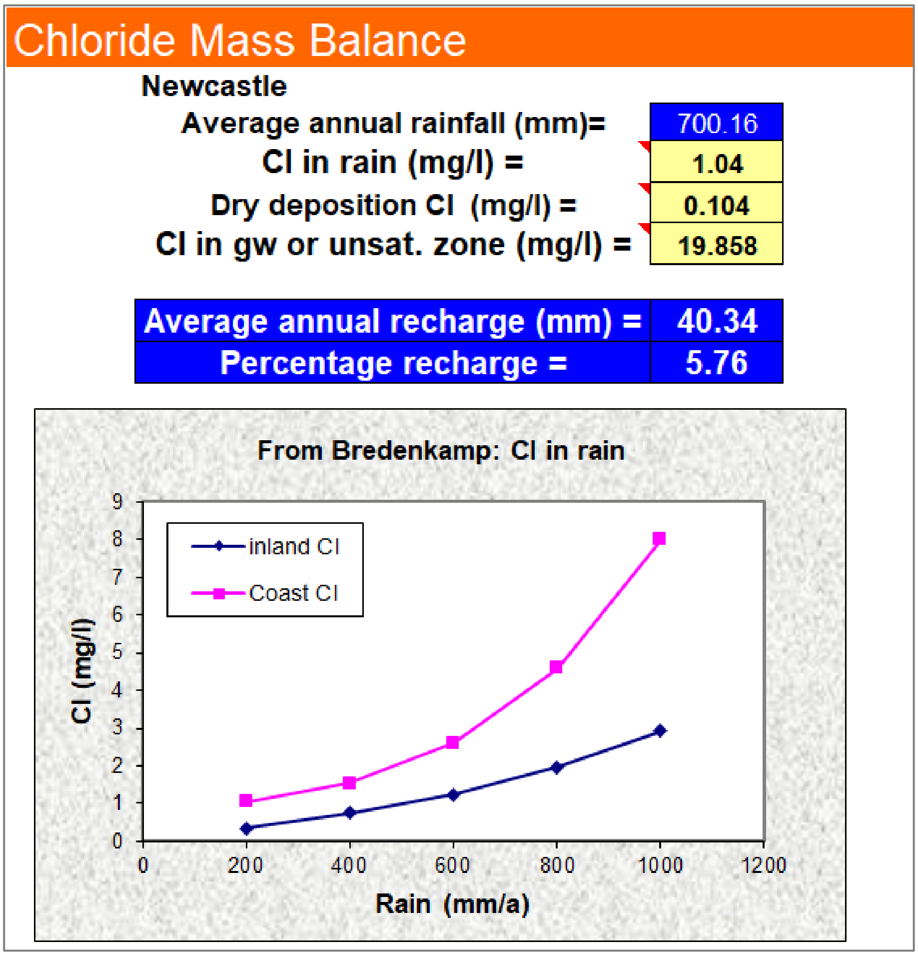



**Figure 6-5 Chloride method summary.**

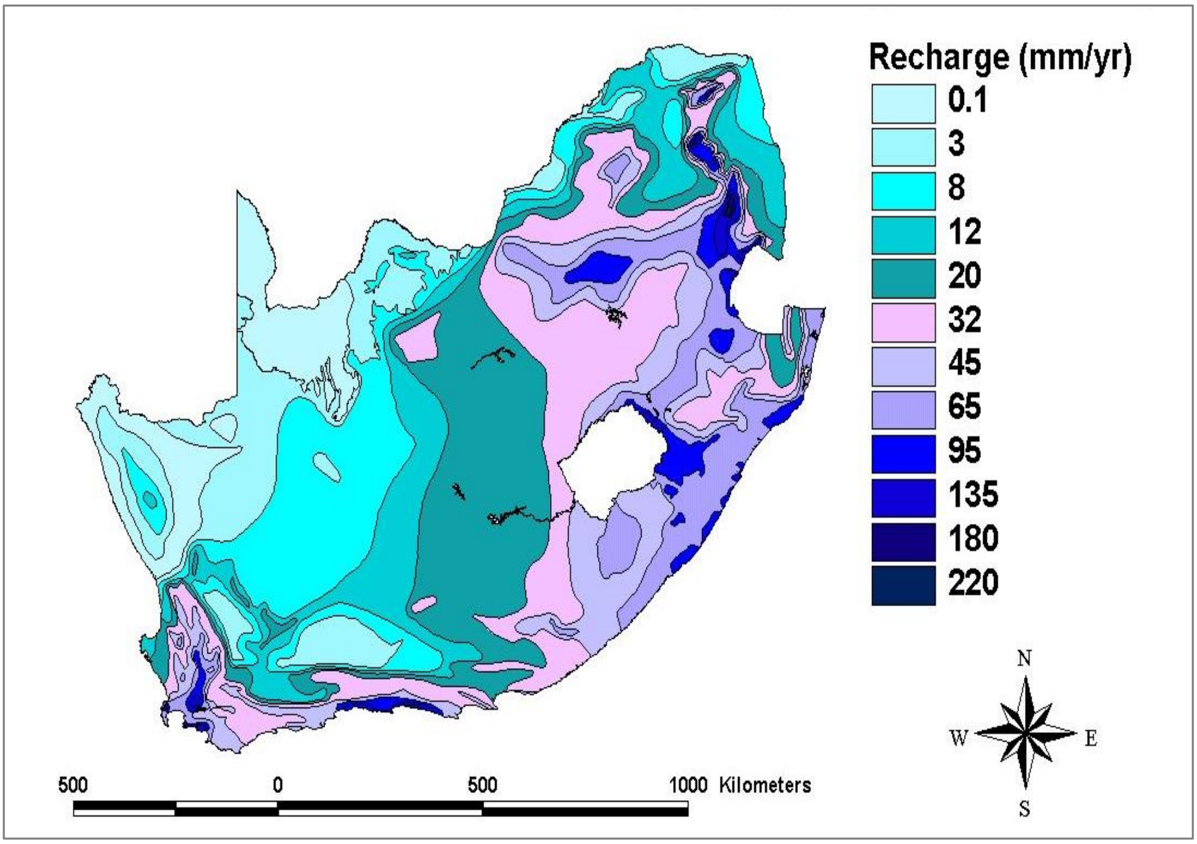



**Figure 6-6** **Groundwater recharge distribution in South Africa (After Vegter, 1995).**

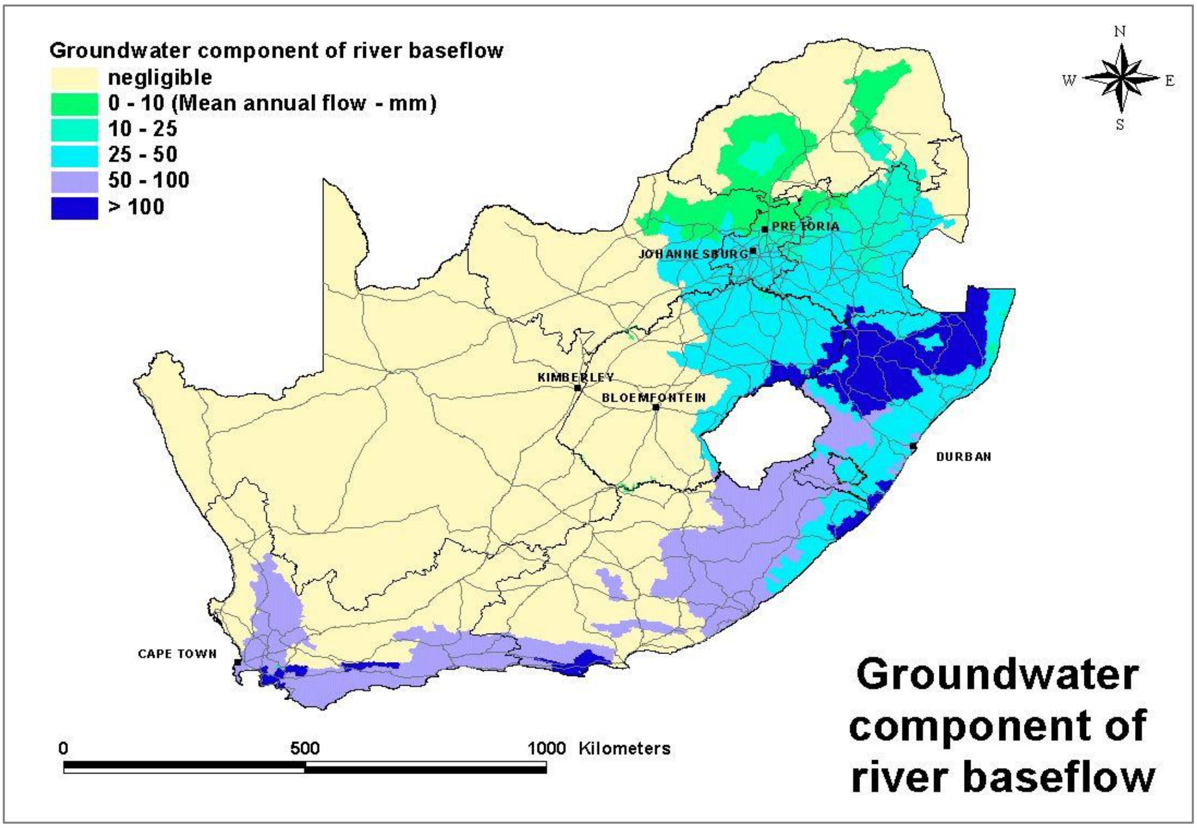



**Figure 6-7** **Groundwater component of river baseflow in South Africa (DWS, 2013).**

## 6.3. Hydrocensus user survey

A hydrocensus user survey within the greater study area was conducted where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater conditions and applications prior to the proposed expansion activities and to identify potential sensitive environmental receptors i.e. groundwater users in the direct vicinity of the operations. Geosites visited include nine (9) boreholes, thirteen (13) spring localities, five (5) streams/rivers as well as a neighboring farm dam. Refer to Figure 6-12 for a map depicting the spatial distribution of geosites with relevant information summarised in Table 6-2.

### 6.3.1. Groundwater status

Of the boreholes and spring localities visited, the majority are in use (>90.0%) with only the two core and exploration boreholes not in use Figure 6-9.

### 6.3.2. Groundwater application

According to the Upper Vaal ISP the fractured rock aquifers within this WMA are well utilised for rural domestic water supplies and stock watering (DWAF 2004). The groundwater application for domestic purposes is >45.0% while stock watering accounts for ~45.0% as summarized in Figure 6-10.

### 6.3.3. Borehole equipment

Most boreholes visited are equipped with submersible pumps (~67.0%) while only one borehole is fitted with a handpump. The two exploration boreholes (HBH04 and HBH09) are not equipped (Figure 6-11).

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

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

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

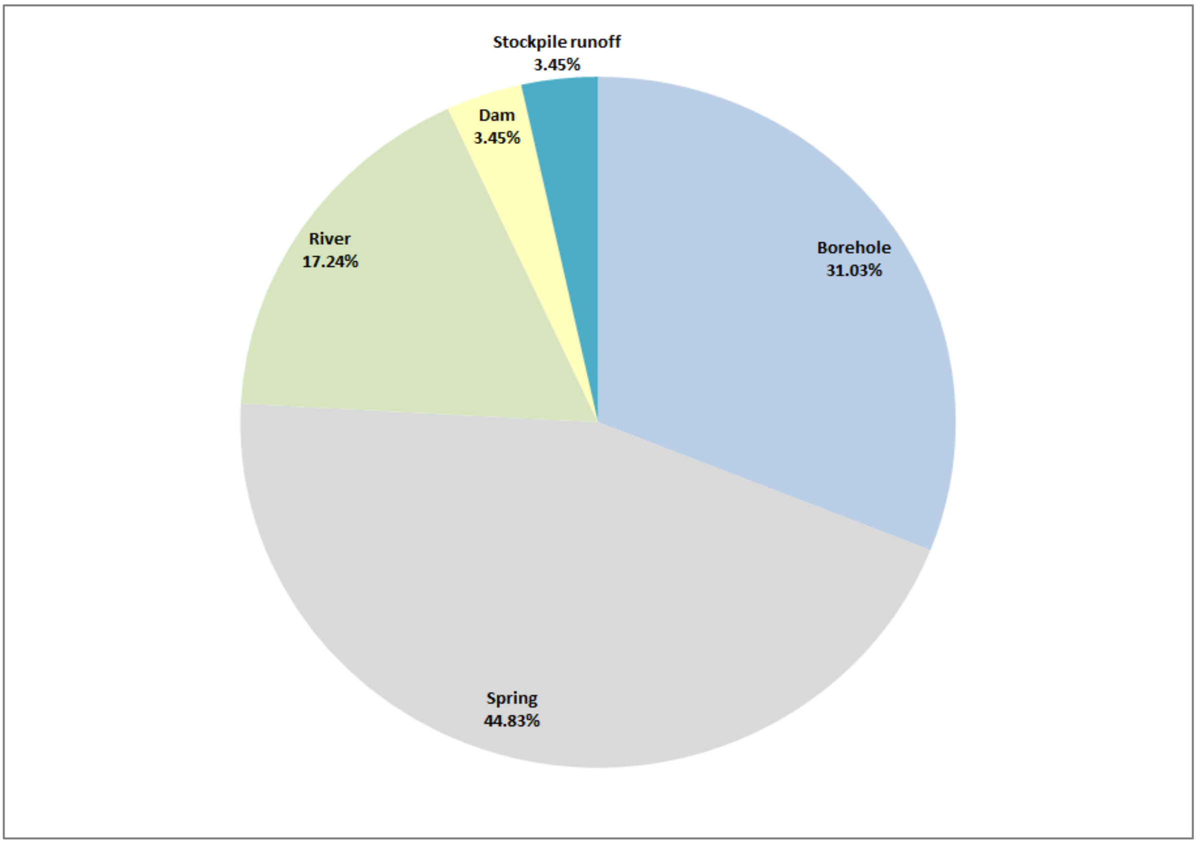



**Figure 6-8 Hydrocensus user survey: Geosite recorded.**

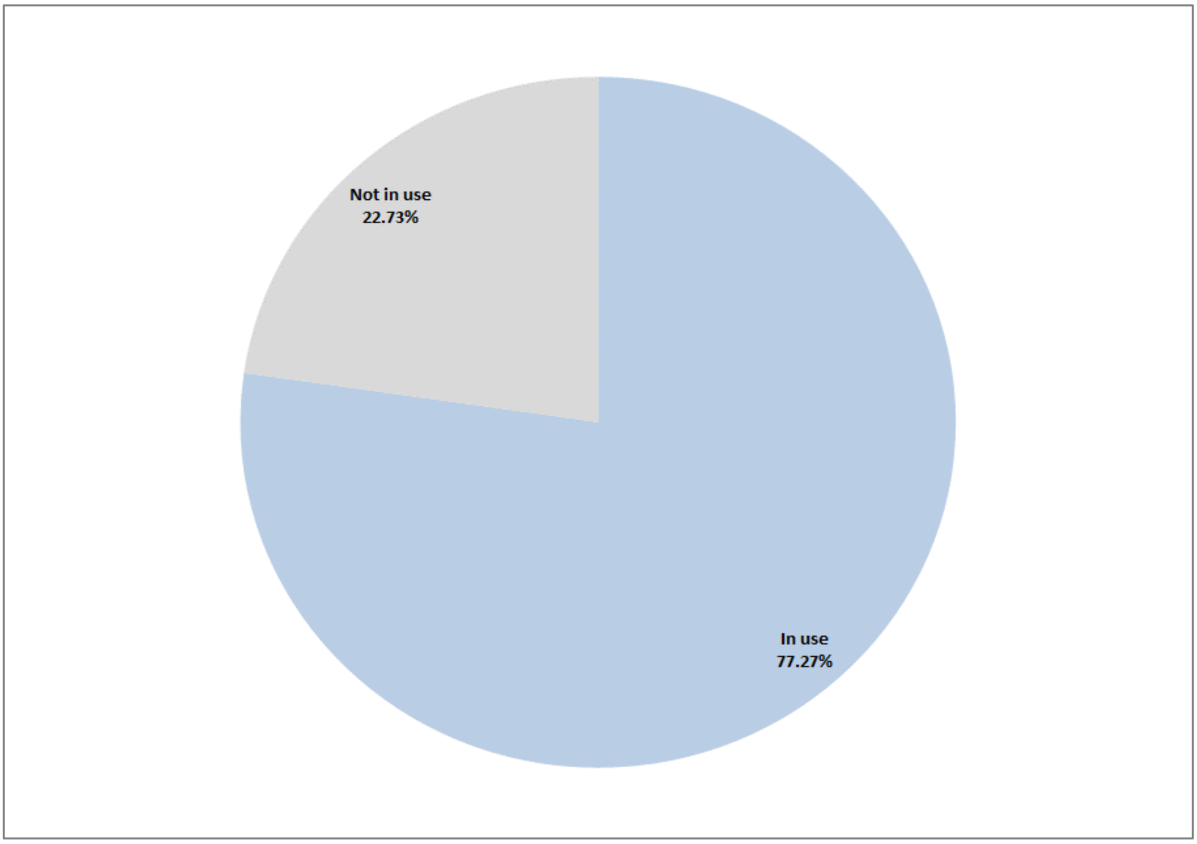



**Figure 6-9 Hydrocensus user survey: Groundwater status.**

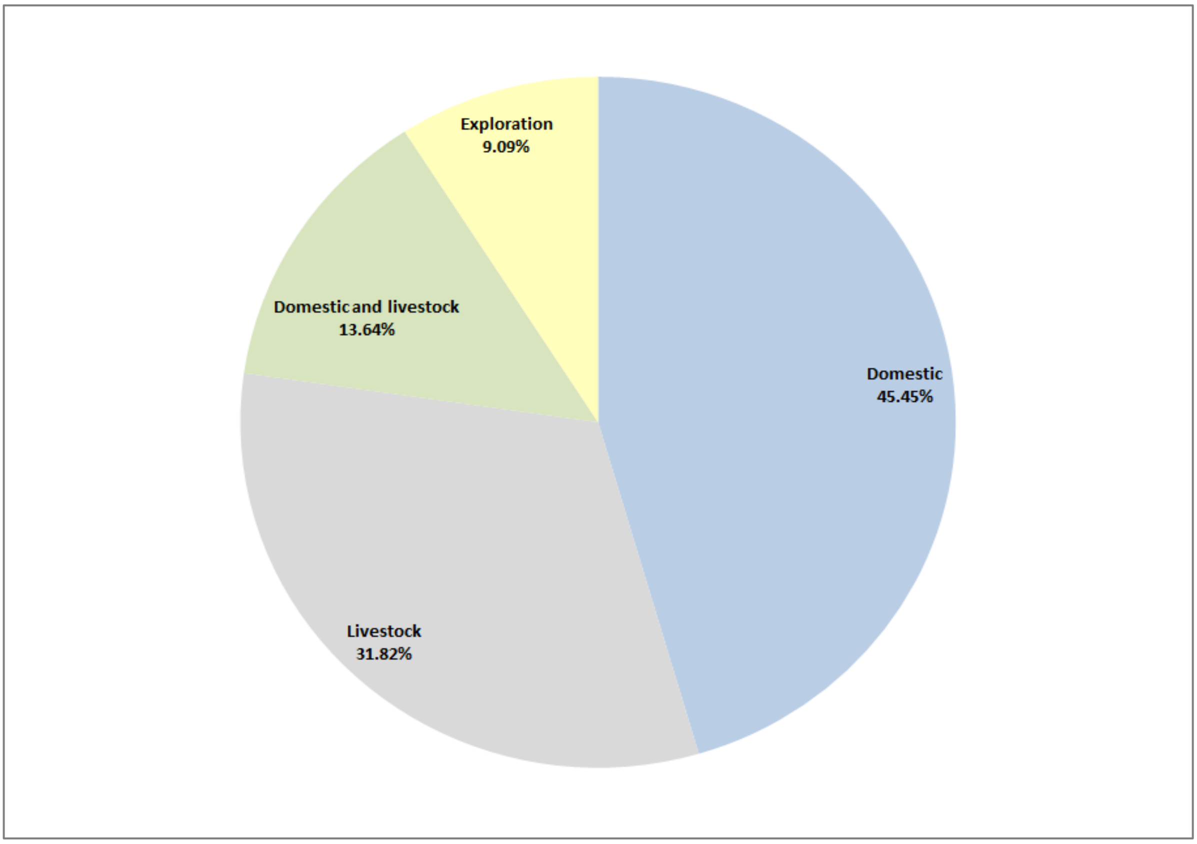



**Figure 6-10 Hydrocensus user survey: Groundwater application.**

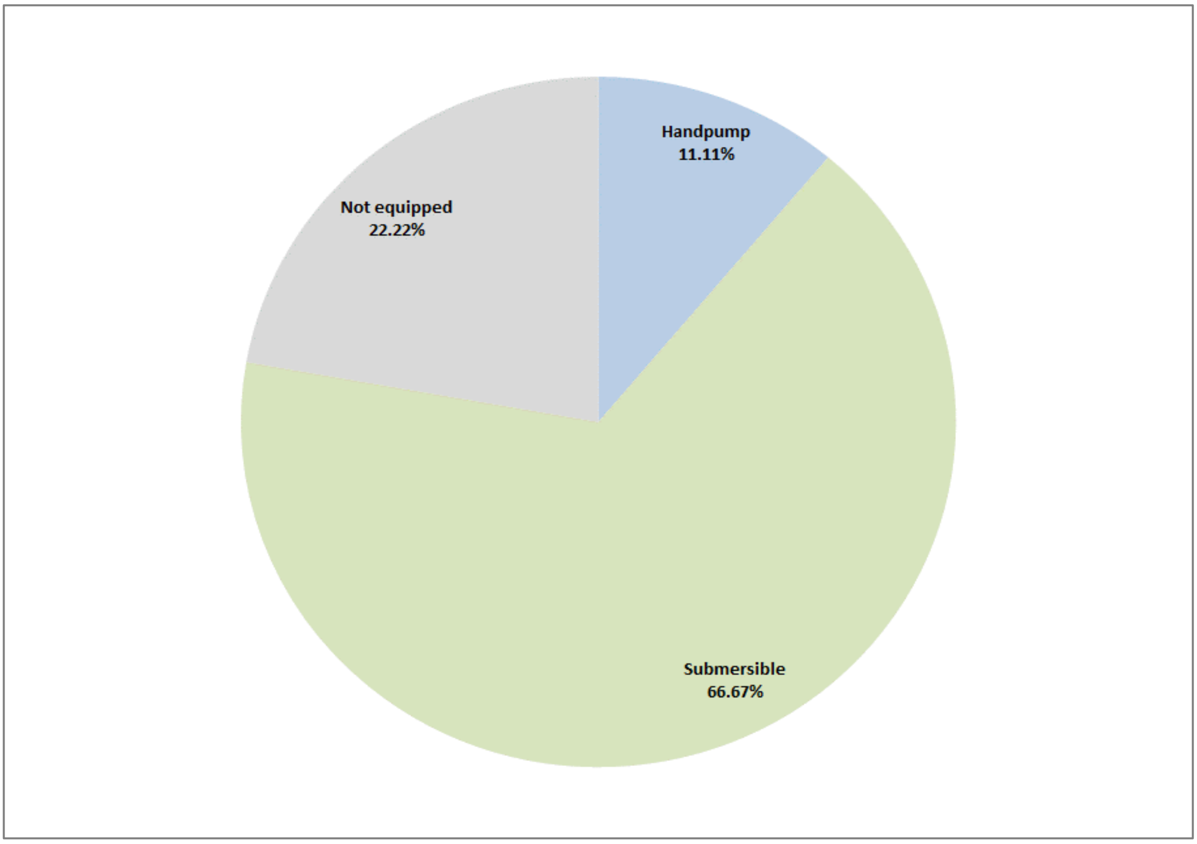



**Figure 6-11 Hydrocensus user survey: Equipment type.**

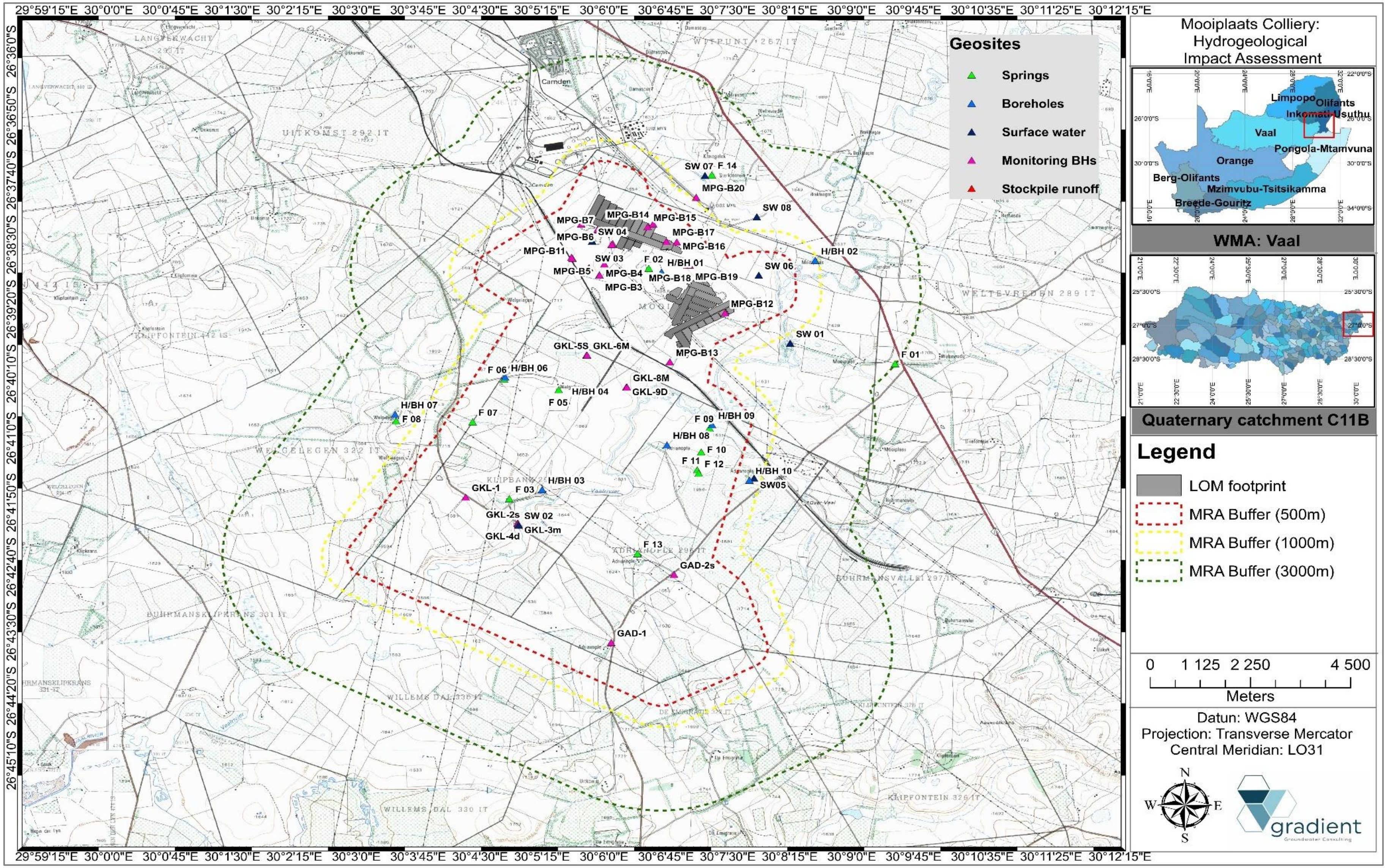



**Figure 6-12** **Spatial distribution of hydrocensus user survey geosites.**

# 7. AQUIFER CHARACTERISATION

In order to determine the sustainable yield at which the proposed production boreholes can be abstracted, boreholes were subjected to constant discharge aquifer tests to obtain site representative aquifer parameters and hydraulic properties. The latter was incorporated into the numerical groundwater flow model development and calibration process. All site characetrisation work was performed in accordance with SANS 10299-4:2003 standards: Development, maintenance and management of groundwater resources.

Important parameters that can be obtained from borehole test pumping include Hydraulic Conductivity (K), Transmissivity (T) and Storativity (S). These parameters are defined as follows (Krusemann and De Ridder, 1991):

i. Hydraulic Conductivity (K): This is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. It is normally expressed in metres per day (m/d).

ii. Transmissivity (T): This is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the full, saturated thickness of the aquifer. Transmissivity is the product of the average hydraulic conductivity and the saturated thickness of the aquifer. Transmissivity is expressed in metres squared per day ($m^2$/d).

iii. Storativity (S): The storativity of a saturated confined aquifer is the volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface. Storativity is a dimensionless quantity.

Transmissivity can also be calculated by using the Cooper-Jacob (Cooper & Jacob, 1946) equation for drawdown in confined aquifers as given below:

**Equation 7-1 Transmissivity (Cooper-Jacob).**

$$\boldsymbol{T = \frac{2.3Q}{4\pi\Delta s}}$$

**where:**

T = Transmissivity ($m^2$/d).

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

$\Delta s$ = Drawdown difference of one log cycle.

Refer to Table 7-1 for a technical summary of hydraulic testing conducted while Table 7-2 provides the aquifer hydraulic parameter estimations. Table 7-3 summarises the borehole sustainable or safe-yield estimations. Borehole specific drawdown and recovery data are included in Appendix C. To follow is a brief description of each production borehole.

### 7.1. Constant Rate Test Potable Water Borehole

A static water level of 58.77mbgl was measured at testing locality Potable Water Borehole. A constant discharge test was performed at a rate of 1.0/s for a duration of 14 hours until the pump inlet was reached. A maximum drawdown depth of 21.23mbsl was reached during the pump test duration, representing ~95.85% of available drawdown utilised. Borehole recovery was good with a full recovery of pre-testing water levels obtained within the pumping duration. Figure 7-1 depicts a scattered plot of the drawdown and recovery data while Figure 7-2 indicates the Theiss method displacement time curve fitment. The derivate plot suggests a good fracture network targeted (Figure 7-3). The constant discharge transmissivity was calculated as 1.33m$^2$/d while the hydraulic conductivity is calculated as 0.04m/d. A sustainable abstraction rate of 1692.0m$^3$/d (0.47l/s) is recommended for a 12-hour duty cycle while an abstraction rate of 1188.0m$^3$/d (0.33l/s) is recommended for a 24-hour duty cycle.

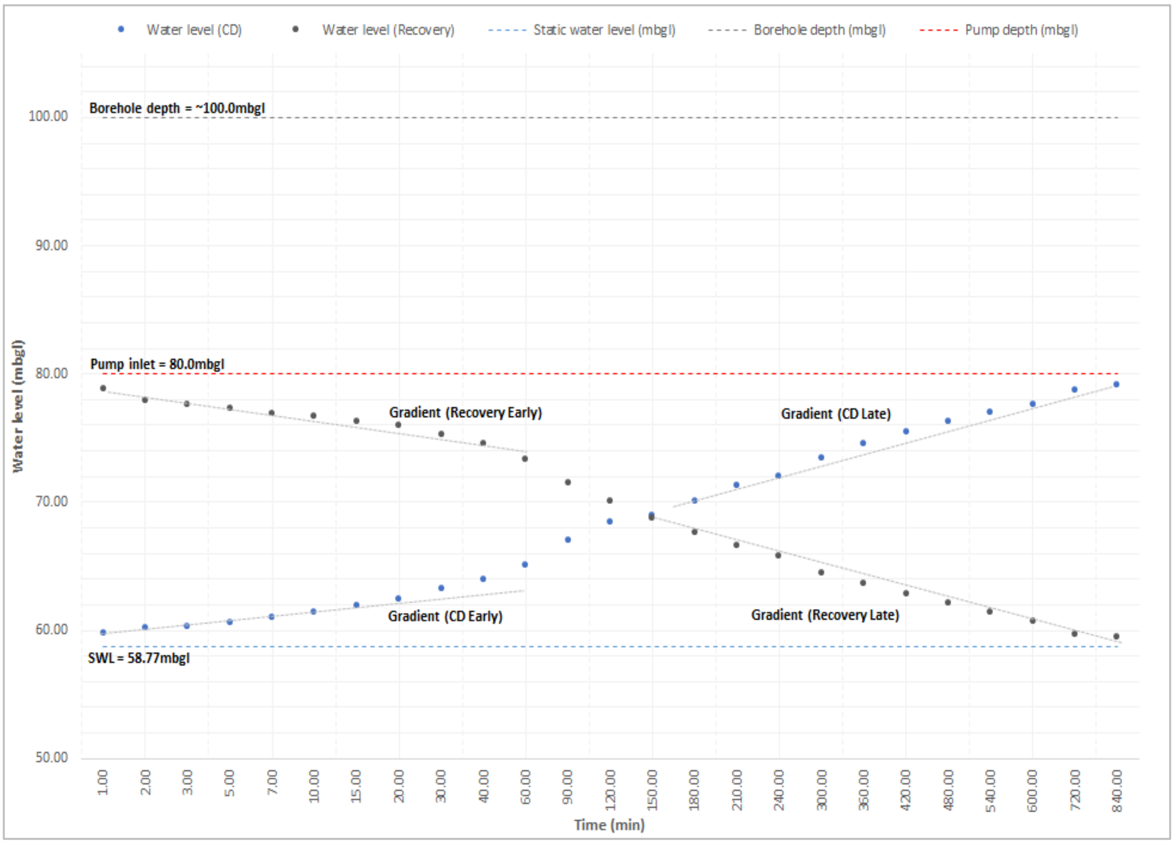



**Figure 7-1** **Aquifer tests: Potable Water BH water level drawdown and recovery scattered plot.**

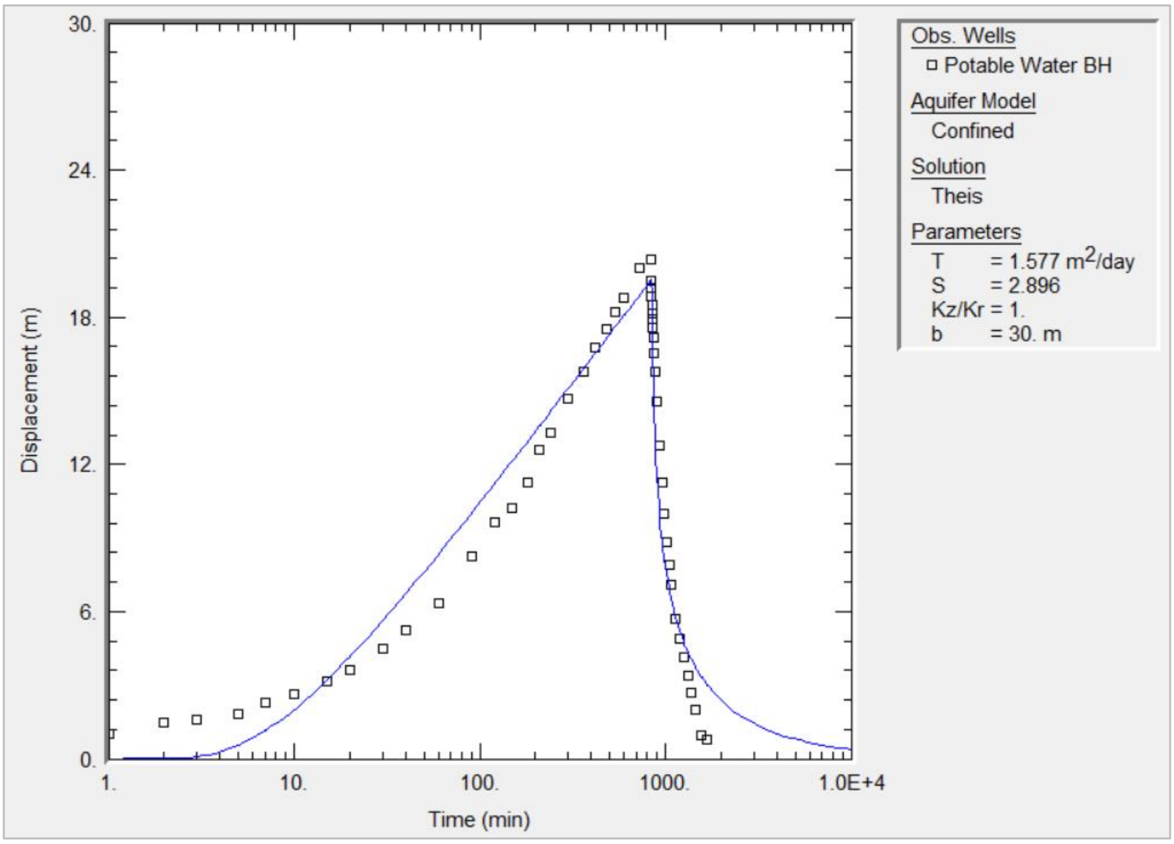



**Figure 7-2** **Aquifer tests: Theiss method displacement time curve for the Potable Water BH.**

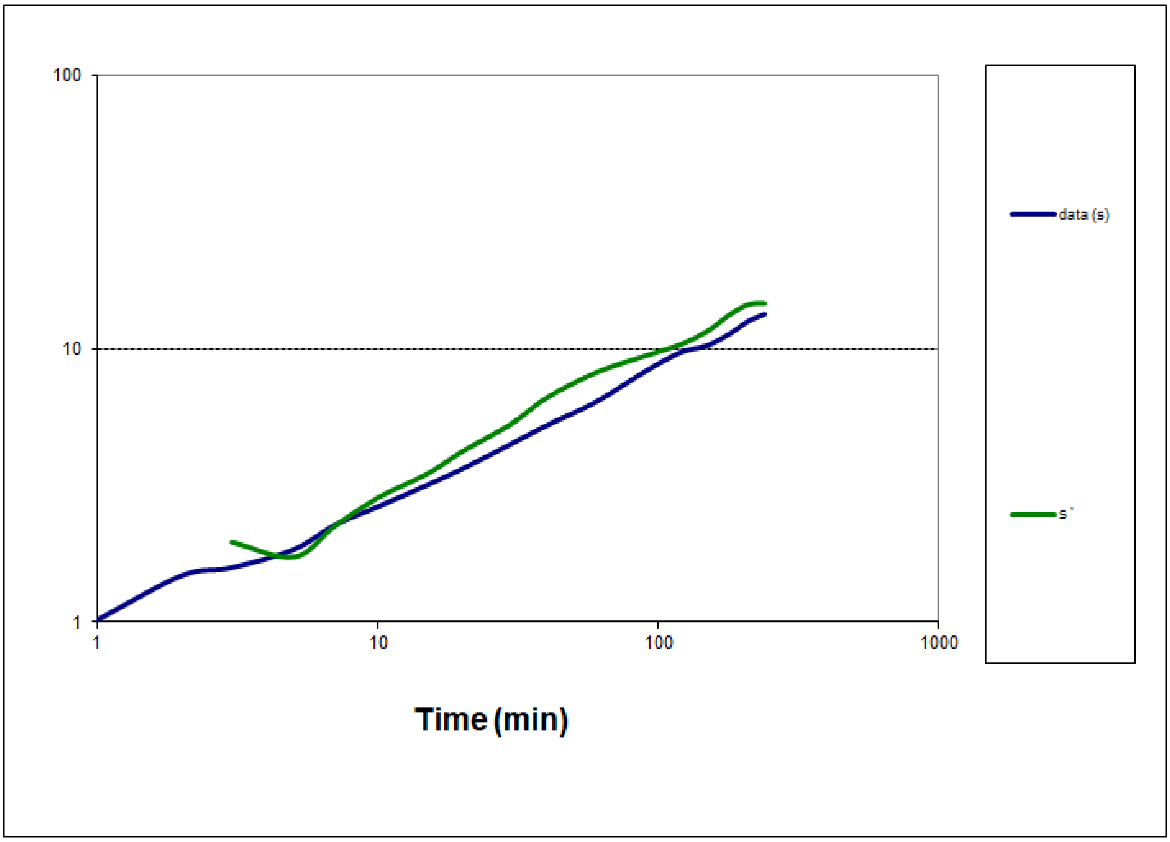



**Figure 7-3** **Aquifer tests: Derivative plots of Transmisivity and Storativty values for the Potable Water BH.**

### 7.2. Constant Rate Test Usuthu Borehole

A static water level of 58.77mbgl was measured at testing locality Usuthu Water Borehole. A constant discharge test was performed at a rate of 3.51/s for a duration of 24 hours. A maximum drawdown depth of 2.95mbsl was reached during the pump test duration, representing ~33.00% of available drawdown utilised. Borehole recovery was good with a full recovery of pre-testing water levels obtained within the pumping duration. Figure 7-4 depicts a scattered plot of the drawdown and recovery data while Figure 7-5 indicates the Theiss method displacement time curve fitment. The derivate plot suggests a good fracture network targeted (Figure 7-6). The constant discharge transmissivity was calculated as 27.91m$^2$/d while the hydraulic conductivity is calculated as 1.40m/d. A sustainable abstraction rate of 19 673.63m$^3$/d (4.46l/s) is recommended for a 12-hour duty cycle while an abstraction rate of 11 358.57m$^3$/d (3.16l/s) is recommended for a 24-hour duty cycle.

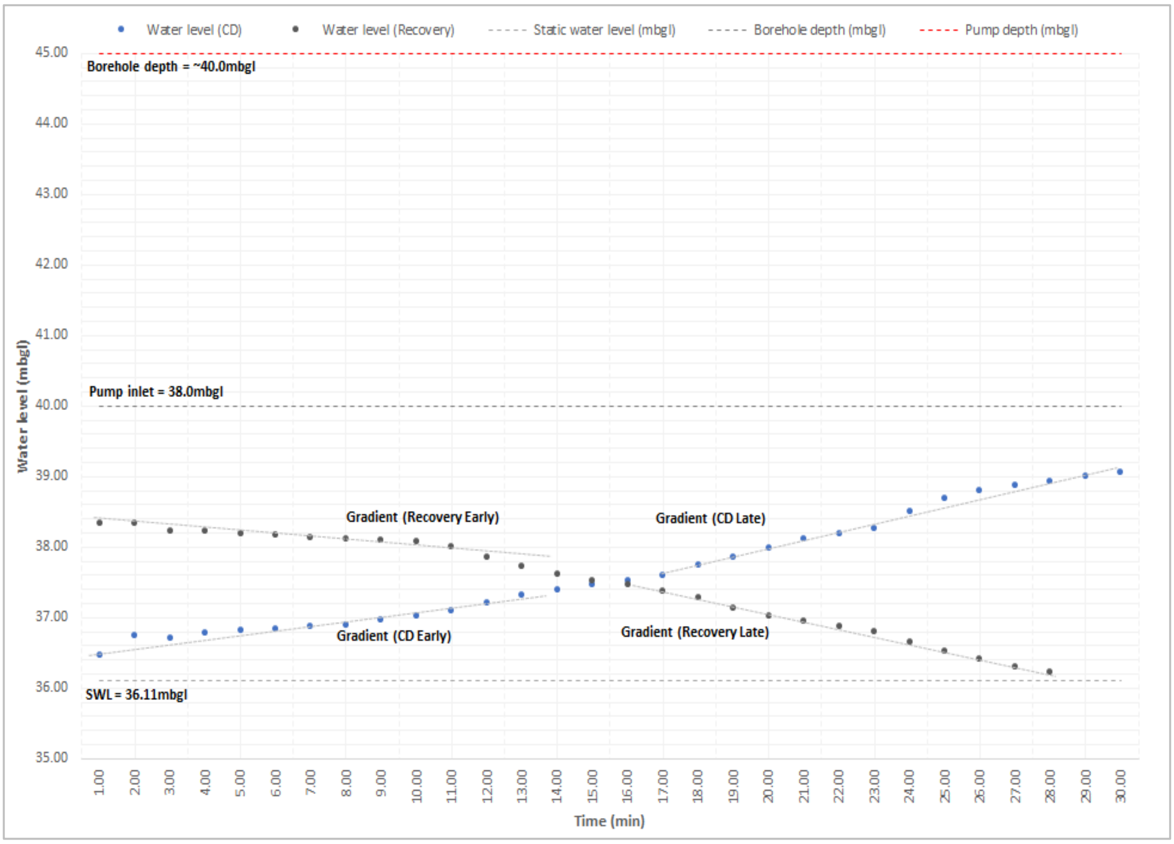



**Figure 7-4** **Aquifer tests: Usuthu BH water level drawdown and recovery scattered plot.**

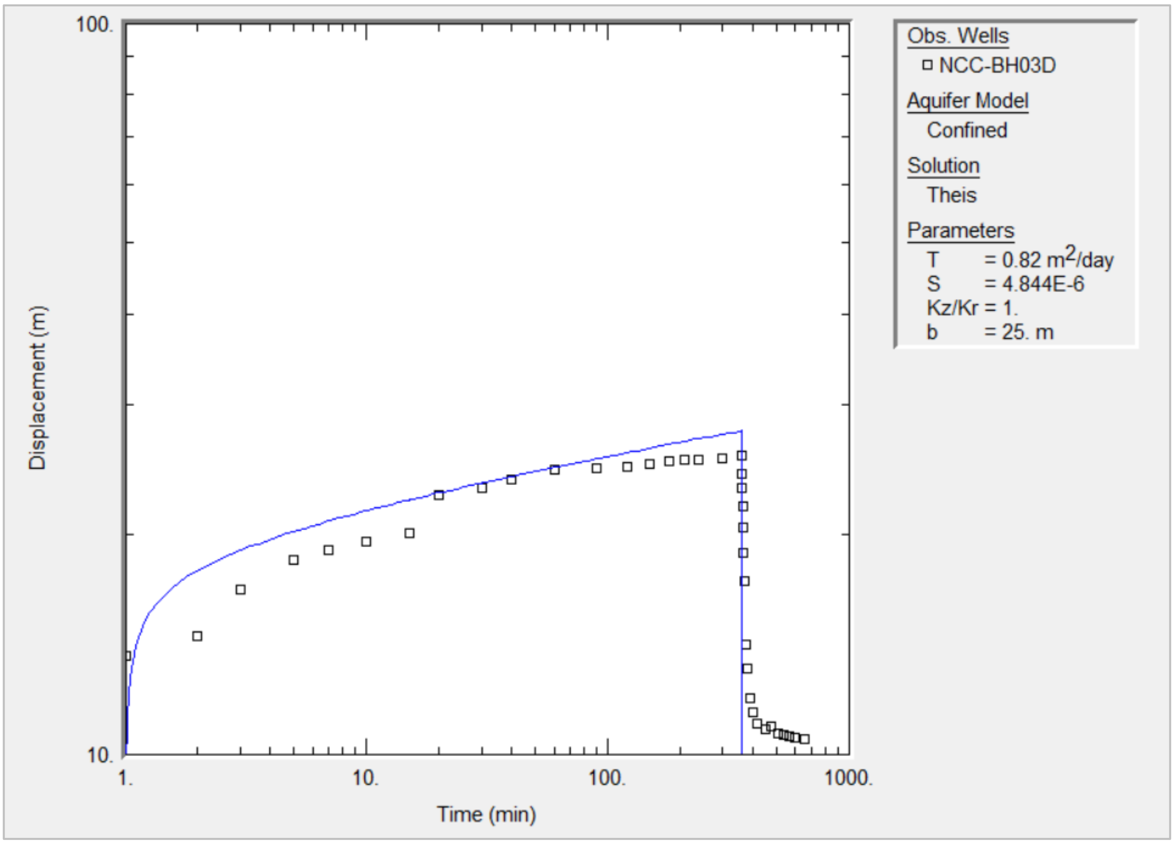



**Figure 7-5** **Aquifer tests: Derivative plots of Transmisivity and Storativty values for the Usuthu Borehole.**

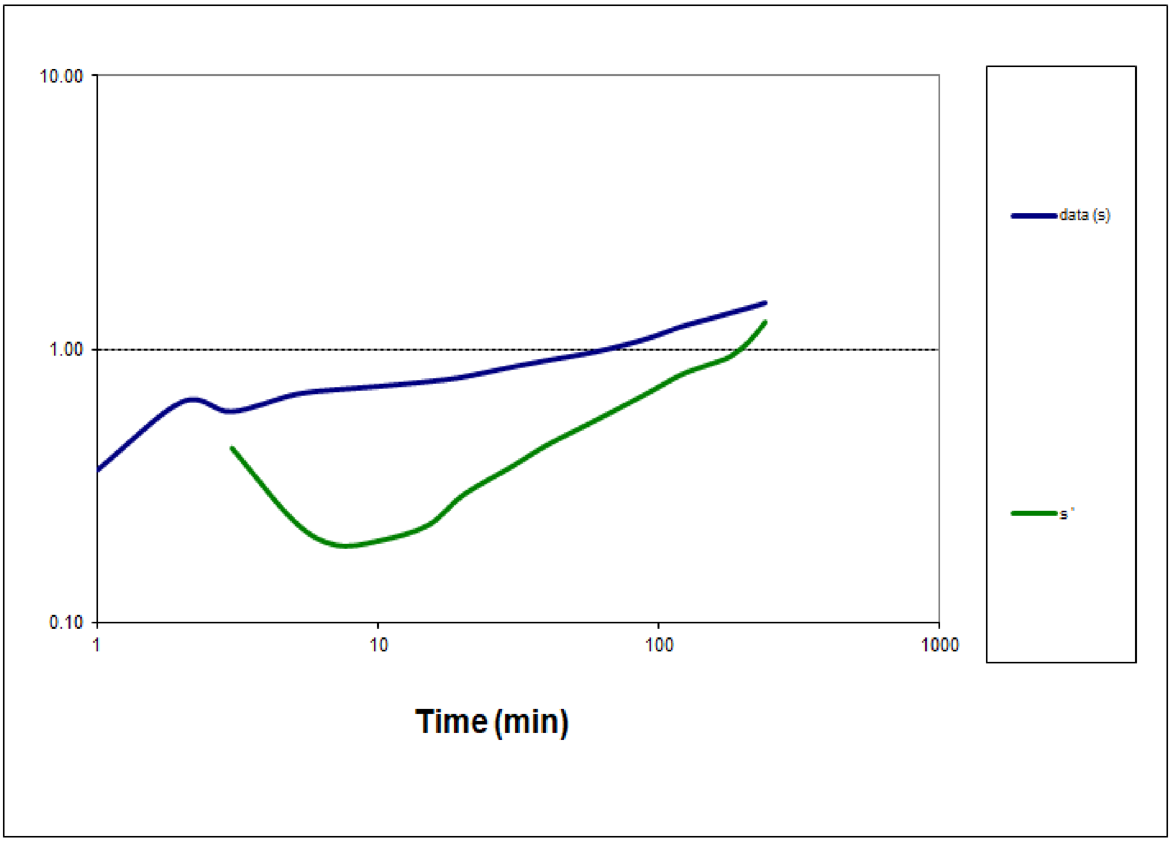



**Figure 7-6** **Aquifer tests: Derivative plots of Transmisivity and Storativty values for the Usuthu Borehole.**

**Table 7-1 Aquifer tests: Technical summary.**

| BH ID | Borehole depth (mbgl) | Tested yield (ℓ/s) | Constant discharge duration (hr) | Water level (mbgl) | Available Drawdown (m) | Drawdown reached (m) | % Drawdown used | Pump depth inlet |
|---|---|---|---|---|---|---|---|---|
| Potable Water BH | 100.00 | 1.00 | 14.00 | 58.77 | 21.23 | 20.35 | 95.85 | 80.00 |
| Usuthu BH | 40.00 | 3.51 | 24.00 | 36.11 | 8.89 | 2.95 | 33.18 | 45.00 |
| **Total** | **140.00** | **4.51** | **38.00** | **94.88** | **30.12** | **23.30** | **129.04** | **125.00** |
| **Maximum** | **100.00** | **3.51** | **24.00** | **58.77** | **21.23** | **20.35** | **95.85** | **80.00** |
| **Minimum** | **40.00** | **1.00** | **14.00** | **36.11** | **8.89** | **2.95** | **33.18** | **45.00** |
| **Average** | **70.00** | **2.26** | **19.00** | **47.44** | **15.06** | **11.65** | **64.52** | **62.50** |

**Table 7-2 Aquifer tests: Hydraulic parameter estimation.**

| Basic Information | HYDROSOLV analysis | FC analysis | | |
|---|---|---|---|---|
| BH ID | Constant discharge Transmissivity (m²/d) | Constant discharge Transmissivity (m²/d) | Average Transmissivity (m²/d) | Hydraulic conductivity (m/d) |
| Potable Water BH | 1.57 | 1.08 | 1.33 | 0.04 |
| Usuthu BH | 33.33 | 22.48 | 27.91 | 1.40 |
| **Total** | **34.90** | **23.56** | **29.23** | **1.44** |
| **Maximum** | **33.33** | **22.48** | **27.91** | **1.40** |
| **Minimum** | **1.57** | **1.08** | **1.33** | **0.04** |
| **Average** | **17.45** | **11.78** | **14.62** | **0.72** |

**Table 7-3 Aquifer tests: Sustainable yield estimation.**

| BH ID | Sustainable yield @8h duty cycle (ℓ/s) | Sustainable yield @8h duty cycle (m³/h) | Sustainable yield @12h duty cycle (ℓ/s) | Sustainable yield @12h duty cycle (m³/h) | Sustainable yield @24h duty cycle (ℓ/s) | Sustainable yield @24h duty cycle (m³/h) | Estimated pump inlet depth (mbgl) |
|---|---|---|---|---|---|---|---|
| Potable Water BH | 0.57 | 2052.00 | 0.47 | 1692.00 | 0.33 | 1188.00 | 80.00 |
| Usuthu BH | 5.46 | 19673.63 | 4.46 | 16063.45 | 3.16 | 11358.57 | 40.00 |
| **Total** | **6.03** | **21725.63** | **4.93** | **17755.45** | **3.49** | **12546.57** | **120.00** |
| **Maximum** | **5.46** | **19673.63** | **4.46** | **16063.45** | **3.16** | **11358.57** | **80.00** |
| **Minimum** | **0.57** | **2052.00** | **0.47** | **1692.00** | **0.33** | **1188.00** | **40.00** |
| **Average** | **3.02** | **10862.81** | **2.47** | **8877.72** | **1.74** | **6273.29** | **60.00** |

# 8. GROUNDWATER FLOW EVALUATION

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

## 8.1. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water level elevation from corresponding surface topography. The latter will govern the infiltration rate, as well as effective recharge of rainfall to the aquifer. Furthermore, the nature of the formation(s) forming the unsaturated zone will significantly influence the mass transport of surface contamination to the underlying aquifer(s). The unsaturated zone within the study area is in the order of ~0.50m to ~13.0m[5] with a mean thickness of approximately 4.0m.

## 8.2. Depth to groundwater

A distribution of borehole water levels recorded 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 monitoring boreholes in and around the mining areas are summarized in Table 8-1 and depicted in Figure 8-1.The minimum water level recorded is at monitoring borehole GKL-1, 0.82mbgl, with the deepest water level measured IS at the potable water borehole, 58.77 mbgl[6]. The average water level recorded, with inclusion of potential dynamic water levels is 13.32mbgl, while the average water level, only considering the static water levels is calculated at 4.79mbgl. Table 8-2 provides a summary of time-series water level measurements for the existing monitoring boreholes while Figure 8-2 depicts a bar chart of the time-series water levels. The relatively low standard deviation compared to the mean depth to groundwater i.e., Coefficient of Variation (CV) < 100%, suggests a relatively steady state groundwater environment.

**Table 8-1 Regional water level summary.**

| Site ID | Topographical Elevation (mamsl) | Water level (mbgl) | Groundwater Elevation (mamsl) |
|---|---|---|---|
| GAD-1 | 1666.00 | 3.48 | 1662.52 |
| GAD-2S | 1660.00 | 8.08 | 1651.92 |
| GKL-5s | 1647.00 | 4.17 | 1642.83 |
| GKL-6m | 1647.00 | 2.62 | 1644.38 |
| GKL-8m | 1622.00 | 1.53 | 1620.47 |
| GKL-1 | 1678.00 | 0.82 | 1677.18 |
| GKL-4D | 1583.00 | 4.58 | 1578.42 |
| GKL-9d | 1622.00 | 13.03 | 1608.97 |
| Potable water BH** | 1692.13 | 58.77 | 1633.36 |
| Usuthu BH** | 1666.77 | 36.11 | 1630.66 |
| **Average** | **1647.82** | **13.32** | **1634.63** |
| **Minimum** | **1583.00** | **0.82** | **1578.42** |
| **Maximum** | **1692.13** | **58.77** | **1677.18** |
| **Standard deviation** | **30.41** | **18.11** | **26.61** |
| **Correlation** | | **0.81** | |

****Notes: Representative of a dynamic water level.**

[5] This is based on all static groundwater levels measured at surveyed boreholes, however excludes boreholes targeting the existing underground workings.

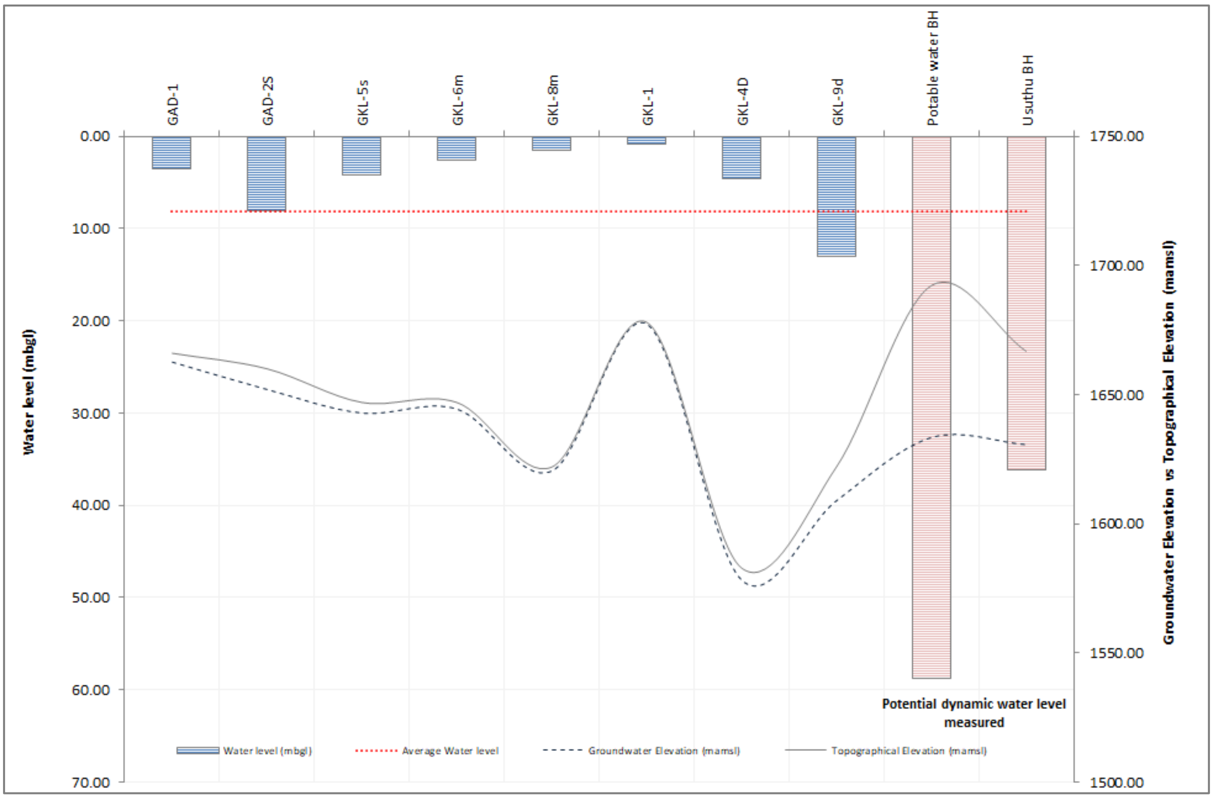



**Figure 8-1** **Topographical elevation vs. groundwater elevation correlation graph.**

**Table 8-2** **Statistical summary of time-series water levels for the exsiting monitoring boreholes.**

| Monitoring period | GAD-1 | GAD-2S | GKL-1 | GKL-2S | GKL-4D | GKL-5s | GKL-6m | GKL-8m | GKL-9d |
|---|---|---|---|---|---|---|---|---|---|
| **April 2022** | 2.55 | 6.55 | 25.64 | 2.41 | 1.46 | 0.86 | 0.00 | 2.79 | 12.14 |
| **July 2022** | 2.48 | 6.69 | 25.44 | 3.60 | 2.51 | 0.90 | 0.00 | NAWL | 12.16 |
| **October 2022** | 3.09 | 8.56 | 25.40 | 3.89 | 1.51 | 1.45 | 0.21 | 3.81 | 12.59 |
| **January 2023** | 2.07 | 4.40 | 25.21 | 2.07 | 2.41 | 0.88 | 0.00 | 2.09 | 11.43 |
| **April 2023** | 2.31 | 5.59 | 24.91 | 3.32 | 2.39 | NAWL | NAWL | NAWL | NAWL |
| **July 2023** | 3.16 | 8.61 | 24.79 | 3.89 | 2.52 | 1.56 | 0.70 | 3.94 | 12.58 |
| **October 2023** | 3.75 | 9.55 | 24.74 | 4.04 | 2.51 | 1.65 | 1.01 | 4.42 | 12.71 |
| **January 2024** | 3.72 | 9.39 | 24.78 | 3.98 | 2.51 | 1.48 | 0.85 | 4.50 | 12.68 |
| **Min** | **2.07** | **4.40** | **24.74** | **2.07** | **1.46** | **0.86** | **0.00** | **2.09** | **11.43** |
| **Max** | **3.75** | **9.55** | **25.64** | **4.04** | **2.52** | **1.65** | **1.01** | **4.50** | **12.71** |
| **Mean** | **2.89** | **7.42** | **25.11** | **3.40** | **2.23** | **1.25** | **0.40** | **3.59** | **12.33** |
| **Standard deviation** | **0.64** | **1.89** | **0.35** | **0.76** | **0.46** | **0.36** | **0.44** | **0.96** | **0.46** |
| **Coefficient of variation (CV)** | **22.01** | **25.42** | **1.41** | **22.29** | **20.70** | **28.38** | **112.10** | **26.64** | **3.74** |

**Notes: NAWL – No Access to the Water Level**

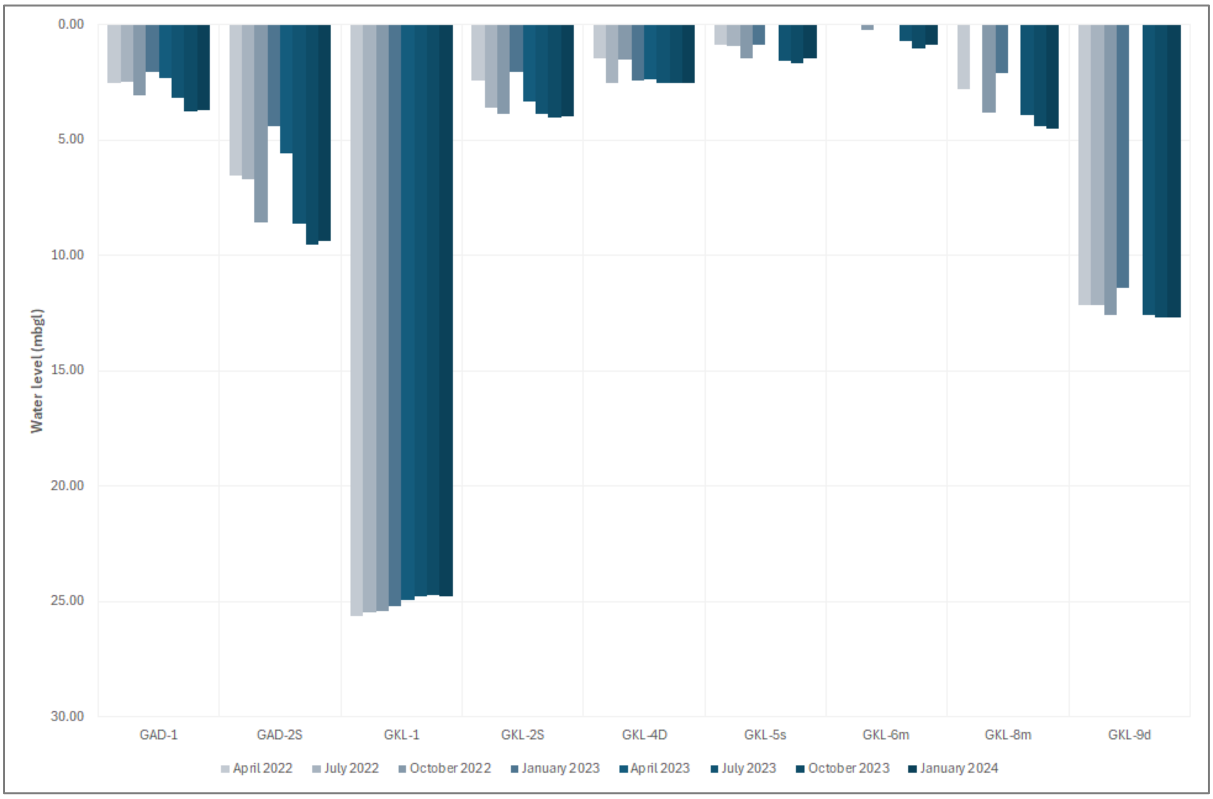



**Figure 8-2** **Bar chart of time-series water levels for exsiting monitoring boreholes.**

## 8.3. Groundwater flow direction and hydraulic gradients

Bayesian interpolation was used to interpolate the groundwater levels throughout the study area. Analysed data indicate that the surveyed static water levels correlate very well to the topographical elevation with the correlation calculated at $R^2$ >0.99 as depicted in Figure 8-3. It should be noted that when static water levels as well as dynamic water levels are considered, the correlation is not good and the $R^2$ ~0.81 as depicted in Figure 8-4. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography, however localised deviation in groundwater flow direction can be observed and is attributed to abstraction causing negative hydraulic gradients towards respective boreholes, altering flow directions. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system of the Vaal River traversing the study area. The groundwater flow in the northern segment of the mining right area will be in a general south to southeastern direction whereas the groundwater flow in the southern section of the mining right area will be in a general north to northwestern direction depicted in Figure 8-5.

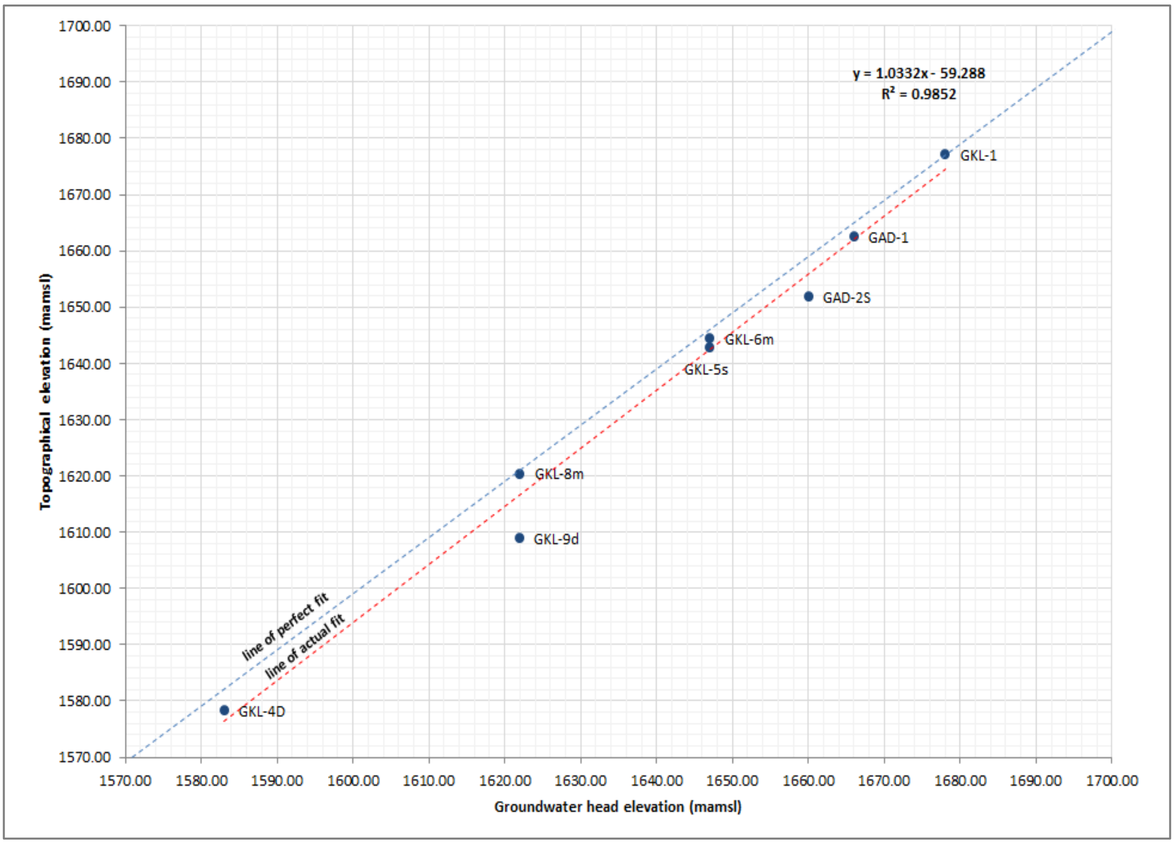



**Figure 8-3** **Topographical elevation vs. groundwater elevation correlation graph for static water level BHs only.**

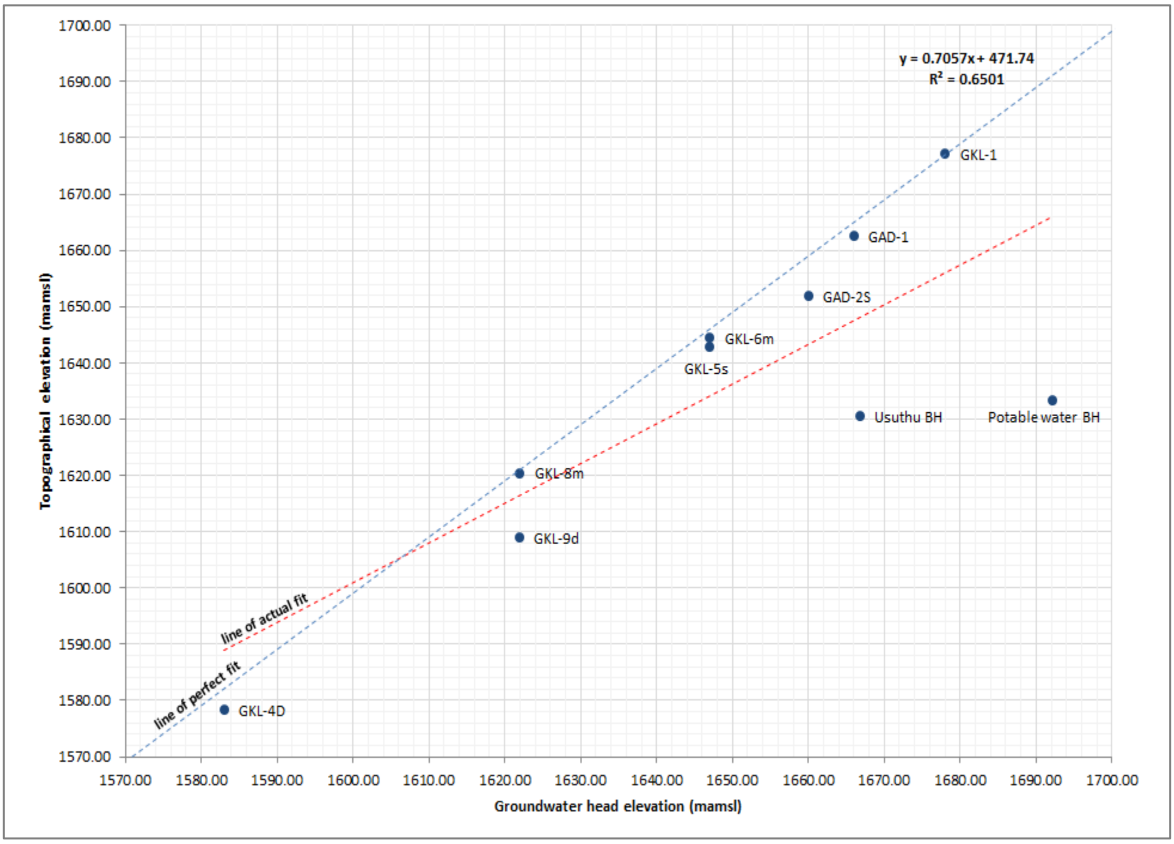



**Figure 8-4** **Topographical elevation vs. groundwater elevation correlation graph for all surveyed boreholes.**

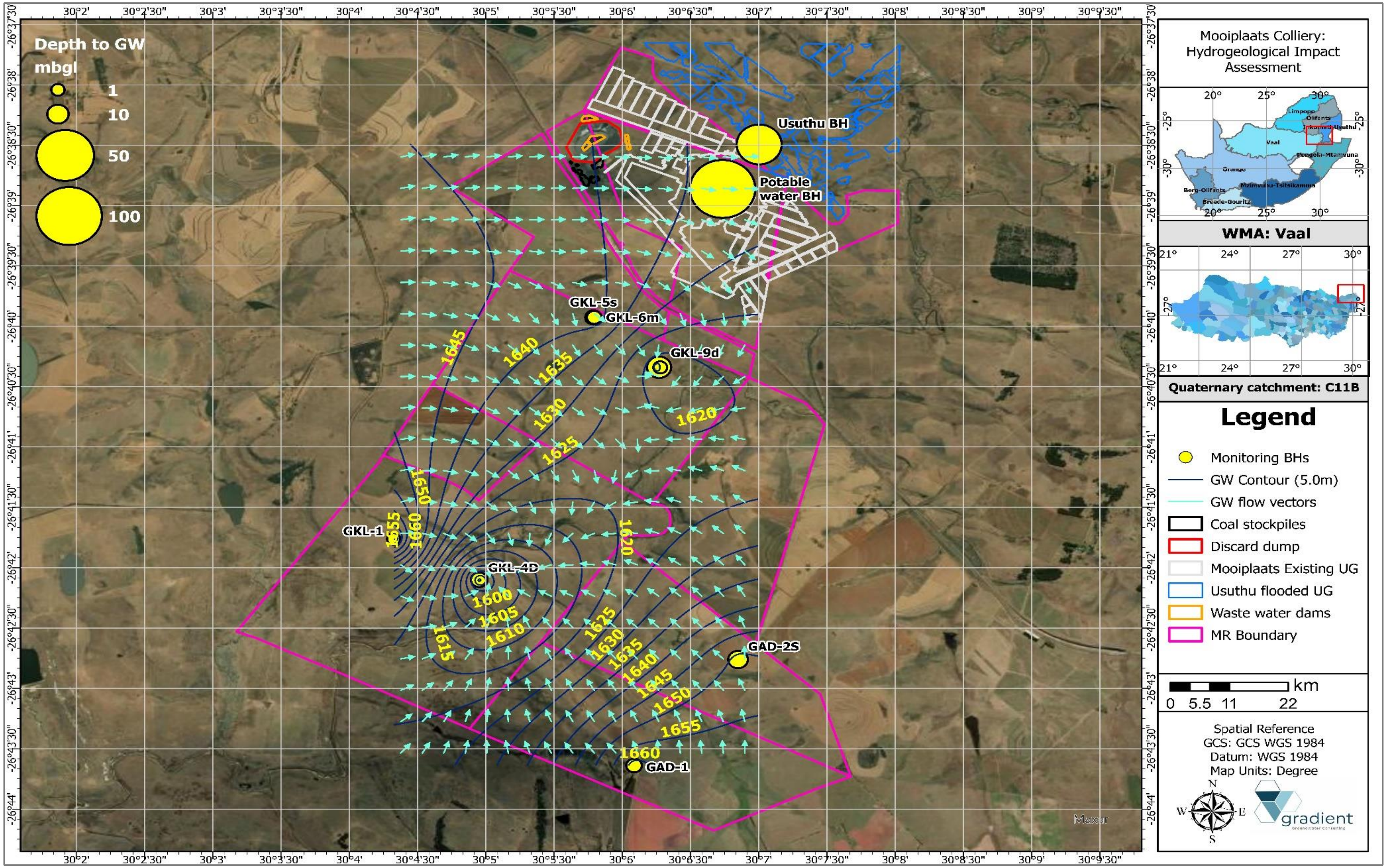



**Figure 8-5** **Regional groundwater flow direction and depth to groundwater.**

Groundwater flow path lines are lines perpendicular to groundwater contours, flow generally occurs faster where contours are closer together and gradients are thus steeper. 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 8-1 Hydraulic gradient.**

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

**where:**

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points...

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the study area is relatively flat and calculated at a mean of 0.004, with a maximum of 0.007 in a southwestern to northeastern orientation as summarised in Table 8-3.

**Table 8-3 Inferred groundwater gradient and seepage direction.**

| Inferred seepage direction | Hydraulic gradient (i) |
|---|---|
| S to N | 0.003 |
| SE to NW | 0.001 |
| SW to NE | 0.007 |
| E to W | 0.003 |
| **Minimum** | **0.001** |
| **Maximum** | **0.007** |
| **Standard deviation** | **0.002** |
| **Geometric Mean** | **0.004** |

## 8.4. 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 8-2 whereas the seepage velocity can be defined as the Darcy flux divided by the effective porosity[7] (Equation 8-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

[7] Effective porosity percentages have been assumed and in situ tests have not been conducted to confirm these ratios.

**Equation 8-2 Darcy flux.**

$$v = Ki$$

**Equation 8-3 Seepage velocity.**

$$v = \frac{Ki}{ø}$$

**where:**

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

The expected seepage rate from contamination originating at surface pollution sources is estimated at an average of approximately 3.63 metres per annum (m/a), with a maximum distance of ~8.39m/a in a southwestern to northeastern orientation as summarised in Table 8-4.

**Table 8-4 Darcy flux and seepage rates[8].**

| Shallow, intergranular aquifer | Hydraulic gradient (i) | Hydraulic conductivity (K) | Darcy flux (m/d) | Effective porosity | Seepage velocity (m/d) | Seepage velocity (m/a) |
|---|---|---|---|---|---|---|
| S to N | 0.003 | 0.050 | 0.0001 | 0.015 | 0.009 | 3.148 |
| SE to NW | 0.001 | 0.050 | 0.000 | 0.015 | 0.004 | 1.592 |
| SW to NE | 0.007 | 0.050 | 0.000 | 0.015 | 0.023 | 8.391 |
| E to W | 0.003 | 0.050 | 0.000 | 0.015 | 0.011 | 4.120 |
| **Minimum** | **0.001** | **0.050** | **0.000** | **0.015** | **0.004** | **1.592** |
| **Maximum** | **0.007** | **0.050** | **0.000** | **0.015** | **0.023** | **8.391** |
| **Standard deviation** | **0.002** | **0.000** | **0.000** | **0.000** | **0.007** | **2.521** |
| **Geometric Mean** | **0.003** | **0.050** | **0.000** | **0.015** | **0.010** | **3.628** |

## 8.5. Groundwater-surface water interaction

Groundwater and surface water interaction is an essential component of the hydrological cycle. The hyporheic zone (stream bed) is the zone of most interaction (Adams et. al.,2012). According to records documented by Van Tonder and Dennis (2003), under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. The two regimes are therefore well-linked and should be integrated to manage any water related issues in these catchments. Regional drainages can be generally classified as influent or gaining stream systems. Groundwater head elevation compared to topographical elevation confirms that there exists groundwater discharge as baseflow to local drainages.

[8] 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.

# 9. HYDROCHEMISTRY

## 9.1. 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 9-1). Water samples were submitted for analysis at a SANAS accredited laboratory (Yanka Laboratories) for inorganic analysis. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health), elemental concentrations above this range are classed as unsuitable for domestic consumption without treatment whereas yellow highlighted cells indicate parameters above aesthetic limits. These standards were selected for use as the current and future water uses in the area are primarily domestic application and/or livestock watering. It should be noted that surface water monitoring points only included the receiving environment and/or receptors and does not include any wastewater of contact water storage facilities. Refer to the quarterly monitoring report (GWS, 2024) for further reading in this regard. Table 9-4, Table 9-5 as well as Table 9-6 classify water quality according to pH, Total Dissolved Solids (TDS) as well as hardness. Refer to Appendix B for laboratory analysis certificates.

**Table 9-1 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 9-2 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** | | | |

| Parameter | Risk | Unit | Standard limits [a] |
|---|---|---|---|
| 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 |
| | Aesthetic | mg/l | ≤0.30 |
| Lead as Pb | Chronic health | mg/l | ≤0.010 |
| Manganese as Mn | Chronic health | mg/l | ≤0.50 |
| | Aesthetic | mg/l | ≤0.10 |
| Mercury as Hg | Chronic health | mg/l | ≤0.006 |
| Nickel as Ni | Chronic health | mg/l | ≤0.07 |
| Selenium as Se | Chronic health | mg/l | ≤0.010 |
| Uranium as U | Chronic health | mg/l | ≤0.015 |
| Vanadium as V | Chronic health | mg/l | ≤0.2 |
| Aluminium as Al | Operational | mg/l | ≤0.3 |

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

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

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

**d This is equivalent to nitrate at 50 mg/l $NO_3^-$.**

**Table 9-3 Laboratory precision and data validity.**

| Sample Localities | Σ Major cations (meq/l) | Σ Major anions (meq/l) | Electro-Neutrality [E.N.] % |
|---|---|---|---|
| WT-S01 | 17.76 | 18.26 | -1.38% |
| WT-S03 | 8.07 | 8.46 | -2.34% |
| WT-S02 | 12.10 | 12.01 | 0.38% |
| WT-S04 | 12.42 | 12.48 | -0.25% |
| WT-S05 | 44.83 | 45.23 | -0.44% |
| WT-S06 | 23.19 | 24.62 | -2.99% |
| GAD-1 | 2.56 | 2.64 | -1.64% |
| GAD-2S | 1.64 | 1.66 | -0.35% |
| GKL-1 | 4.03 | 4.20 | -2.14% |
| GKL-2S | 4.94 | 5.25 | -3.01% |
| GKL-4D | 20.64 | 19.86 | 1.91% |
| GKL-5S | 3.32 | 3.48 | -2.31% |
| GKL-6M | 2.35 | 2.47 | -2.61% |
| GKL-8M | 3.32 | 3.48 | -2.31% |
| GKL-9D | 2.45 | 2.60 | -2.98% |
| Potable water BH | 3.21 | 3.14 | 1.17% |
| Usuthu BH | 33.80 | 35.60 | -2.59% |

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

**Table 9-4 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 9-5 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 9-6 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 |

### 9.1.1. Surface water quality

The overall water quality of groundwater samples analysed is poor with the majority of monitoring points analysed indicating elevated sulphate concentrations. Water quality can be described as neutral to acidic, saline to very saline as well as moderately soft to slightly hard. Isolated sampling localities indicate above limit total dissolved solids (TDS), WT-S05 and WT-S06, with sulphate and sodium the main drivers of the high salt loads observed. Monitoring locality WT-S05 also indicates elevated concentrations of manganese. Table 9-7 summarises water quality analysis per sampling locality with Figure 9-1 depicting a bar-chart of major anion and cation composition. It can be observed that the overall salt load (TDS) is much higher if compared to the groundwater monitoring localities with sulphate the main driver of the higher mass load. Figure 9-3 indicate a spatial distribution map of hydrochemical composition per sampling locality.

### 9.1.2. Groundwater quality

The overall water quality of groundwater samples analysed is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Water quality can be described as neutral, non-saline and slightly to moderately hard. Isolated sampling localities indicate a high salt load i.e., GKL-4D and the Usuthu borehole. It should be noted that monitoring locality GKL-4D suggests elevated fluoride, sodium as well as aluminum and iron concentration while monitoring locality Usuthu BH suggest a very high TDS (very saline) with elevated sulphate and sodium concentrations. The latter can be attributed to the defunct underground workings targeted. Table 9-8 summarises water quality analysis per sampling locality with Figure 9-2 depicting a bar-chart of major anion and cation composition. Figure 9-3 indicate a spatial distribution map of hydrochemical composition per sampling locality.

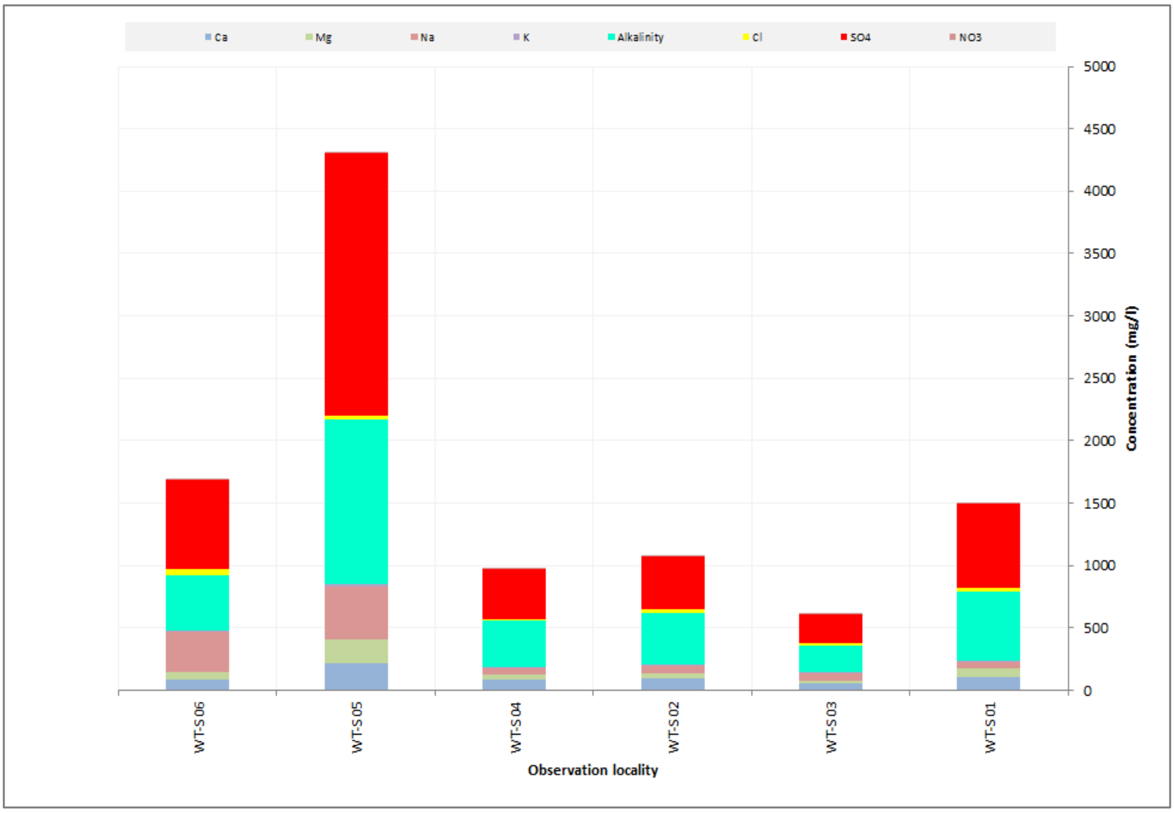



**Figure 9-1** **Hydrochemistry: Composite bar-chart indicating major anion cation composition of surface water samples (mg/l).**

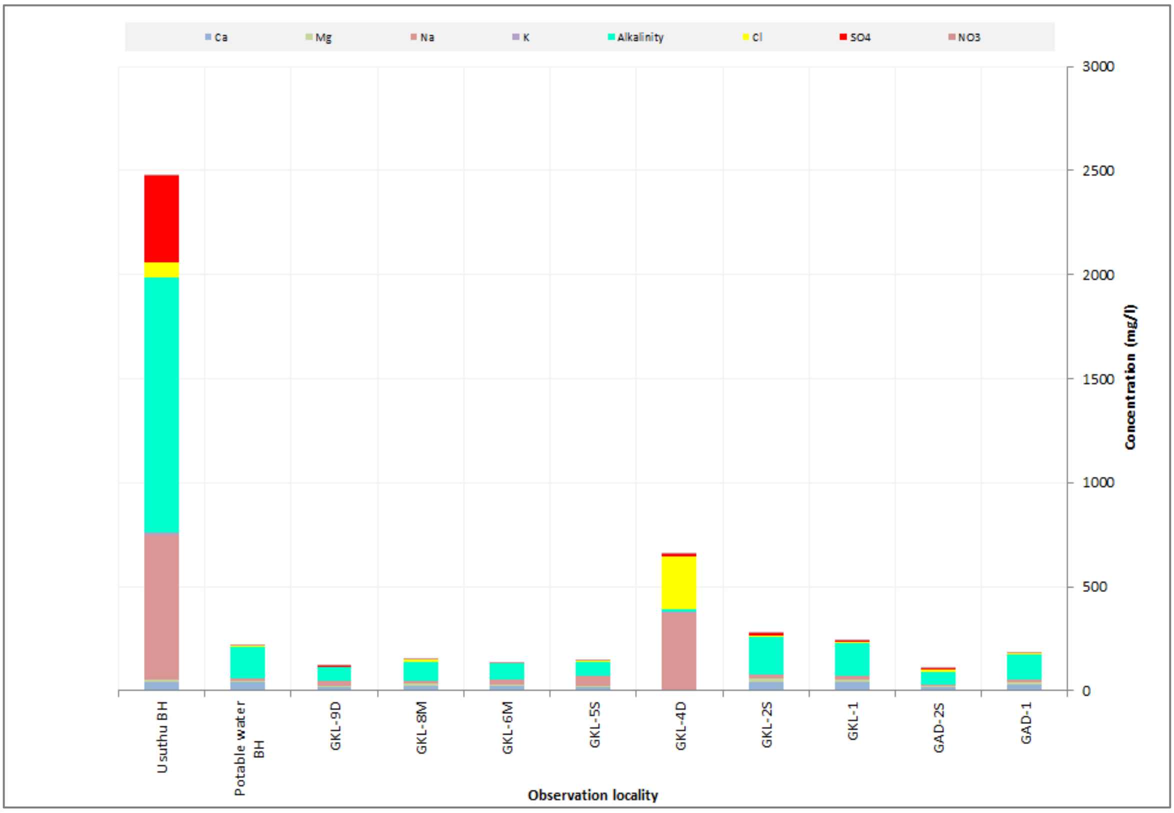



**Figure 9-2** **Hydrochemistry: Composite bar-chart indicating major anion cation composition of groundwater samples analysed (mg/l).**

**Table 9-7 Hydrochemistry: Water quality results of surface water monitoring localities (SANS 241:2015).**

| Determinant | Unit | Risk | SANS 241:2015 limits | WT-S01 | WT-S03 | WT-S02 | WT-S04 | WT-S05 | WT-S06 |
|---|---|---|---|---|---|---|---|---|---|
| **General parameters** | | | | | | | | | |
| **pH** | **-** | **Operational** | **≥5.0 ≤ 9.5** | 5.02 | 6.78 | 6.38 | 6.68 | 6.55 | 7.60 |
| **EC** | **mS/m** | **Aesthetic** | **≤170.0** | 122.50 | 69.60 | 100.63 | 94.60 | **388.50** | **215.67** |
| **TDS** | | **Aesthetic** | **≤ 1 200.0** | 960.00 | 459.00 | 698.00 | 651.00 | **3007.00** | **1475.00** |
| **Total Alkalinity** | **CaCO3/l** | **-** | **-** | 560.00 | 218.00 | 418.00 | 369.00 | 1323.00 | 448.00 |
| **Total Hardness** | **mg/l** | **-** | **-** | 11.73 | 111.50 | 63.77 | 81.85 | 25.40 | 393.72 |
| **Anions** | | | | | | | | | |
| **Cl** | **mg/l** | **Aesthetic** | **≤300.0** | 22.70 | 17.23 | 28.37 | 13.16 | 34.85 | 45.07 |
| **$SO_4$** | **mg/l** | **Acute health** | **≤250.0** | **676.27** | 231.67 | **427.63** | **397.00** | **2103.18** | **713.52** |
| **F** | **mg/l** | **Acute health** | **≤1.50** | 0.11 | 0.05 | 0.10 | 0.17 | 0.41 | 0.95 |
| **$NO_3$< N** | **mg/l** | **Acute health** | **≤11.0** | 0.59 | 0.51 | 0.24 | 0.73 | 0.05 | 0.45 |
| **Cations and metals** | | | | | | | | | |
| **Ca** | **mg/l** | **-** | **-** | 108.70 | 53.80 | 91.13 | 81.90 | 218.30 | 85.90 |
| **Mg** | **mg/l** | **-** | **-** | 70.20 | 20.37 | 46.27 | 40.05 | 189.00 | 56.65 |
| **Na** | **mg/l** | **Aesthetic** | **≤200.0** | 42.00 | 61.40 | 56.33 | 57.10 | **423.24** | **323.06** |
| **K** | **mg/l** | **-** | **-** | 11.00 | 4.59 | 7.65 | 8.57 | 15.25 | 10.71 |
| **Al** | **mg/l** | **Operational** | **0.3** | 0.08 | 0.05 | 0.01 | 0.03 | 0.01 | 0.01 |
| **Fe** | **mg/l** | **Acute health** | **2.0** | 0.04 | 0.14 | 0.03 | 0.07 | 0.04 | 0.03 |
| **Mn** | **mg/l** | **Operational** | **0.4** | 0.14 | 0.01 | 0.08 | 0.02 | **6.78** | 0.14 |

**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 9-8 Hydrochemistry: Water quality results of groundwater monitoring boreholes (SANS 241:2015).**

| Determinant | Unit | Risk | SANS 241:2015 limits | GAD-1 | GAD-2S | GKL-1 | GKL-2S | GKL-4D | GKL-5S | GKL-6M | GKL-8M | GKL-9D | Potable water BH | Usuthu BH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **General parameters** | | | | | | | | | | | | | | |
| pH | - | Operational | ≥5.0 ≤ 9.5 | 7.27 | 7.56 | 7.41 | 7.51 | 8.30 | 7.85 | 7.65 | 7.66 | 7.81 | 7.44 | 7.62 |
| EC | mS/m | Aesthetic | ≤170.0 | 28.20 | 15.28 | 36.35 | 41.05 | **174.25** | 31.80 | 25.27 | 24.50 | 21.27 | 28.00 | **302.00** |
| TDS | | Aesthetic | ≤ 1 200.0 | 145.00 | 81.00 | 198.00 | 223.00 | 949.00 | 178.00 | 142.00 | 130.00 | 119.00 | 156.28 | **1994.48** |
| Total Alkalinity | CaCO3/l | - | - | 119.00 | 61.00 | 155.00 | 180.00 | 13.00 | 68.00 | 73.00 | 92.00 | 66.00 | 152.00 | 1228.00 |
| Total Hardness | mg/l | - | - | 140.00 | 47.53 | 189.50 | 206.25 | 475.51 | 167.79 | 132.33 | 118.67 | 110.33 | 133.24 | 159.99 |
| **Anions** | | | | | | | | | | | | | | |
| Cl | mg/l | Aesthetic | ≤300.0 | 6.03 | 15.88 | 5.61 | 5.93 | 254.02 | 3.61 | 4.50 | 7.82 | 3.60 | 1.24 | 70.80 |
| $SO_4$ | mg/l | Acute health | ≤250.0 | 1.06 | 1.06 | 6.20 | 14.67 | 12.65 | 0.14 | 0.45 | 0.98 | 1.39 | 2.92 | **419.24** |
| F | mg/l | Acute health | ≤1.50 | 0.04 | 0.04 | 0.03 | 0.02 | **2.74** | 0.26 | 0.51 | 0.00 | 0.08 | 0.09 | 0.09 |
| $NO_3$< N | mg/l | Acute health | ≤11.0 | 0.35 | 1.69 | 0.35 | 0.35 | 0.35 | 0.06 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| **Cations and metals** | | | | | | | | | | | | | | |
| Ca | mg/l | - | - | 30.60 | 13.90 | 39.13 | 41.24 | 3.42 | 18.37 | 22.08 | 25.70 | 17.95 | 38.70 | 39.50 |
| Mg | mg/l | - | - | 10.24 | 6.48 | 13.92 | 18.80 | 1.17 | 5.42 | 4.44 | 6.72 | 5.03 | 8.89 | 14.90 |
| Na | mg/l | Aesthetic | ≤200.0 | 10.27 | 5.71 | 17.40 | 16.40 | **368.57** | 45.33 | 28.30 | 14.17 | 21.63 | 11.10 | **693.18** |
| K | mg/l | - | - | 1.88 | 0.95 | 1.30 | 1.47 | 3.96 | 1.59 | 1.19 | 1.74 | 2.13 | 2.14 | 10.00 |
| Al | mg/l | Operational | 0.3 | 0.01 | 0.01 | 0.08 | 0.00 | **1.99** | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 |
| Fe | mg/l | Acute health | 2.0 | 0.40 | 0.38 | 0.09 | 0.71 | **7.25** | 0.88 | 1.23 | 0.89 | 0.48 | 0.01 | 0.01 |
| Mn | mg/l | Operational | 0.4 | 0.18 | 0.08 | 0.15 | 0.11 | 0.02 | 0.07 | 0.15 | 0.09 | 0.09 | 0.01 | 0.01 |

**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.**

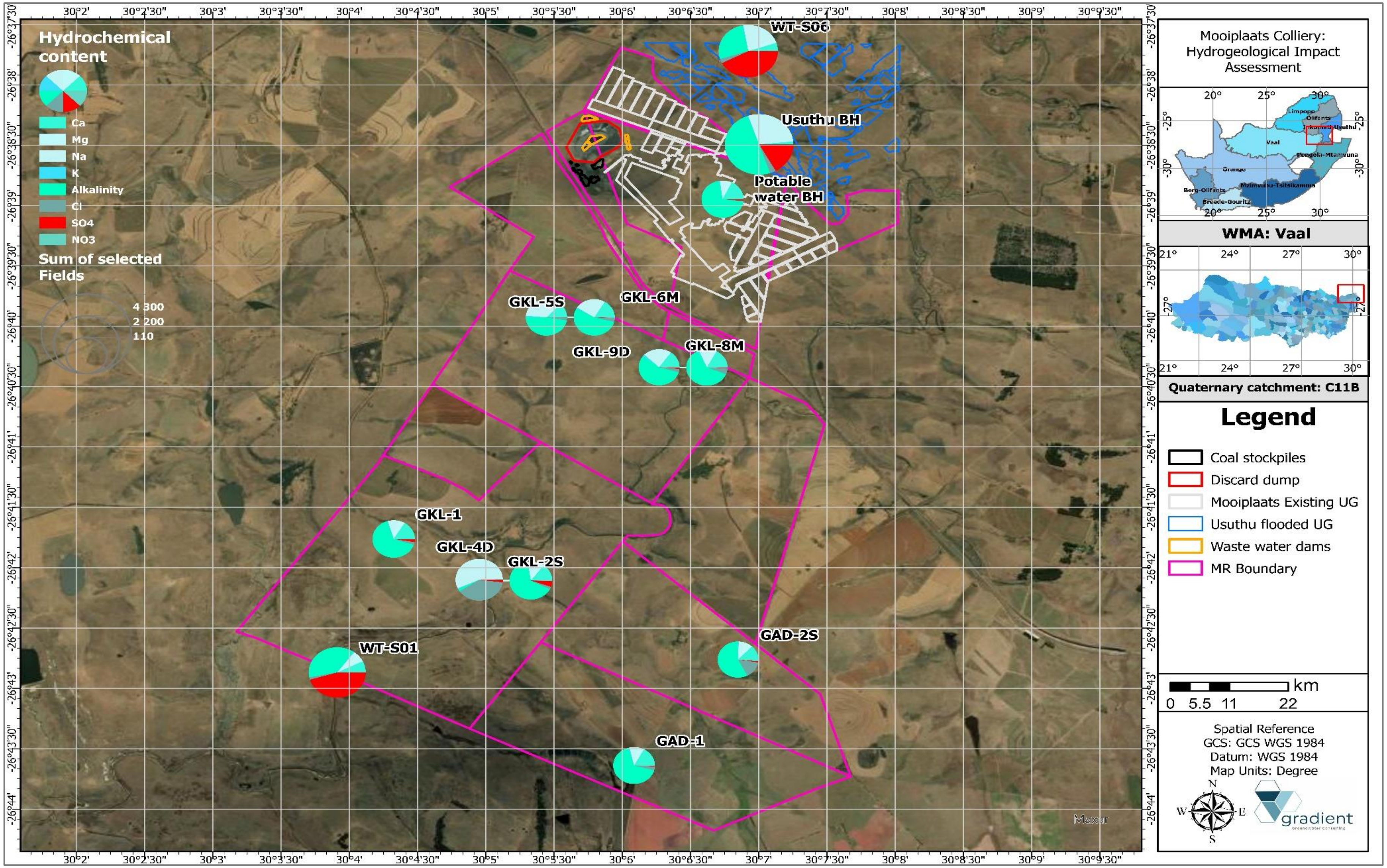



**Figure 9-3** **Hydrochemical analysis spatial distribution (mg/l).**

### 9.2. Hydrochemical signature

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

#### 9.2.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 9-4). 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 9-5 depicts a piper diagram developed from the monitoring points water quality analysis results. All the surface water monitoring localities can be distinguished as being of a Magnesium- Sulphate dominance suggestive of a dynamic and coordinated environment which have potentially been impacted by mining related activities. It is evident that the majority of groundwater monitoring localities can be characterized as being recently recharged groundwater and unimpacted groundwater environment (Magnesium-Bi-carbonate dominance) while isolated boreholes suggest Sodium-Chloride dominance (GKL-4D) and the Usuthu borehole and GKL-5S indicating an area of a dynamic and coordinated environment (Sodium-Bi-carbonate dominance).

#### 9.2.2. 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 9-6 depicts Stiff diagrams compiled from the surface water monitoring localities while Figure 9-7 show Stiff diagrams from the groundwater monitoring localities. Figure 9-8 indicates the Stiff diagrams from all surface water and groundwater monitoring localities combined. The Stiff diagrams of the majority of surface water monitoring localities correlate well with the exception of WT-S05 suggesting a higher salt load probably driven by increased sulphate concentrations observed. GKL-4D and the Usuthu BH, Stiff diagrams of the remaining groundwater localities indicate a relatively low salt load and unimpacted groundwater regime. The Usuthu borehole suggests very high salt load with the main drivers being sodium and bicarbonate. The latter can be attributed to underground water being in contact with mined out faces over a long period of time.

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

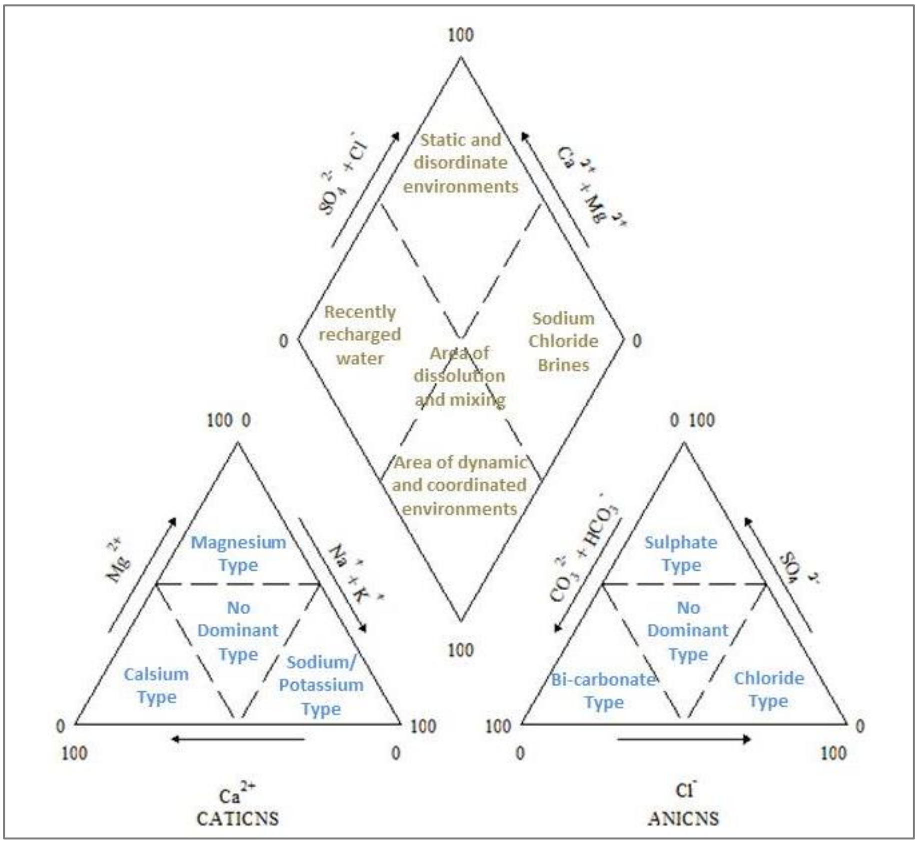



**Figure 9-4** **Piper diagram indicating classification for anion and cation facies in terms of ion percentages.**

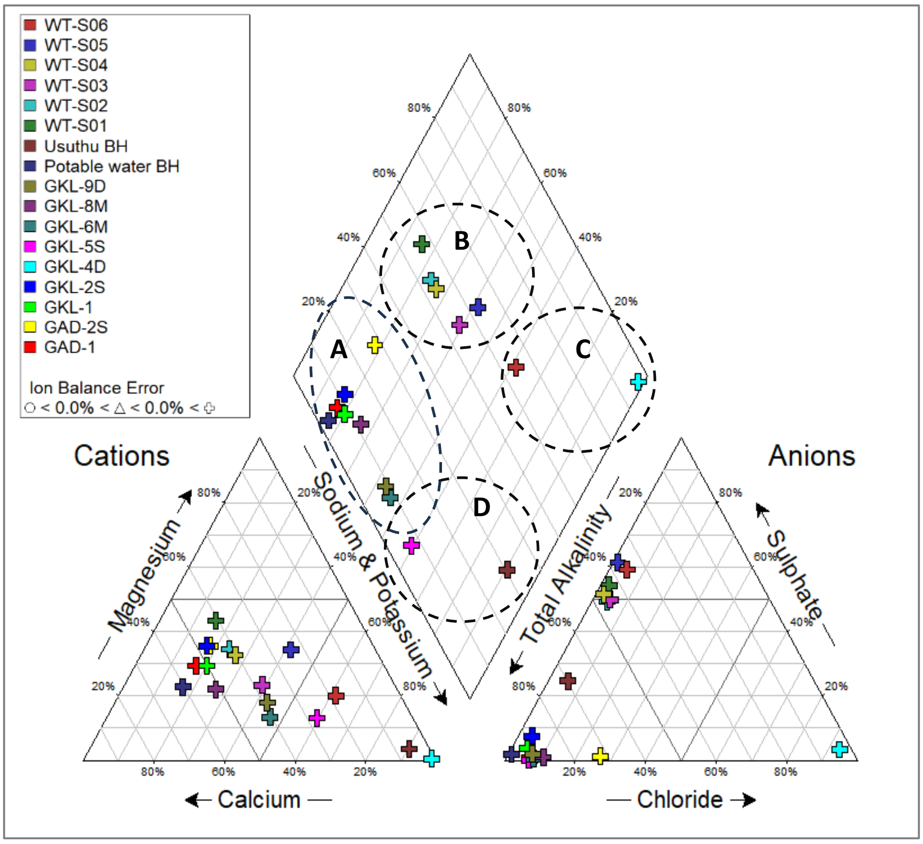



**Figure 9-5** **Piper diagram indicating major anions and cations of monitoring localities analysed.**

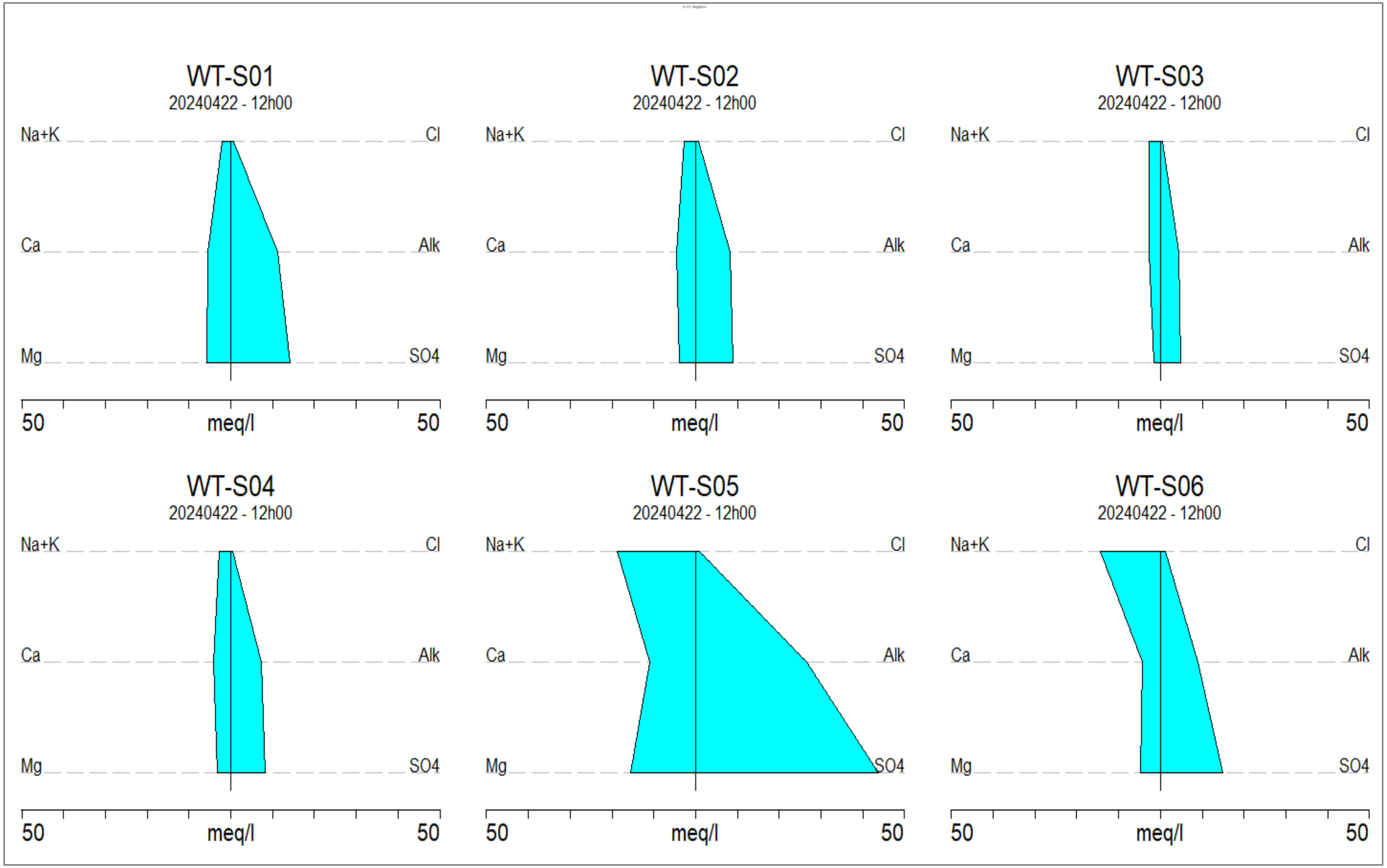



**Figure 9-6** **Stiff diagrams representing surface water monitoring localities analysed.**

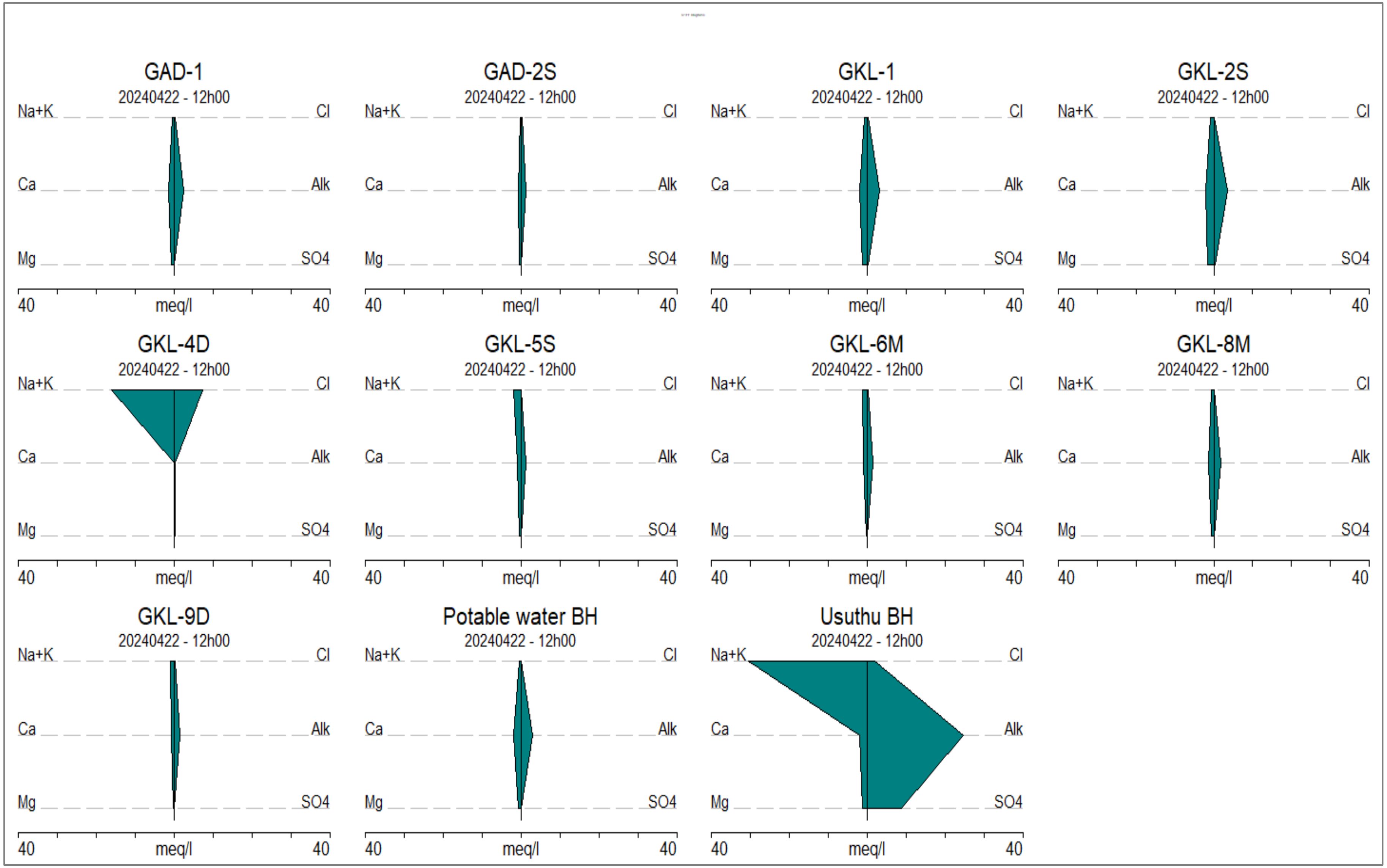



**Figure 9-7** **Stiff diagrams representing groundwater monitoring localities analysed.**

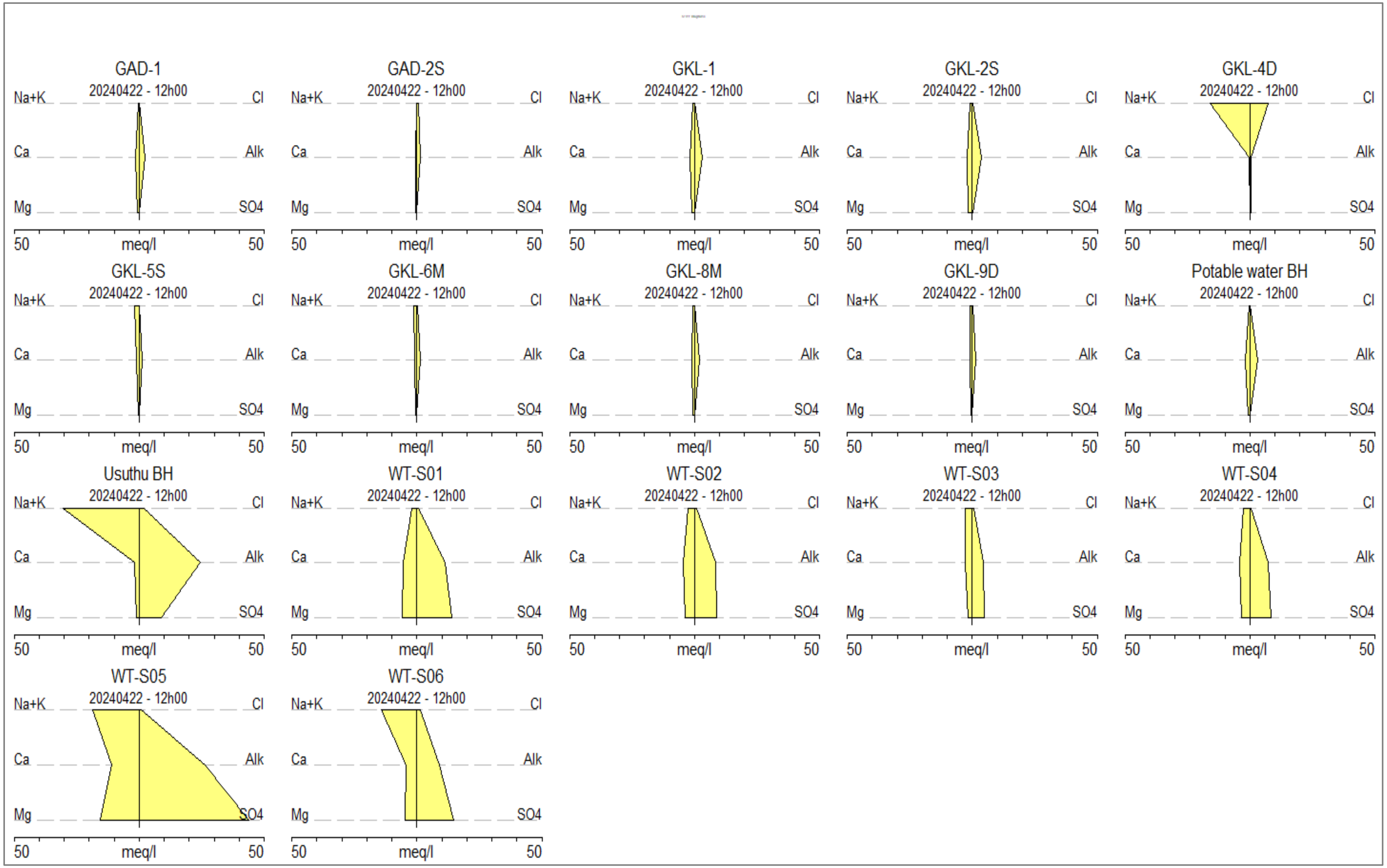



**Figure 9-8** **Stiff diagrams representing surafce and groundwater monitoring localities combined.**

### 9.3. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems as summarised in Figure 9-9. 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 surface water samples analysed can be classified as either Field 01 or Field 02 i.e. mostly fresh, clean and relatively young with $HCO_3$- and $CO_3$ dominance evident. All surface water samples analysed can be classified as either Field 05 i.e., groundwater that has undergone $SO_4$ and NaCl mixing/contamination or old stagnant NaCl dominated water that has mixed with clean water or Field 06; dominated water that resides in sodium rich host rock/material. The Usuthu BH and monitoring locality GKL-5S water qualities can be classified under Field03, associated with sodium ion exchange between groundwater and aquifer material while monitoring locality GKL-4D categorized under Field09 i.e., very old stagnant water that has reached the end of the geohydrological cycle. Refer to Figure 9-10.

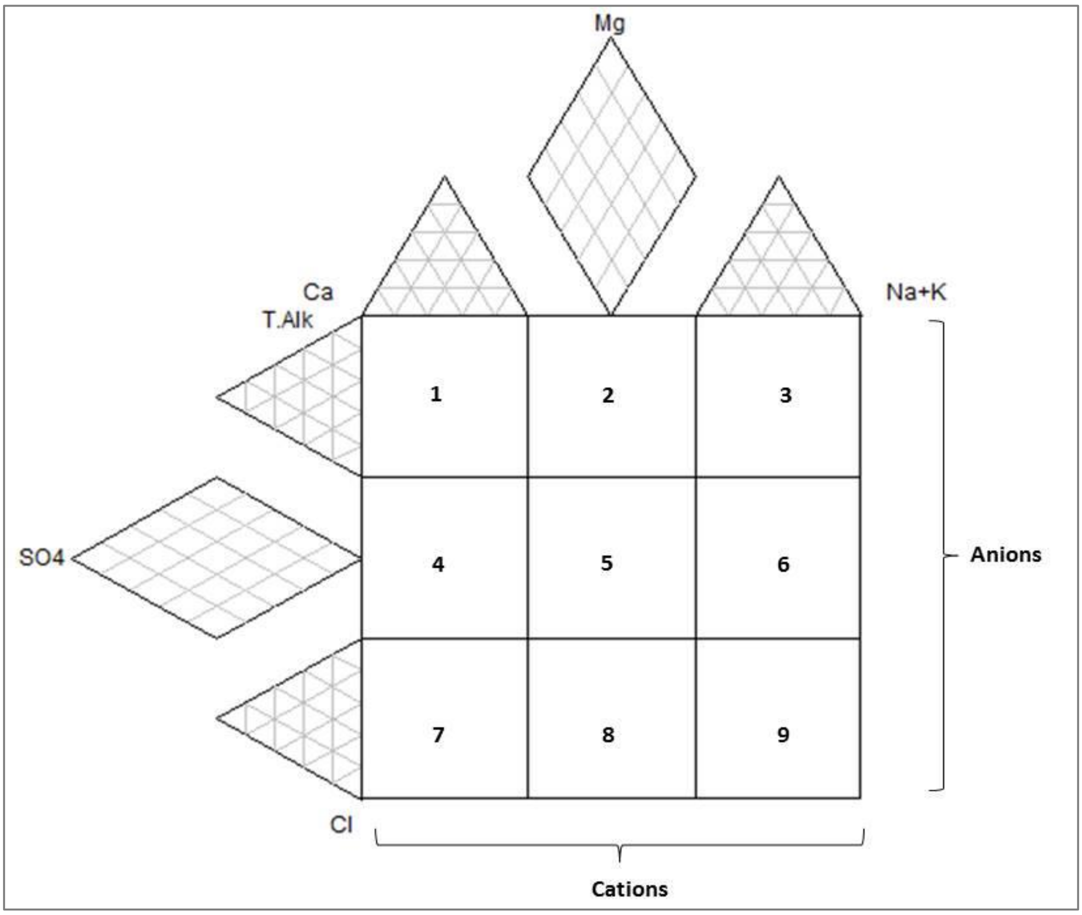



**Figure 9-9** **Extended Durov diagram indicating major anions and cations.**

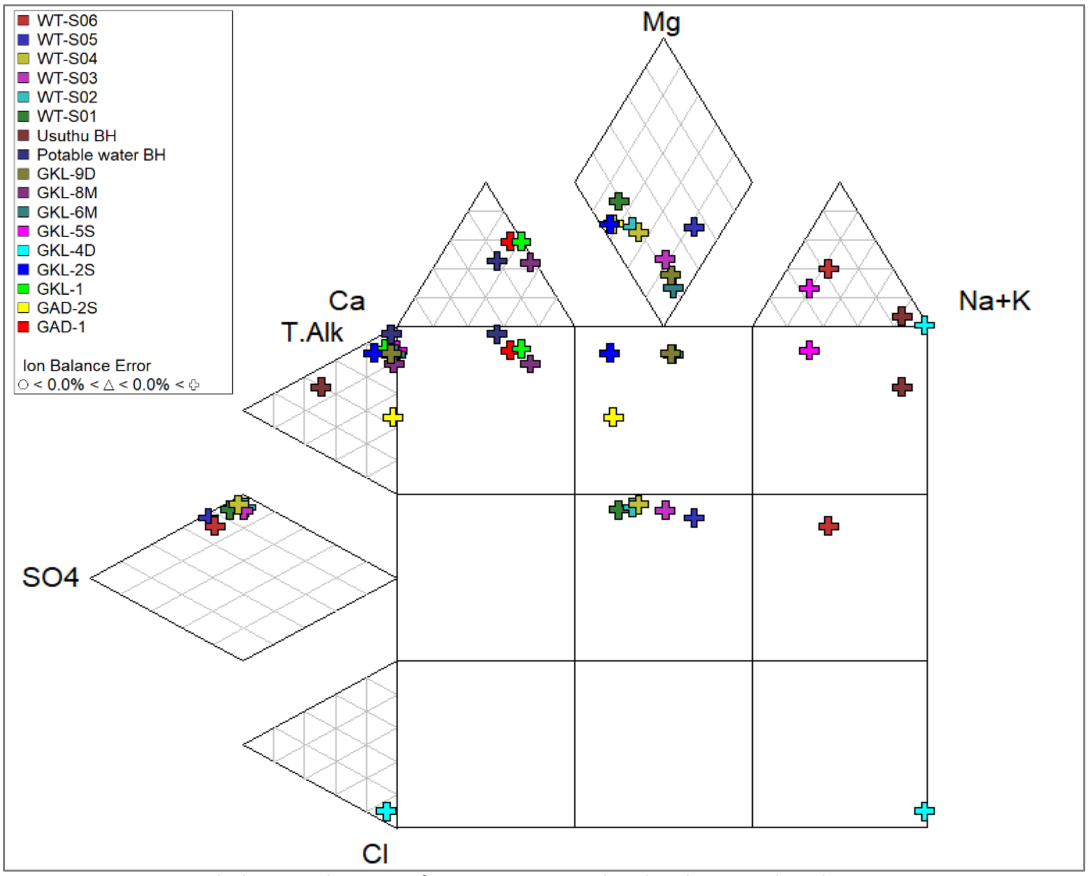



**Figure 9-10** **Extended Durov diagram of monitoring sampling localities analysed.**

## 10. GEOCHEMISTRY

The primary objective of this geochemical assessment is to determine the chemical nature and character of the potential product and waste material to be handled on-site, evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for Acid Rock Drainage (ARD) occurring. Geochemical analysis was performed during various phases of this project and entailed a combination of geochemical methodologies as summarised in Table 10-1. Table 10-2 and Table 10-3 outlines the different materials analysed as well as specific tests per sample. Refer to Appendix D for laboratory results and certificates. It should be noted that the geochemical results compare well with coal and discard analysis of other regional collieries and is representative of the geochemical character of lithologies mined within the Ermelo Coalfield where the washing plant will source it's coal product from.

**Table 10-1 Geochemical analysis test methodologies.**

| Test procedure | Objectives | Methodology |
|---|---|---|
| X-Ray diffraction (XRD) | Minor to dominant minerals present in rocks. | PANalytical Aeris diffractometer |
| Acid-base accounting (ABA) test | Determine the balance between the acid production and acid consumption properties of the sampled 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. |

**Table 10-2 Description of geochemical samples evaluated as part of Phase 01 samping analysis.**

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

**Table 10-3 Description of geochemical samples evaluated as part of Phase 02 samping analysis.**

| Sample ID | Sample type | * | Test procedure | Description | Photo |
|---|---|---|---|---|---|
| MCG01 | Composite | | XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC)) | Sludge material |  |
| MCG02 | Composite | | XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC)) | Discard material |  |

### 10.1. Minerology and total element analysis

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

#### 10.1.1. XRD Analysis

The results from the XRD analyses of the minerals for the composite samples are presented in Table 10-4 to Table 10-7. The following is noted:

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

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

iii. The coal sludge sample (MCG01) consist mainly of organic carbon (52.80%), kaolinite (26.30%) and quartz (12.90%). Minor amounts of dolomite (0.6%), gypsum, microcline, muscovite, pyrite (0.2%) as well as sepiolite were also present within this sample.

iv. The discard material sample (MCG02) consist mainly of kaolinite (34.00%), organic carbon (23.40 %), quartz (24.90 %) as well as jarosite (9.10%). Minor amounts of gypsum, microcline, muscovite, pyrite (0.70%) as well as sepiolite were also present within this sample.

v. It is noted that both samples contain pyrite which, as being one of the main ARD generating sulphide minerals, can pose a risk to acid generation.

vi. The presence of dolomite is also observed which may contribute to an increased buffer capacity.

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

**Table 10-4 Description of major minerals identified as part of Phase 01 samping analysis.**

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

**Table 10-5 Description of major minerals identified as part of Phase 02 samping analysis.**

| Mineral | * | Formula | Mineral type (Group) | Sub-group |
|---|---|---|---|---|
| Dolomite | | $CaMgCO_3$ | Anhydrous Carbonates | Dolomite group |
| Gypsum | | Ca(sulphate).$H_2O$ | Hydrated Sulphates | Gypsum |
| Jarosite | | $KFe_3(SO_4)_2(OH)_6$ | Hydrated Sulphates | |
| Kaolinite | | $Al_2Si_2O_5(OH)_4$ | Phyllosilicate | Clay mineral group |
| Microcline | | $KAl_2Si_3O_8$ | Tectosilicate | K-Feldspar subgroup |
| Muscovite | | $KAl_2(AlSi_3O_{10})(OH,F)_2$ | Phyllosilicate | Mica group |
| Organic Carbon | | C | Carbon | |
| Pyrite | | FeS | Sulfides | Pyrite Group |
| Quartz | | $SiO_2$ | Tectosilicate | Tectosilicate |
| Sepiolite | | $Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O$ | Phyllosilicate | Clay mineral group |

**Table 10-6 XRD Analyses of the composite samples as part of Phase 01 samping analysis.**

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

**Table 10-7 XRD Analyses of the composite samples as part of Phase 02 samping analysis.**

| Mineral | * | Chemical composition | Sample (weight %) | |
|---|---|---|---|---|
| | | | MCG01 | MCG02 |
| Dolomite | | $CaMgCO_3$ | 0.6 | 0 |
| Gypsum | | Ca(sulphate).$H_2O$ | 3.80 | 4.00 |
| Jarosite | | $KFe_3(SO_4)_2(OH)_6$ | 0.00 | 9.10 |
| Kaolinite | | $Al_2Si_2O_5(OH)_4$ | 26.30 | 34.00 |
| Microcline | | $KAl_2Si_3O_8$ | 1.40 | 3.30 |
| Muscovite | | $KAl_2(AlSi_3O_{10})(OH,F)_2$ | 1.40 | 3.30 |
| Organic Carbon | | C | 52.80 | 23.40 |
| Pyrite | | FeS | 0.40 | 0.70 |
| Quartz | | $SiO_2$ | 12.90 | 24.90 |
| Sepiolite | | $Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O$ | 0.10 | 0.50 |

### 10.1.2. XRF Analysis

The element specific concentrations were obtained from the XRF analyses as summarised in Table 10-8. Also referenced in Table 10-8 are the Alloway Crustal Abundance (ACU) concentrations of the particular elements. The latter provides an indication of the average abundance of an element in the earth's crust (Alloway *et al*, 1995). By calculating the ratio of the trace element concentrations to the average composition of the earth's crust (Crustal Abundances) an indication can be obtained whether the concentration of a particular element is raised above the average for the earth or enriched above the average due to some process. The comparison to the average Crustal Abundance is geochemically accepted as a means of highlighting elements, which may possibly be enriched in the various lithologies[11]. The following is noted:

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

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

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

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

**Table 10-8 XRF analysis and Major Element Concentrations for Phase 01 samping analysis.**

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

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

**Shaded cells exceed SANS 241:2015 drinking water guidelines.**

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

**Table 10-9 XRF analysis and Major Element Concentrations for Phase 02 samping analysis.**

| Mineral | Major element concentration (wt %) [s] | | **AUC |
|---|---|---|---|
| | MCG01 | MCG02 | |
| $Fe_2O_3$ | 7.274 | 8.897 | 11.2 |
| $SiO_2$ | 53.246 | 54.064 | 66.6 |
| $Al_2O_3$ | 21.61 | 21.75 | 15.4 |
| $K_2O$ | 1.644 | 1.465 | 2.8 |
| $P_2O_5$ | 0.50 | 0.72 | 0.15 |
| $Mn_3O_4$ | 0.025 | 0.017 | |
| CaO | 7.42 | 5.51 | 3.59 |
| MgO | 1.552 | 1.410 | 2.48 |
| $TiO_2$ | 1.20 | 1.16 | 0.64 |
| $Na_2O$ | 0.570 | 0.404 | 3.27 |
| $V_2O_5$ | 0.025 | 0.021 | |
| BaO | 0.124 | 0.166 | |
| $Cr_2O_3$ | 0.020 | 0.020 | |
| SrO | 0.172 | 0.235 | |
| $ZrO_2$ | 0.059 | 0.061 | |
| MnO | 0.024 | 0.016 | 0.1 |
| $SO_3$ | 5.224 | 4.824 | |
| **Total XRF** | **99.03** | **99.48** | |

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

Shaded cells exceed SANS 241:2015 drinking water guidelines.

## 10.2. Acid rock drainage

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

Acid rock drainage is produced through the natural oxidation of sulfidic minerals by air and water, accelerated by bacterial action (*thiobacillus*); thus, exposed sulphide-bearing tailings/discard (and waste rock) are prone to ARD generation. Pyrite and pyrrhotite are the main ARD generating sulphide minerals and are found in many deposits associated with coal. The resulting acid leaches other heavy and toxic metals into the ARD (Weisener et al., 2003). Coal mining is associated with ARD and mining activities usually expose pyrite to oxidising agents such as oxygen and ferric iron ($Fe^{3+}$). During the oxidation process of sulphide ores, the sulphidic component ($S^{2-}$) in pyrite is oxidised to sulphate ($SO_4^{2-}$); acidity ($H^+$) is generated and ferrous iron ($Fe^{2+}$) ions are released.

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

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

**Reaction 1.**

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

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.**

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

$Fe^{3+}$ 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.**

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

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.**

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

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

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

**Reaction 5.**

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

Leaching from carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity ($H^+$), sulphates ($SO_4^{2-}$) and ferric ($Fe^{3+}$) and ferrous ($Fe^{2+}$) iron species and the movement of other conservative contaminants with groundwater in a downgradient direction from the source. The resulting acidity will mobilise reactive metal contaminants which will create a pollution plume and can migrate in a downgradient direction polluting aquifers and surfacing at seepage points, contaminating surface waters along the way. Within wetland systems, oxidation of $Fe^{2+}$ to $Fe^{3+}$ will result in the precipitation of ferric hydroxide (FeOH), typically as a gel, which can coat the reactive surfaces of the plants and sediment, thereby greatly reducing the ability of the wetland to remove pollutants by adsorption. In addition, the high salt load is often toxic to aquatic life. Figure 10-1 indicates a site conceptual geochemical model summarising the dynamics of ARD within the greater hydrogeological regime while Figure 10-2 shows recorded pH levels vs sulphate concentrations for groundwater and surface water monitoring localities in the vicinity of the discard dump. It can be noted that surface water localities down-gradient of the discard dump, including isolated groundwater monitoring localities in close proximity to the source (MPG-B2 and MPG-B7) indicate relatively high sulphate concentrations and potential AMD conditions, however pH conditions of groundwater monitoring localities situated further away still suggest neutral to alkaline conditions.

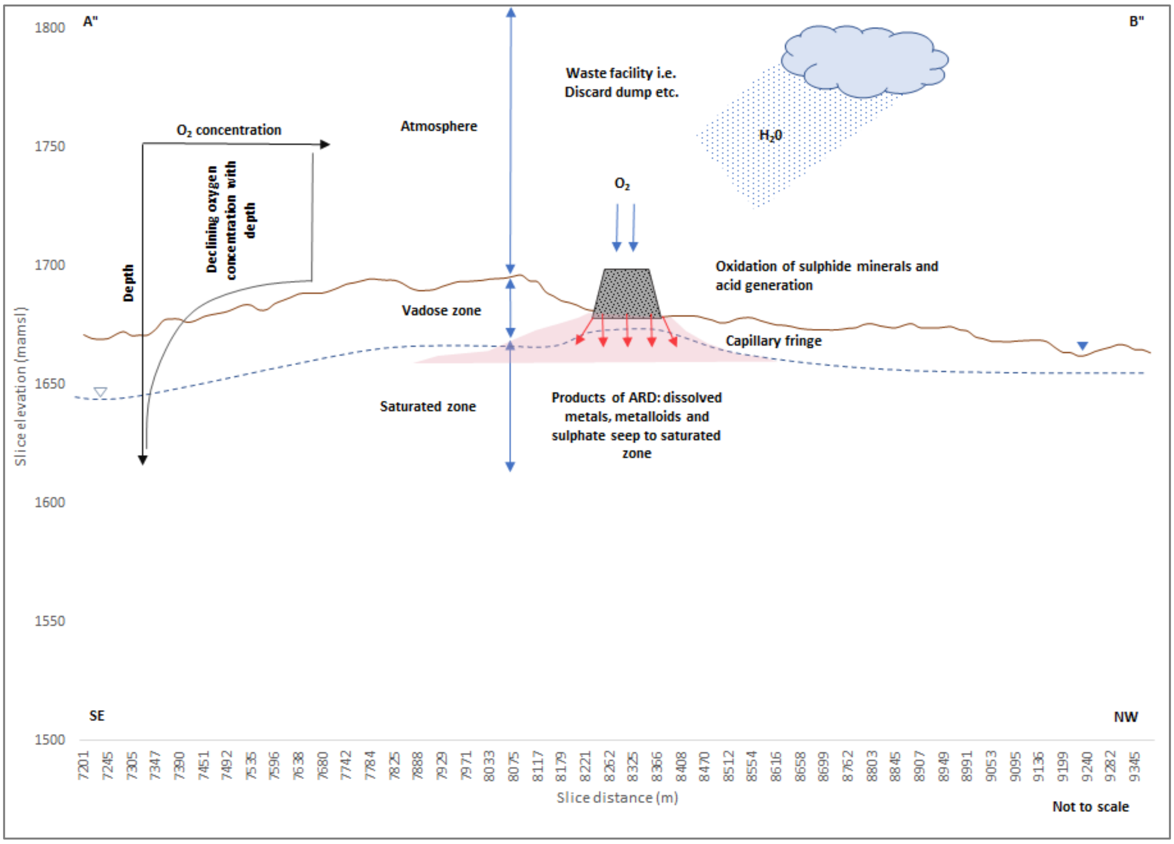



**Figure 10-1** **Conceptual geochemical model.**

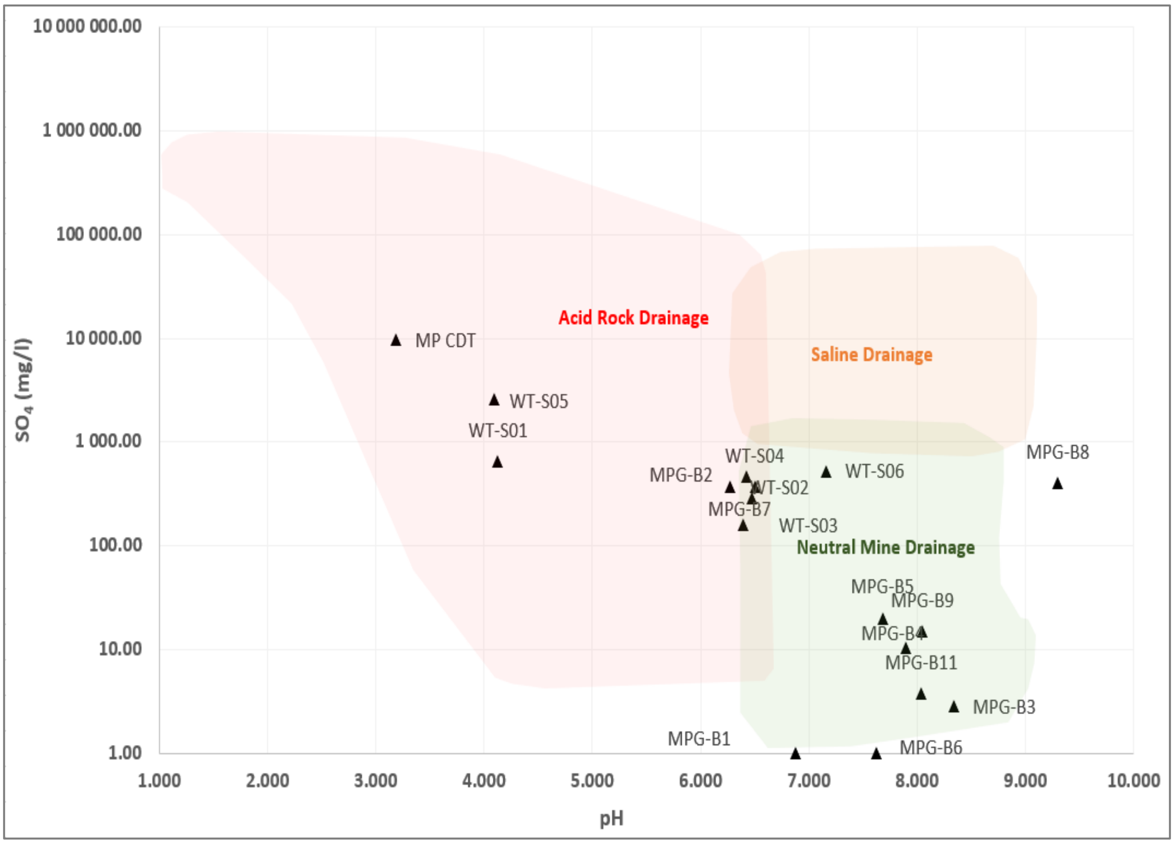



**Figure 10-2** **Diagram showing mine observed pH vs sulphate concentration.**

### 10.2.1. Acid Base Accounting

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

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

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

- A rock with NNP < 0 kg $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg $CaCO_3$/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg $CaCO_3$/t to 20 kg $CaCO_3$/t exists that is defined as a "grey" area in determining the net acid generation or neutralization potential of a rock. Material with an NNP above this range is classified as R*ock Type IV - No Potential for Acid Generation,* and material with an NNP below this range as *Rock Type I - Likely Acid Generating*. Table 10-10 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 10-11 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 10-12).

**Table 10-10 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 10-11 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 10-12 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 % |

### 10.2.2. Net-acid Generation (NAG)

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

- In general, the static NAG test involves the addition of 25 ml of 15% $H_2O_2$ to 0.25 g of sample in a 250 ml wide mouth conical flask or equivalent. The sample is covered with a watch glass and placed in a fume hood or well-ventilated area.
- Once "boiling" or effervescing ceases, the solution can cool to room temperature and the final pH (NAG pH) is determined.
- A quantitative estimation of the amount of net acidity remaining (the NAG capacity) in the sample is determined by titrating it with sodium hydroxide (NaOH) to pH 4.5 (and/or pH 7.0) to obtain the NAG Value. In order to determine the acid generation potential of a sample, the screening method of Miller et al. (1997) is used. Refer to Table 10-3 below:

**Table 10-13 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.**

### 10.2.3. ABA, NAG test and Sulphur speciation results

The ABA analysis for Phase 1 sampling run as well as Phase 2 sampling run is summarised in Table 10-14 and Table 10-15 while, NAG tests as well as sulphur speciation results are summarised in Table 10-16 and Table 10-17. Figure 10-3 and Figure 10-4 provide a comparison of sulphide percentage vs NPR while Figure 10-5 and Figure 10-6 indicate NP:AP ratios of respective samples. Figure 10-7 and Figure 10-8 summarises NAG pH vs NAG value per sample. It is evident that all samples have a high risk to generate acid mine drainage and can sustain long term acid generation. Refer to Table 10-18 and Table 10-19 for a summary of AMD potential per sample evaluated. To follow is a brief summary of the potential risk of relevant samples analysed to cause ARD.

***Discard dump***

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

***Coal sample***

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

***Sample MCG01***

As expected, the coal sludge sample indicate a high sulphide content (1.78%), and negative NNP value of -38.11. The NPR ratio of 0.46 suggest that the material does not have buffering capacity and is likely to generate acid. The NAG pH is 2.60 with the NAG value 15.10 (at pH 4.5). It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

***Sample MCG02***

The discard material sample analysed record a relatively high sulphide content of 0.71% with a negative NNP value of -28.88. The NPR ratio of 0.52 suggest that the material does not have buffering capacity and is likely to generate acid. The NAG pH is 4.11 with the NAG value 2.31 (at pH 4.5), also indicating capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

**Table 10-14 ABA test results summary table for Phase 01 samping analysis.**

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

**Table 10-15 ABA test results summary table for Phase 02 samping analysis.**

| Sample ID | Lithology | Paste pH | Total Sulphur (%) | Sulphide (%) | AP CaCO3 (kg/t) | NP CaCO3 (kg/t) | NNP CaCO3 (kg/t) | NPR (NP/AP) |
|---|---|---|---|---|---|---|---|---|
| MCG01 | | 8.23 | 2.240 | 1.78 | 70.00 | 31.89 | -38.11 | 0.46 |
| MCG02 | | 7.22 | 1.910 | 0.71 | 59.70 | 30.81 | -28.89 | 0.52 |

**Table 10-16 NAG test results summary table for Phase 01 samping analysis.**

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

**Table 10-17 NAG test results summary table for Phase 02 samping analysis.**

| 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) |
|---|---|---|---|---|
| MCG01 | | 4.11 | 2.31 | 17.40 |
| MCG02 | | 2.60 | 15.10 | 31.70 |

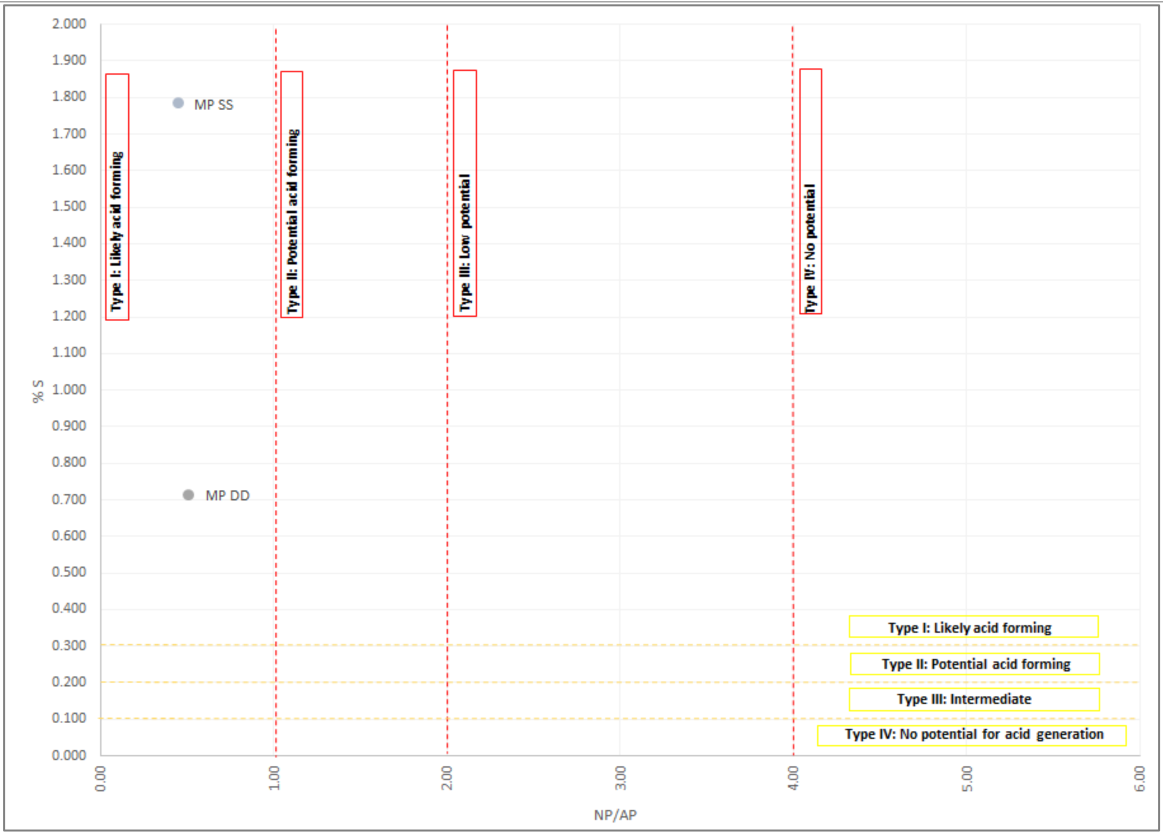



**Figure 10-3** Classification of samples in terms of %S and NP/AP ratio for Phase 01 samping analysis.

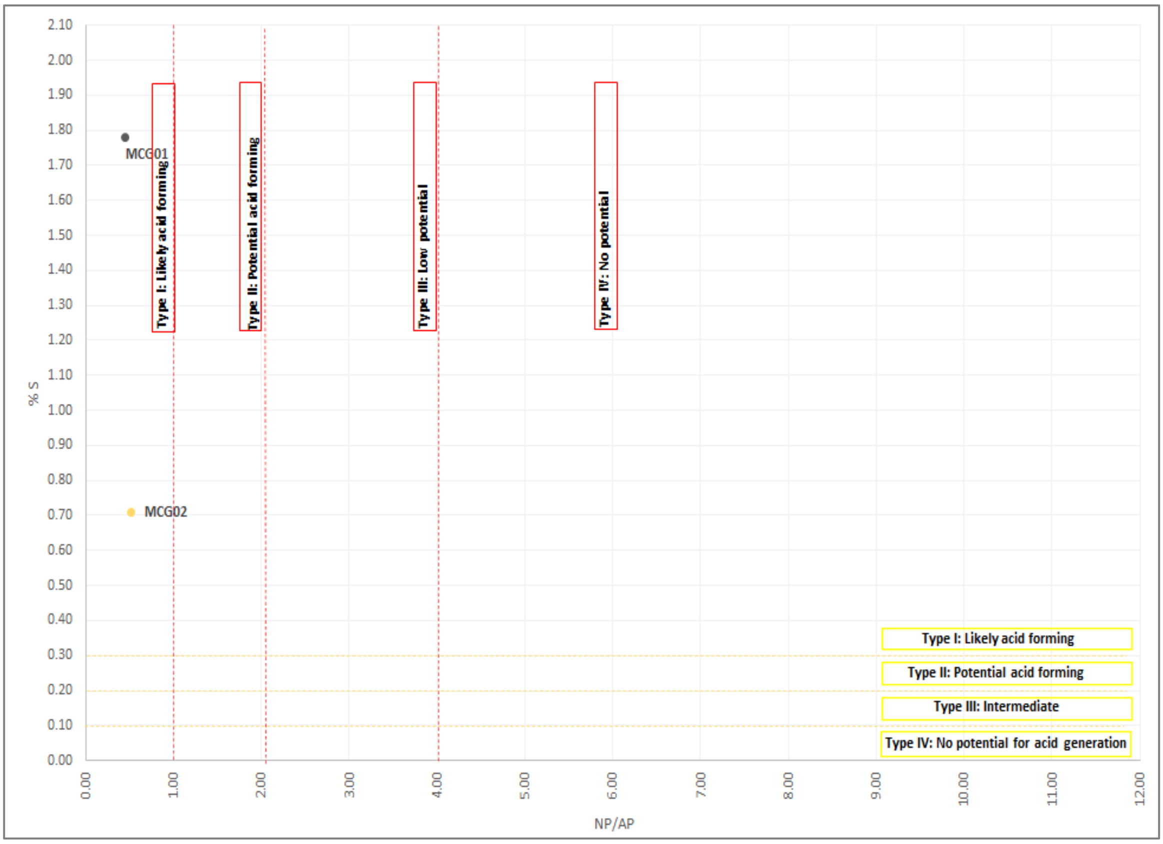



**Figure 10-4** Classification of samples in terms of %S and NP/AP ratio for Phase 02 samping analysis.

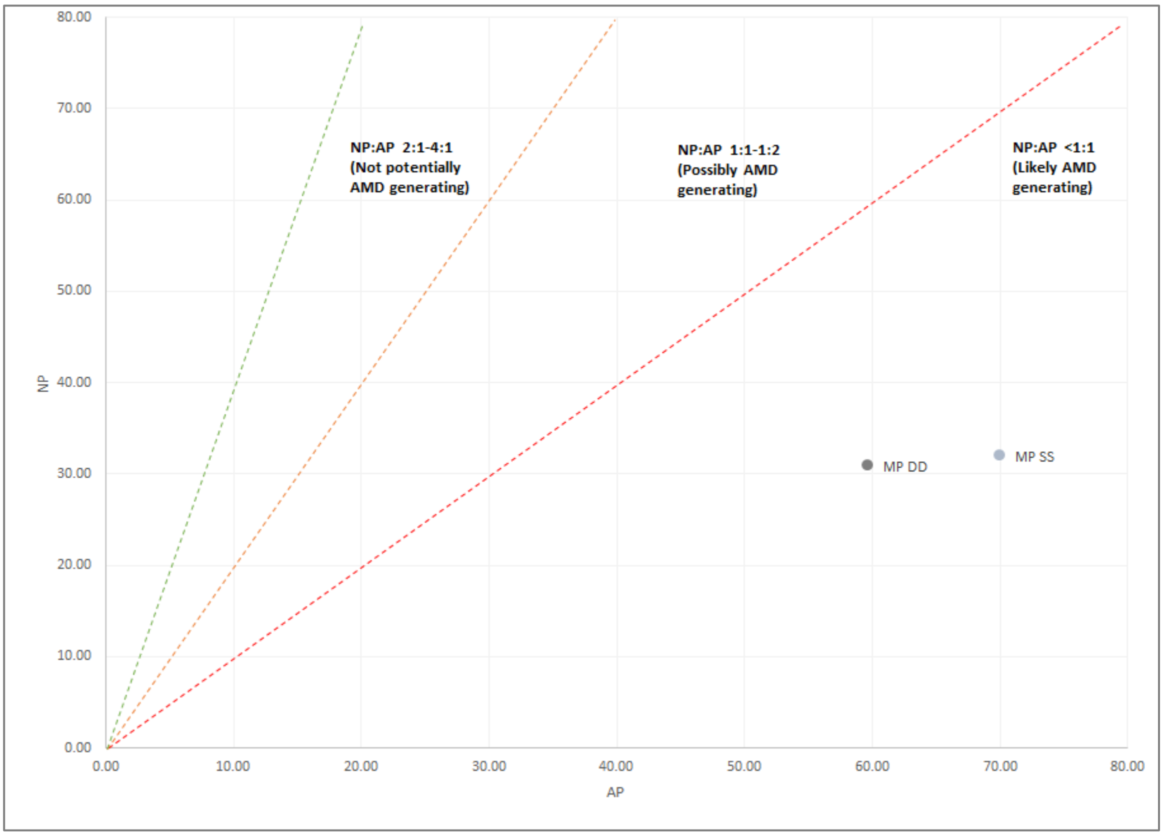



**Figure 10-5 Comparison graph: NP vs. AP for Phase 01 samping analysis.**

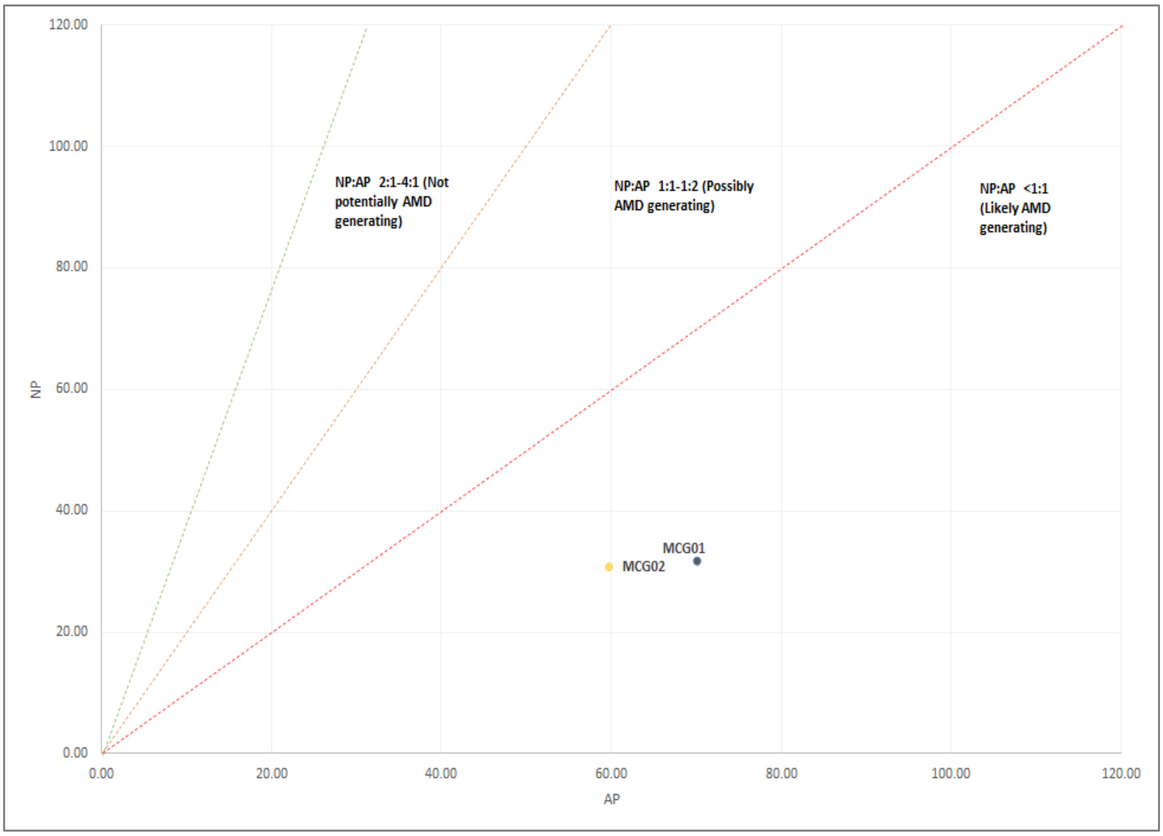



**Figure 10-6 Comparison graph: NP vs. AP for Phase 02 samping analysis.**

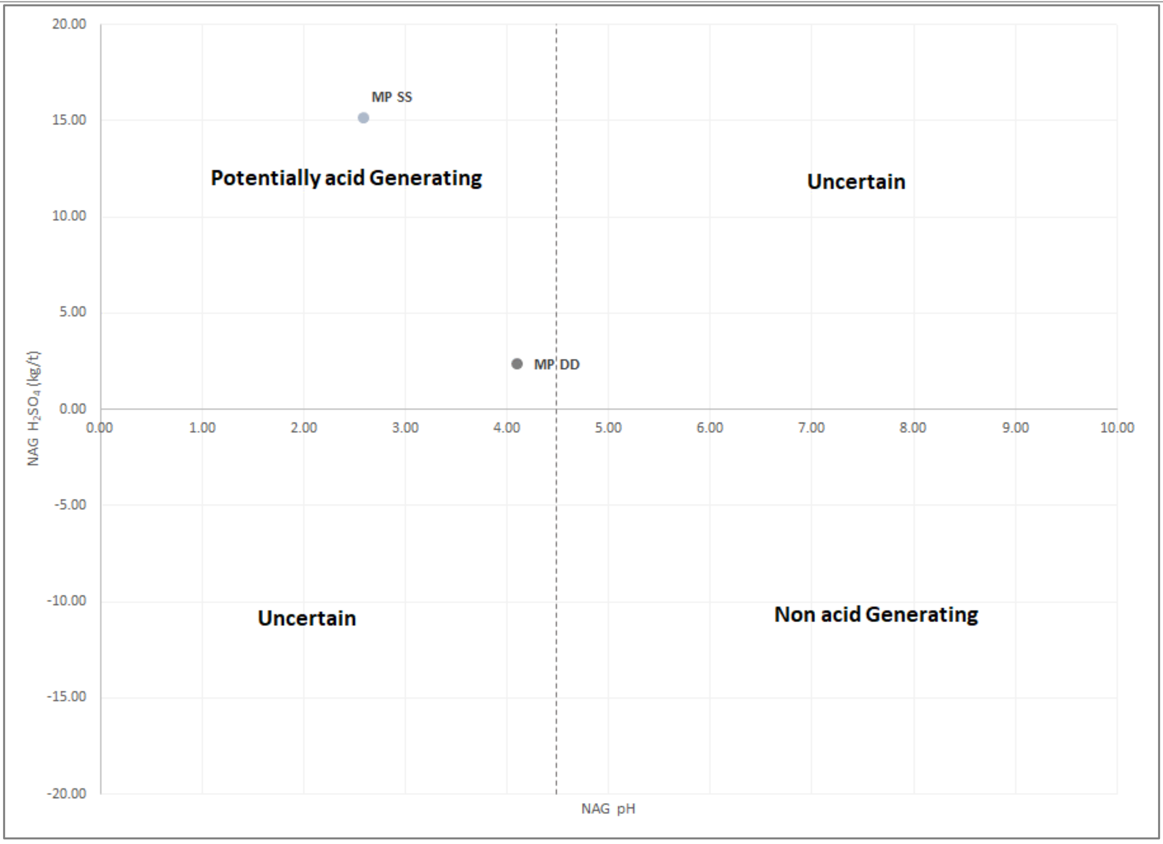



**Figure 10-7 Comparison graph: NAG pH vs NAG Value for Phase 01 samping analysis.**

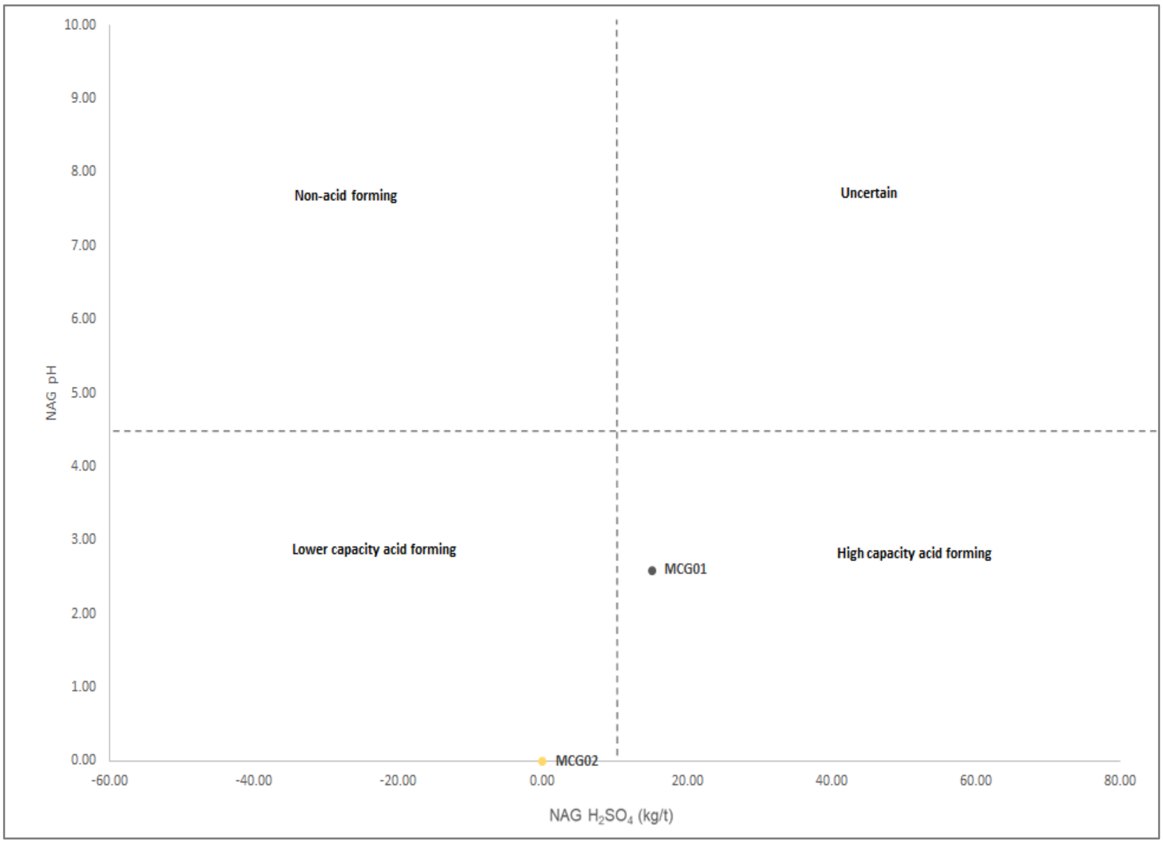



**Figure 10-8 Comparison graph: NAG pH vs NAG Value for Phase 02 samping analysis.**

**Table 10-18 Summary table: ARD potential per sample for Phase 01 samping analysis.**

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

**Table 10-19 Summary table: ARD potential per sample for Phase 02 samping analysis.**

| Sample | %S >0.3<br>NP/AP < 2.0 | %S > 0.3<br>NP/AP > 2.0 | %S < 0.1 - 0.3<br>NP/AP < 2.0 | %S < 0.1 - 0.3<br>NP/AP > 2.0 | %S < 0.1<br>NP/AP < 2.0 | %S < 0.1<br>NP/AP > 2.0 |
|---|---|---|---|---|---|---|
| MCG01 | | | | | | |
| MCG02 | | | | | | |
| Potential for ARD | Likely/possibly acid generating. High salt load. | Medium potential for acid generation. Medium to high salt load | Low to medium potential for acid generation. Low to medium salt load. | Very low potential for acid generation. Very low to low salt load. | No potential for acidic drainage. Very low/no salt load. | No potential for acidic drainage. Very low/no salt load. |

### 10.3. Static leach test: Distilled water leach

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

Refer to Table 10-18 for a summary of the leachate results. The only elevated element detected in the water leach of the discard dump material is sulphate, while no elevated elements were detected for the coal product sample.

**Table 10-20 ICP-OES results of ditilled water leach (1:4 dilution).**

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

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

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

### 10.4. Waste assessment

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

The TC and LC threshold limits, according to Section 6 of R635, is presented in Table 10-21 and Table 10-22. These concentrations limits are used to classify the waste as explained below. The concentrations were derived from a combination of South African soil screening, land remediation and human health effect values as well as from Australian standards[13]. Different waste categories/types are summarised in Table 10-23.

**Table 10-21 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.**

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

**Table 10-22 Leachable Concentration Threshold (LCT) Limits (mg/l).**

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

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

**Table 10-23 Waste types.**

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

Figure 10-9 and Figure 10-11 indicate a bar-chart comparison of the Total Concentration analysis of elements per sample whereas Figure 10-10 and Figure 10-12 show a bar-chart comparison of Leachable Concentrations analysis per sample. Dominant total concentrations include boron (B), barium (Ba) and chromium (VI) ($Cr^6$) whereas dominant leachate concentrations include boron (B), barium (Ba), manganese (Mn), vanadium (V) as well as chromium (Cr Total). The following is noted regarding the waste assessment results:

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

In terms of the TC's, however, the concentrations barium as well as mercury exceed their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 10-24 for a summary of leachate results compared to TC and LC thresholds.

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

In terms of the TC's, however, the concentrations barium as well as mercury exceed their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 10-25 for a summary of leachate results compared to TC and LC thresholds.

**MCG01 (Coal slurry):** In terms of the LC's, none of the constituents exceed the Leach Concentration Threshold 0 (LCT0) values. In terms of the TC's, however, the concentrations of barium (159.80mg/kg) as well as mercury (1.20mg/kg) exceeded their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 10-26 for a summary of leachate results compared to TC and LC thresholds.

**MCG02 (Discard material):** In terms of the LC's, none of the constituents exceed the Leach Concentration Threshold 0 (LCT0) values. In terms of the TC's, however, the concentrations arsenic (12.63mg/kg, barium (235.2mg/kg), copper (27.58mg/kg as well as mercury (2.40mg/kg) exceeded their respective Total Concentration Threshold 0 (TCT0) values. Based on the National Norms and Standards for the Assessment of Waste for Landfill Disposal, this material is therefore assessed as a Type 3 waste (low hazardous waste). Refer to Table 10-27 for a summary of leachate results compared to TC and LC thresholds.

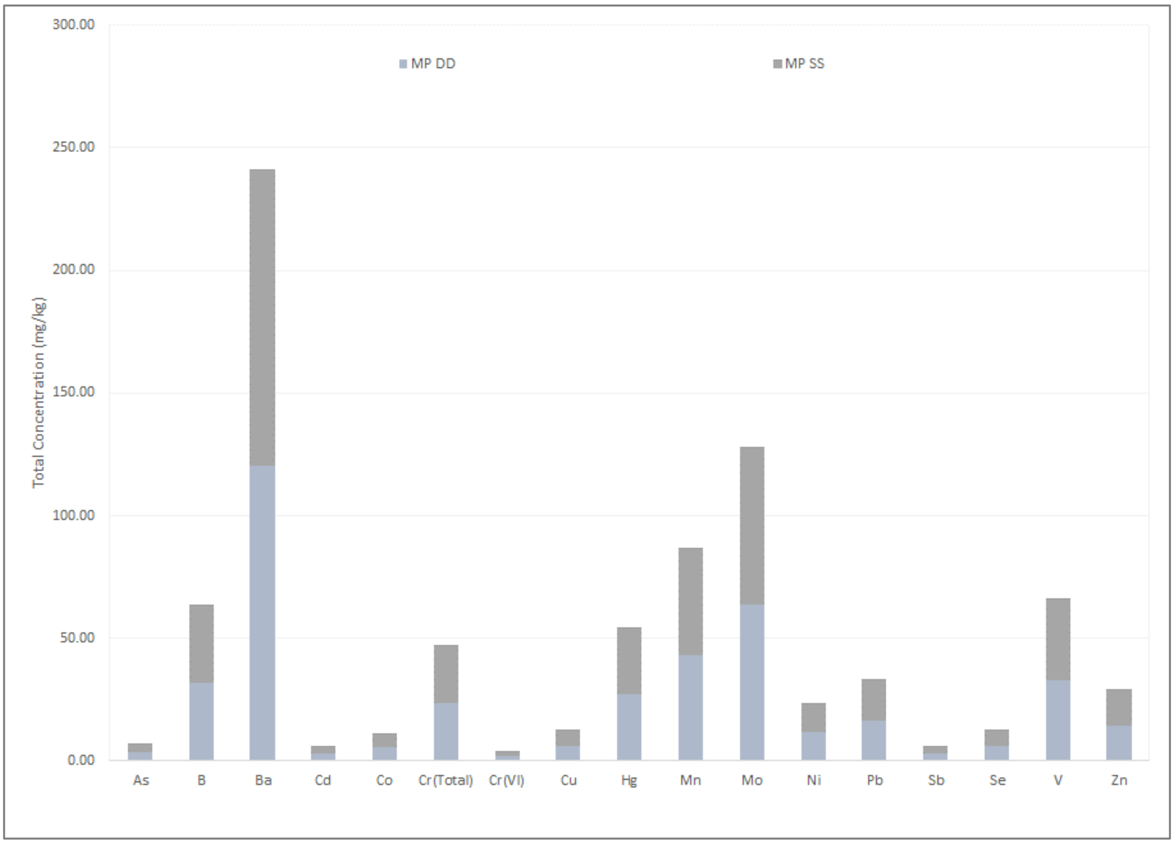



**Figure 10-9** **Comparison of Total Concentration analysis of Elements for Phase 01 samping analysis.**

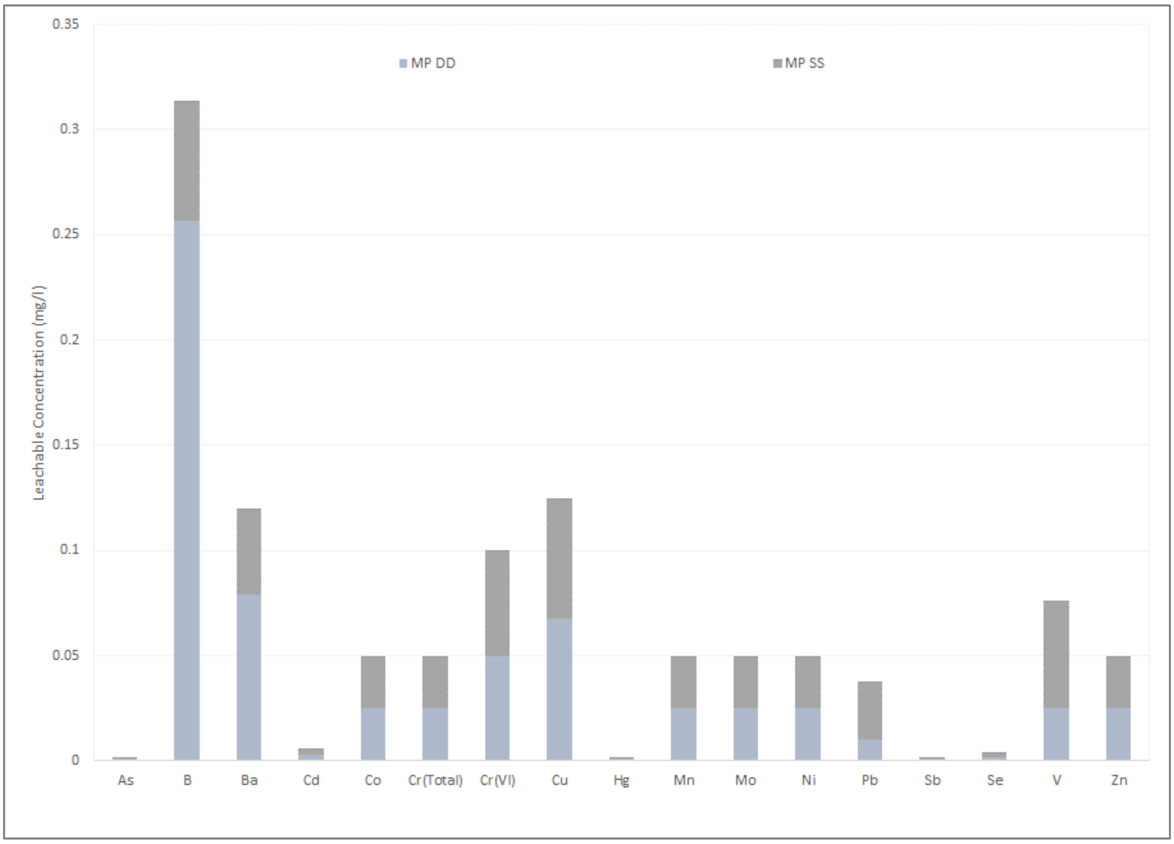



**Figure 10-10** **Comparison of Leachable Concentrations analysis of samples for Phase 01 samping analysis.**

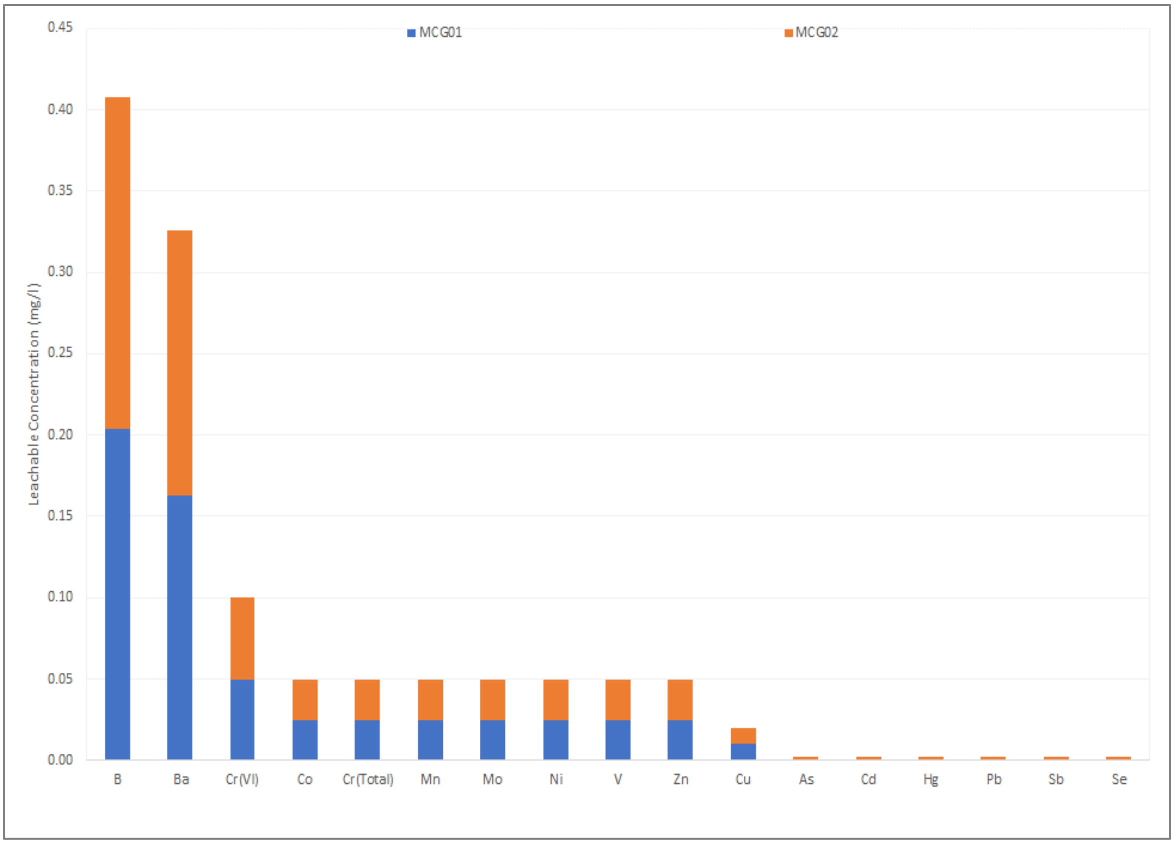



**Figure 10-11** **Comparison of Total Concentration analysis of Elements for Phase 02 samping analysis.**

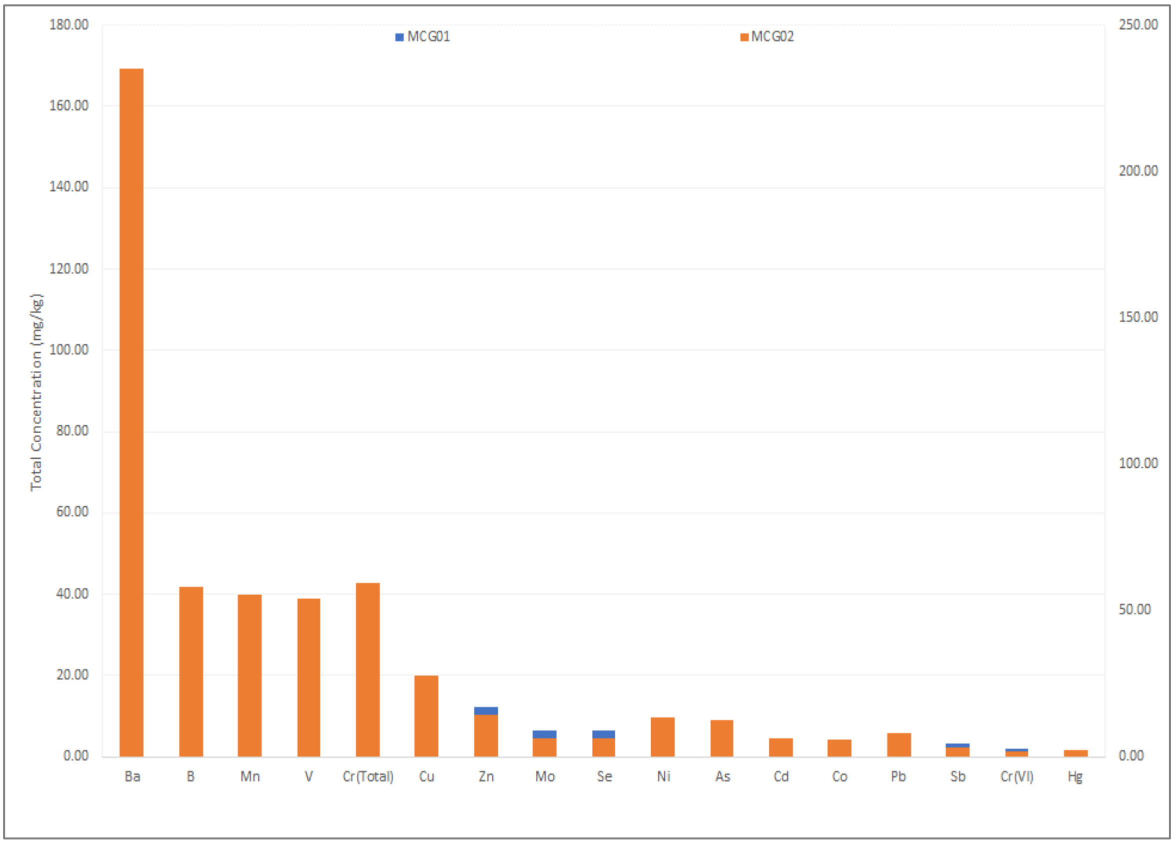



**Figure 10-12** **Comparison of Leachable Concentrations analysis of samples for Phase 02 samping analysis.**

**Table 10-24 Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MP DD (1:20 dilution).**

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

**Table 10-25 Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MP SS (1:20 dilution).**

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

**Table 10-26 Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MCG01 (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** | <3.20 | <0.001 | | 5.80 | 0.01 | | 500.00 | 0.50 | | 500.00 | 1.00 | | 2000.00 | 4.00 | |
| **B** | <32.0 | 0.204 | | 150.00 | 0.50 | | 15000.00 | 25.00 | | 15000.00 | 50.00 | | 60000.00 | 200.00 | |
| **Ba** | **159.800** | 0.163 | | 62.50 | 0.70 | | 6250.00 | 35.00 | | 6250.00 | 70.00 | | 25000.00 | 280.00 | |
| **Cd** | <3.20 | <0.001 | | 7.50 | 0.003 | | 260.00 | 0.15 | | 260.00 | 0.30 | | 1040.00 | 1.20 | |
| **Co** | <3.20 | <0.025 | | 50.00 | 0.50 | | 5000.00 | 25.00 | | 5000.00 | 50.00 | | 20000.00 | 200.00 | |
| **Cr(Total)** | 20.740 | <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** | 14.360 | <0.01 | | 16.00 | 2.00 | | 19500.00 | 100.00 | | 19500.00 | 200.00 | | 78000.00 | 800.00 | |
| **Hg** | **1.200** | <0.001 | | 0.93 | 0.006 | | 160.00 | 0.30 | | 160.00 | 0.60 | | 640.00 | 2.40 | |
| **Mn** | 29.08 | <0.025 | | 1000.00 | 0.50 | | 2500.00 | 25.00 | | 2500.00 | 50.00 | | 100000.00 | 200.00 | |
| **Mo** | <6.40 | <0.025 | | 40.00 | 0.07 | | 1000.00 | 3.50 | | 1000.00 | 7.00 | | 4000.00 | 28.00 | |
| **Ni** | 5.85 | <0.025 | | 91.00 | 0.07 | | 10600.00 | 3.50 | | 10600.00 | 7.00 | | 42400.00 | 28.00 | |
| **Pb** | <3.20 | <0.001 | | 20.00 | 0.01 | | 1900.00 | 0.50 | | 1900.00 | 1.00 | | 7600.00 | 4.00 | |
| **Sb** | <3.20 | <0.001 | | 10.00 | 0.02 | | 75.00 | 1.00 | | 75.00 | 2.00 | | 300.00 | 8.00 | |
| **Se** | <6.4 | <0.001 | | 10.00 | 0.01 | | 50.00 | 0.50 | | 50.00 | 1.00 | | 200.00 | 4.00 | |
| **V** | 25.02 | <0.025 | | 150.00 | 0.20 | | 2680.00 | 10.00 | | 2680.00 | 20.00 | | 10720.00 | 80.00 | |
| **Zn** | 12.130 | <0.025 | | 240.00 | 5.00 | | 160000.00 | 250.00 | | 160000.00 | 500.00 | | 640000.00 | 2000.00 | |
| **Inorganic ions** | | | | | | | | | | | | | | | |
| pH | 7.65 | 7.49 | | | | | | | | | | | | | |
| TDS | | **1065.000** | | | 1000.00 | | | 12500.00 | | | 25000.00 | | | 100000.00 | |
| Chloride | | <2.0 | | | 300.00 | | | 15000.00 | | | 30000.00 | | | 120000.00 | |
| Sulphate as $SO_4$ | | **736.500** | | | 250.00 | | | 12500.00 | | | 25000.00 | | | 100000.00 | |
| $NO_3$ as N | | **11.160** | | | 11.00 | | | 550.00 | | | 1100.00 | | | 4400.00 | |
| Fluoride | 2.03 | 0.13 | | 100.00 | 1.50 | | 10000.00 | 75.00 | | 10000.00 | 150.00 | | 40000.00 | 600.00 | |
| Cyanide | <1.55 | <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 10-27 Leachable Concentration (LC) and Total Concentration (TC) results of sampling locality MCG02 (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** | **12.63** | <0.001 | | 5.80 | 0.01 | | 500.00 | 0.50 | | 500.00 | 1.00 | | 2000.00 | 4.00 | |
| **B** | 58.160 | 0.204 | | 150.00 | 0.50 | | 15000.00 | 25.00 | | 15000.00 | 50.00 | | 60000.00 | 200.00 | |
| **Ba** | **235.20** | 0.163 | | 62.50 | 0.70 | | 6250.00 | 35.00 | | 6250.00 | 70.00 | | 25000.00 | 280.00 | |
| **Cd** | 6.31 | <0.001 | | 7.50 | 0.003 | | 260.00 | 0.15 | | 260.00 | 0.30 | | 1040.00 | 1.20 | |
| **Co** | 5.830 | <0.025 | | 50.00 | 0.50 | | 5000.00 | 25.00 | | 5000.00 | 50.00 | | 20000.00 | 200.00 | |
| **Cr(Total)** | 59.540 | <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** | **27.58** | <0.01 | | 16.00 | 2.00 | | 19500.00 | 100.00 | | 19500.00 | 200.00 | | 78000.00 | 800.00 | |
| **Hg** | **2.40** | <0.001 | | 0.93 | 0.006 | | 160.00 | 0.30 | | 160.00 | 0.60 | | 640.00 | 2.40 | |
| **Mn** | 55.21 | <0.025 | | 1000.00 | 0.50 | | 2500.00 | 25.00 | | 2500.00 | 50.00 | | 100000.00 | 200.00 | |
| **Mo** | <6.40 | <0.025 | | 40.00 | 0.07 | | 1000.00 | 3.50 | | 1000.00 | 7.00 | | 4000.00 | 28.00 | |
| **Ni** | 13.46 | <0.025 | | 91.00 | 0.07 | | 10600.00 | 3.50 | | 10600.00 | 7.00 | | 42400.00 | 28.00 | |
| **Pb** | 8.040 | <0.001 | | 20.00 | 0.01 | | 1900.00 | 0.50 | | 1900.00 | 1.00 | | 7600.00 | 4.00 | |
| **Sb** | <3.20 | <0.001 | | 10.00 | 0.02 | | 75.00 | 1.00 | | 75.00 | 2.00 | | 300.00 | 8.00 | |
| **Se** | <6.4 | <0.001 | | 10.00 | 0.01 | | 50.00 | 0.50 | | 50.00 | 1.00 | | 200.00 | 4.00 | |
| **V** | 54.16 | <0.025 | | 150.00 | 0.20 | | 2680.00 | 10.00 | | 2680.00 | 20.00 | | 10720.00 | 80.00 | |
| **Zn** | 14.360 | <0.025 | | 240.00 | 5.00 | | 160000.00 | 250.00 | | 160000.00 | 500.00 | | 640000.00 | 2000.00 | |
| **Inorganic ions** | | | | | | | | | | | | | | | |
| pH | 3.13 | 3.05 | | | | | | | | | | | | | |
| TDS | | **1999.00** | | | 1000.00 | | | 12500.00 | | | 25000.00 | | | 100000.00 | |
| Chloride | | <2.0 | | | 300.00 | | | 15000.00 | | | 30000.00 | | | 120000.00 | |
| Sulphate as $SO_4$ | | **1176.00** | | | 250.00 | | | 12500.00 | | | 25000.00 | | | 100000.00 | |
| $NO_3$ as N | | 1.390 | | | 11.00 | | | 550.00 | | | 1100.00 | | | 4400.00 | |
| Fluoride | <0.50 | <0.05 | | 100.00 | 1.50 | | 10000.00 | 75.00 | | 10000.00 | 150.00 | | 40000.00 | 600.00 | |
| Cyanide | <1.55 | <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**

## 11. 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 11-2 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 11-1 GMQ Index.**

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

### 11.1. 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 11-1 cells shaded in blue indicate the classification of the aquifer.

**Table 11-1 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. |

### 11.2. 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).

### 11.3. 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 11-2 Groundwater Quality Management Index.**

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

### 11.4. 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 11-4 while the aquifer risk matrix is summarised in Table 11-4 below. The DRASTIC index (DI) can be computed using the following formula.

**Equation 11-2 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 11-3 below (Lynch et al, 1994).

**Table 11-3 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 11-4 DRASTIC Index.**

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

According to the DRASTIC index methodology applied, this mining activities and associated infrastructure's risk to groundwater pollution is rated as "**High**", **Di** = 121 due to the relatively shallow groundwater table/ piezometric head as well as fairly flat topographical slopes within the greater study area (Table 11-5).

**Table 11-5 DRASTIC weighting factors.**

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

### 11.5. 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 11-1).

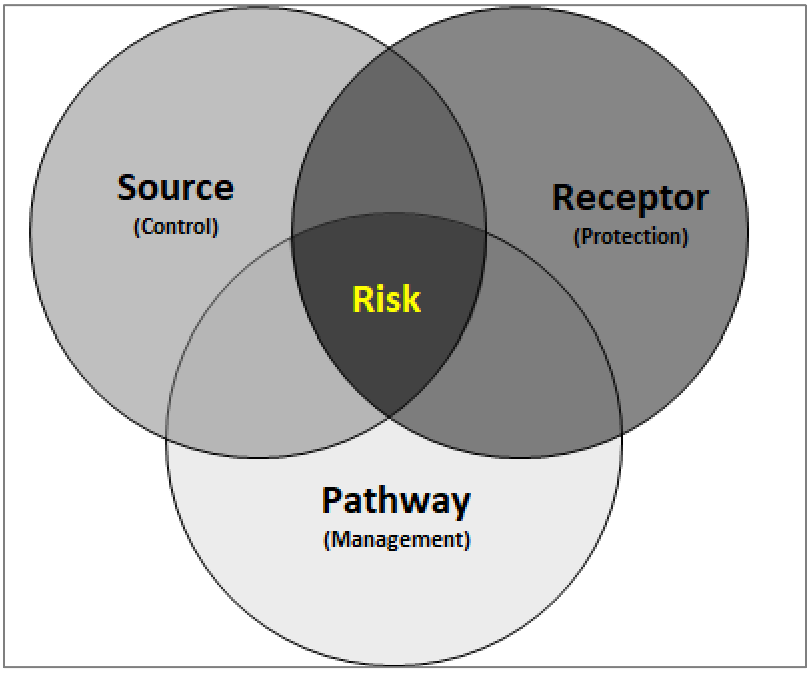



**Figure 11-1** **Source pathway receptor principle.**

#### 11.5.1. Potential sources

The following potential sources have been identified:

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

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

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

#### 11.5.2. 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.

#### 11.5.3. Potential receptors

The following receptors were identified:

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

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

## 12. RESERVE DETERMINATION

### 12.1. Existing water demand and scale of abstraction

The Department classifies groundwater abstraction categories based on the existing abstraction[14] volumes from the groundwater management unit as well as volume of recharge which is abstracted by the Applicant/Licensee in relation to the specified property[15]:

i. Category A: Small scale abstractions (<60% recharge on property).
ii. Category B: Medium scale abstractions (60-100% recharge on property).
iii. Category C: Small scale abstractions (>100% recharge on property).

An abstraction scale can be calculated by application of the following equation:

**Equation 12-1 Groundwater abstraction scale.**

$$ABS_{(Scale)} = ABS_{(Total)} / RE_{(Area)} \times 100$$

**where:**

**ABS** $_{(Scale)}$ = Scale of Abstraction

**ABS** $_{(Total)}$ = Total property/catchment abstraction

**RE** $_{(Area)}$ = Recharge on the area

Abstraction of water from the study area’s host-aquifer, expressed as a percentage of recharge on the mining properties, is classified as **Category A** (Proposed abstraction = ~43.56% of rainfall recharge) (refer to Table 12-1), while abstraction of water from the study area’s host-aquifer, expressed as a percentage of recharge reporting to the delineated sub-catchment, is also classified as **Category A** (Proposed abstraction =

[14] It should be noted that the hydrocensus user survey aimed to verify existing abstraction volumes, however this is not a quantitative measure and validity as well as legality should be confirmed.

[15] The recharge of the host-aquifer on the registered property is not indicative of the total volume of groundwater available for abstraction as property boundaries do not coincide with aquifer boundaries.

~19.35% of rainfall recharge) (refer to Table 12-2). The latter indicates a small scale of abstraction (<60% recharge on property) and consequently low levels of stress in terms of the abstraction recharge ratio.

**Table 12-1 Groundwater abstraction scale as a percentage of the property size.**

| | |
|---|---|
| **Groundwater abstraction scale** | |
| **Groundwater recharge** | |
| Rainfall recharge reporting to host-aquifer underneath the relevant property ($m^3/a$) | 266 363.00 |
| **Groundwater demand** | |
| Total groundwater abstraction on the relevant property ($m^3/a$) | 116 017.92 |
| **Scale of abstraction** | |
| Category A - Small scale of abstraction (>100.0% of recharge on the property) | 43.56% |

**Table 12-2 Groundwater abstraction scale as a percentage of the delineated catchment size.**

| | |
|---|---|
| **Groundwater abstraction scale** | |
| **Groundwater recharge** | |
| Rainfall recharge reporting to host-aquifer underneath the relevant catchment ($m^3/a$) | 1 049 708.50 |
| **Groundwater demand** | |
| Total groundwater abstraction on the relevant catchment ($m^3/a$) | 87 091.20 |
| Total groundwater abstraction on the relevant property ($m^3/a$) | 116 017.92 |
| **Scale of abstraction** | |
| Category A - Small scale of abstraction (>100.0% of recharge on the property) | 19.35% |

## 12.2. Rapid Reserve Determination

### 12.2.1. Methodology

The Department of Water Affairs, Human Settlements and Sanitation is required to determine the Reserve for all or part of any significant water resource before any water use can be allocated and/or licensed. Reserve can be defined as the quantity and quality of water required to:

(a) Satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No 108 of 1997), for people who are now or who will, in the reasonably near future, be -

- relying upon;
- taking water from; or
- being supplied from the relevant water resource; and

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use the relevant water resource.[Source: National Water Act (Act No. 36 of 1998)].

The groundwater component of the Reserve is determined according to Equation 13-1, below:

**Equation 12-2 Reserve Determination[16].**

$$\mathrm{GW}_{(\mathrm{Allocate})} = (\mathrm{Re} + \mathrm{GW}_{(\mathrm{In})} - \mathrm{GW}_{(\mathrm{Out})}) - \mathrm{BHN} - \mathrm{GW}_{(\mathrm{Bf})}$$

**where:**

[16] It should be noted that these calculations are based on a Rapid Reserve Determination and do not evaluate the entire groundwater management unit. Accordingly, these calculations should support the Department however it is recommended that a comprehensive Reserve Determination be performed as part of any authorisation process in order to verify existing and authorised abstraction volumes from this catchment.

**GW $_{(Allocate)}$** = Groundwater Allocation

**Re** = Recharge

**GW $_{(In)}$** = Groundwater Inflow

**GW $_{(Out)}$** = Groundwater Outflow

**BHN** = Basic Human Needs

**GW $_{(Bf)}$** = Groundwater Contribution to Baseflow

The Groundwater Reserve and water available for abstraction was calculated through a Rapid Reserve Determination methodology using the Aquiworx software developed by the North-West University (Dennis, 2016).

### 12.2.2. Resource Directed Measures Assessment: Quaternary catchment

The main objective of the Chief Directorate: Resource Directed Measures (RDM) is to ensure protection of water resources. The regional RDM info should be submitted with the request for a Reserve Determination to render more confidence to the Reserve calculation. The study area is situated within quaternary catchment C11B (nett surface area of 534.60km$^2$) and falls under the Vaal Water Management Area. Table 12-3 summarises the relevant parameters for the specific quaternary catchment.

**Table 12-3 Quaternary catchment C11B parameters.**

| Area | Population | General Authorisation (m$^3$/ha/a | Rainfall (mm/a) | Current wate use (Mm$^3$/a) |
|---|---|---|---|---|
| 534.60 | 1554 | 150.00 | 705.30 | 0.09 |

Note: Data summarised in this table is sourced from Aquiworx (2016).

Table 12-4 summarises the Reserve Determination for the quaternary catchment C11B. From the calculations it is evident that the Ecological Water Requirement (EWR) i.e., groundwater contribution to baseflow is the main driver in groundwater consumption and totals 16.32% of recharge to the quaternary catchment. Based on the calculations it can be concluded that there is a surplus volume/allocable groundwater volume of 18.84M/m$^3$/a for this quaternary catchment.

**Table 12-4 Quantification of Reserve: Quaternary catchment C11B.**

| **Quantification of Reserve: Local catchment** | |
|---|---|
| **Basic Human Need (BHN)** | |
| Population | 1 554 |
| Basic Human Need (l/d/p) | 25.00 |
| Basic Human Need Total (M/m$^3$/a) | 0.01 |
| **Rainfall Recharge** | |
| Recharge (M/m$^3$/a) | 22.75 |
| **Ecological Water Requirements** | |
| Baseflow (M/m$^3$/a) | 3.70 |
| **Reserve** | |
| Groundwater Reserve as a % of Recharge | 16.32 |
| Existing groundwater abstraction (M/m$^3$/a) | 0.09 |
| Newly proposed groundwater abstraction: Cavalier production BHs (M/m3/a) | 0.12 |
| **Groundwater available for allocation** | |
| Groundwater available for allocation (M/m$^3$/a) | 18.84 |
| Groundwater available for allocation (l/s) | 605.86 |

### 12.2.3. RDM Assessment: Local catchment

The following table summarises the Reserve Determination for the local catchment. Groundwater divides have been assumed to align with surface water divides and it is expected that groundwater will not flow across this type of boundaries. For the purposes of this investigation, it can be assumed that groundwater abstraction will be limited to the meso-catchment (resource management unit (RMU)) i.e., sub-catchment for the simulated groundwater capture zone which has a total area of 27.68km$^2$ as shown in Figure 12-1. If current abstraction and ecological water requirement (Reserve) is accounted for there exists a surplus volume/allocable groundwater volume of 0.78M/m$^3$/a (25.14l/s) within the RMU. Accordingly, it can be concluded that the proposed volume of groundwater to be abstracted from the production boreholes, falls within the calculated groundwater available for allocation, which also accounts for the Reserve.

**Table 12-5 Quantification of Reserve: Local catchment.**

| **Quantification of Reserve: Local catchment** | |
|---|---|
| **Basic Human Need (BHN)** | |
| Population | 1 554 |
| Basic Human Need (l/d/p) | 25.00 |
| Basic Human Need Total (M/m$^3$/a) | 0.01 |
| **Rainfall Recharge** | |
| Recharge (M/m$^3$/a) | 1.18 |
| **Ecological Water Requirements** | |
| Baseflow (M/m$^3$/a) | 0.19 |
| **Reserve** | |
| Groundwater Reserve as a % of Recharge | 17.51 |
| Existing groundwater abstraction (M/m$^3$/a) | 0.09 |
| Newly proposed groundwater abstraction: Cavalier production BHs (M/m$^3$/a) | 0.12 |
| **Groundwater available for allocation** | |
| Groundwater available for allocation (M/m$^3$/a) | 0.78 |
| Groundwater available for allocation (m$^3$/a) | 782 104.47 |
| Groundwater available for allocation (l/s) | 25.14 |

## 12.3. Resource Quality Objectives

The following Resource Quality Objectives should be met:

i. Ensure that Schedule 1 water users within the catchment have adequate water supply to sustain the basic human need.

ii. Ensure that adequate water is available to maintain base flow in the Vaal River and associated drainage system.

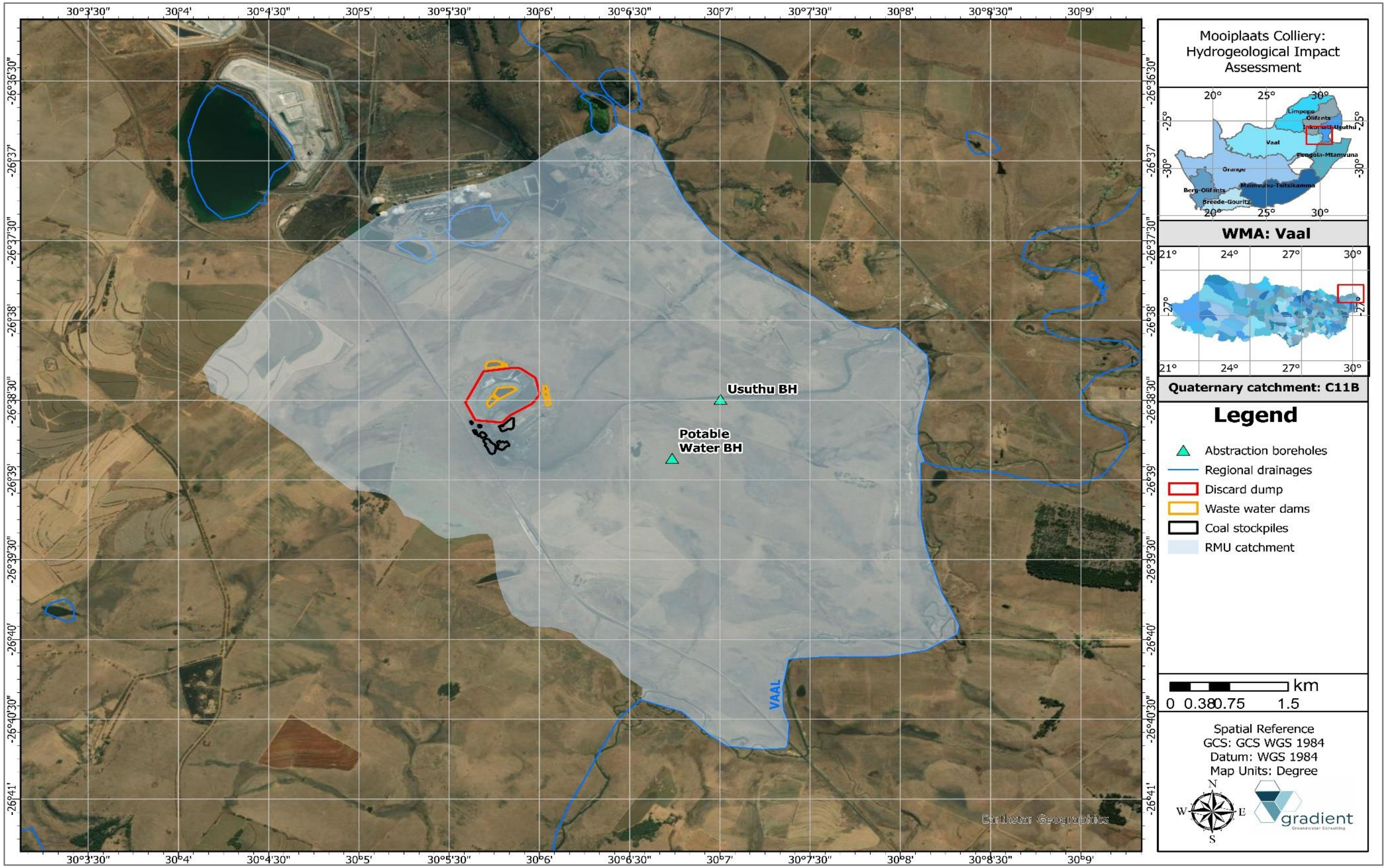
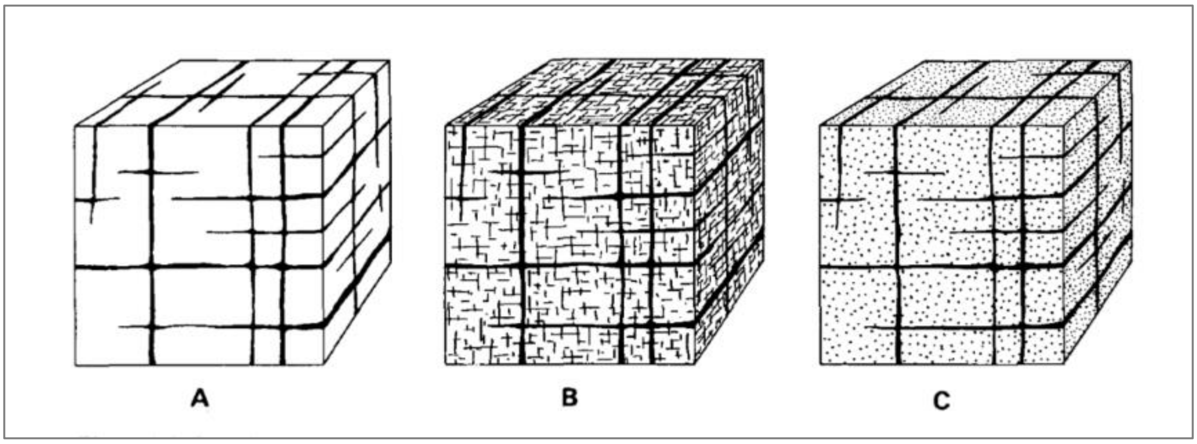



**Figure 12-1** **Map depicting the delineated Resource Management Unit (RMU).**

## 13. HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. The latter defines the hydrogeological environment and is used to design and construct the numerical model. Data gathered during the desk study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system. Figure 13-1 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 13-2 and Figure 13-3 depicts west-east cross sections of the study area during different phases of the development with relevant data and information included (refer to Figure 14-2 for spatial reference).




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

**Figure 13-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).**

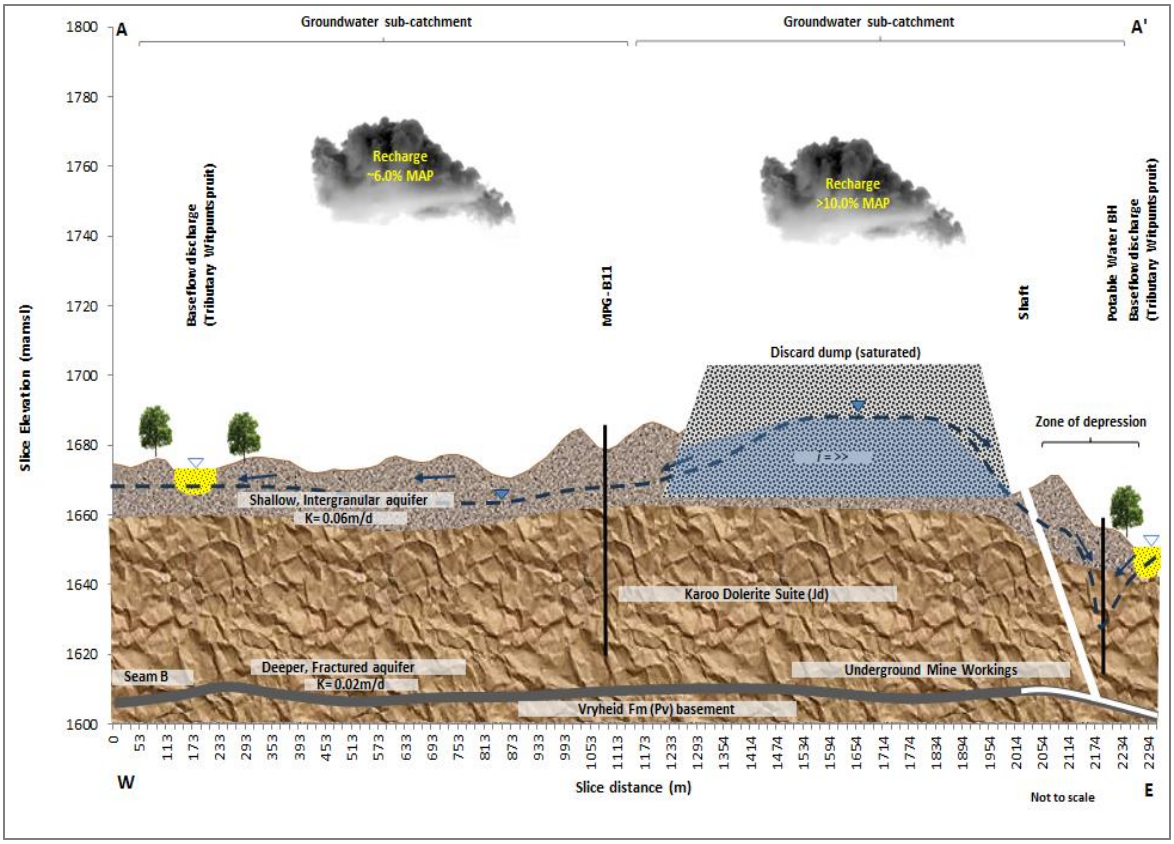



**Figure 13-2** Conceptual hydrogeological model indicating the saturated discard dump (Operational phase).

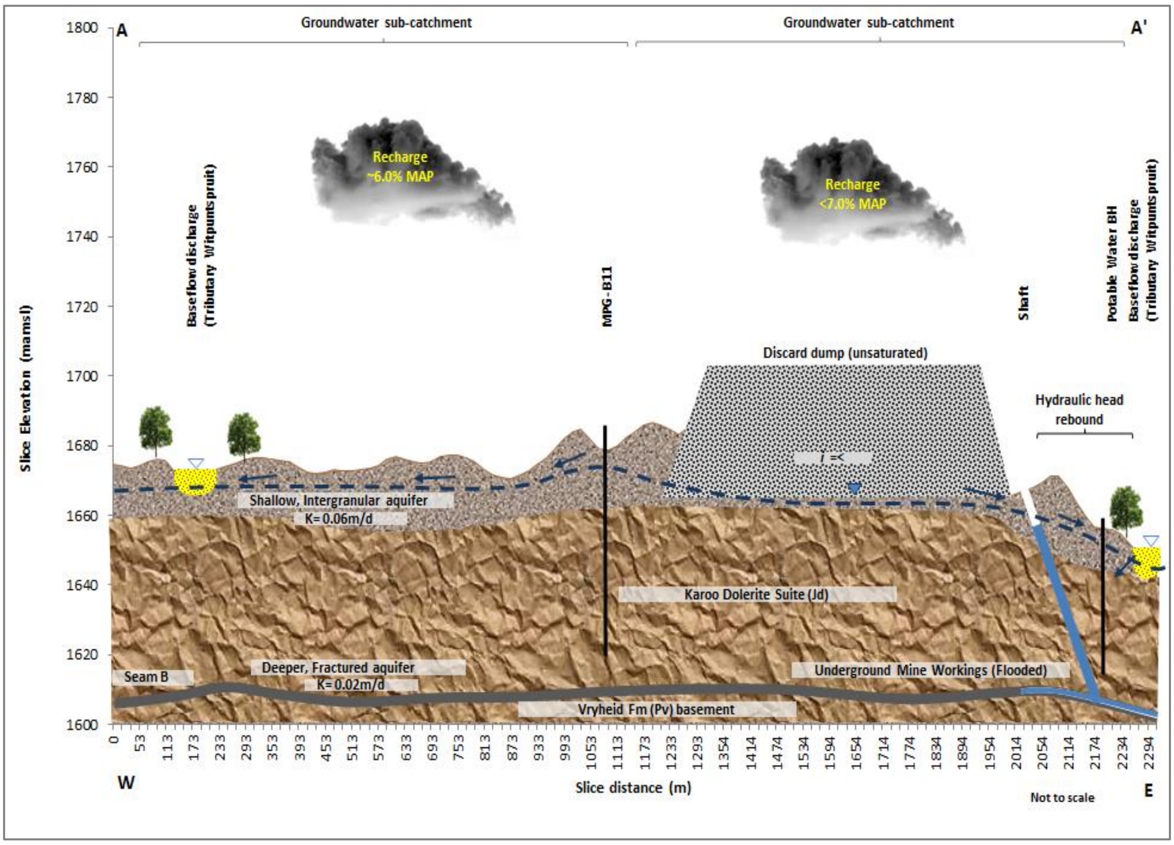



**Figure 13-3** Conceptual hydrogeological model indicating the unsaturated discard dump (Post-closure phase).

# 14. HYDROGEOLOGICAL NUMERICAL MODEL

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

## 14.1. Approach to modeling

The typical workflow and modelling approach employed is summarised in Figure 14-1 below and encompass a conceptualisation phase, calibration phase as well as a prediction phase.

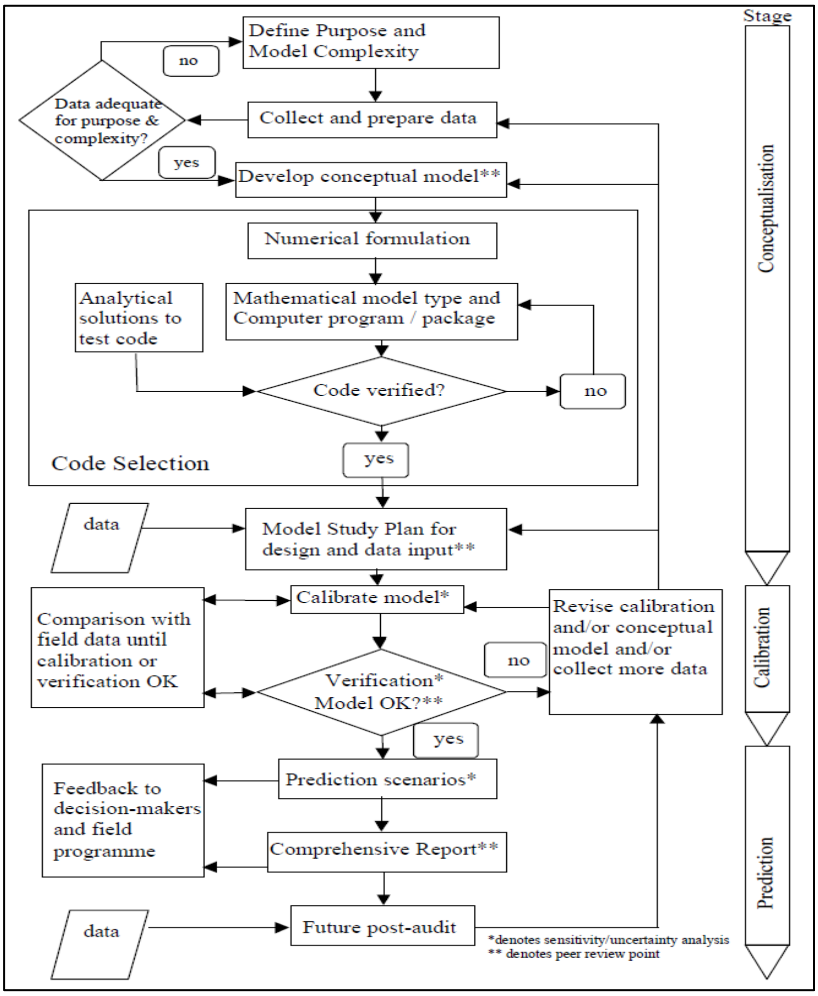



**Figure 14-1 Workflow numerical groundwater flow model development.**

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 14-1 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).

## 14.2. 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.

## 14.3. Model development

### 14.3.1. Model domain

A model grid was created with global origin X: -90103.13 [m] and Y: -2950804.97 [m] using triangular prism type of elements. The model has a width of 20268.7 [m], height of 20823.4 [m], depth of 405.76 [m] and spans an area of $2.65E^{+8}$ $m^2$ with a volume of ~3.76 $E^{+10}$ $m^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e. discharge zones and no-flow zones) as depicted in Figure 14-2 . Figure 14-3 indicates the model super-mesh view from which the finite element mesh was generated while Figure 14-4 (plan view), Figure 14-5 (west-east orientation) and Figure 14-6 (cross sectional view) shows the model finite element mesh (FEM) construction. Figure 14-7 depicts a W-E hydraulic head cross section.

### 14.3.2. Model construction

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

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

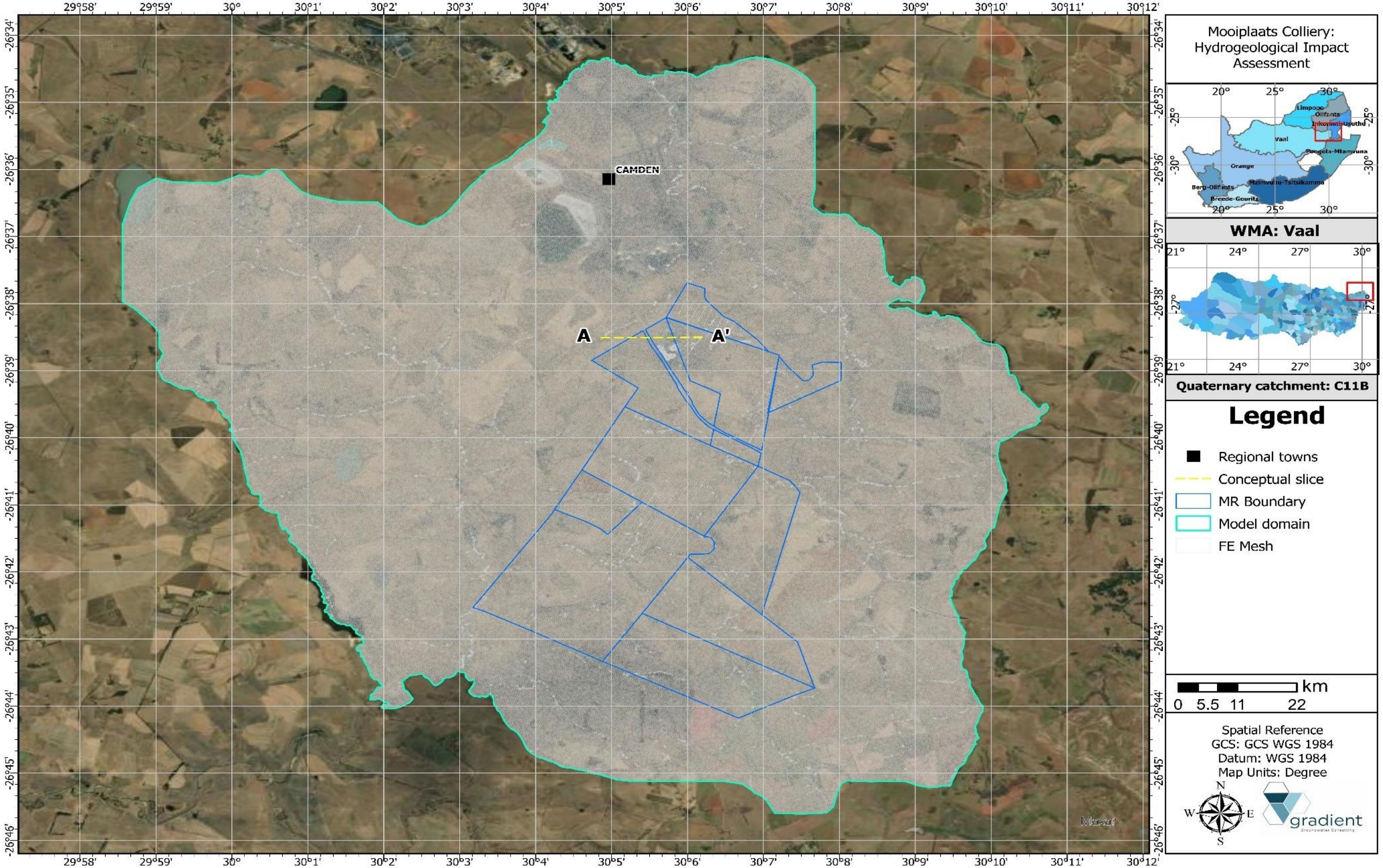



**Figure 14-2** **Model development: Aerial extent of the delineated model domain.**

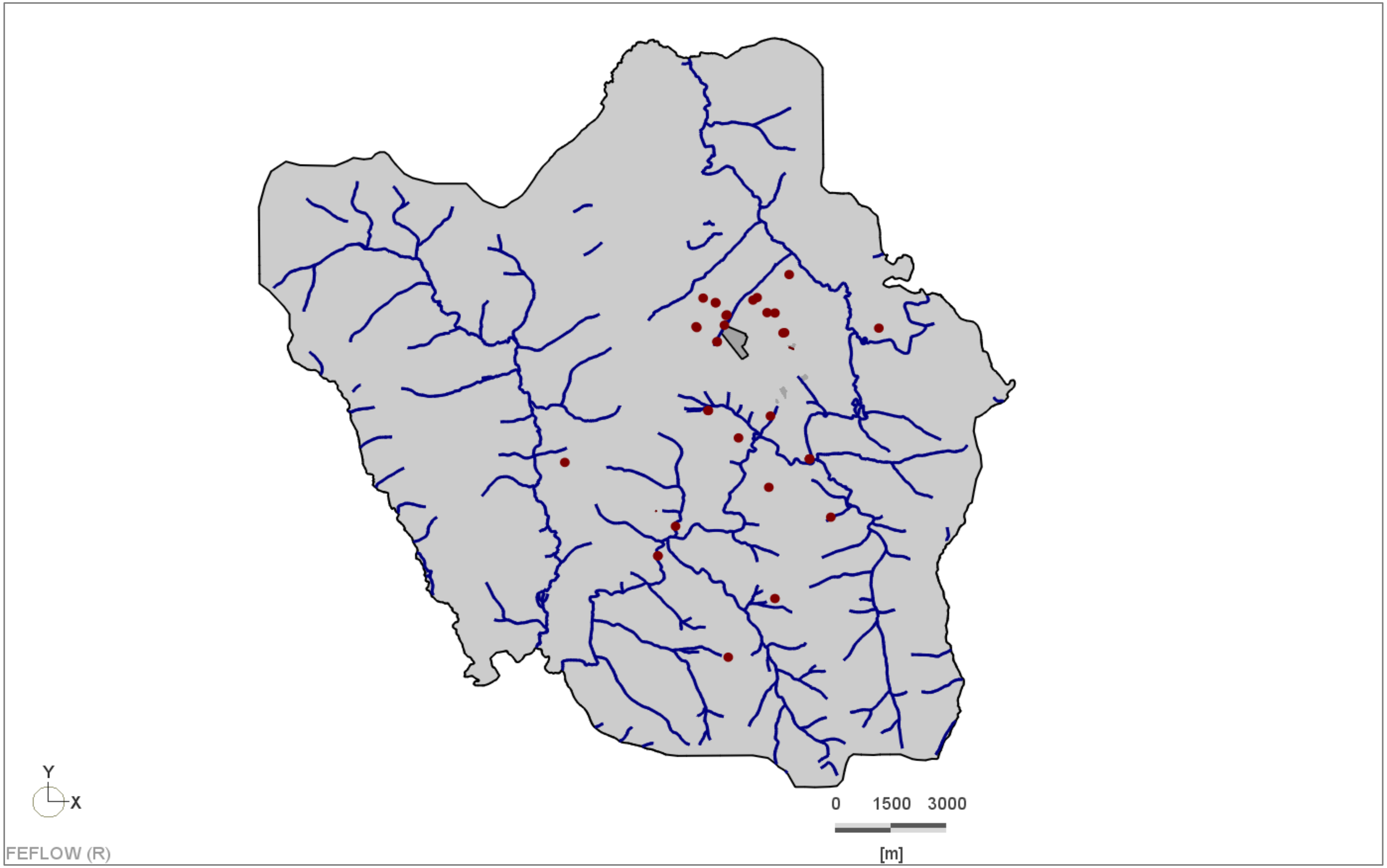



**Figure 14-3** **Model development: Super mesh view.**

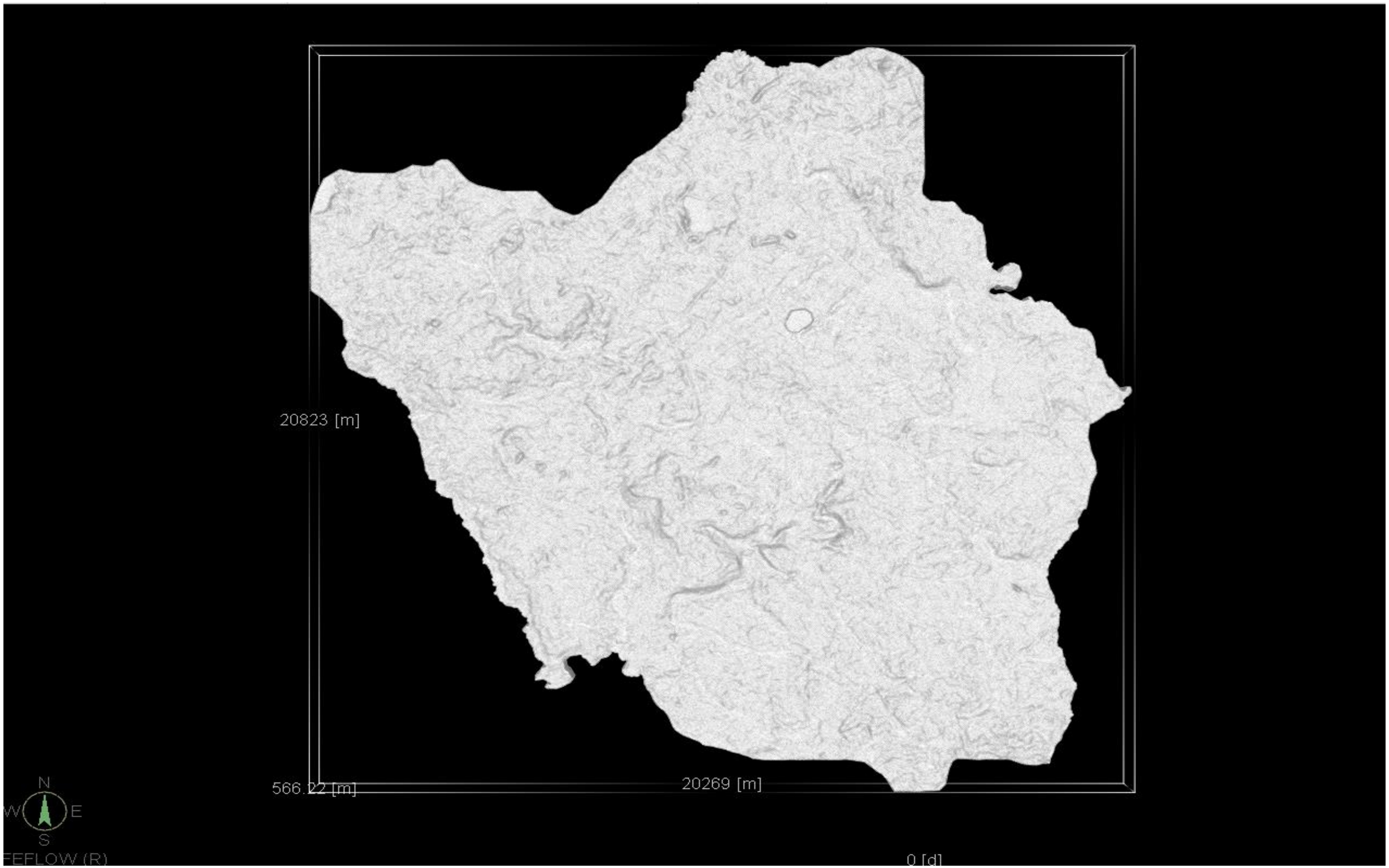



**Figure 14-4 Model development: 3-D FEM mesh view of the model domain depicting a plan-view orientation.**

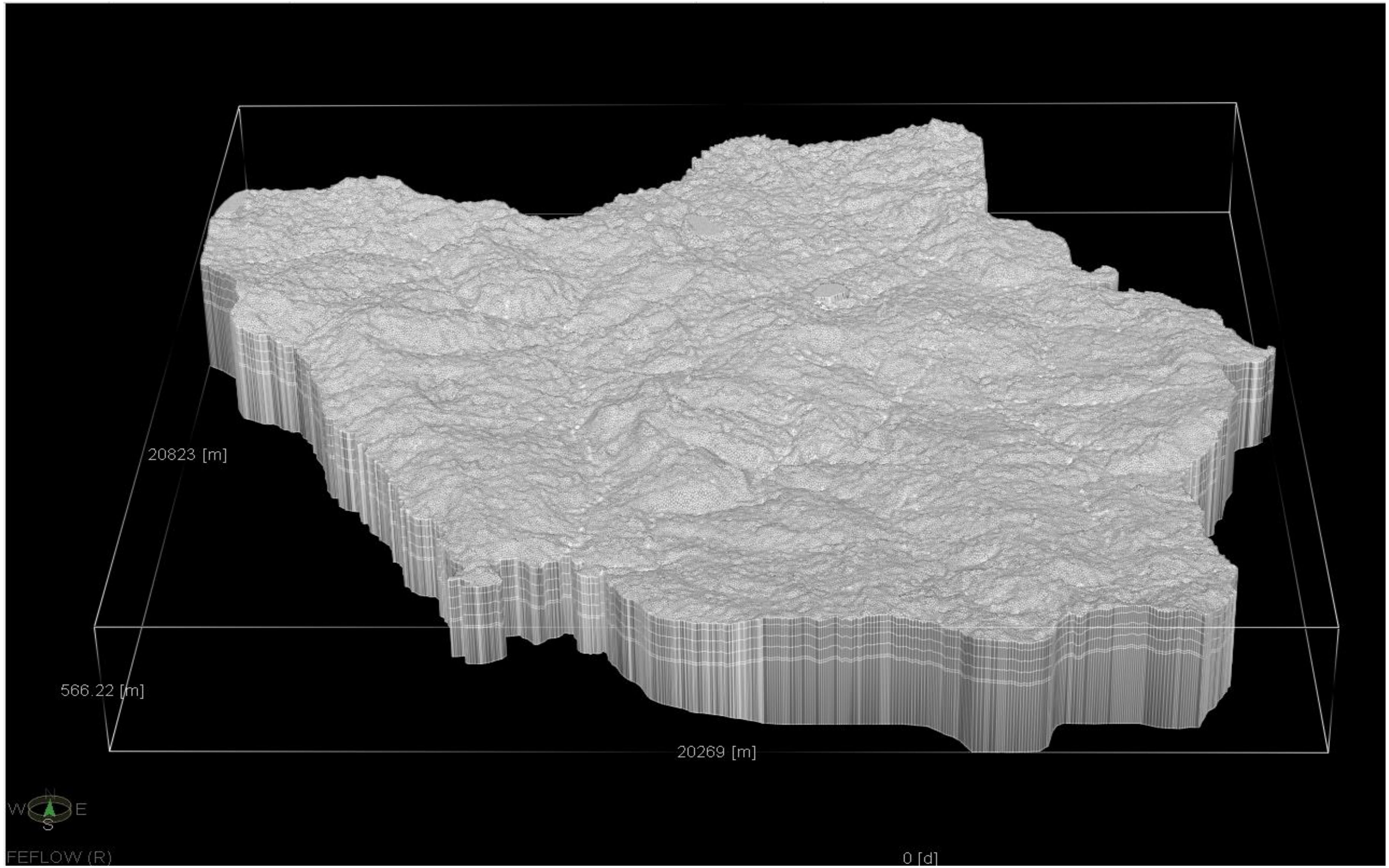



**Figure 14-5** **Model development: 3-D FEM mesh view of the model domain depicting a plan view in a west-east orientation.**

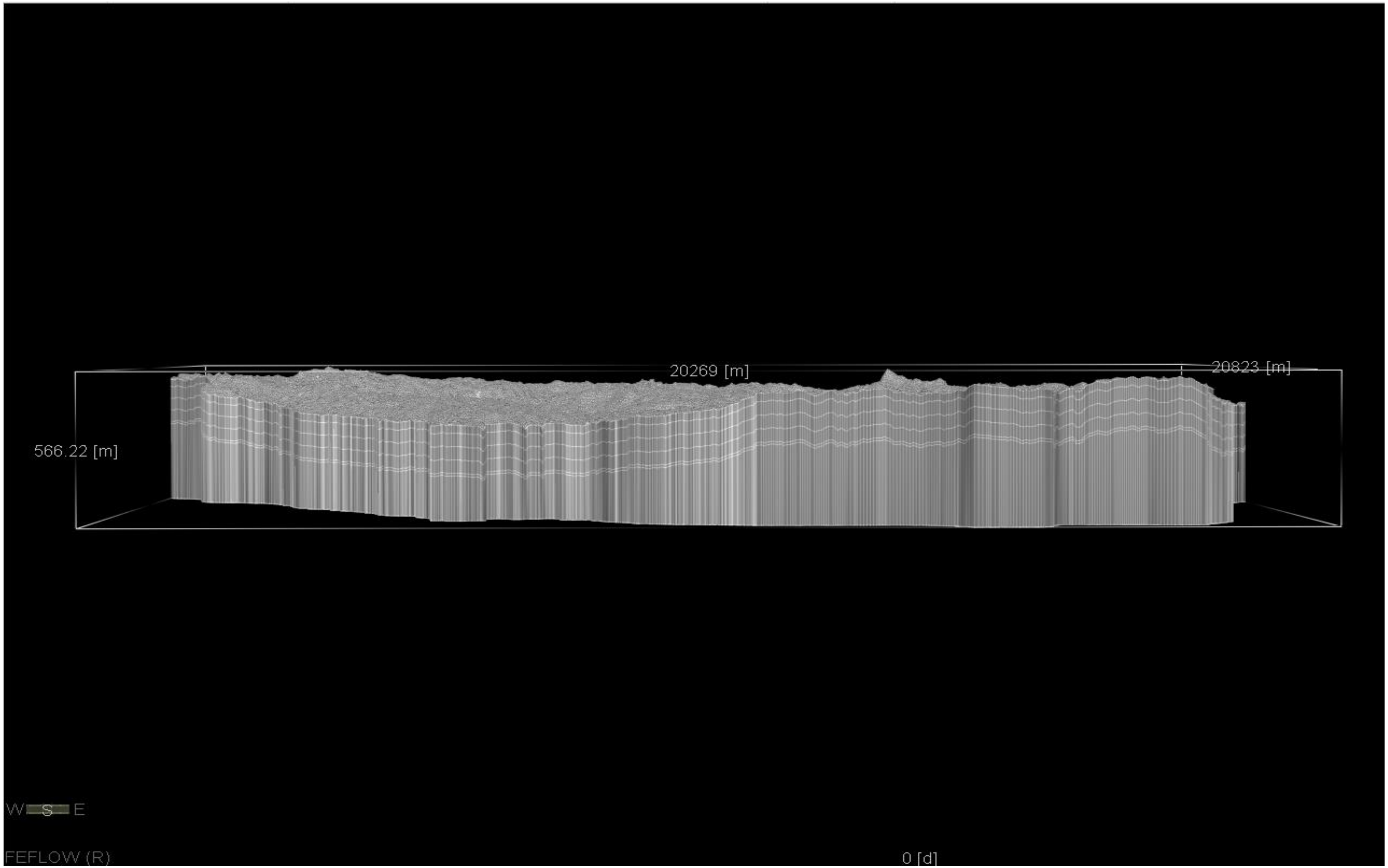



**Figure 14-6 Model development: 3-D FEM mesh view of the model domain depicting a cross sectional view in a west-east orientation.**

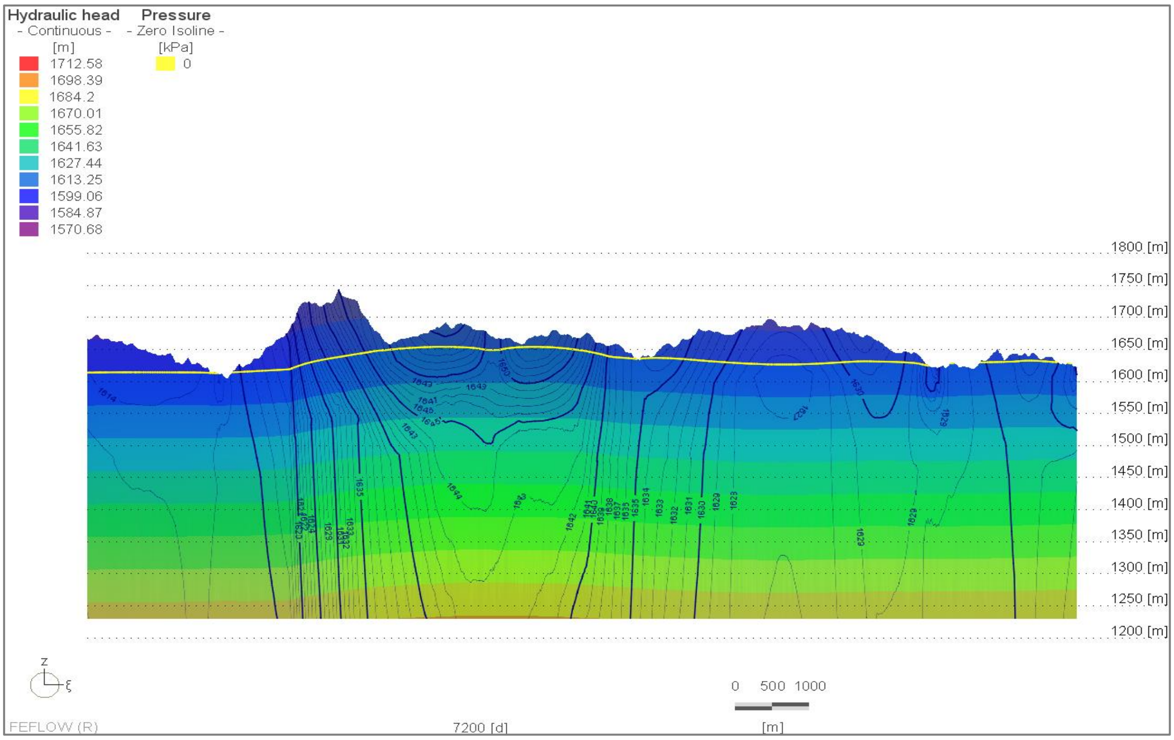



**Figure 14-7 Model domain 3-D FEM mesh view (cross sectional view west--east orientation (Refer to conceptual slice A-A').**

### 14.3.3. 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[17]. Layer sequence and average thickness are listed below (Table 14-1):

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: A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations (Average thickness = 50.0 m).

iii. Layer 03: 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 = ~50.0 m).

iv. Layer 04: A deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock (Average thickness = ~50.0 m).

v. Layer 05: The coal-seam (Seam B) aquifer (Average thickness = ~10.0 m).

vi. Layer 06: A deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock (Average thickness = ~150.0 m).

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

#### 14.3.4. Boundary conditions

For the purposes of this model, it is assumed that the lower perimeter of the model domain i.e. competent Karoo basement is generally impermeable. Accordingly, this boundary is represented numerically as a "no-flow" boundary condition and was assigned as such. Topographical high perimeters (groundwater divides) were assigned as no-flow boundaries while major rivers i.e. Vaal Rivers and Witpuntspruit were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[18]. Neighbouring boreholes identified as part of the regional hydrocensus survey were assigned as pumping well boundary conditions[19]. Following the steady state calibration phase, well boundary conditions were adjusted catering for scenario specific outcomes. Figure 14-8 indicates different boundary conditions assigned within the model domain.

[18] Refer to "gaining stream" assumption.

[19] 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.

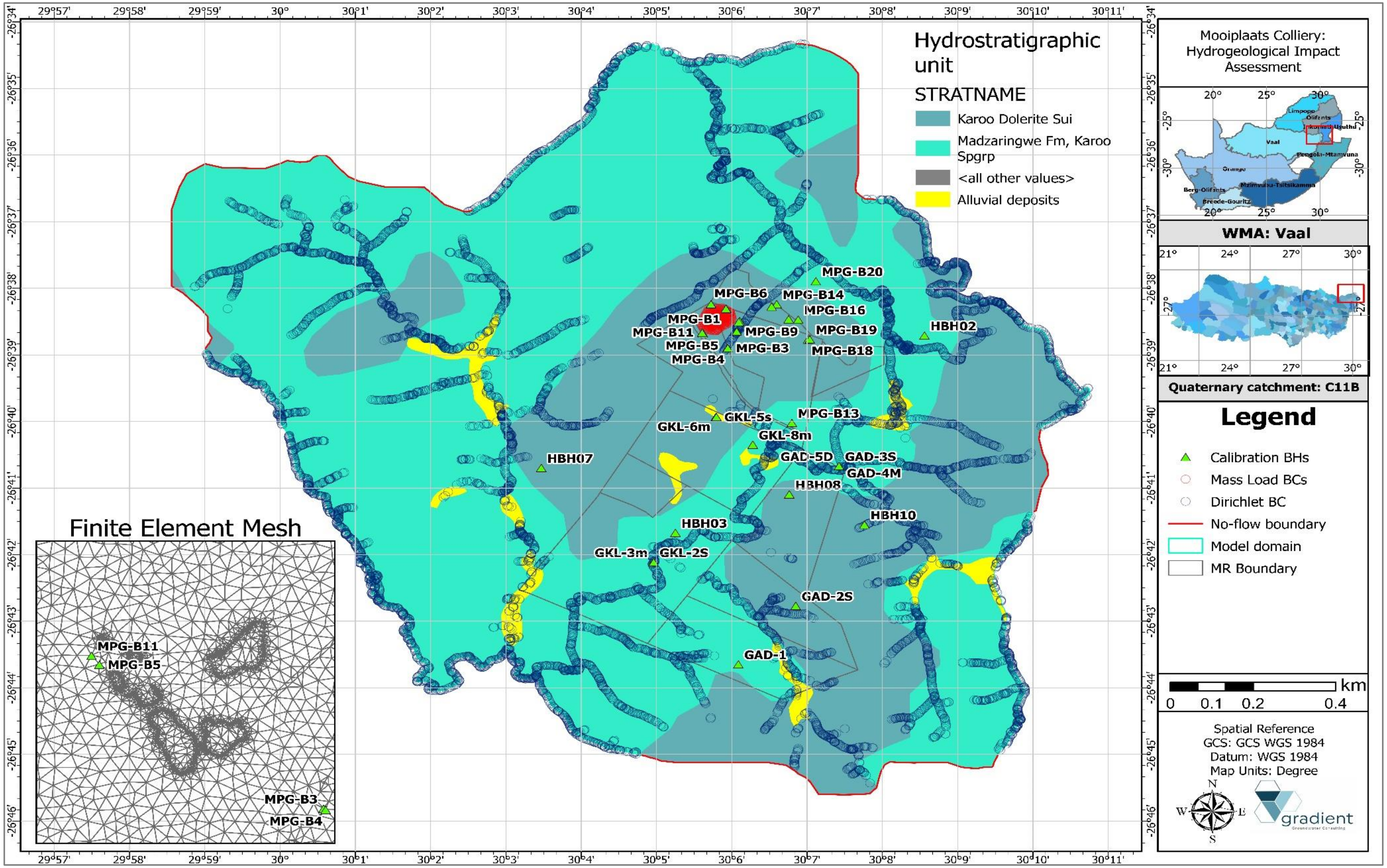



**Figure 14-8** **Model domain and boundary conditions.**

#### 14.3.5. Model hydraulic properties

The following sections provide a brief overview of the model hydraulic parameters assigned as summarised in Table 14-1.

#### 14.3.6. 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[20]. Hydraulic conductivity values range from 0.0075m/d for dyke matrices, to 0.15 m/d for more permeable alluvial deposit zones. The coal seam#B (layer 05) was assigned a hydraulic conductivity value of 0.05m/d. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in Figure 14-13 and Figure 14-9 . 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. Figure 14-9 depicts the spatial hydraulic conductivity distribution for the model domain.

#### 14.3.7. Sources and sinks

The primary source to groundwater is through recharge. Recharge refers to the addition of water to the saturated zone either through downward percolation from the unsaturated zone or from seepage from an adjacent aquifer. An approximation of recharge for the study area is estimated at between 1.5%~3.50 % of MAP as summarised shown in Figure 14-10. The recharge volume on the discard dump footprint was assigned variable recharge rates of between 5% - 7%. Sinks in the model domain include groundwater abstraction from privately owned and community boreholes[21] as well as groundwater discharge to baseflow.

#### 14.3.8. Storativity and specific storage

Specific storage values per layer were assigned as follows: (Layer01/ Layer02 / Layer05 = 1.00E$^{-4}$, Layer03/ Layer04/ Layer06 = 1.00E$^{-5}$) as indicated in Figure 14-11 below.

#### 14.3.9. Porosity

A porosity value of 3.0 % was assigned for the matrix of the weathered formations whereas fractured formations of layer 2 to layer 6 was assigned a porosity value of 1.0 %. The coal seam #B (layer 05) was assigned a porosity value of 3% as well (refer to Figure 14-12).

#### 14.3.10. 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.

[20] 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.

[21] 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.

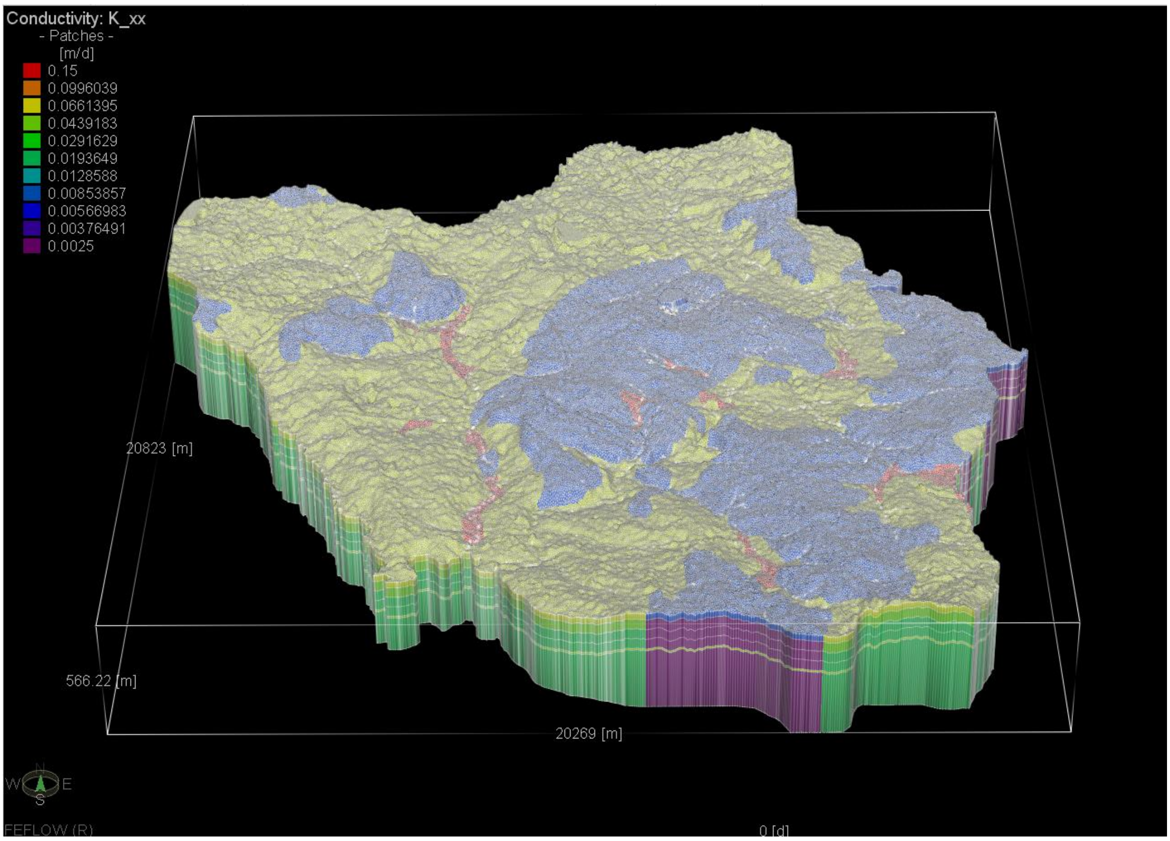



**Figure 14-9** **Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.**

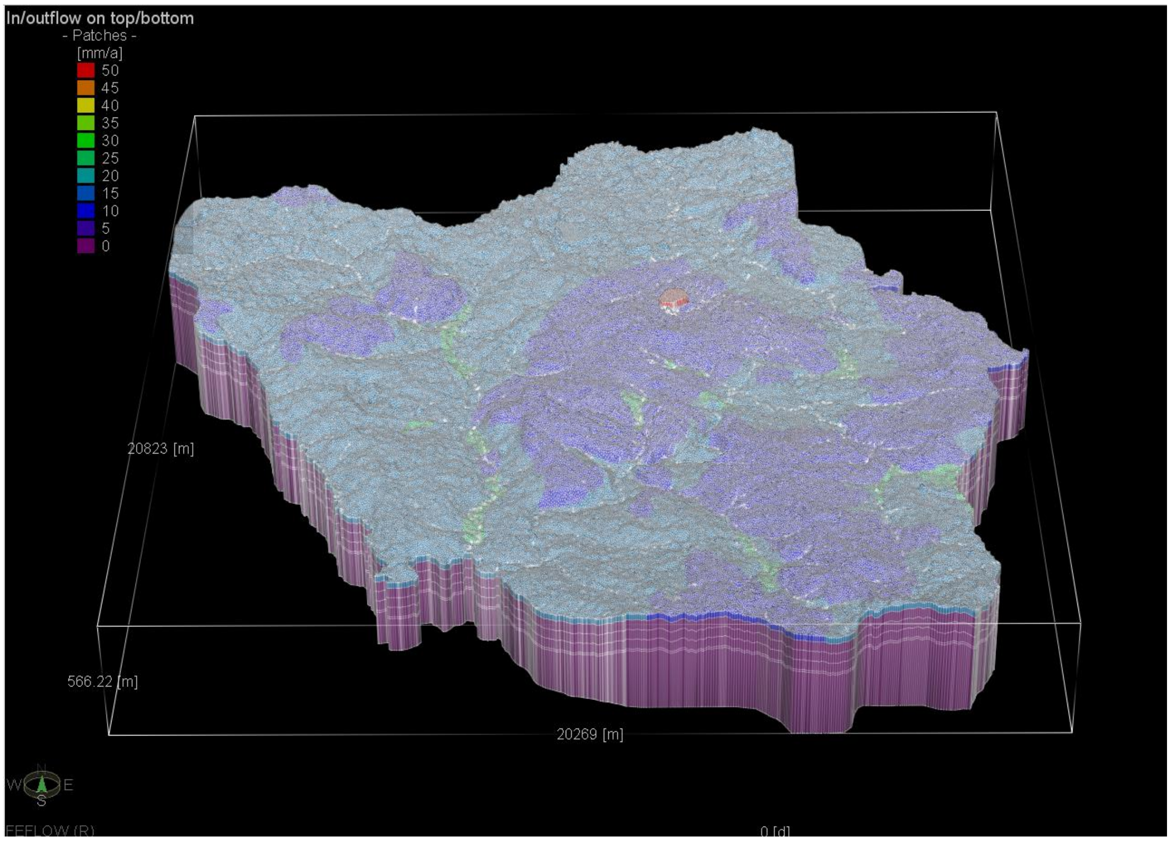



**Figure 14-10** **Model development: Numerical groundwater flow model: Recharge distribution.**

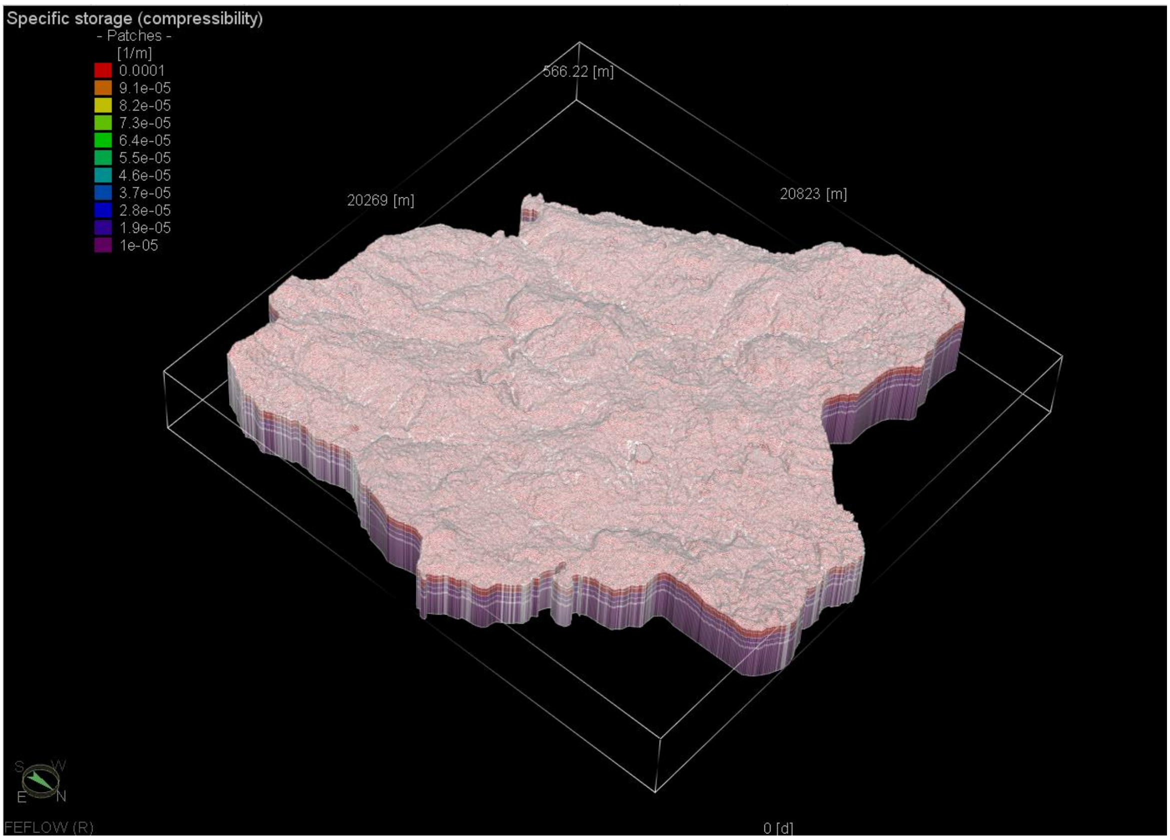



**Figure 14-11 Model development: Numerical groundwater flow model: Specific storage distribution.**

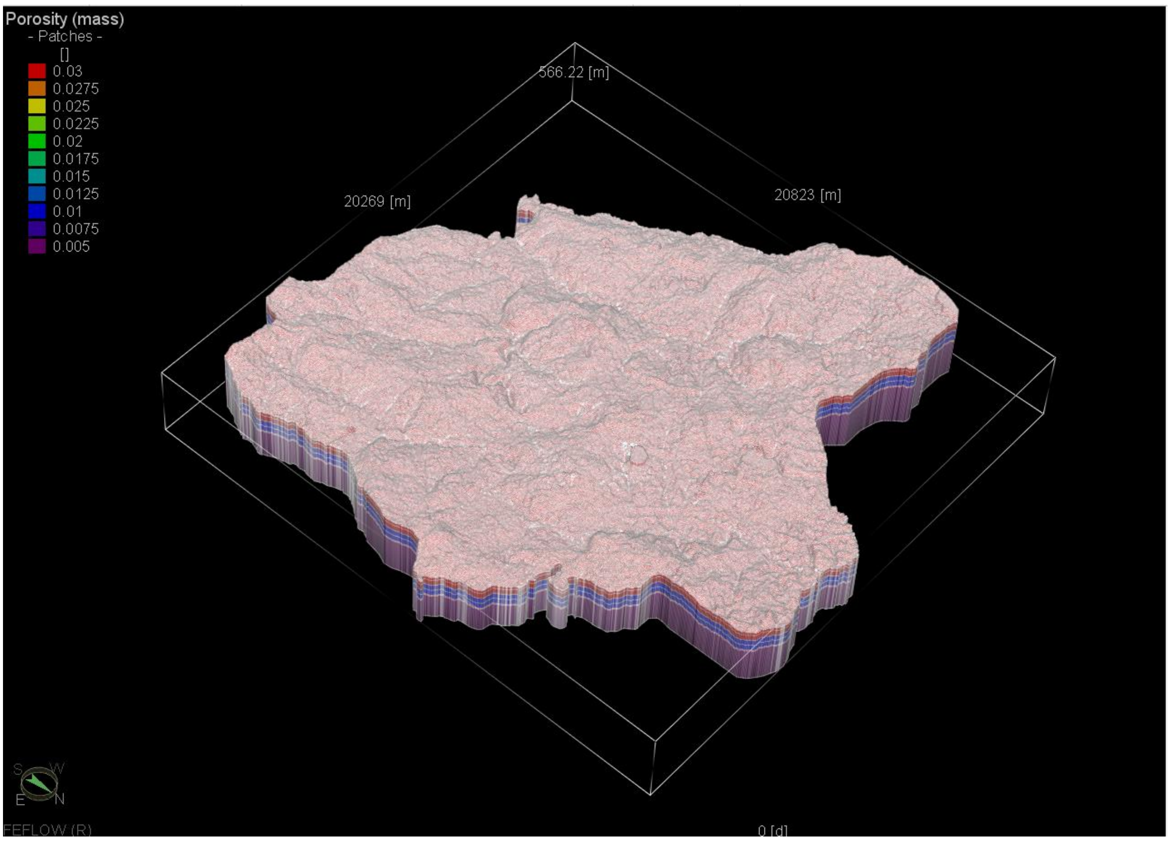



**Figure 14-12 Model development: Numerical groundwater flow model: Porosity distribution.**

**Table 14-1 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** | Alluvium | 30.00 | 0.150 | 0.150 | 25.0 | 1.00E-04 | 3.00E-02 |
| | Vryheid | | 0.060 | 0.006 | 16.7 | | |
| | Dolerite | | 0.008 | 0.001 | 10.0 | | |
| **Layer 02** | Vryheid | 50.00 | 0.040 | 0.004 | 0.0 | 1.00E-04 | 3.00E-02 |
| | Dolerite | | 0.003 | 0.000 | | | |
| **Layer 03** | Vryheid | 50.00 | 0.040 | 0.004 | 0.0 | 1.00E-05 | 1.00E-02 |
| | Dolerite | | 0.003 | 0.000 | | | |
| **Layer 04** | Vryheid | 50.00 | 0.020 | 0.002 | 0.0 | 1.00E-05 | 1.00E-02 |
| | Dolerite | | 0.003 | 0.000 | | | |
| **Layer 05** | Coal seam (#B) | 10.00 | 0.050 | 0.050 | 0.0 | 1.00E-04 | 3.00E-02 |
| **Layer 06** | Vryheid | 150.00 | 0.020 | 0.002 | 0.0 | 1.00E-05 | 1.00E-02 |
| | Dolerite | | 0.003 | 0.0003 | | | |

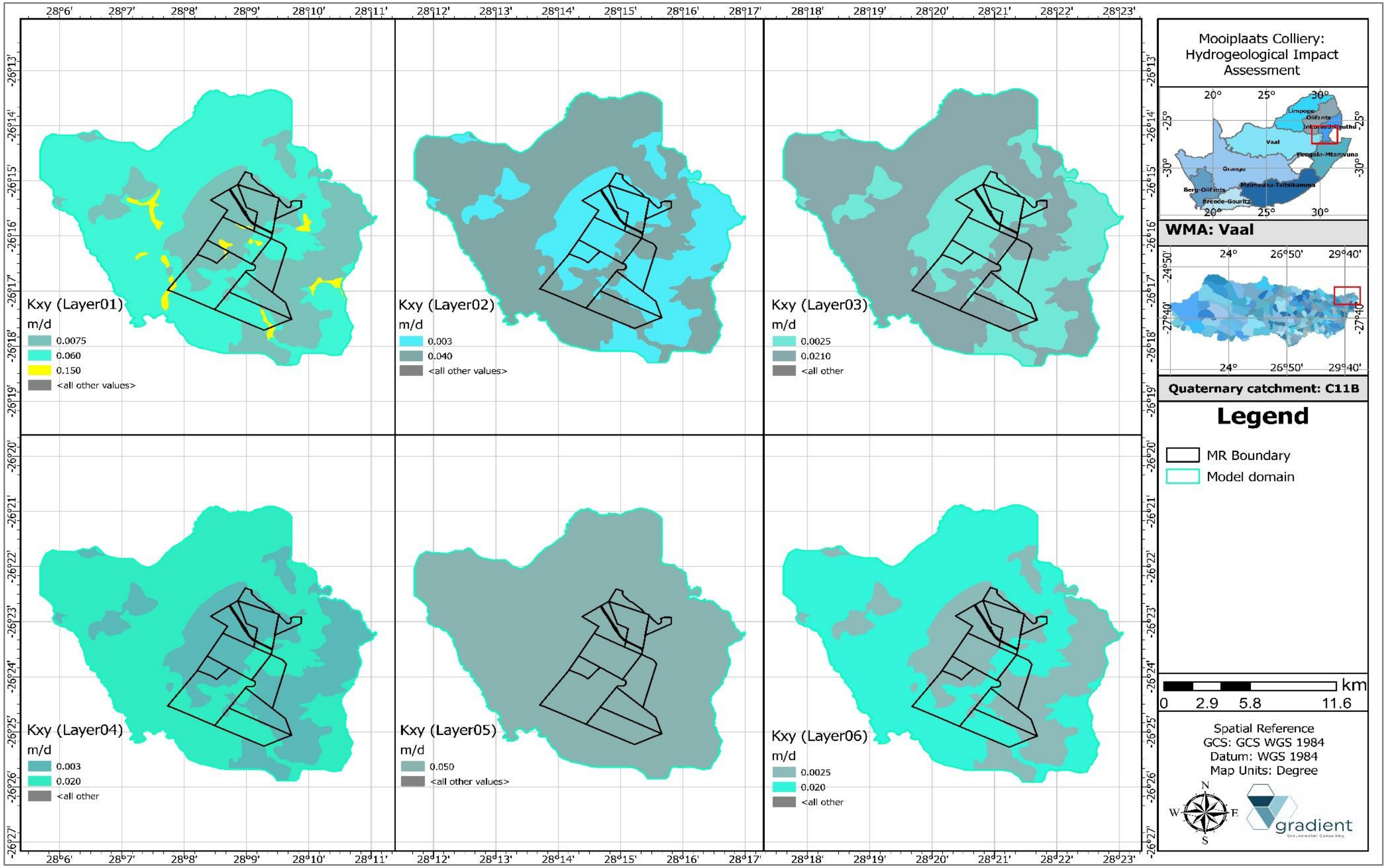



**Figure 14-13** **Numerical groundwater flow model: Hydraulic properties.**

### 14.4. 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 14-14 depicts steady state hydraulic head contours and groundwater flow directions. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.94 was obtained (refer to Figure 14-16, Figure 14-17 and Figure 14-18) while Figure 14-19 indicates calibration error margin per borehole observation locality. Figure 14-14 depicts steady state hydraulic head contours and groundwater flow directions with Figure 14-15 shows the steady state Darcy flux vectors within the host aquifer. 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): 1.51m.

ii. Mean Absolute Error (MAE): 5.59m.

iii. Normalised Root Mean Square Deviation (NRMSD): 8.84% i.e. represents the deviation between observed and calibration water levels across the model domain.

The calibrated steady state groundwater flow model was refined and adjusted to simulate and reflect current mining conditions, i.e. existing dewatering impacts and drawdown zone, which will be used as background hydrogeological conditions for management scenarios. Under transient conditions, the groundwater flow equation is modified to include storativity. Groundwater levels of existing dewatering boreholes were simulated by varying aquifer storativty values until an acceptable fit between the measured and simulated hydraulic heads is obtained.

**Table 14-2 Steady State Model Calibration – Statistical Summary.**

| Calibration BH | Topographical Elevation (mamsl) | Water Level (mbs) | Measured head elevation (mamsl) | Simulated head elevation (mamsl) | Mean Error (m) | Mean Absolute Error (m) | Root Mean Square Error (m) |
|---|---|---|---|---|---|---|---|
| MPG-B1 | 1668.33 | 1.73 | 1666.60 | 1669.19 | -2.59 | 2.59 | 6.72 |
| MPG-B2 | 1659.21 | 1.97 | 1657.24 | 1657.16 | 0.08 | 0.08 | 0.01 |
| MPG-B3 | 1669.00 | 11.33 | 1657.67 | 1663.54 | -5.87 | 5.87 | 34.51 |
| MPG-B4 | 1669.00 | 12.12 | 1656.88 | 1663.85 | -6.97 | 6.97 | 48.55 |
| MPG-B5 | 1684.71 | 5.44 | 1679.27 | 1682.81 | -3.54 | 3.54 | 12.51 |
| MPG-B6 | 1668.86 | 3.87 | 1664.99 | 1666.95 | -1.96 | 1.96 | 3.83 |
| MPG-B7 | 1665.98 | 1.69 | 1664.29 | 1668.56 | -4.27 | 4.27 | 18.20 |
| MPG-B8 | 1663.47 | 2.11 | 1661.36 | 1658.54 | 2.82 | 2.82 | 7.95 |
| MPG-B9 | 1658.00 | 11.55 | 1646.45 | 1657.21 | -10.76 | 10.76 | 115.68 |
| MPG-B11 | 1685.90 | 4.40 | 1681.50 | 1683.13 | -1.63 | 1.63 | 2.65 |
| MPG-B14 | 1656.24 | 17.12 | 1639.12 | 1638.02 | 1.10 | 1.10 | 1.22 |
| MPG-B15 | 1649.79 | 9.56 | 1640.23 | 1639.21 | 1.02 | 1.02 | 1.05 |
| MPG-B16 | 1660.51 | 29.56 | 1630.95 | 1640.55 | -9.59 | 9.59 | 92.00 |
| MPG-B17 | 1671.65 | 6.31 | 1665.34 | 1642.06 | 23.28 | 23.28 | 541.94 |
| MPG-B18 | 1680.44 | 27.23 | 1653.21 | 1643.52 | 9.69 | 9.69 | 93.97 |
| MPG-B19 | 1684.20 | 23.89 | 1660.31 | 1643.21 | 17.10 | 17.10 | 292.39 |
| MPG-B20 | 1640.66 | 2.73 | 1637.93 | 1634.73 | 3.20 | 3.20 | 10.21 |
| GAD-2s | 1670.96 | 10.32 | 1660.64 | 1662.44 | -1.80 | 1.80 | 3.24 |
| GAD-5d | 1629.08 | 1.67 | 1627.41 | 1625.22 | 2.19 | 2.19 | 4.81 |
| GKL-2s | 1596.76 | 4.06 | 1592.70 | 1594.41 | -1.71 | 1.71 | 2.93 |
| GKL-5S | 1648.34 | 0.87 | 1647.47 | 1636.95 | 10.52 | 10.52 | 110.68 |
| GKL-6M | 1648.64 | 1.58 | 1647.06 | 1636.90 | 10.16 | 10.16 | 103.15 |
| GKL-8M | 1624.78 | 4.48 | 1620.30 | 1615.24 | 5.06 | 5.06 | 25.63 |
| GKL-4d | 1598.29 | 2.63 | 1595.66 | 1593.11 | 2.55 | 2.55 | 6.51 |
| GKL-9D | 1627.76 | 12.81 | 1614.95 | 1615.18 | -0.23 | 0.23 | 0.05 |
| **Average** | **1655.22** | **8.44** | **1646.78** | **1645.27** | **1.51** | **5.59** | **61.62** |
| **Minimum** | **1596.76** | **0.87** | **1592.70** | **1593.11** | **-10.76** | **0.08** | **0.01** |
| **Maximum** | **1685.90** | **29.56** | **1681.50** | **1683.13** | **23.28** | **23.28** | **541.94** |
| **Correlation** | | | **0.94** | | | | |
| **∑** | | | | | **37.87** | **139.69** | **1540.38** |
| **1/n** | | | | | **1.51** | **5.59** | **61.62** |
| **Root Mean Square Deviation (RMSD)** | | | | | | **2.36** | **7.85** |
| **Normalised Root Mean Square Deviation (NRMSD) (% of water level range)** | | | | | | | **8.84** |

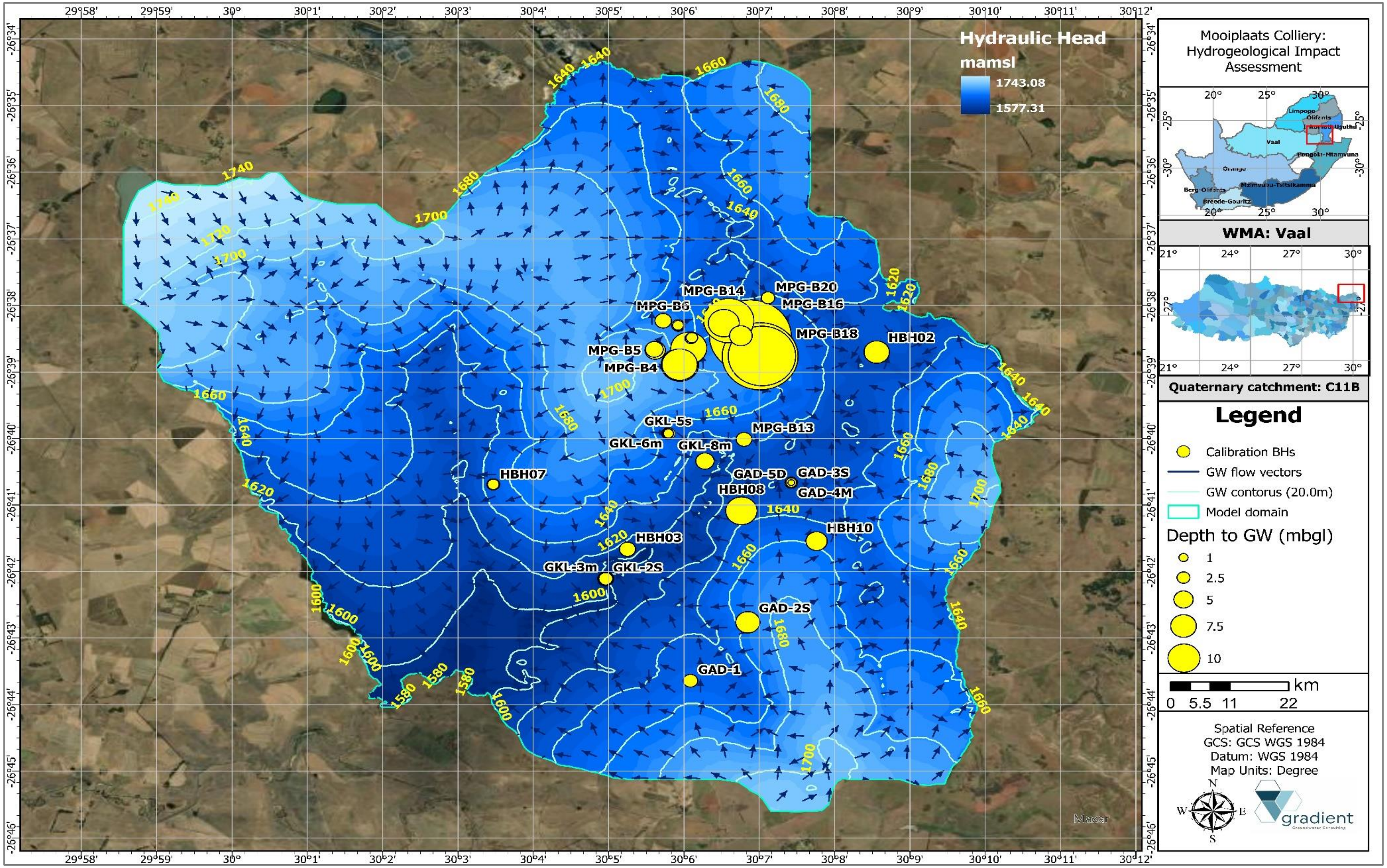



**Figure 14-14** **Model calibration: steady state hydraulic heads and groundwater flow direction.**

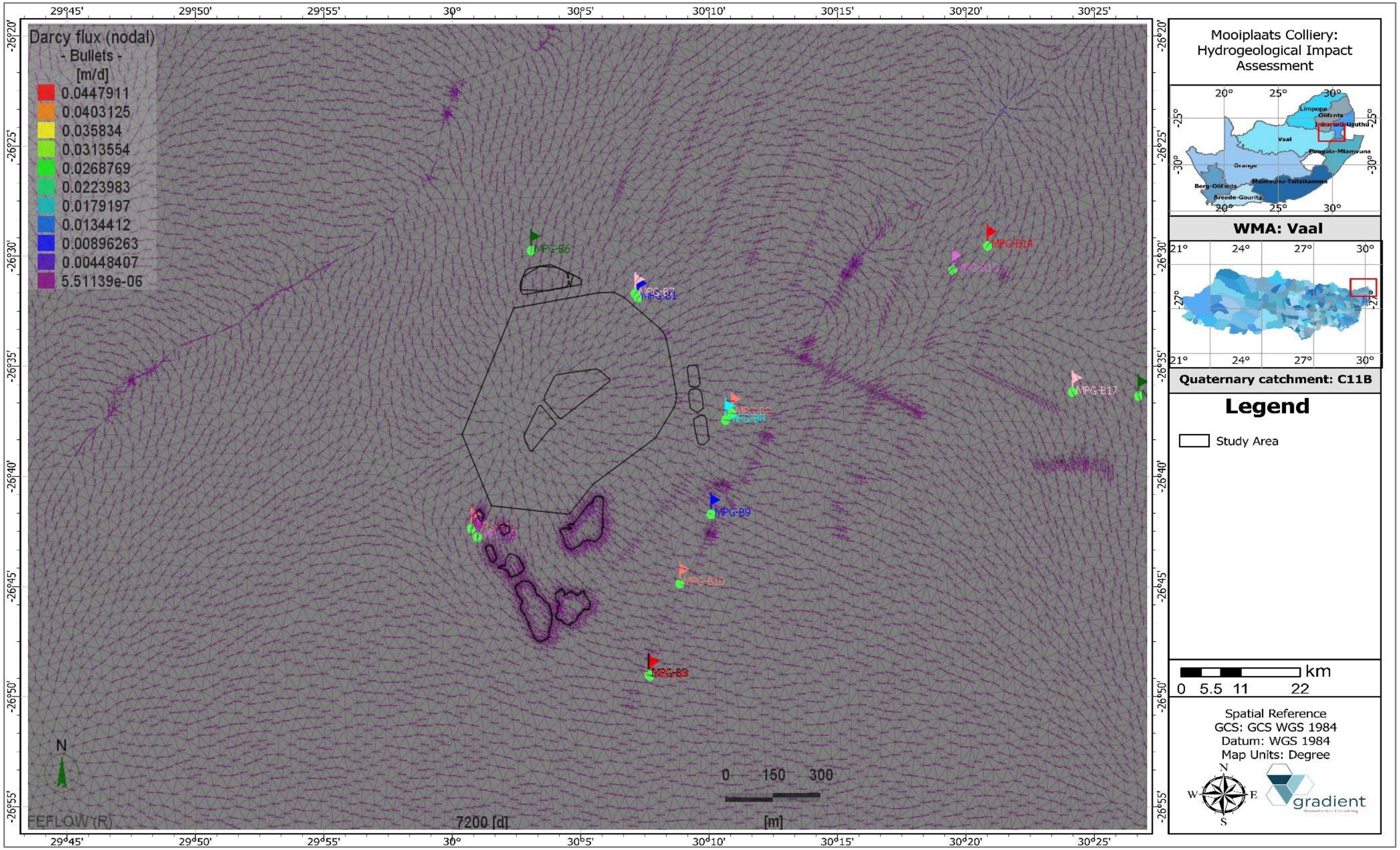



**Figure 14-15** **Model calibration: Steady State Darcy flux vectors within the host aquifer.**

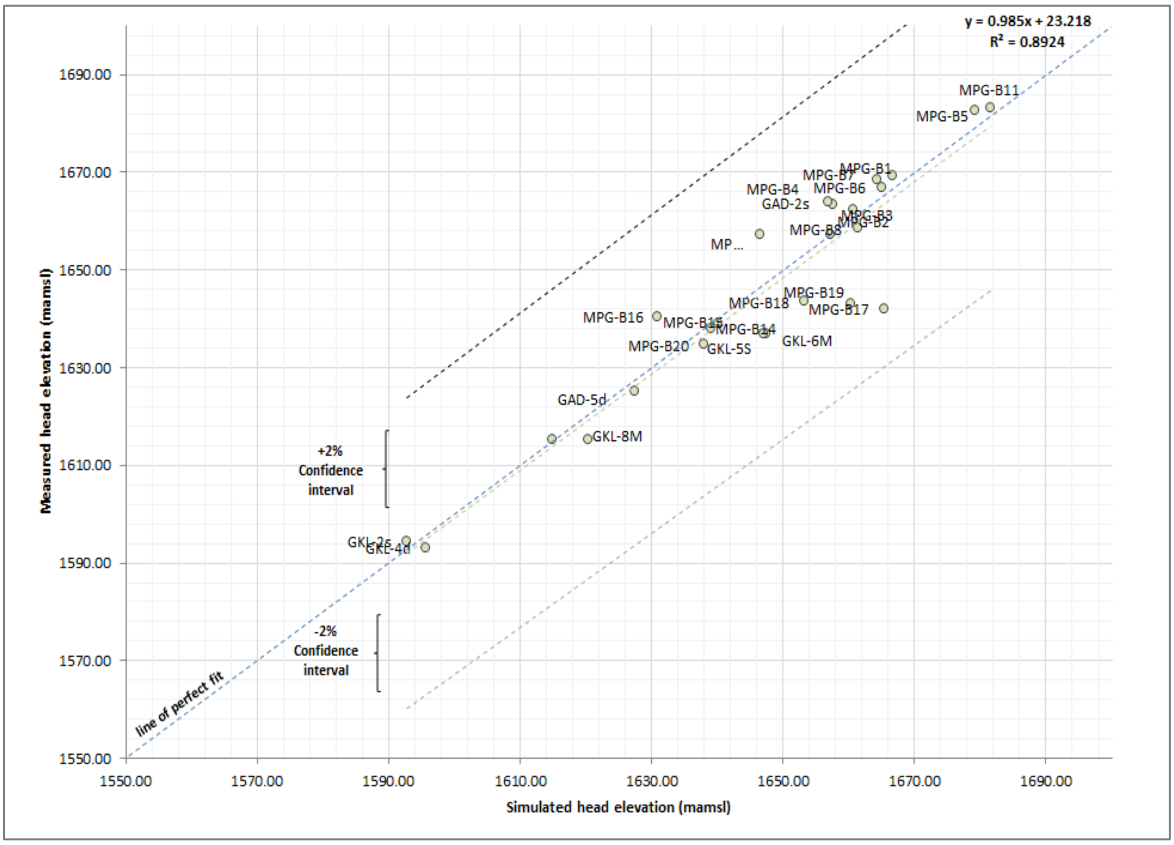



**Figure 14-16** **Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.**

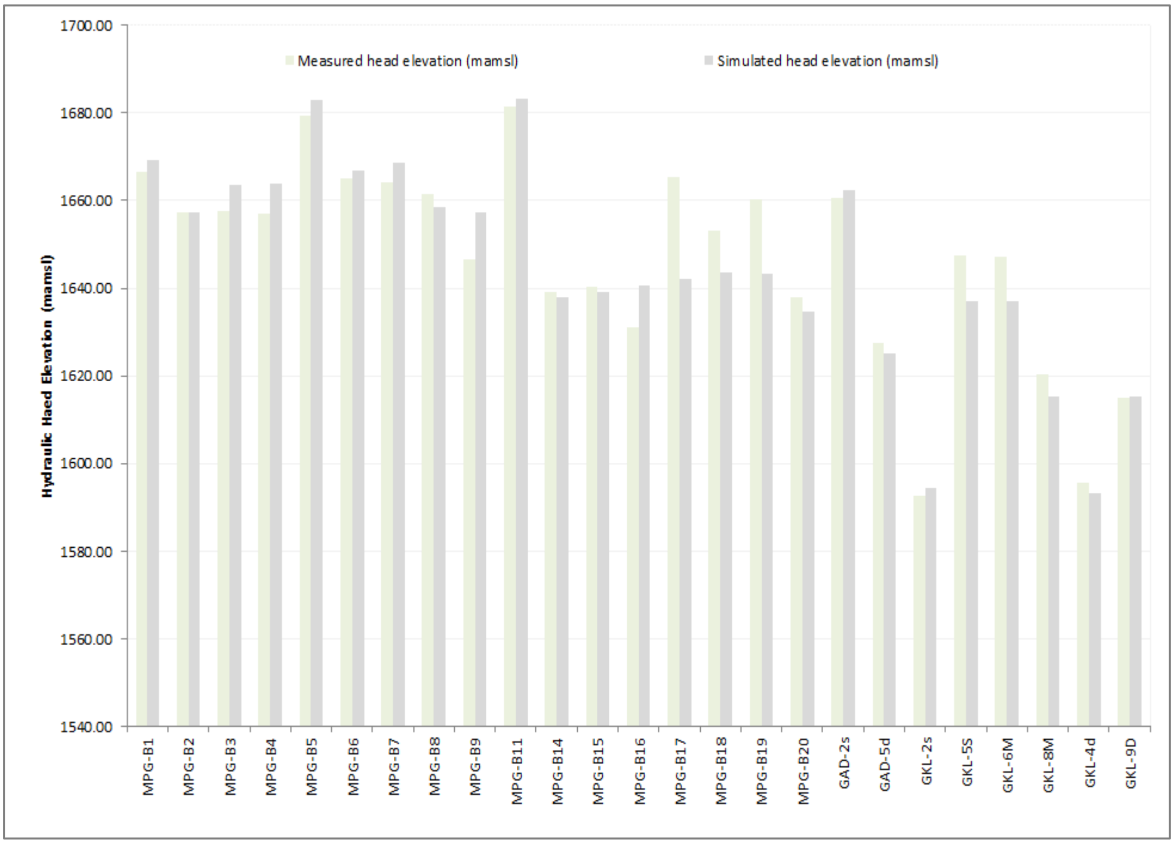



**Figure 14-17** **Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.**

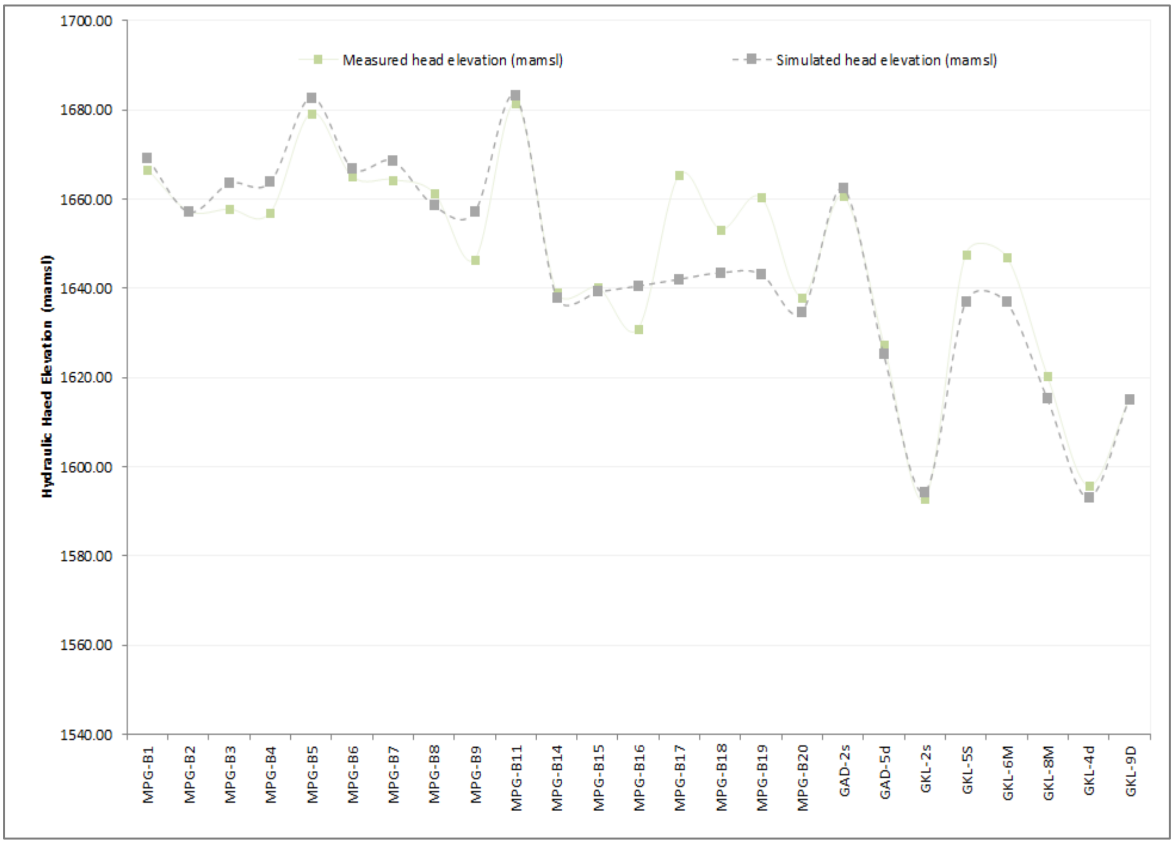



**Figure 14-18** **Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.**

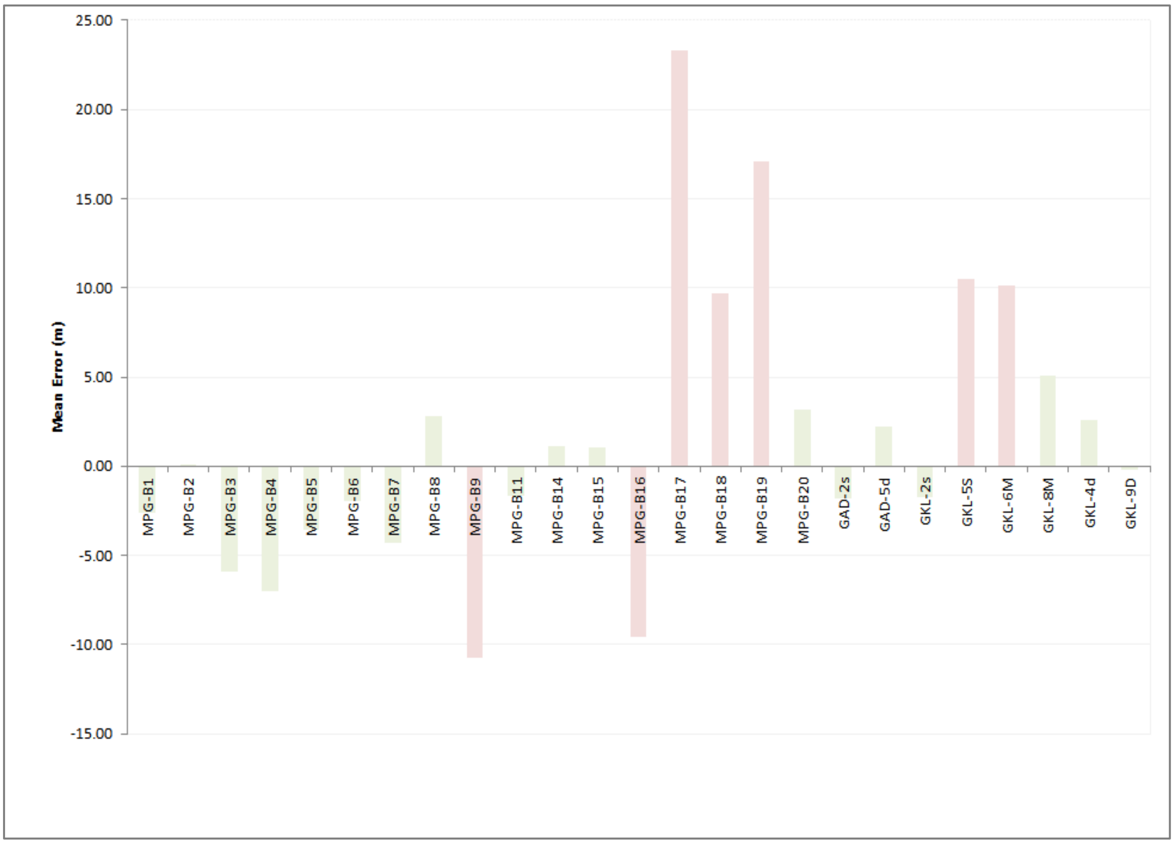



**Figure 14-19** **Bar chart summarising mean error per calibration borehole.**

### 14.5. 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. It is noted that the model tends to be more sensitive to upwards variations in recharge and downward changes in hydraulic conductivity as indicated in Figure 14-20, Figure 14-21 and Figure 14-22)[22].

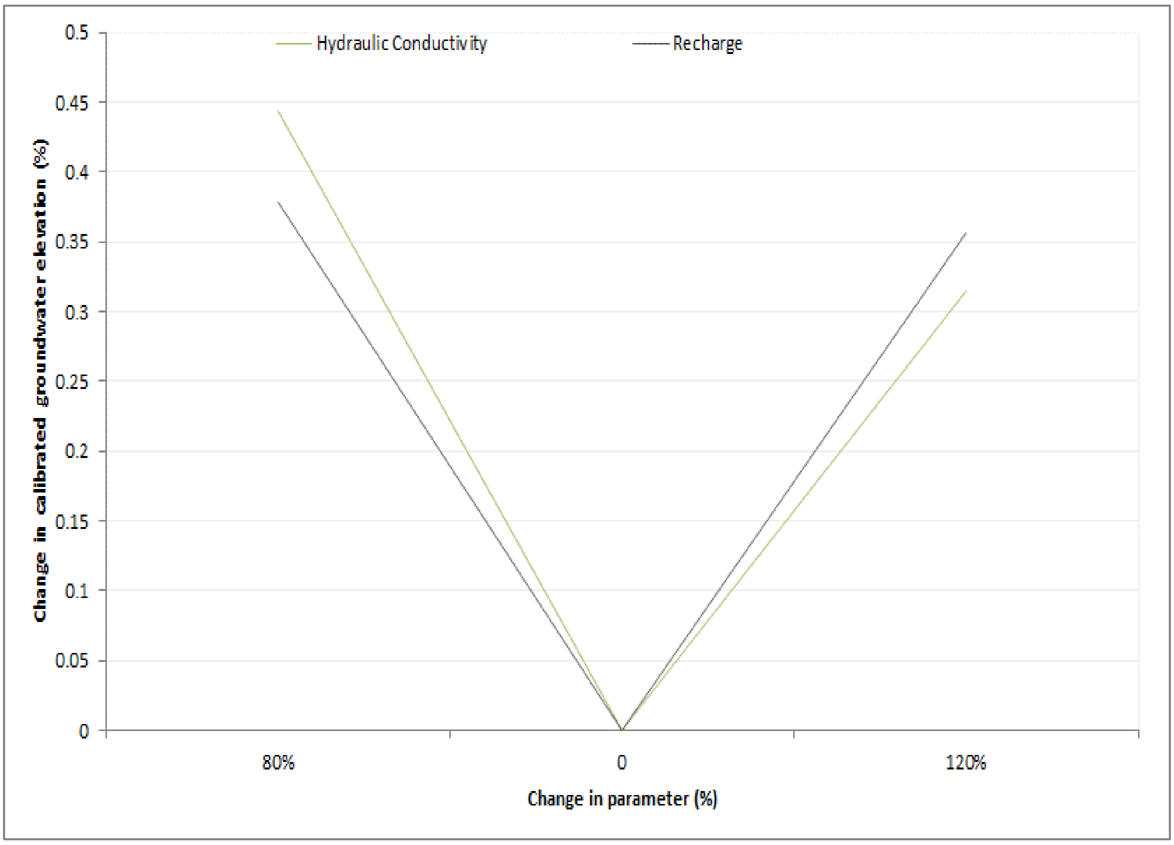



**Figure 14-20 Model steady state calibration: sensitivity analysis for monitoring locality MPG-B05.**

[22]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.

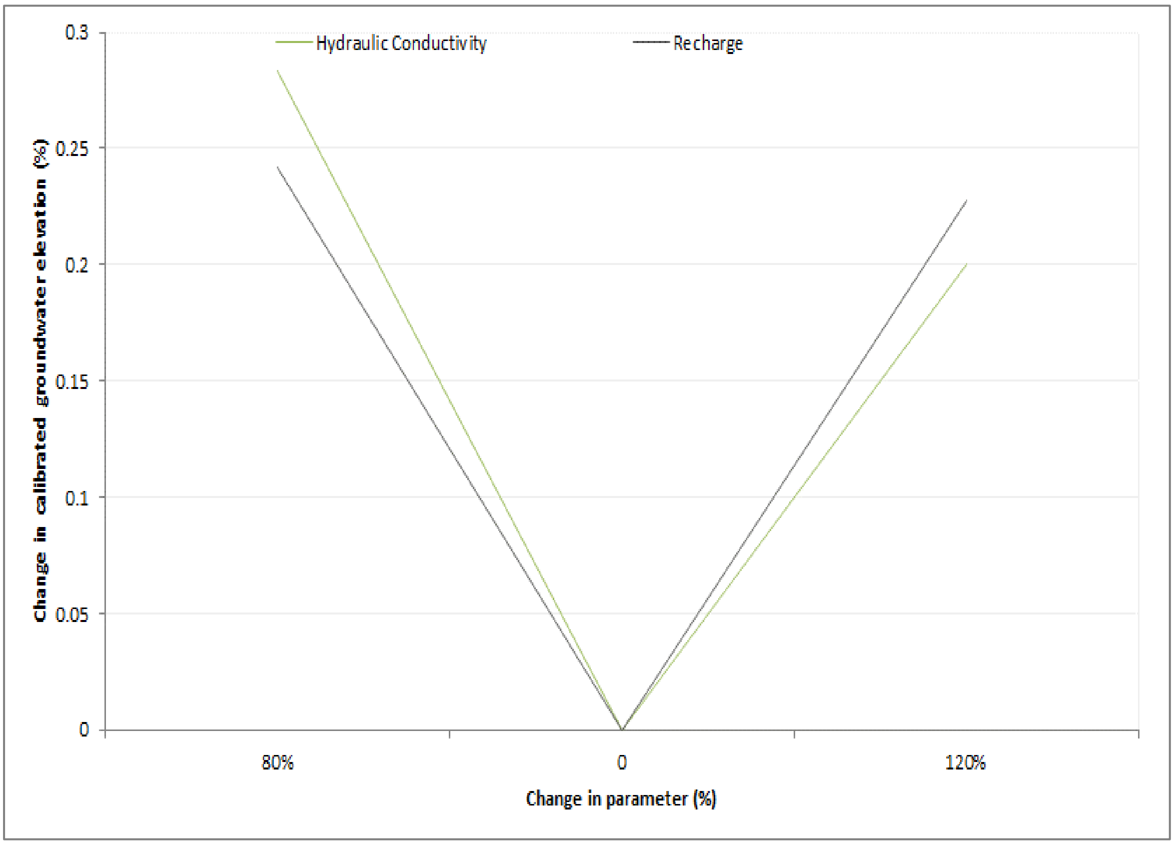



**Figure 14-21** **Model steady state calibration: sensitivity analysis for monitoring locality MPG-B6.**

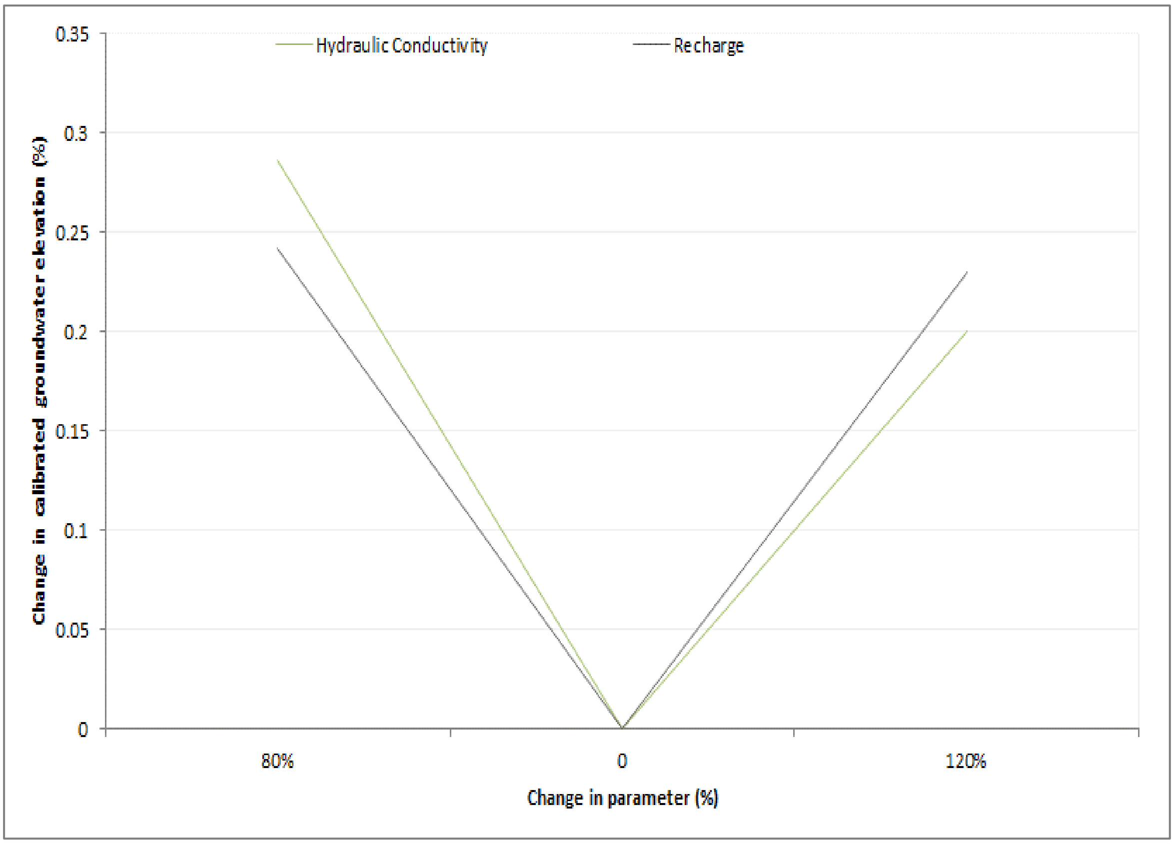



**Figure 14-22** **Model steady state calibration: sensitivity analysis for monitoring locality MPG-B7.**

## 14.6. 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 14-2 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]

### 14.6.1. Model simulation scenarios

Various management scenarios were modelled for the purposes of planning and decision making with stress periods listed in Table 14-3:

i. **Scenario 01:** Pre-mining water balance (Quasi steady state).

ii. **Scenario 02:** Groundwater abstraction from proposed production boreholes for the operational phase(s).

iii. **Scenario 03:** Sulphate pollution plume migration within the shallow, intergranular aquifer for the operational phase(s).

iv. **S0cenario 04:** Sulphate pollution plume migration within the shallow, intergranular aquifer for the post-closure phase(s).

v. **Scenario 05a (mitigation and management):** Sulphate pollution plume migration within the shallow, intergranular aquifer with establishment of scavenger or seepage capturing boreholes down-gradient of proposed waste infrastructure.

vi. **Scenario 05b (mitigation and management):** Sulphate pollution plume migration within the shallow, intergranular aquifer with implementation of a cut-off or fracturing trench constructed down-gradient of proposed waste infrastructure.

vii. **Scenario 05c (mitigation and management):** Sulphate pollution plume migration within the shallow, intergranular aquifer with a barrier or liner system implemented on the proposed waste infrastructure footprints.

**Table 14-3 Summary of model stress-periods.**

| Stress period | Description |
|---|---|
| Year 01 - Year 20 | Operational period |
| Year 20 - Year 70 | Post-closure (50-years) |
| Year 70 - Year 120 | Post-closure (100-years) |

#### 14.6.2. Scenario 01: Baseline catchment water balance

Scenario 01 simulated the baseline conditions. Table 14-4 summarises the groundwater catchment water balance representing steady state conditions. Recharge is assumed the only source of inflow to the system and has been simulated at $1.45E^{+04}m^3/d$, while the largest loss to the groundwater system is via baseflow, $1.41E^{+04}m^3/d$. An assumption has been made for the total volume of groundwater abstraction from privately owned water supply boreholes account to $4.96E^{+02}m^3/d$. An imbalance, ignoring internal transfer, for the modelled catchment is calculated at a volume of $3.50E^{+01}m^3/d$.

**Table 14-4 Scenario 01: Catchment water balance – Baseline conditions.**

| **Scenario 01 – Steady state pre-mining (Quasi steady-state)**<br>**Parameter** | **Inflow ($m^3/d$)** | **Outflow ($m^3/d$)** | **Balance ($m^3/d$)** |
|---|---|---|---|
| Recharge ($m^3/d$) | 1.45E+04 | 0.00E+00 | 1.45E+04 |
| Catchment abstraction ($m^3/d$)** | 0.00E+00 | 4.96E+02 | -4.96E+02 |
| Dirichlet/ Groundwater discharge to baseflow contribution (m3/d) | 0.00E+00 | 1.41E+04 | -1.41E+04 |
| Imbalance ignoring internal transfer ($m^3/d$) | 0.00E+00 | 3.50E-01 | -3.50E-01 |
| **Total ($m^3/d$)** | **1.45E+04** | **1.45E+04** | **0.00E+00** |

#### 14.6.3. Scenario 02: Groundwater abstraction from proposed production boreholes for the operational phase(s)

Scenario 02 simulated the water level drawdown caused by abstraction from proposed production boreholes for the operational phase(s). Figure 14-23 shows a cross section the simulated hydraulic head drawdown in conjunction with the zero-pressure isoline i.e. piezometric surface. It is evident that the abstraction activities change the hydraulic gradient as groundwater is removed from storage. Table 14-5 summarises the groundwater catchment water balance for stress periods representing the operational phase. Recharge is assumed the only source of inflow to the system and has been simulated at $1.45E^{+04}m^3/d$, while the largest loss to the groundwater system is via baseflow, $1.37E^{+04}m^3/d$. The average combined groundwater abstraction has been simulated at approximately $3.33E^{+02}m^3/d$ (as sourced from the sustainable yield calculations in Section 7 of this report) while the volume of groundwater released from storage account to approximately $5.51E^{+01}m^3/d$ .

**Table 14-5 Scenario 02: Catchment water balance –Groundwater abstraction from scavenger boreholes for the operational phase(s).**

| **Scenario 02: Groundwater abstraction from proposed production boreholes for the operational phase(s).**<br>**Parameter** | **Inflow ($m^3/d$)** | **Outflow ($m^3/d$)** | **Balance ($m^3/d$)** |
|---|---|---|---|
| Recharge ($m^3/d$) | 1.45E+04 | 0.00E+00 | 1.45E+04 |
| Catchment abstraction (m3/d)** | 0.00E+00 | 4.96E+02 | -4.96E+02 |
| Dirichlet/ Groundwater discharge to baseflow contribution ($m^3/d$) | 0.00E+00 | 1.37E+04 | -1.37E+04 |
| Groundwater abstraction from production boreholes ($m^3/d$) | 0.00E+00 | 3.33E+02 | -3.33E+02 |
| Storage Capture(-)/Release(+)($m^3/d$) | -5.51E+01 | 0.00E+00 | -5.51E+01 |
| **Total ($m^3/d$)** | **1.45E+04** | **1.45E+04** | **-5.68E-14** |

Figure 14-24 shows the simulated groundwater drawdown within the existing production boreholes. It should be noted that the simulated groundwater drawdown zone intercepts various monitoring boreholes and stretches to the drainage systems or associated wetlands in the proximity of the site. The groundwater drawdown during the simulated abstraction period will range from <1.0mbsl (meter below static level), i.e., relatively little drawdown expected within the Usuthu boreholes to >21.0mbsl simulated within the Potable water borehole. The groundwater capture zone i.e. drawdown zone of influence extent will cover an estimated footprint of approximately 3.36km$^2$ propagating radially reaching a maximum distance of approximately 1.40km in a general south to southeastern direction.

As mentioned there exist a pronounced interaction between surface and groundwater as the two regimes are well-linked. Groundwater contribution to baseflow discharge[23] accounts to approximately 1.33E$^{+04}$m$^3$/d during baseline conditions, whereas groundwater contribution to baseflow discharge during the operational period decreases to ~1.29E$^{+04}$m$^3$/d (Refer to Figure 14-25). The latter accounts for an average loss of 3.68E$^{+02}$m$^3$/d, ~2.84% with a maximum reduction of 4.21% for the operational phase(s). Figure 14-26 depicts the Darcy flux vectors in the direct vicinity of the proposed production borehole alternating the local hydraulic gradient a. Figure 14-27 indicates the simulated groundwater drawdown and depression zone created from abstraction activities.

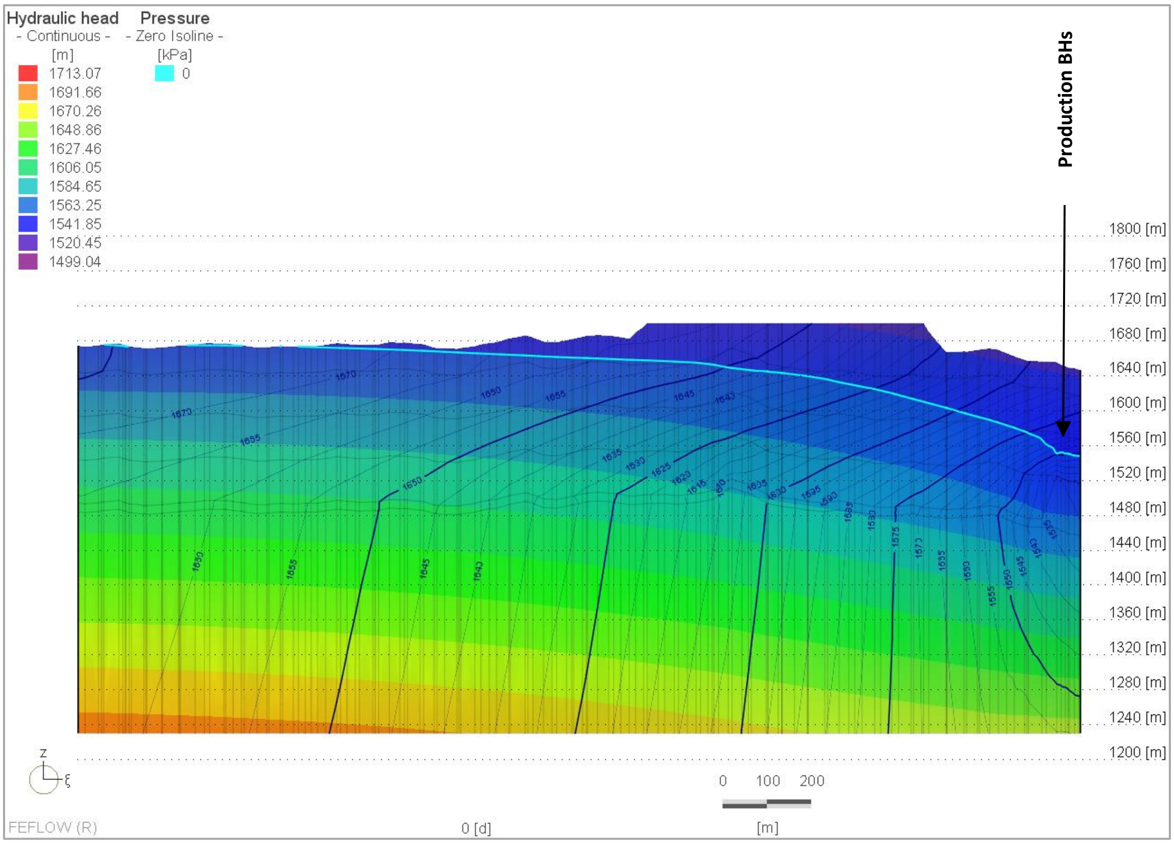



**Figure 14-23** **Scenario 02: Cross sectional view of the simulated hydraulic head in a northwest-southeast orientation (Slice A-A').**

23 Baseflow calculations is expressed as the observed loss based on the drainage system traversing the project area.

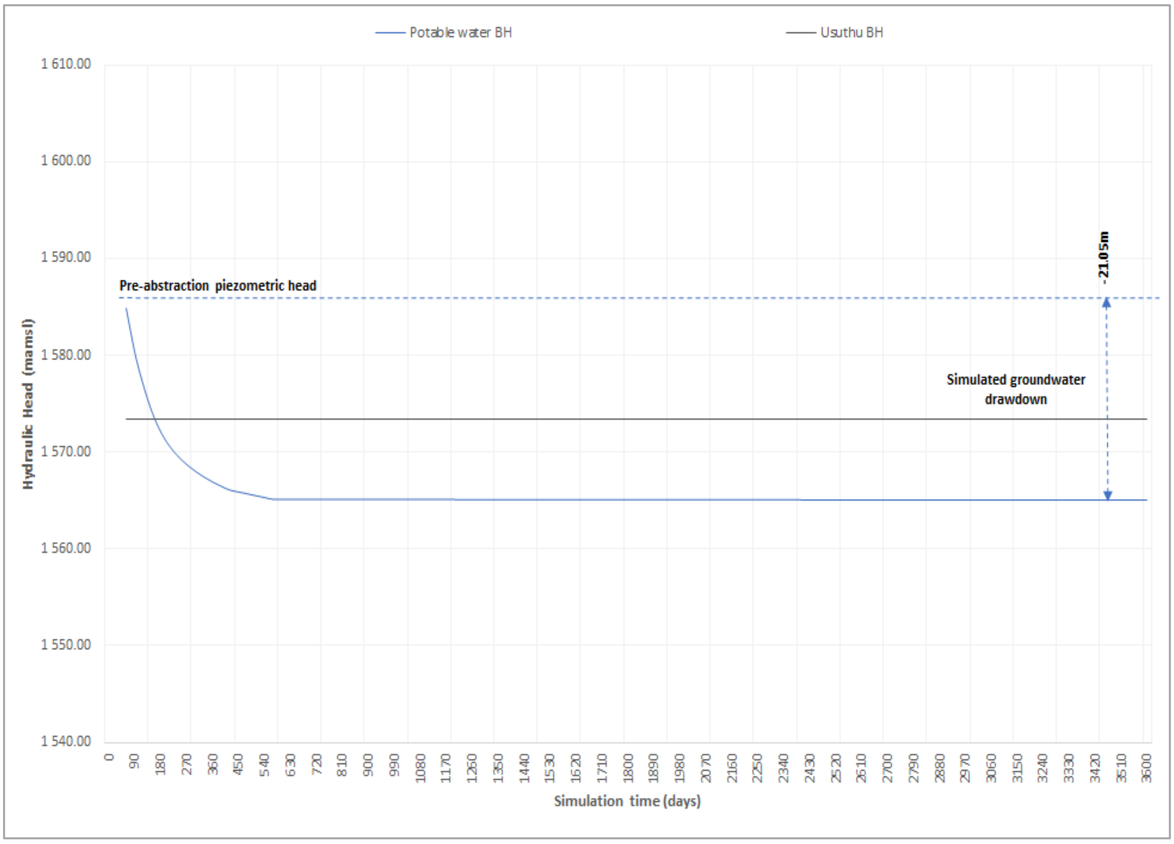



**Figure 14-24** **Scenario 02: Time-series water level drawdown within existing scavenger boreholes.**

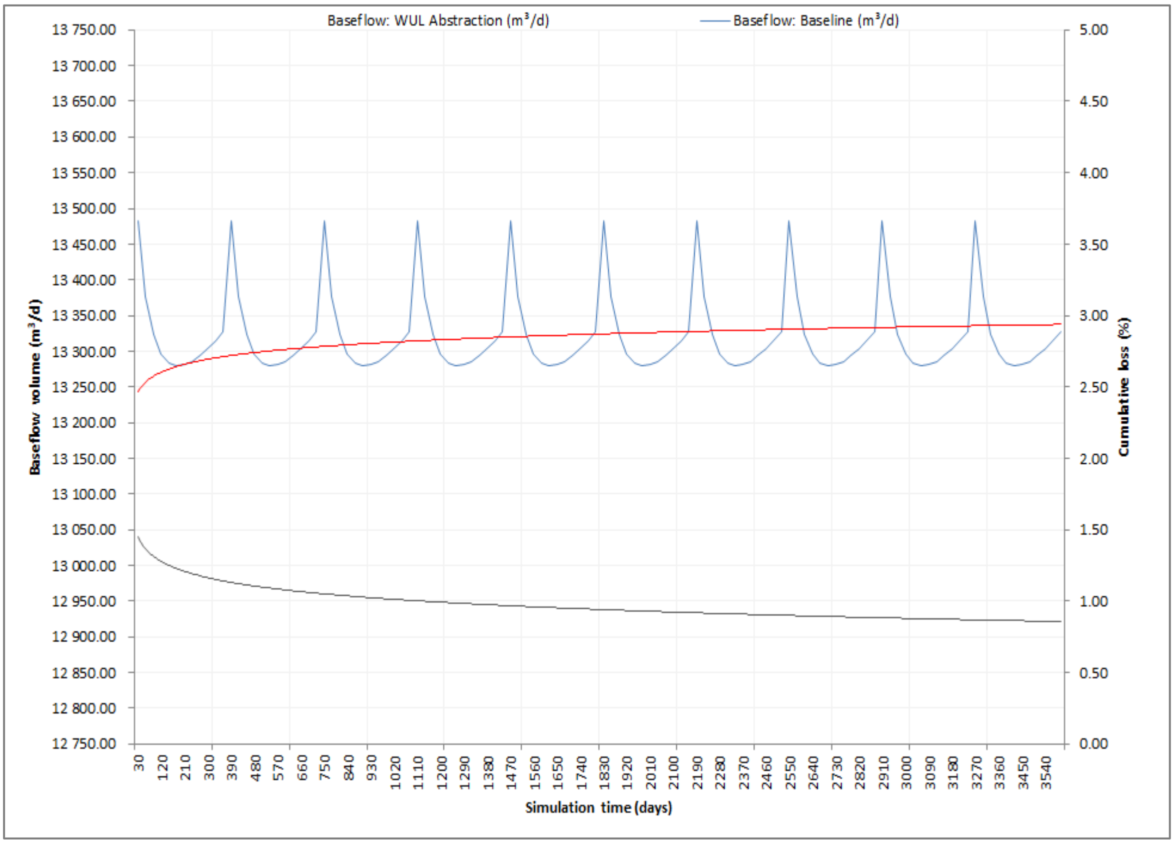



**Figure 14-25** **Scenario 02a: Baseflow comparison curve: Pre-abstraction vs abstraction from scavenger boreholes.**

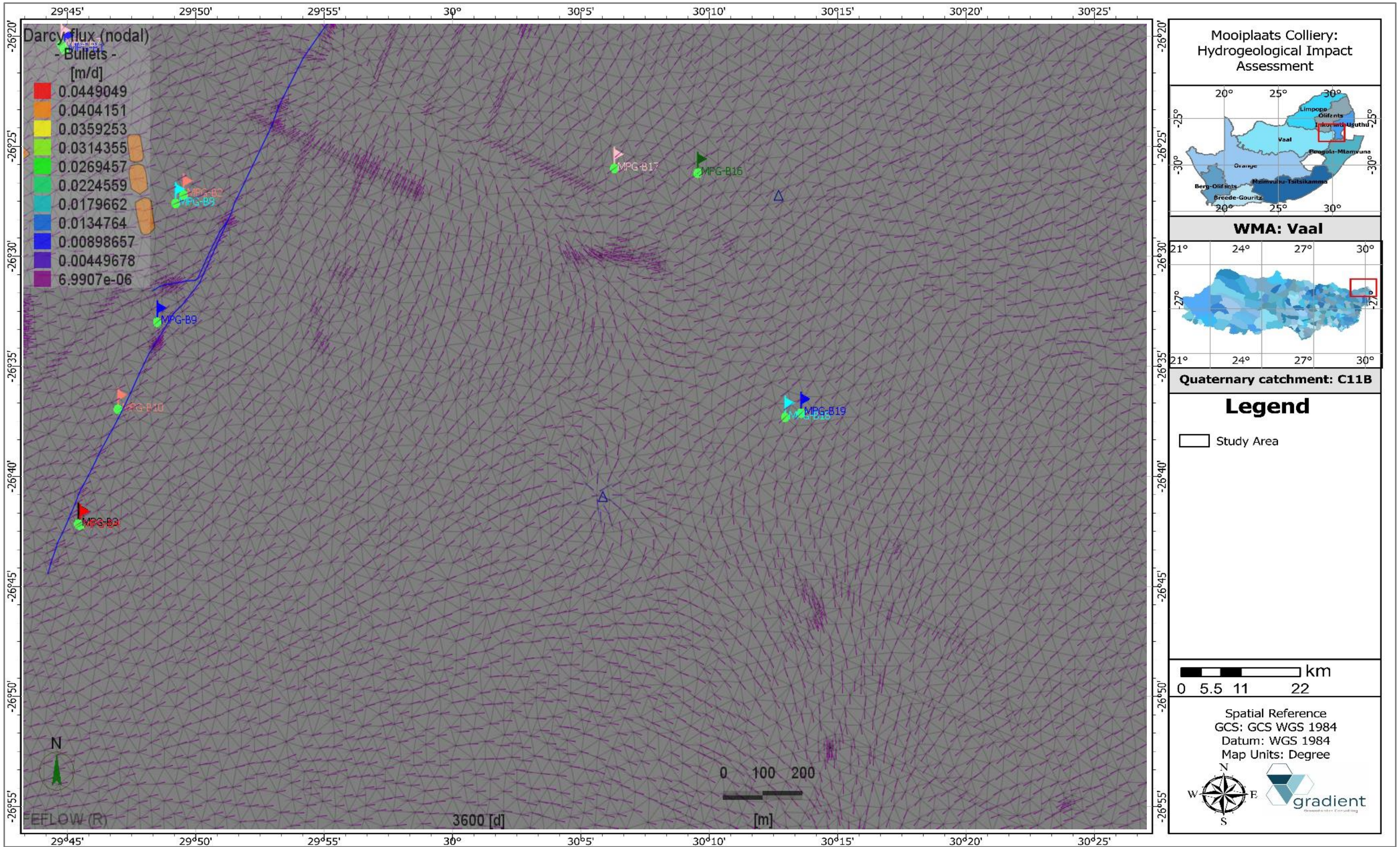



**Figure 14-26** **Scenario 02a: Darcy flux vectros in the vicinity of the Southern Pit during the operational period.**

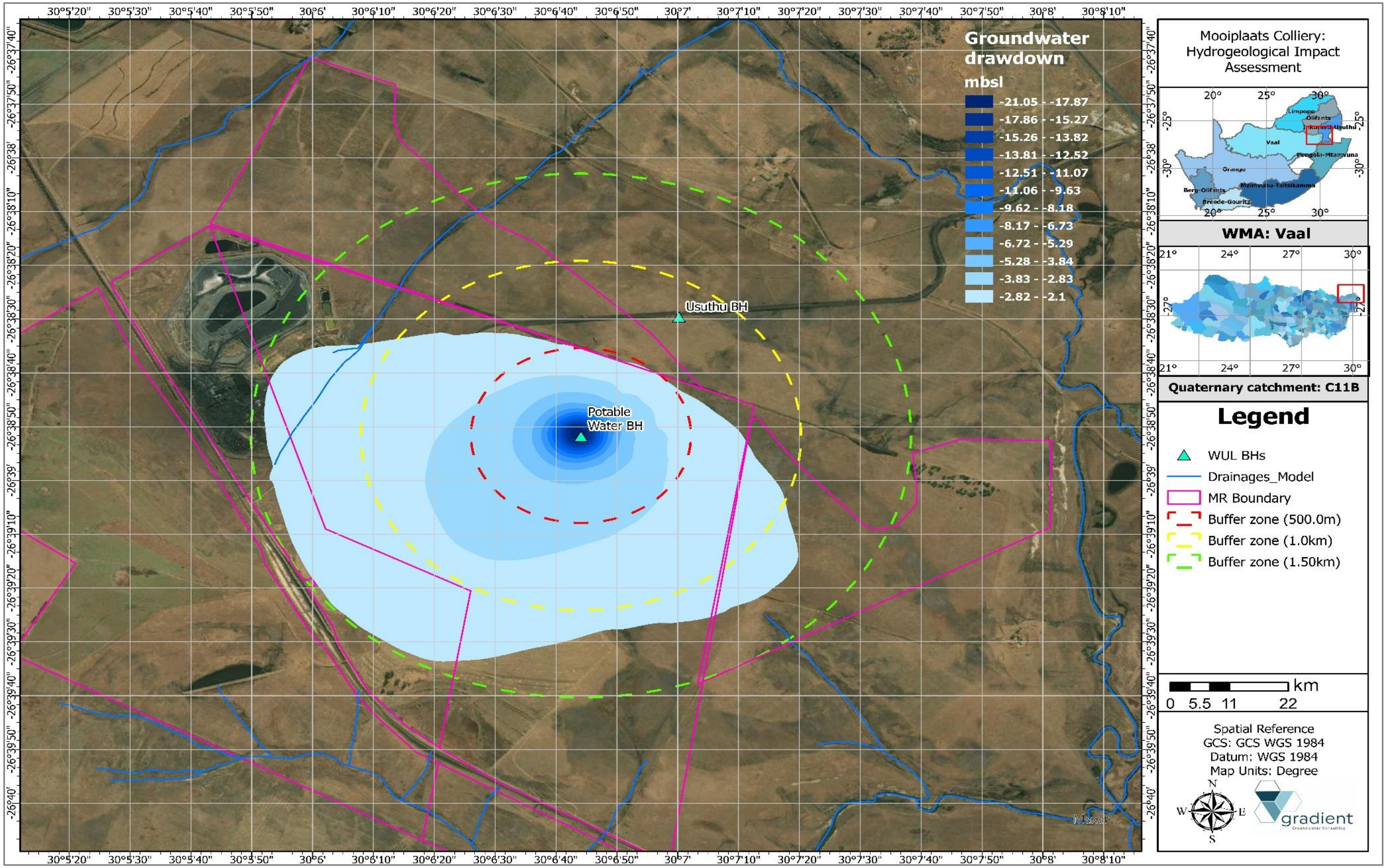



**Figure 14-27** **Scenario 02: Time-series water level drawdown and groundwater capture zones of the shallow, intergranular aquifer formed by abstraction activities.**

### 14.7. Numerical mass transport model

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

**Equation 14-3 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[24];

$\Gamma$ = 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. The calibrated groundwater flow model was used as basis to perform the solute/mass transport scenarios. 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.

[24] 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 are taking place in the aquifer.

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. Source term assumptions is based on existing geochemical analysis and published literature of the Ermelo Coalfield lithologies. It can be assumed the carbonaceous, discard material will generate a sulphate concentration of up to 4000.0mg/l and, as such, were assigned as the source term concentration on the waste infrastructure footprints. Model domain background values were interpreted from the hydrochemical data analysis as gathered during the hydrocensus user survey and assigned as ~ 150.0 mg/l. Figure 14-28 depicts a model cross section of the pollution plume migration within the shallow, intergranular aquifer receptor. It is evident that the mass transport of the pollution plume is not only limited to the shallow, intergranular aquifer, however, does migrate to the deeper, fractured aquifer as well.

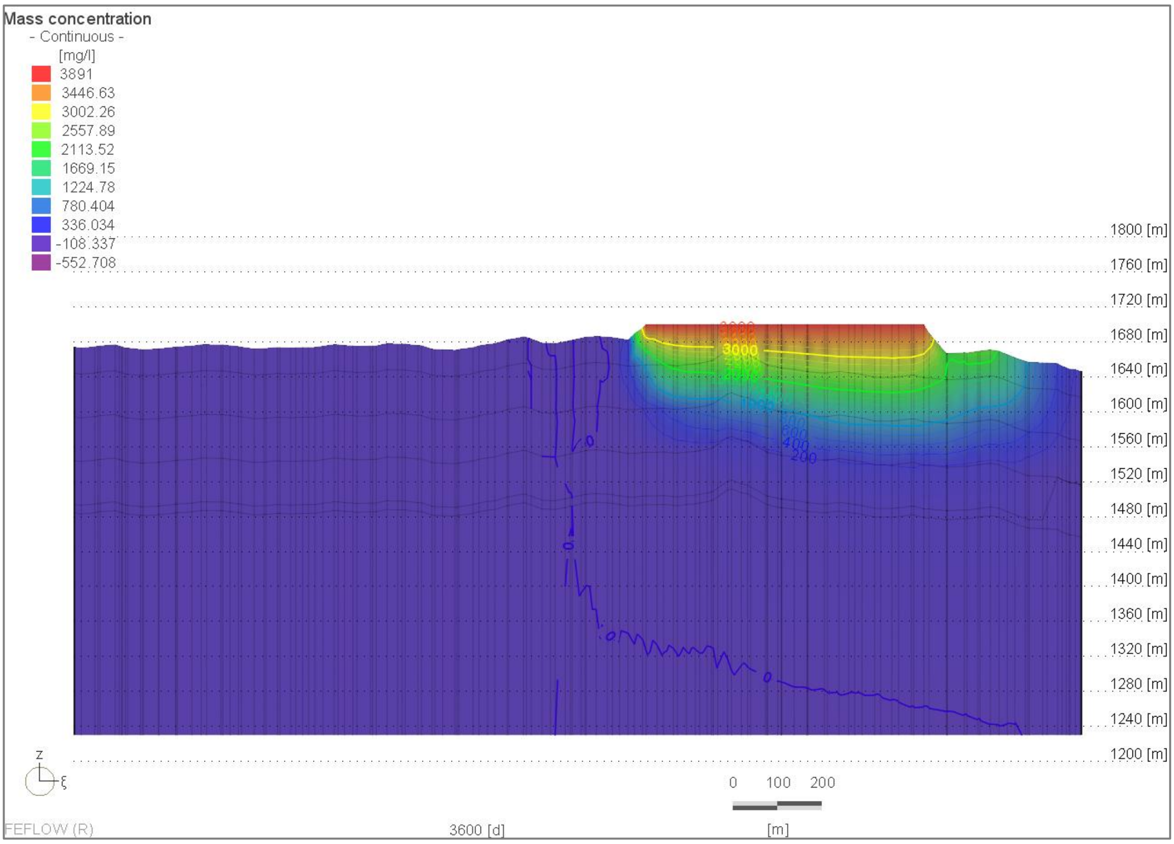



**Figure 14-28** **Scenario03: Cross sectional view of the simulated sulphate pollution plume migration within the shallow, intergranular aquifer for the operational phase (Conceptual slice A-A).**

### 14.7.1. Scenario 03: Sulphate pollution plume migration within the shallow, intergranular aquifer for the operational phase(s)

Scenario 03 simulated the pollution plume migration within the intergranular aquifer originating from the waste infrastructure footprints for the duration of the operational period without any mitigation or management measures applied i.e., worst-case scenario. Figure 14-30 indicates the simulated flow pathways of contaminant particles within the receiving aquifer. It can be observed that the pollution plume migration is generally in a northeastern to eastern direction towards the lower lying drainage system. The pollution plume extent covers a total area of approximately 0.95km$^2$, reaching a maximum distance of ~330.0m in a general northeastern to eastern direction. Figure 14-31 indicates the simulated sulphate pollution plume migration for various phases during the operational phase whereas Figure 14-32depitcs the simulated pollution plume extend at the end of the operational phase. The simulation indicates that the pollution plume generated is mostly confined to the mining right area, however, does intercept various monitoring boreholes and reach to the local drainage system and associated wetlands. Figure 14-29 indicates a time-series graph of the simulated mass load contribution originating from the waste infrastructure to down-gradient receptors. It can be observed that the sulphate mass load contribution to local observation boreholes increases to a maximum of between 950.0mg/l to 1500.0mg/l and is a function of the distance towards the waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure is above the SANS 241:2015 acute health threshold concentration[25] after a simulation period of approximately 20 years. It can be observed that the mass load contribution to the local drainage system increases to a maximum of 130.0mg/l however remain below the SANS 241:2015 acute health threshold concentration for the duration of the simulation period.

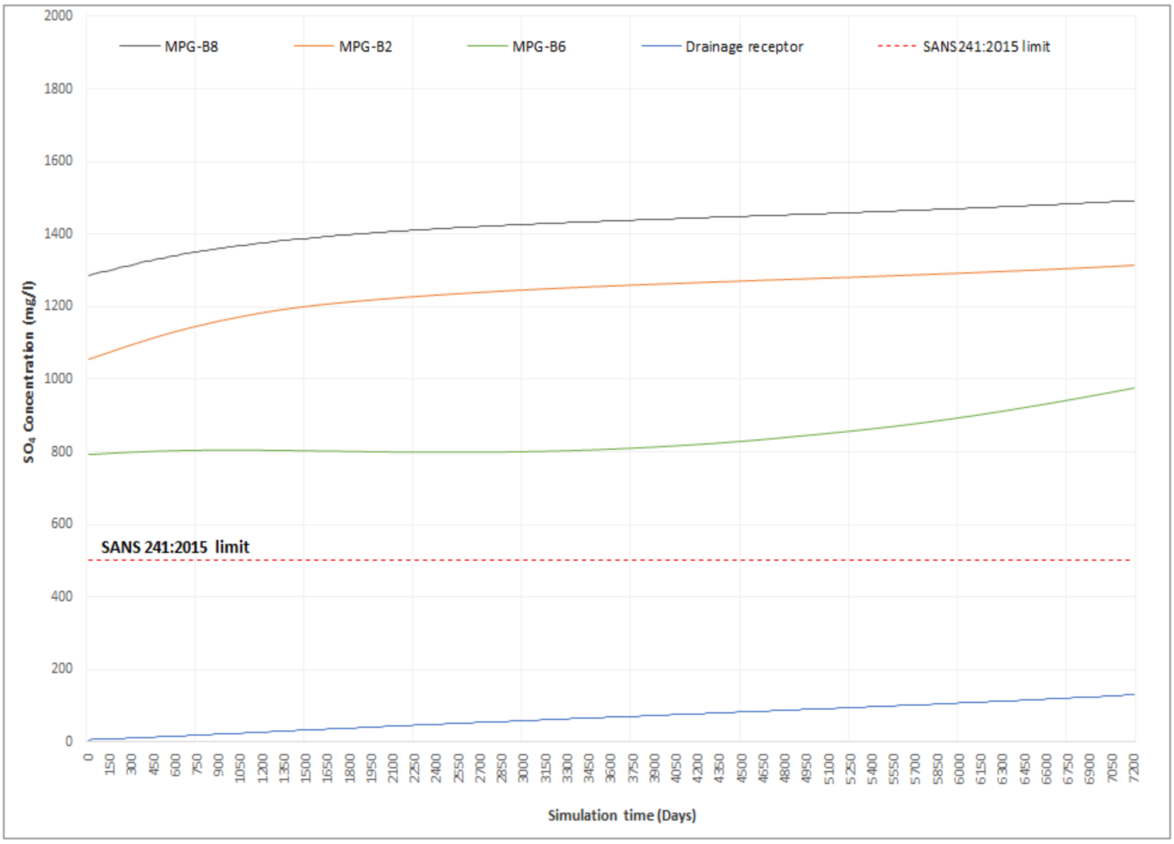



**Figure 14-29 Scenario 03: Time-series graph indicating the sulphate mass load contribution of waste footprints to down-gradient receptors within the intergranular aquifer host during the operatinal phase.**

[25] The SANS241:2015 acute health limit for sulphate is 500.0mg/l.

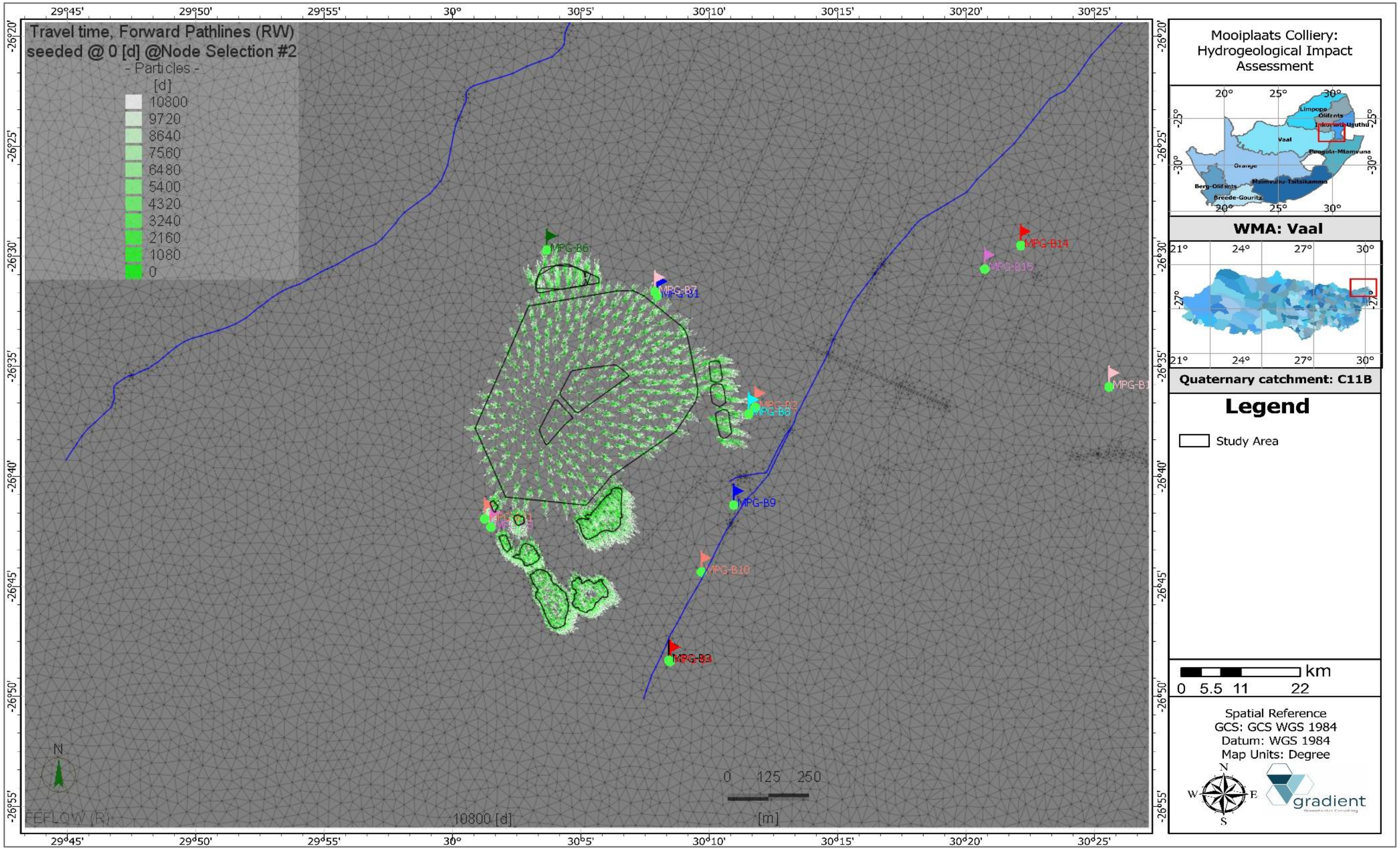



**Figure 14-30** **Scenario03: Simulated particle tracking of contaminants within the host aquifer unit(s).**

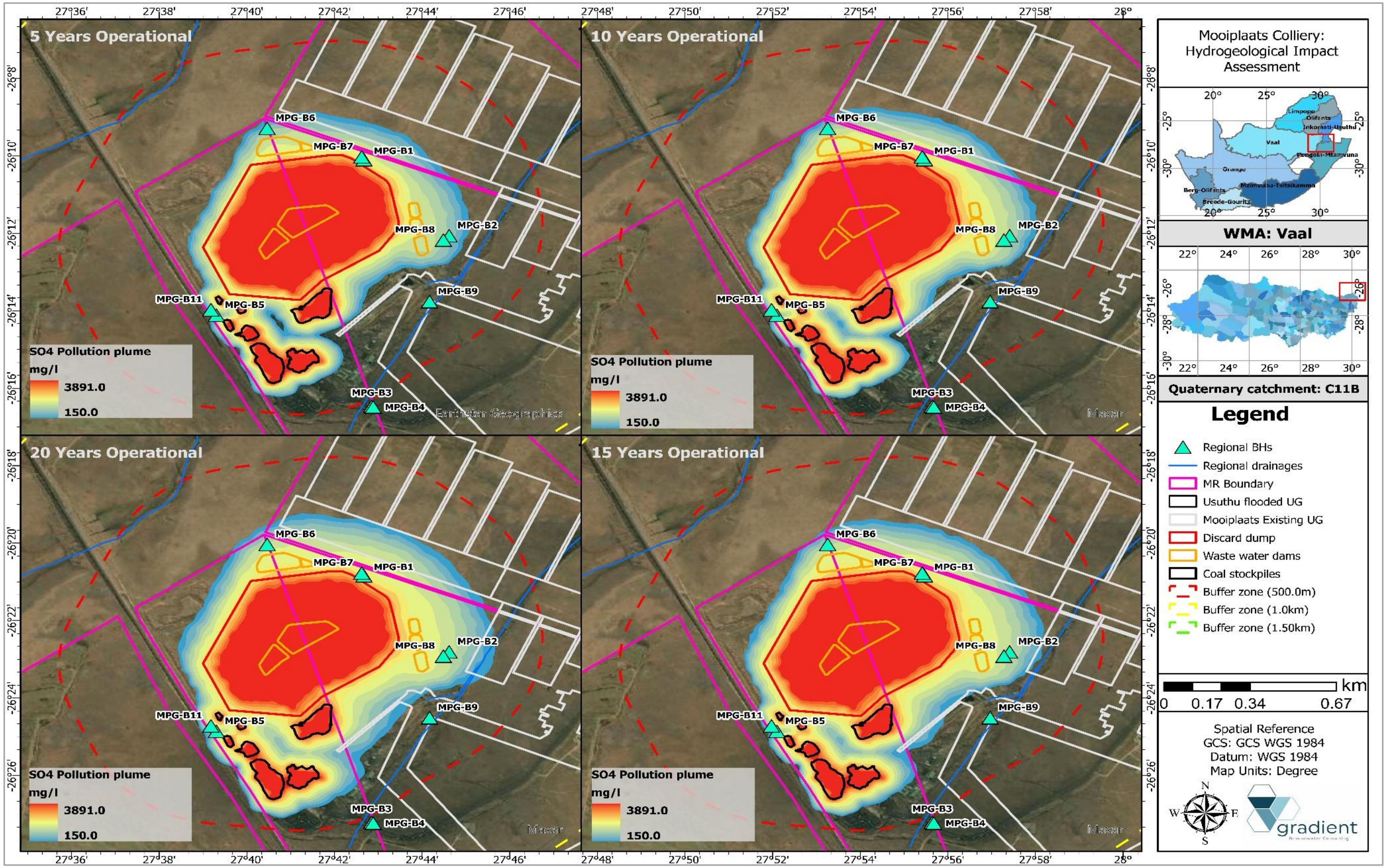



**Figure 14-31** **Scenario 03: Sulphate (SO4) pollution plume migration within the intergranular aquifer host fro various periods during the operational phase.**

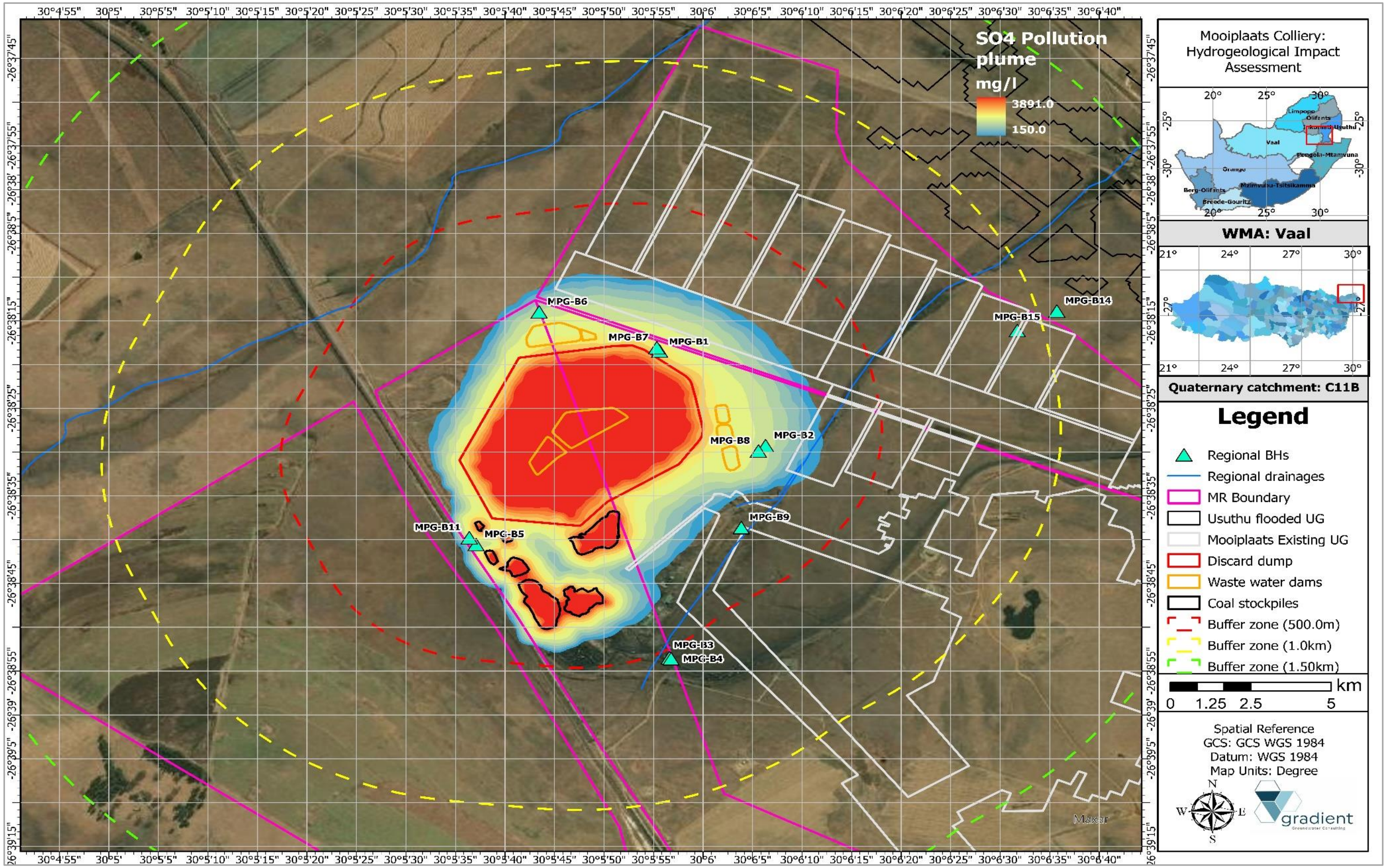



**Figure 14-32** **Scenario 03: Sulphate (SO4) pollution plume migration within the intergranular aquifer host at the end of the operational phase.**

#### 14.7.2. Scenario 04: Sulphate pollution plume migration within the shallow, intergranular aquifer for the post-closure phase(s)

A post-closure scenario was simulated to evaluate the pollution plume migration within the intergranular aquifer host after discontinuing of current activities. Figure 14-34 indicates the simulated flow pathways of contaminant particles within the receiving aquifer. It can be observed that the post-closure pollution plume migration remains in a general northeastern to eastern direction towards the lower lying drainage system.

The 50-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.25km$^2$, reaching a maximum distance of ~500.0m in a general northeastern to eastern direction towards the lower laying drainage systems. The 100-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.47km$^2$, reaching a maximum distance of ~570.0m in a general northeastern to eastern direction towards the lower laying drainage systems. The simulation indicates that the pollution plume generated slightly extends beyond the mining right area and intercepts various monitoring boreholes situated towards the north and northeast. Furthermore, it is noted that the simulated pollution plume reaches the local drainage system and associated wetlands.

Figure 14-33 indicates a time-series graph of the simulated mass load contribution originating from the waste infrastructure to down-gradient receptors. It can be observed that the sulphate mass load contribution to local observation boreholes continues to increase during the post-closure phase, reaching a maximum concentration of between 1950.0mg/l to 2150.0mg/l and is a function of the distance towards the waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure remains above the SANS 241:2015 acute health threshold concentration for the duration of the post-closure period. It can be observed that the mass load contribution to the local drainage system increases to a maximum of >1400.0mg/l, breaking through the SANS 241:2015 acute health threshold concentration after a simulation period of approximately 15 years post-closure. It can be noted that the mass load contribution during the post-closure phase for all borehole receptors have not reached a quasi-state conditions and remains in an upward trend.

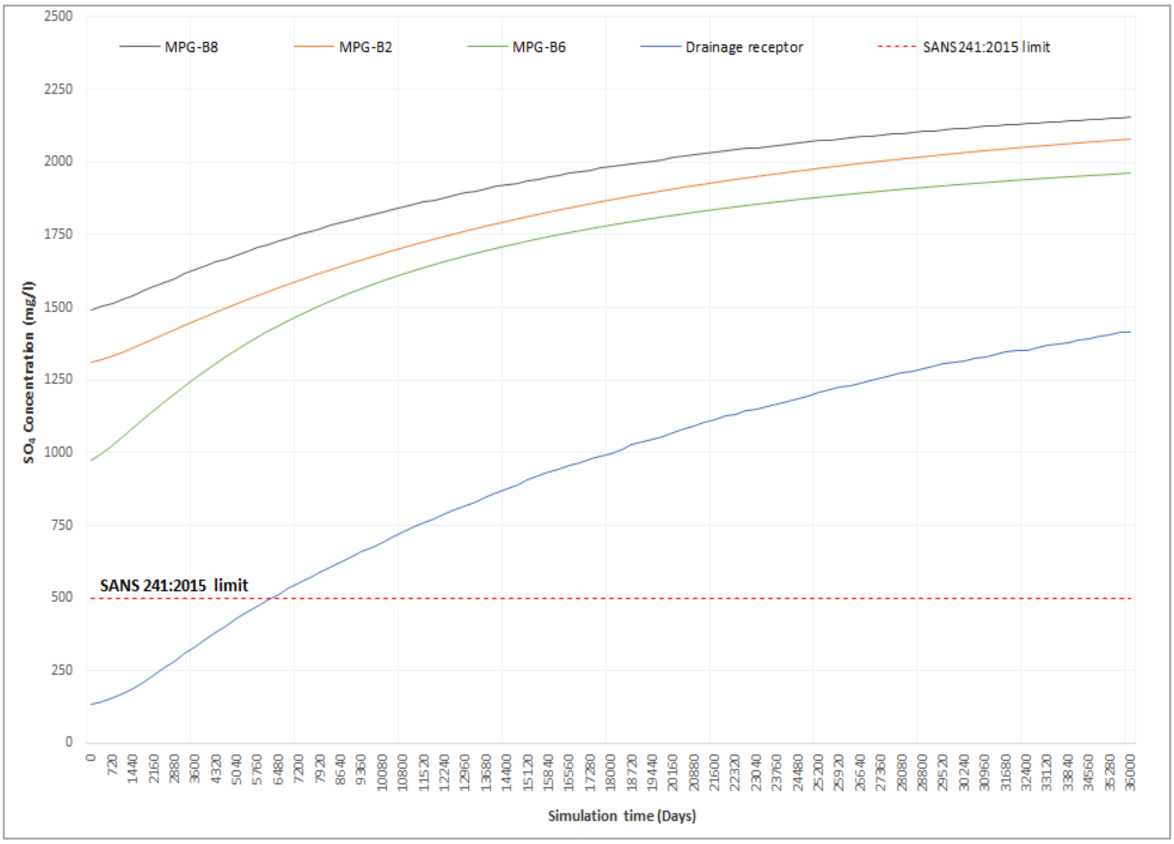



**Figure 14-33 Scenario 04: Time-series graph indicating the sulphate mass load contribution of waste footprints to down-gradient receptors within the intergranular aquifer host during the post-closure phase.**

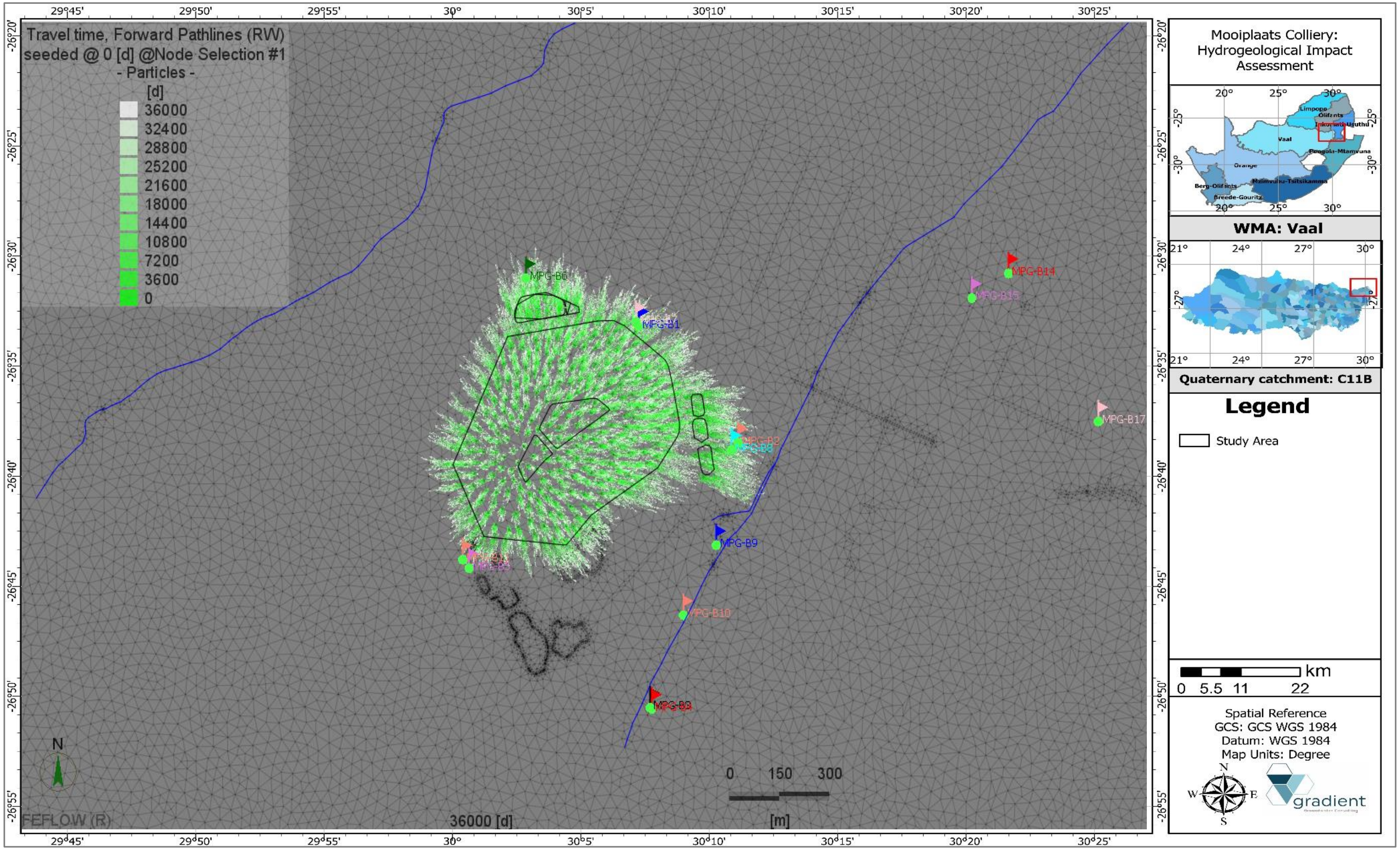



**Figure 14-34** **Scenario 04: Simulated particle tracking of contaminants within the host aquifer unit(s).**

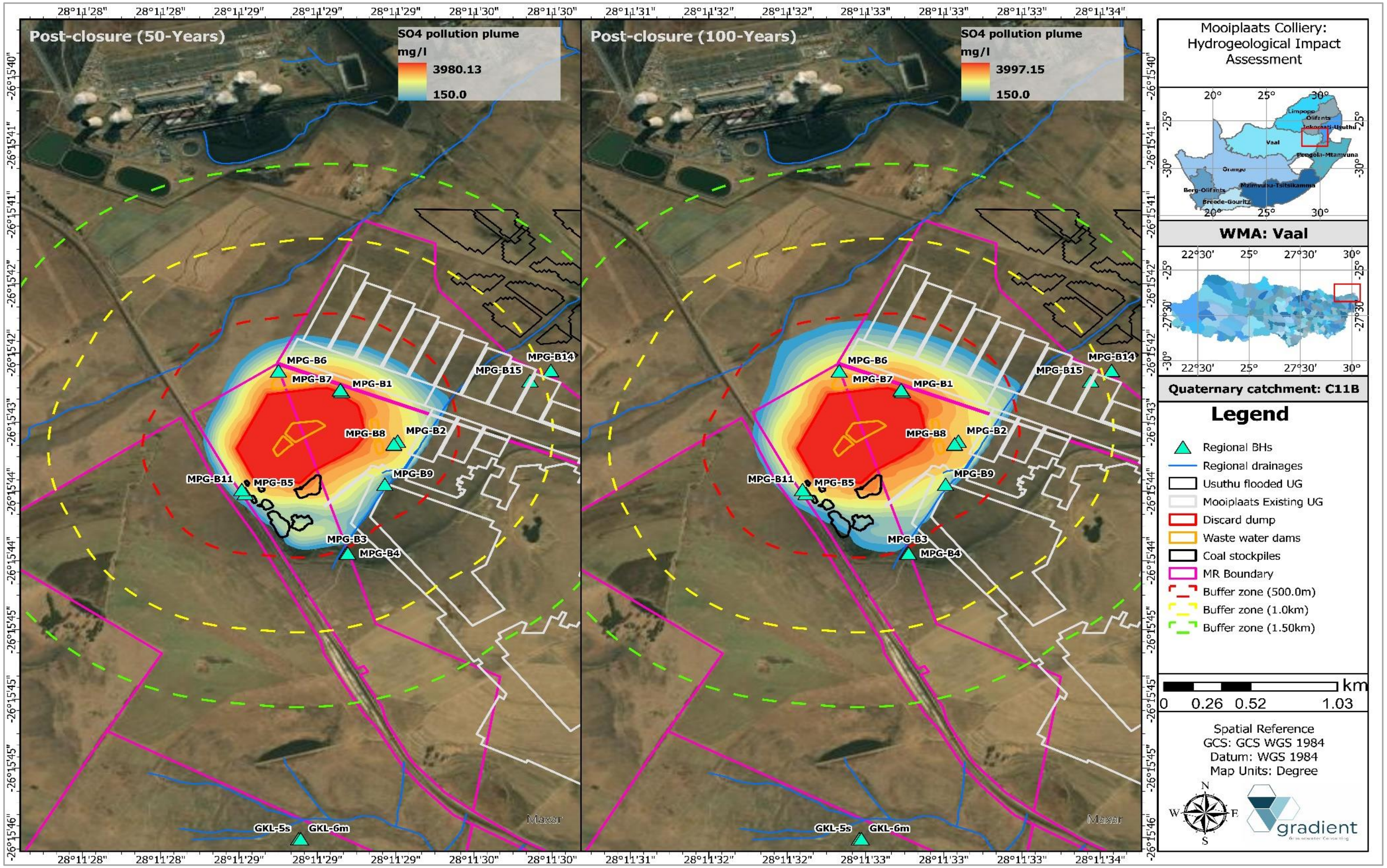



**Figure 14-35** **Scenario 04: Post-closure pollution plume migration.**

### 14.8. Scenario 05: Mitigation and management

Various alternative management and mitigation scenarios which include active water management strategies were simulated to evaluate the remedial options available. Table 14-6 provides a summary of the mitigatory effect and effectiveness of proposed management alternatives on the pollution plume migration while Figure 14-36 shows a time-series graph indicating mass load contribution on down-gradient receptors (Pre-mitigation vs Post-mitigation). It is noted that if implemented successfully, the proposed mitigation and management measures can constrain the pollution plume propagation and reduce the sulphate mass load to below the SANS241 threshold. Below a brief description of each mitigation and management scenario simulated.

#### 14.8.1. Scenario 05a: Sulphate pollution plume migration within the shallow, intergranular aquifer with establishment of scavenger or seepage capturing boreholes down-gradient of proposed waste infrastructure

An active management scenario evaluating the mitigating effect of seepage capturing boreholes i.e. scavenger boreholes on the plume migration via active pumping were simulated. A series of seepage capturing boreholes were established down-gradient of existing waste infrastructure as indicated in Figure 14-37. Due to the negative groundwater gradient created, the pollution plume footprint is reduced by approximately >55.0% to ~0.65km$^2$ with an abstraction volume of ~0.25l/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 302.40m$^3$/d, which should be treated before discharge and re-established into the local groundwater catchment balance. Based on the constraining effect of this mitigation scenario on both the pollution plume migration as well as reduced mass load contribution, this alternative can be viewed as the best remedial option for implementation.

#### 14.8.2. Scenario 05b: Sulphate pollution plume migration within the shallow, intergranular aquifer with implementation of a cut-off or fracturing trench constructed down-gradient of proposed waste infrastructure

A passive management scenario evaluating the mitigating effect of a sub-surface cut-off trench/fracturing curtain[26] on the plume migration were simulated as depicted in Figure 14-38. Due to the deeper groundwater levels i.e. relatively thick vadose zone experienced, this mitigation alternative will not intercept adequate water to create a negative gradient within these zones and accordingly, the pollution plume footprint is reduced by only ~28.57% to ~1.05km$^2$. Intercepted groundwater volumes expected is approximately 50.83m$^3$/d, however this will be dependable on the depth of the proposed cut-off trench.

[26] 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.

### 14.8.3. Scenario 05c: Sulphate pollution plume migration within the shallow, intergranular aquifer with a barrier/ liner system underneath waste infrastructure

A passive management scenario evaluating the mitigating effect of the implementation of a liner or barrier system underneath existing waste infrastructure on the plume migration were simulated as depicted in Figure 14-39. Due to the significant reduction in recharge and infiltration of leachate reporting to the receiving aquifer unit(s), the pollution plume footprint is reduced to ~49.0% to ~0.75km$^2$.

**Table 14-6 Scenario 05: Effectiveness of mitigation and management alternatives on pollution plume areas.**

| Mitigation and management scenarios | Combined plume area (pre-mitigation)(km²) | Combined plume area (post-mitigation)(km²) | Improvement (%) | Intercepted contact water volume (m³/d) |
|---|---|---|---|---|
| Scenario 05a: Establishment of seepage capturing/scavenger boreholes | 1.47 | 0.65 | 55.78 | 302.40 |
| Scenario 05b: Implementation of a cut-off trench/ fracturing curtain | 1.47 | 1.05 | 28.57 | 50.83 |
| Scenario 05c: Implementation of a barrier/ liner system underneath waste infrastructure | 1.47 | 0.75 | 48.98 | 0.00 |

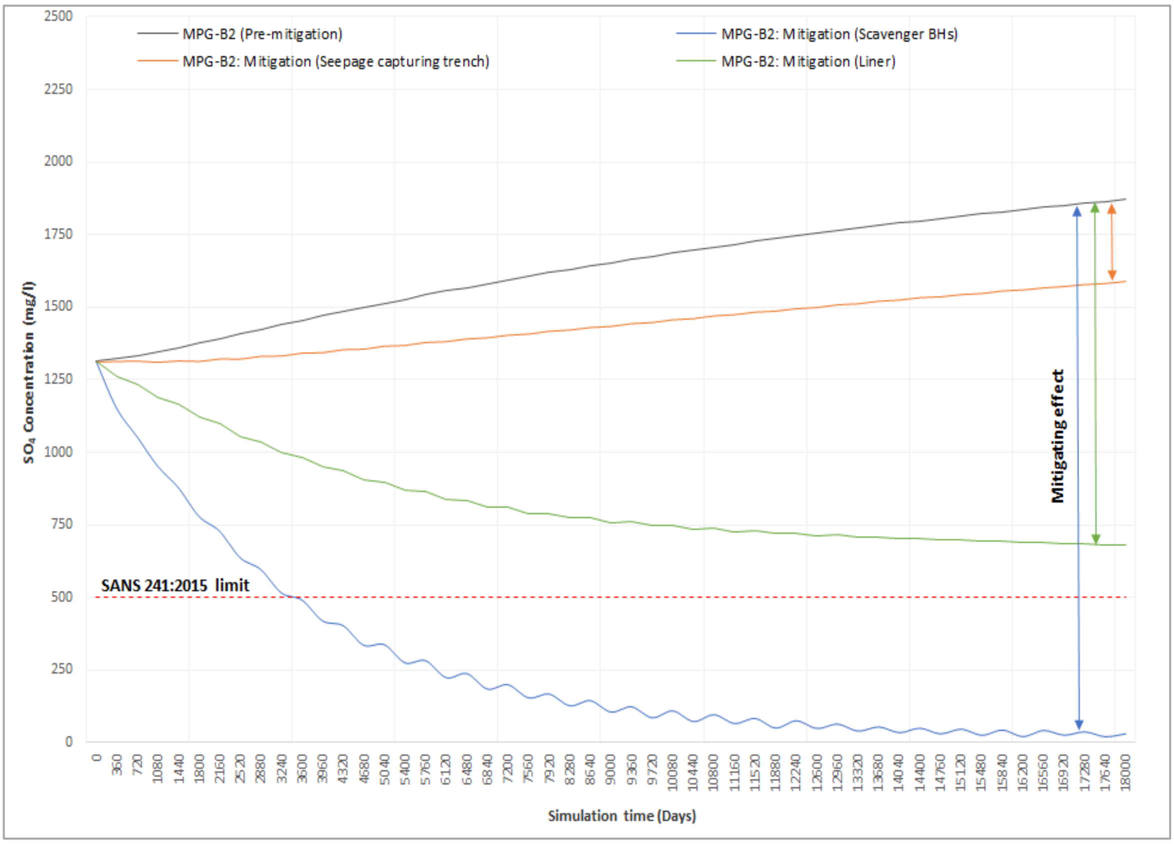



**Figure 14-36 Scenario 05: Time-series graph indicating mass load contribution on down-gradient receptors (Pre-mitigation vs Post-mitigation).**

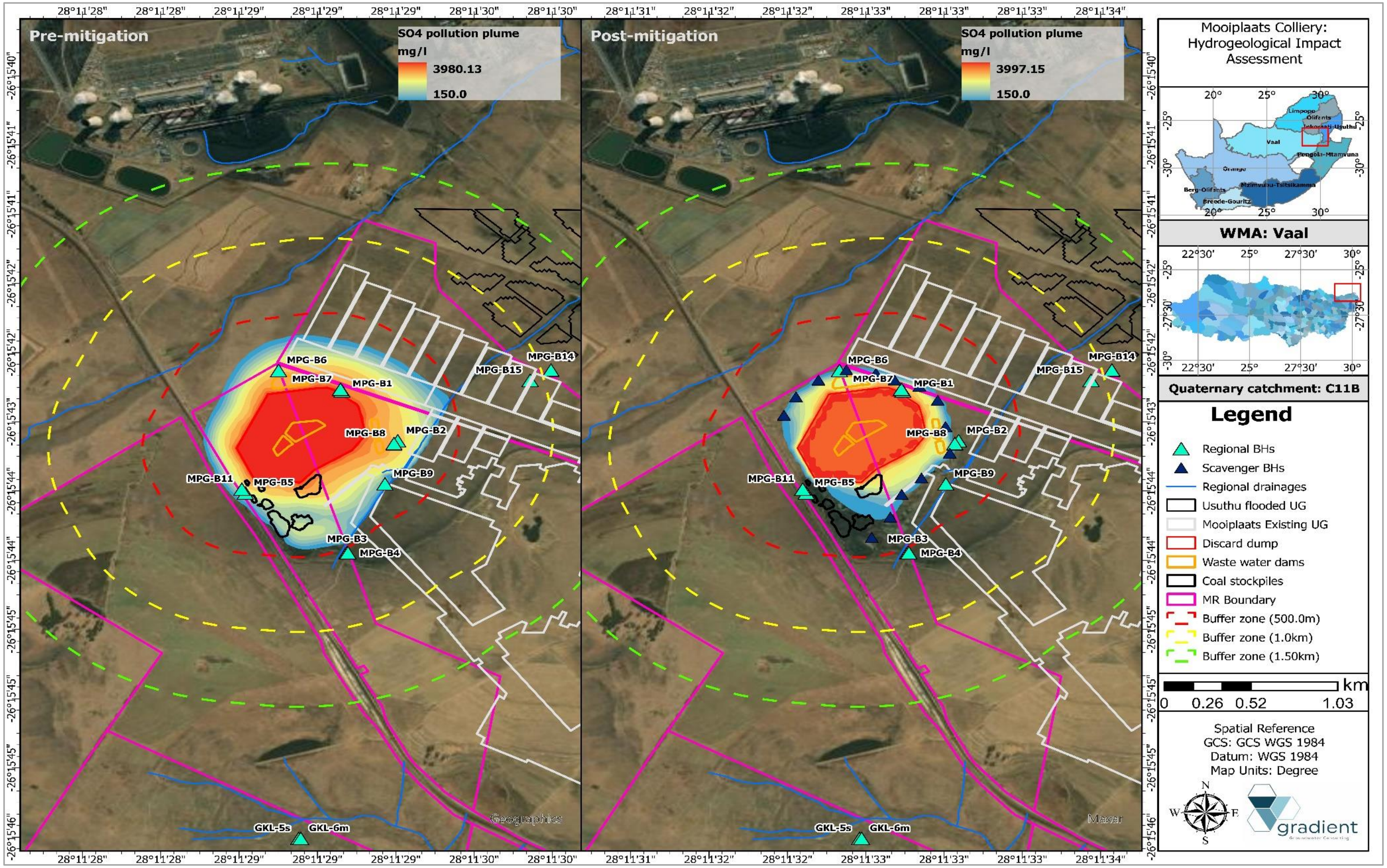



**Figure 14-37** **Scenario 05a: Mitigation and management- Establishment of existing seepage capturing/ scavenger boreholes down-gradient of waste infrastructure footprints.**

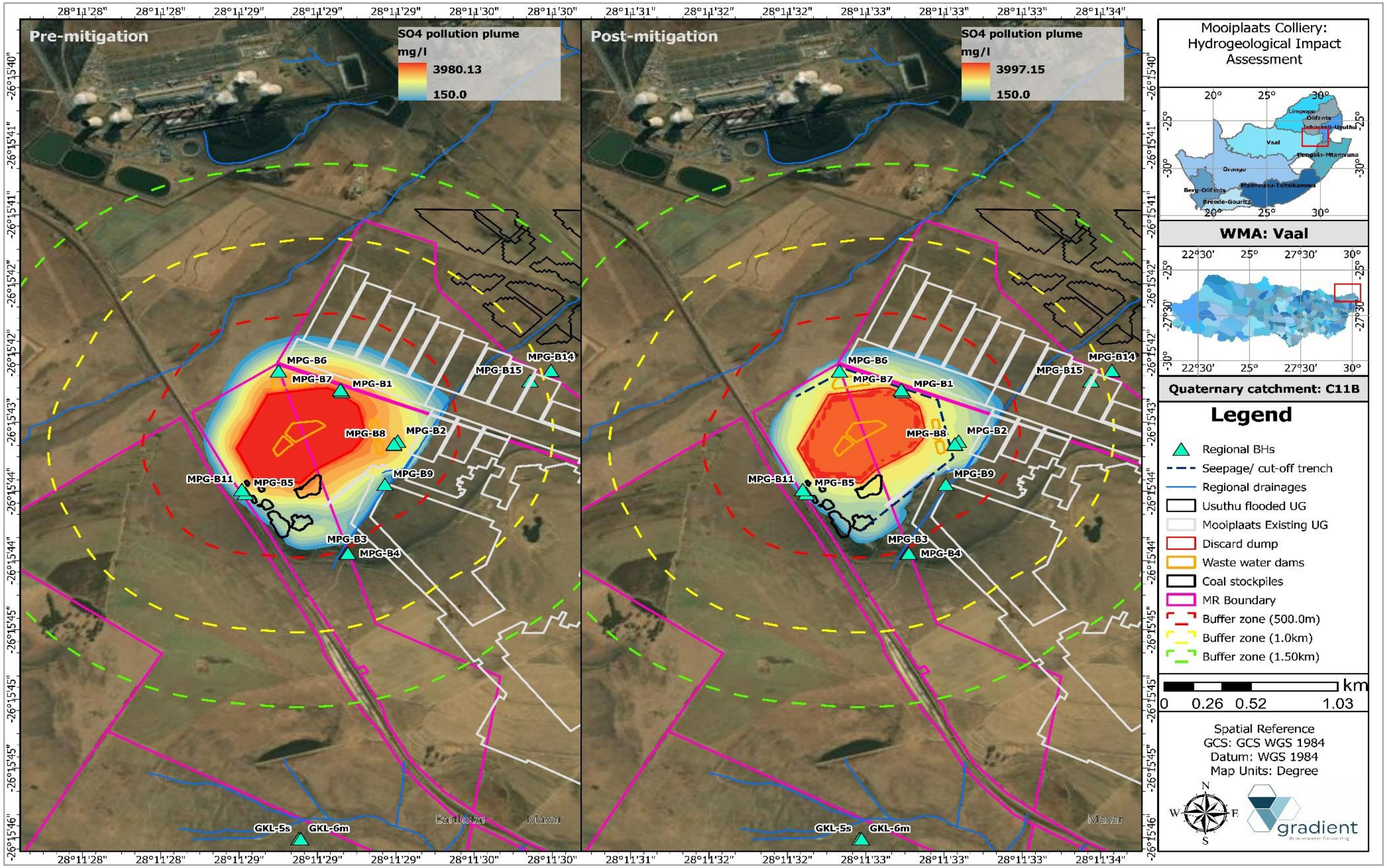



**Figure 14-38** **Scenario 05b: Mitigation and management- Implementation of a cut-off or fracturing trench constructed down-gradient of proposed waste infrastructure.**

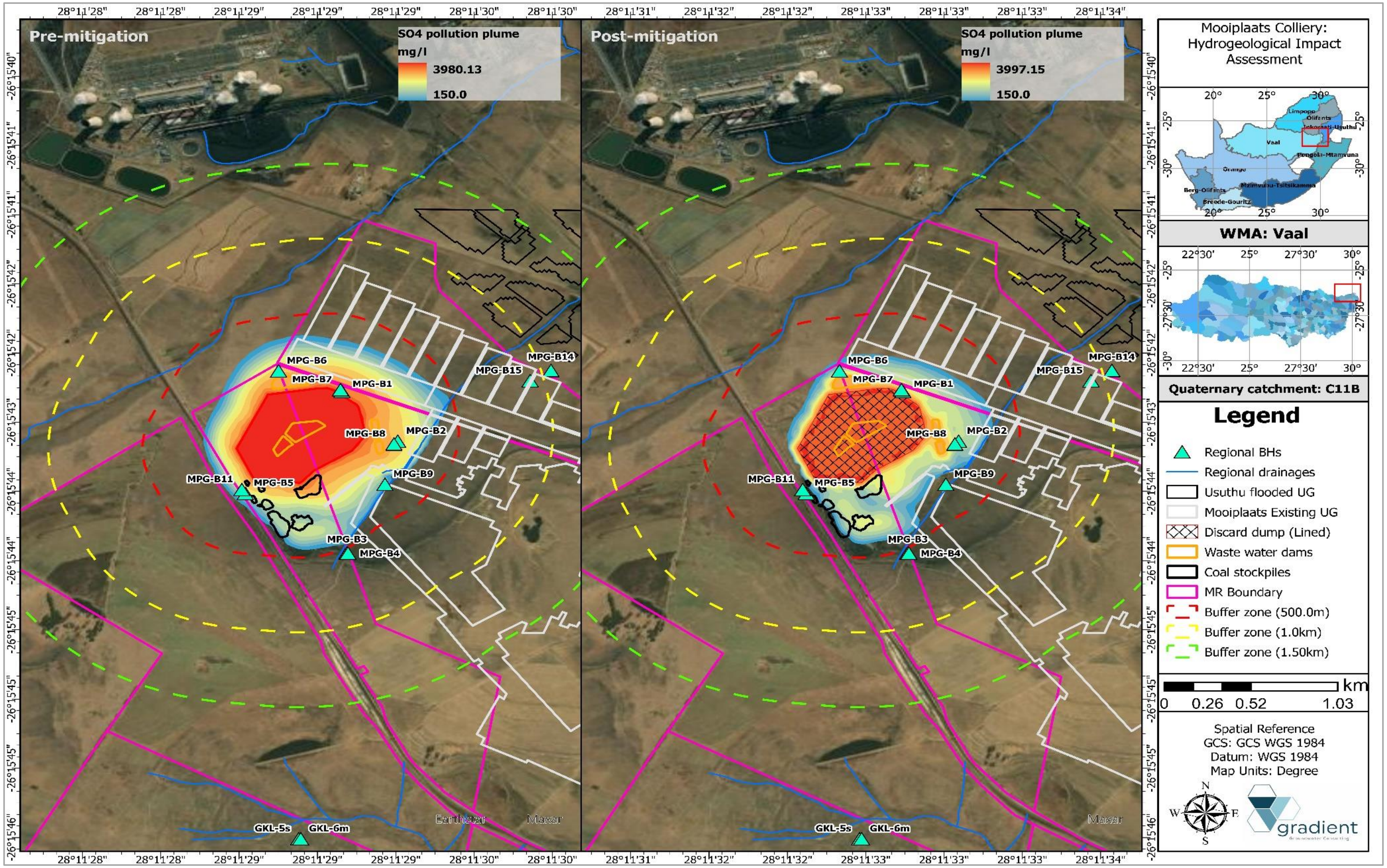



**Figure 14-39** **Scenario 05c: Mitigation and management- Implementation of a Class 3 liner system implemented on the proposed waste infrastructure footprints.**

# 15. ENVIRONMENTAL IMPACT ASSESSMENT

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

## 15.1. Methodology

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

## 15.2. 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 15-1 Impact Consequence.**

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

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 15-1 below.

**Table 15-1 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 15-2 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 15-2 Impact Consequence.**

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

**Table 15-3 Determination of Environmental Risk.**

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

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in Table 15-4.

**Table 15-4 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.

## 15.3. Impact prioritization

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

i. Cumulative impacts; and

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

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

**Table 15-5 Criteria for Determining Prioritisation.**

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

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in Table 15-5 . The impact priority is therefore determined as follows:

**Equation 15-3 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 15-6 below).

**Table 15-6 Determination of Prioritisation Factor.**

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

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

**Table 15-7 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.

### 15.4. Impact Identification and significance ratings

Impacts and significant ratings associated different project phases are briefly discussed below.

#### 15.4.1. Construction phase: Associated activities and impacts

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

#### 15.4.2. Operational phase: Associated activities and impacts

During the operational phase the environmental significance rating of groundwater yield (aquifer dewatering) impacts on down-gradient receptors are rated as **medium negative** whereas the groundwater quality related impacts are rated **as low negative**. Groundwater quality impacts from the discard dump and coal stockpile areas are rated as **medium negative** without implementation of remedial measures and **low negative** with implementation of mitigation measures (Refer to Table 15-8). The main impacts associated with operational phase activities include the following:

i. Groundwater drawdown caused by abstraction from production boreholes 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.

ii. Should the groundwater zone of influence i.e. capture zone reach local drainages, a reduction in groundwater contribution to baseflow of local rivers and streams will occur.

iii. The geochemical character of the carbonaceous overburden material handled on site suggest high acid forming capacity and due to adequate oxidisable sulphides, it has the potential to sustain long-term acid generation.

iv. Poor quality leachate may emanate from various source areas and waste generated, e.g. coal stockpiles, discard dump, pollution control dam, slurry ponds, dirty roads, etc. which will have a negative impact on water quality.

v. Mobilisation and maintenance of mine heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.

vi. Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.

vii. Surface and groundwater deterioration and siltation due to contaminated stormwater run-off.

### 15.4.3. Post-operational phase: Associated activities and impacts

During the operational post-closure phase the environmental significance rating of water quality impacts resulting from seepage and leachate from mine waste facilities on down-gradient receptors are rated as **medium negativ**e without the implementation of remedial measures and **low negative** with implementation of mitigation measures (Refer to Table 15-9). The main impacts associated with mine post-operational phase activities include the following:

i. Hydraulic head recovery and relaxation of groundwater gradients will have a positive effect on groundwater levels and spring flow discharge.

ii. Hydraulic head recovery and relaxation of groundwater gradients will have a positive effect on groundwater levels causing a normalisation in groundwater contribution to baseflow of local drainages and/or groundwater supported wetlands.

iii. Seepage of poor water quality caused by leachate of sulphide bearing minerals from mine waste facilities including discard dumps as well as defunct waste facilities

**Table 15-8 Impact assessment and significance rating: Operational phase.**

| IMPACT DESCRIPTION | | Pre-Mitigation | | | | | | | Post Mitigation | | | | | | | | Priority Factor Criteria | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identifier | Impact | Nature | Extent | Duration | Magnitude | Reversibility | Probability | Pre-mitigation ER | Nature | Extent | Duration | Magnitude | Reversibility | Probability | Post-mitigation ER | Confidence | Cumulative Impact | Irreplaceable loss | Priority Factor | Final score |
| 1.1.1 | Groundwater abstraction can potentially have a negative impact on groundwater and surface water quantities. Lowering of regional groundwater levels due to a depletion in aquifer storage will cause the formation of a cone of depression i.e. groundwater zone of influence and consequently lowering of the regional phreatic/ piezometric levels. | -1 | 3 | 3 | 2 | 1 | 5 | -11.25 | -1 | 3 | 3 | 2 | 1 | 3 | -6.75 | High | 2 | 2 | 1.25 | -8.44 |
| 1.1.2 | Should the groundwater zone of influence i.e. capture zone reach local drainages, a reduction in groundwater contribution to baseflow of local rivers and streams will occur. | -1 | 2 | 3 | 4 | 2 | 4 | -11 | -1 | 2 | 3 | 4 | 2 | 4 | -11 | Medium | 1 | 2 | 1.13 | -12.38 |
| 1.1.3 | Poor quality leachate may emanate from various source areas and waste generated, e.g. coal stockpiles, discard dump, pollution control dam, slurry ponds, dirty roads, etc. which will have a negative impact on water quality. | -1 | 4 | 4 | 4 | 3 | 4 | -15 | -1 | 1 | 3 | 2 | 2 | 3 | -6 | High | 2 | 2 | 1.25 | -7.50 |
| 1.1.4 | Mobilisation and maintenance of mine heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.Impact on groundwater quality due to hydrocarbon contamination caused by mine heavy vehicles and machinery. | -1 | 2 | 4 | 4 | 4 | 3 | -10.5 | -1 | 1 | 3 | 2 | 2 | 3 | -6 | High | 2 | 2 | 1.25 | -7.50 |
| 1.1.5 | Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution. | -1 | 2 | 4 | 4 | 2 | 3 | -9 | -1 | 1 | 2 | 2 | 2 | 2 | -3.5 | High | 2 | 2 | 1.25 | -4.38 |
| 1.1.6 | Surface and groundwater deterioration and siltation due to contaminated stormwater run-off. | -1 | 3 | 4 | 3 | 2 | 3 | -9 | -1 | 2 | 3 | 2 | 2 | 3 | -6.75 | High | 2 | 2 | 1.25 | -8.44 |

**Table 15-9 Impact assessment and significance rating: Post-closure phase.**

| IMPACT DESCRIPTION | | Pre-Mitigation | | | | | | | Post Mitigation | | | | | | | | Priority Factor Criteria | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identifier | Impact | Nature | Extent | Duration | Magnitude | Reversibility | Probability | Pre-mitigation ER | Nature | Extent | Duration | Magnitude | Reversibility | Probability | Post-mitigation ER | Confidence | Cumulative Impact | Irreplaceable loss | Priority Factor | Final score |
| 1.1.7 | Aquifer dewatering effects lessening, post-operational re-watering and hydraulic head rebound. | 1 | 3 | 3 | 2 | 1 | 4 | 9 | 1 | 3 | 3 | 2 | 1 | 4 | 9 | High | 2 | 2 | 1.25 | 11.25 |
| 1.1.8 | Seepage of poor water quality caused by leachate of sulphide bearing minerals from mine waste facilities including discard dumps as well as defunct waste facilities. | -1 | 4 | 4 | 4 | 3 | 4 | -15 | -1 | 2 | 3 | 3 | 2 | 2 | -5 | High | 2 | 2 | 1.25 | -6.25 |
| 1.1.9 | Alteration to stormwater drainage and increase in recharge of aquifer due to poor and incorrect rehabilitation. | -1 | 2 | 3 | 3 | 2 | 3 | -7.5 | -1 | 2 | 2 | 3 | 2 | 2 | -4.5 | High | 2 | 2 | 1.25 | -5.63 |

# 16. GROUNDWATER MANAGEMENT PLAN

The purpose of the groundwater management plan is to provide a guideline and framework for the applicant to identify, mitigate and minimize potential impacts of the proposed operations on sensitive environmental and groundwater receptors. This management plan is applicable to the construction, operational and decommissioning/ post-closure phases of the project.

## 16.1. Potential impacts and associated risks

The following main impacts and associated risks have been identified as part of the groundwater impact assessment:

i. Negative impact on groundwater quantity i.e., lowering of groundwater levels and reduction in borehole yields and spring discharge yields due to abstraction activities.

ii. Negative impact in groundwater quality i.e., deterioration of water quality due to introduction of contaminants as part of the mine development as well as mobilisation of contaminants caused by mining activities.

## 16.2. Key responsibilities

The following management and mitigation measures should be implemented as part of the integrated groundwater management plan. The applicant will be responsible for compliance with the proposed groundwater management plan. Operational staff should implement the following measures:

i. Annual external audits should be conducted to ensure that mine infrastructure are maintained and functioning effectively and according to water use licence and EMPr conditions.

ii. Compile annual audit reports that will be submitted to the applicable regulatory authorities.

## 16.3. Mitigation and management

To follow is a brief description of mitigation and management measures to be implemented per phase.

### 16.3.1. Operational phase: Management and mitigation measures

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

i. Groundwater drawdown caused by abstraction from production boreholes 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. 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 borehole and spring water levels and yields be affected, necessary actions such as provision of alternative water supply measures should be taken to ensure continual water supply.

ii. Groundwater abstraction from proposed production boreholes should not exceed recommended sustainable or safe yields and pump duty cycles.

iii. 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 down-gradient of the mining infrastructure in order to constrain the contamination plume migration as well as manage the groundwater cone of depression.

iv. All material analysed can be classed as Type 3 waste (low hazardous waste) which suggest a low to no risk for contamination.

v. The existing groundwater flow model should be recalibrated with time-series monitoring data on a biennial (once every two years) basis in order to be applied as a water management tool. Scenario predictions and model simulations should be conducted and interpreted by an external and independent specialist.

vi. 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.

vii. All hazardous substances used on-site should have an applicable Material Safety Data Sheet (MSDS) to provide information regarding the hazards, emergency response, protective measures and correct storage methodology.

viii. All hazardous substances and material used on-site should be stored in a dedicated, closed-off facility with an impervious floor and bunded area to prevent seepage and/or run-off in case of accidental spills.

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

x. Develop and implement 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 maintained to have adequate freeboard (0.8m below overflow level) to be able to contain water from 1:50 year rain events.

xi. Stockpiling of material shall not be done within a 1:100-year flood line, unless where such stockpiling has been authorized in terms of the WUL and relevant GN704 Exemption.

xii. Monitoring results should be evaluated on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation. 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.

#### 16.3.2. Post-operational and decommissioning phase: Management and mitigation measures

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

i. It is important to development and implement a post-closure groundwater monitoring program to assess the regional groundwater level rebound as well as pollution plume propagation to serve as early warning mechanism to implement mitigation measures. Should neighbouring borehole and spring water levels and yields remain affected, necessary actions such as provision of alternative water supply measures should be taken to ensure continual water supply.

ii. Rehabilitation should be implemented in accordance with the rehabilitation model and limit areas and volumes of ponding water as far as possible.

iii. Plume migration mitigation and management alternatives i.e., establishment of seepage capturing cut-off trenches, seepage capturing boreholes of implementation of a barrier or capping system should be explored as active mine water management techniques in order to constrain the migration of pollution plumes emanating from pollution sources.

iv. 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 available for nearby users if impacted on.

# 17. 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 17-1 used as guideline for the development of this water monitoring program.

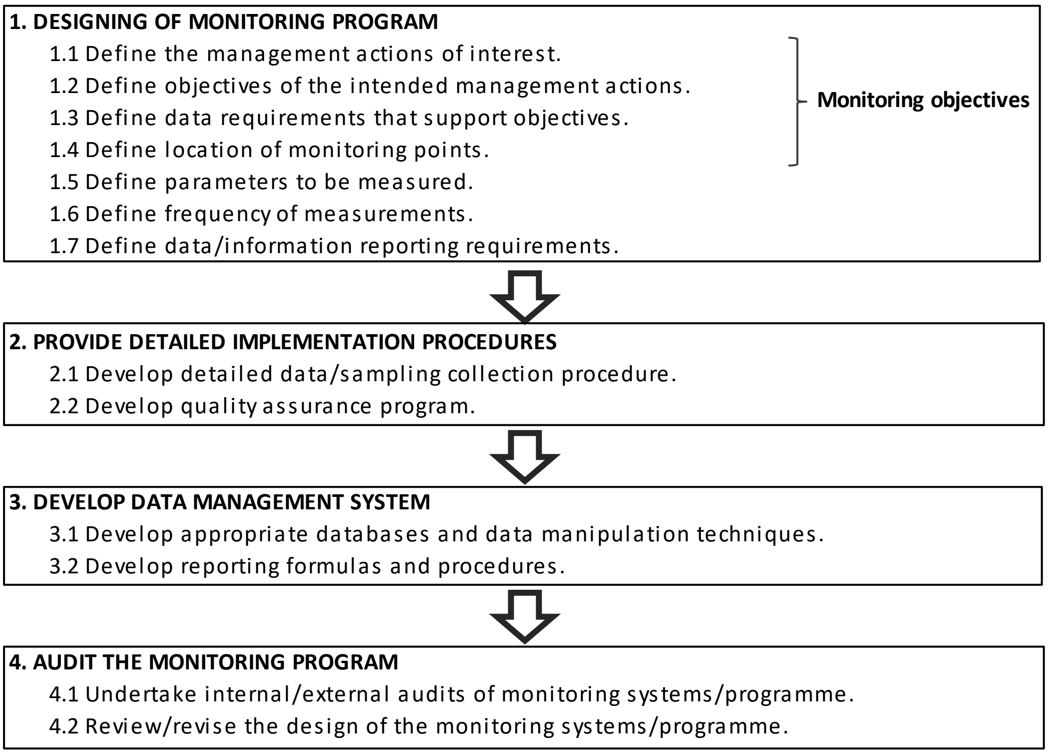



**Figure 17-1 Monitoring programme (DWA, 2006).**

## 17.1. 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.

### 17.2. Monitoring network

Mooiplaats Colliery have an existing monitoring protocol and network in place. The current monitoring program consists of fifteen (15) regular surface water monitoring localities as well as nine (9) dedicated monitoring boreholes. It is recommended that additional monitoring boreholes be established down-gradient of existing waste body footprints consisting of four new monitoring boreholes to evaluate the expected pollution plume migration as well as mass load contribution to environmental and groundwater receptors. Drilling localities for the newly proposed boreholes 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. Depending on the outcome of the geophysical survey, proposed boreholes can be established as a pair in order to target the shallow, intergranular as well as deeper, fractured aquifer units should it be applicable. Table 17-1 summarises the proposed updated and revised monitoring network and program, with relevant information depicted in Figure 17-2.

### 17.3. 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[27]. Chemical variables to form part of the sampling run are listed below.

#### 17.3.1. Groundwater

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

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

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

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

### 17.4. 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 monitoring reports summarising monitoring results should be submitted to the Regional Head: DWS within timeframes as stipulated in the WUL conditions.

[27] 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.

### 17.5. Water levels

It is important to note that the impact of abstraction on the local and regional groundwater environment can only be determined accurately if comparisons are performed based on static water level conditions. Thus, production borehole pumps should be switched off and water levels should be allowed to recover prior to water level recordings.

### 17.6. Groundwater abstraction volumes

A calibrated mechanical or electronic flow meter must be installed at all production boreholes in order to monitor and record abstraction volumes on a daily basis or as utilised. 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.

### 17.7. Sampling procedure

#### 17.7.1. Groundwater

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

i. Calibrate the field instruments before every sampling run. Read the manufacturers manual and instructions carefully before calibrating and using the instrument.
ii. Bail the borehole.
iii. 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.
iv. Leave sample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
v. Replace the cap immediately.
vi. 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.
vii. A unique sample number and description
viii. The date and time of sampling
ix. The name of the sampler
x. 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.
xi. 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 17-1 Revised monitoring network and programme.**

| Monitoring locality | Latitude | Longitude | Locality description | Monitoring frequency | | Parameters |
|---|---|---|---|---|---|---|
| | | | | Water quality | Water level | |
| **Existing groundwater monitoring boreholes (*ad hoc*)** | | | | | | |
| MPG-B1 | -26.638430 | 30.098780 | Monitoring of the discard dump impact (s) - Up-gradient | Quarterly | Monthly | As in Chapter 17.3 |
| MPG-B2 | -26.641430 | 30.101750 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B3 | -26.648160 | 30.099050 | Monitoring of the discard dump impact (s) - Up-gradient | Quarterly | Monthly | |
| MPG-B4 | -26.648190 | 30.099100 | Monitoring of the discard dump impact (s) - Up-gradient | Quarterly | Monthly | |
| MPG-B5 | -26.644570 | 30.093630 | Monitoring of the discard dump impact (s) - Up-gradient | Quarterly | Monthly | |
| MPG-B6 | -26.637190 | 30.095400 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B7 | -26.638320 | 30.098700 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B8 | -26.641600 | 30.101550 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B9 | -26.644030 | 30.101070 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B11 | -26.644350 | 30.093440 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| MPG-B18 | -26.646080 | 30.116850 | Monitoring of UG water level recovery and flooding. Between Usutu/MPN | Quarterly | Monthly | |
| MPG-B19 | -26.646000 | 30.117250 | Monitoring of UG water level recovery and flooding. Between Usutu/MPN | Quarterly | Monthly | |
| **Production boreholes (WUL Section 21a)** | | | | | | |
| Usuthu BH | -26.647678 | 30.112250 | Usuthu UG production borehole | Quarterly | Monthly | As in Chapter 17.3 |
| Potable water BH | -26.641525 | 30.116718 | Potable water production borehole | Quarterly | Monthly | |
| **Newly monitoring boreholes**** | | | | | | |
| Conceptual BH | -26.646306 | 30.097892 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | As in Chapter 17.3 |
| Conceptual BH | -26.639265 | 30.093700 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| Conceptual BH | -26.636971 | 30.099817 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |
| Conceptual BH | -26.639502 | 30.101610 | Monitoring of the discard dump impact (s) - Down-gradient | Quarterly | Monthly | |

**** Newly recommended monitoring boreholes are conceptually placed and preferred groundwater pathways should be delineated by means of a geophysical survey to be targeted for drilling.**

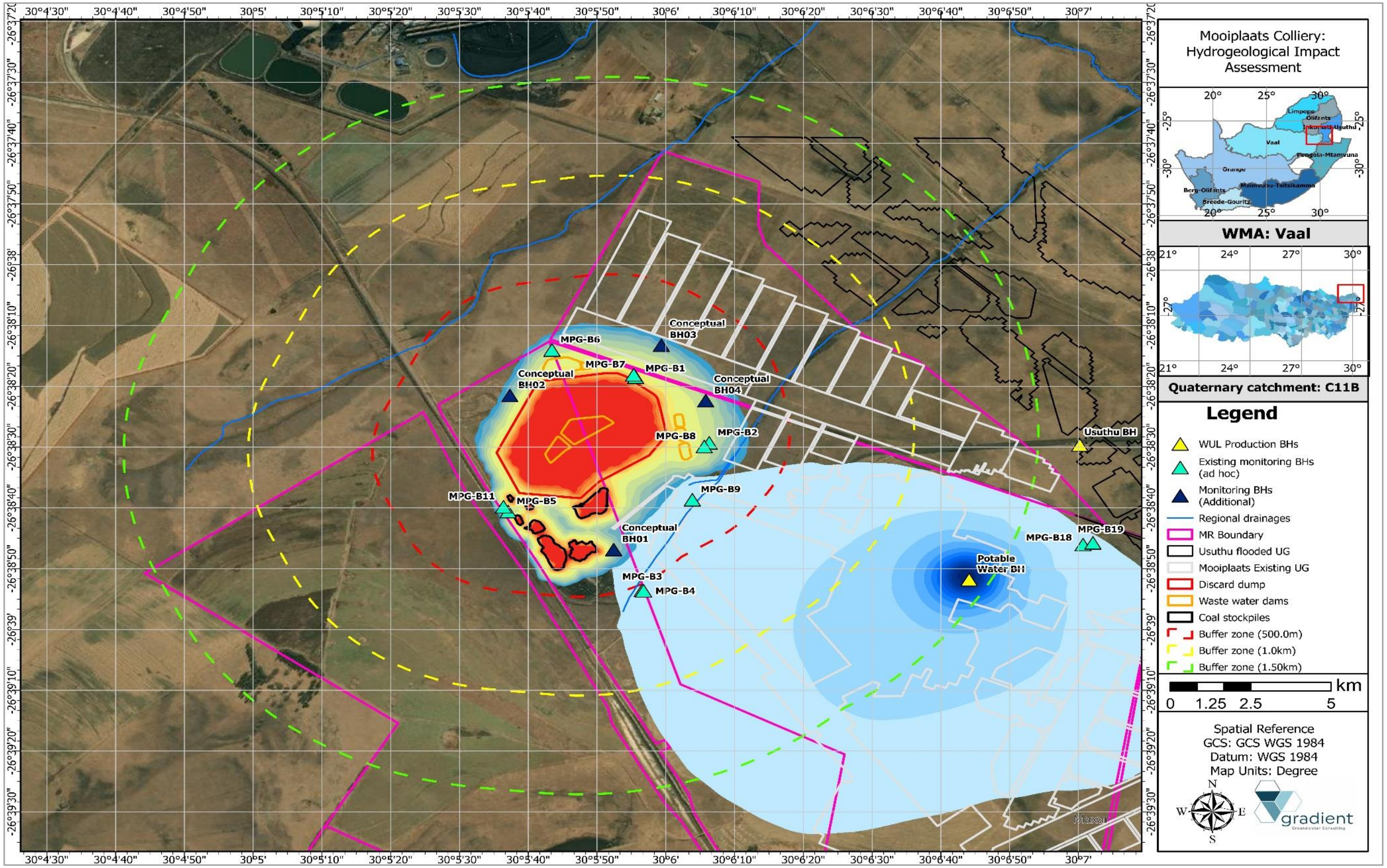



**Figure 17-2** **Updated integrated groundwater monitoring network.**

## 18. CONCLUSIONS

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

i. The site is predominantly underlain by an intergranular and fractured aquifer system comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks. It should be noted that the Ecca Group consists mainly of sandstones, mudstones and shales that are very dense with permeability usually very sluggish due to poorly sorted matrices.

ii. On a local scale, three potential aquifer units can be inferred in the saturated zone:

   a. 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.

   b. An intermediate/deeper fractured where the underground mine void is situated.

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

iii. Various neighbouring boreholes in close proximity (< 500 m) to the mining operations are utilized for domestic purposes and livestock watering.

iv. The unsaturated/ vadose zone within the study area is limited (< 5.0 mbgl) with shallow water levels of the weathered aquifer posing a risk to groundwater contamination.

v. The minimum water level recorded is at monitoring borehole GKL-1, 0.82mbgl, with the deepest water level measured IS at the potable water borehole, 58.77 mbgl. The average water level recorded, with inclusion of potential dynamic water levels is 13.32mbgl, while the average water level, only considering the static water levels is calculated at 4.79mbgl. The relatively low standard deviation compared to the mean depth to groundwater i.e., Coefficient of Variation (CV) < 100%, suggests a relatively steady state groundwater environment.

vi. Analysed data indicate that the surveyed static water levels correlate very well to the topographical elevation with the correlation calculated at $R^2$ >0.99. It should be noted that when static water levels as well as dynamic water levels are considered, the correlation is not good and the $R^2$ ~0.81. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography, however localised deviation in groundwater flow direction can be observed and is attributed to abstraction causing negative hydraulic gradients towards respective boreholes, altering flow directions. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system of the Vaal River traversing the study area. The groundwater flow in the northern segment of the mining right area will be in a general south to southeastern direction whereas the groundwater flow in the southern section of the mining right area will be in a general north to northwestern direction.

vii. The groundwater gradient increases towards the east while a gentler gradient exists to the south. The existing waste facilities are located towards the north with moderate gradients to influence seepage rates.

viii. The overall water quality of groundwater samples analysed is poor with the majority of monitoring points analysed indicating elevated sulphate concentrations which have potentially been impacted on by mining related activities.

ix. The overall water quality of groundwater samples analysed is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Water quality can be described as neutral, non-saline and slightly to moderately hard. Isolated sampling localities indicate a high salt load i.e., GKL-4D and the Usuthu borehole. It should be noted that monitoring locality GKL-4D suggests elevated fluoride, sodium as well as aluminum and iron concentration while monitoring locality Usuthu BH suggest a very high TDS (very saline) with elevated sulphate and sodium concentrations. The latter can be attributed to the defunct underground workings targeted.

x. It is evident that both discard as well as coal product material analysed have a likely acid generation capacity, and due to the relatively high sulphide concentrations observed, there are enough oxidisable sulphides to sustain long term acid generation.

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

xii. Abstraction of water from the study area’s host-aquifer, expressed as a percentage of recharge on the mining properties, is classified as **Category A** (Proposed abstraction = ~19.35% of rainfall recharge). The latter indicates a small scale of abstraction (<60% recharge on property) and consequently low levels of stress in terms of the abstraction recharge ratio.

xiii. If current abstraction and ecological water requirement (Reserve) is accounted for there exists a surplus volume/allocable groundwater volume of 0.78M/m$^3$/a (25.14l/s) within the RMU. Accordingly, it can be concluded that the proposed volume of groundwater to be abstracted from the production boreholes, falls within the calculated groundwater available for allocation, which also accounts for the Reserve.

xiv. Data and information gathered during the site investigation was incorporated to develop a conceptual understanding of the regional hydrogeological system on which the numerical groundwater flow model was based on. The latter was calibrated to an acceptable error margin by using site specific hydrogeological data to serve as a tool to evaluate various water management options and scenarios.

xv. Scenario 02 simulated the water level drawdown caused by abstraction from proposed production boreholes for the operational phase(s). It is evident that the abstraction activities change the hydraulic gradient as groundwater is removed from storage. It should be noted that the simulated groundwater drawdown zone intercepts various monitoring boreholes and stretches to the drainage systems or associated wetlands in the proximity of the site. The groundwater drawdown during the simulated abstraction period will range from <1.0mbsl (meter below static level), i.e., relatively little drawdown expected within the Usuthu boreholes to >21.0mbsl simulated within the Potable water borehole. The groundwater capture zone i.e. drawdown zone of influence extent will cover an estimated footprint of approximately 3.36km$^2$ propagating radially reaching a maximum distance of approximately 1.40km in a general south to southeastern direction. As there exist a pronounced interaction between surface and groundwater it can be assumed that the two regimes are well-linked. Groundwater contribution to baseflow discharge[28] accounts to approximately 1.33E$^{+04}$m$^3$/d during baseline conditions, whereas groundwater contribution to baseflow discharge during the operational period decreases to ~1.29E$^{+04}$m$^3$/d. The latter accounts for an average loss of 3.68E$^{+02}$m$^3$/d, ~2.84% with a maximum reduction of 4.21% for the operational phase(s).

xvi. Scenario 03 simulated the pollution plume migration within the intergranular aquifer originating from the waste infrastructure footprints for the duration of the operational period without any mitigation or management measures applied i.e., worst-case scenario. It can be observed that the pollution plume migration is generally in a northeastern to eastern direction towards the lower lying drainage system. The pollution plume extent covers a total area of approximately 0.95km$^2$, reaching a maximum distance of ~330.0m in a general northeastern to eastern direction. The simulation indicates that the pollution plume generated is mostly confined to the mining right area, however, does intercept various monitoring boreholes and reach to the local drainage system and associated wetlands. It can be observed that the sulphate mass load contribution to local observation boreholes increases to a maximum of between 950.0mg/l to 1500.0mg/l and is a function of the distance towards the waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure is above the SANS 241:2015 acute health threshold concentration after a simulation period of approximately 20 years. It can be observed that the mass load contribution to the local drainage system increases to a maximum of 130.0mg/l however remain below the SANS 241:2015 acute health threshold concentration for the duration of the simulation period.

xvii. A post-closure scenario was simulated to evaluate the pollution plume migration within the intergranular aquifer host after discontinuing of current activities. It can be observed that the post-closure pollution plume migration remains in a general northeastern to eastern direction towards the lower lying drainage system. The 50-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.25km$^2$, reaching a maximum distance of ~500.0m in a general northeastern to eastern direction towards the lower laying drainage systems. The 100-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.47km$^2$, reaching a maximum distance of ~570.0m in a general northeastern to eastern direction towards the lower laying

[28] Baseflow calculations is expressed as the observed loss based on the drainage system traversing the project area.

drainage systems. The simulation indicates that the pollution plume generated slightly extends beyond the mining right area and intercepts various monitoring boreholes situated towards the north and northeast. Furthermore, it is noted that the simulated pollution plume reaches the local drainage system and associated wetlands. It can be observed that the sulphate mass load contribution to local observation boreholes continues to increase during the post-closure phase, reaching a maximum concentration of between 1950.0mg/l to 2150.0mg/l and is a function of the distance towards the waste body footprints. The sulphate concentration for all the monitoring boreholes situated in relatively close proximity to the waste infrastructure remains above the SANS 241:2015 acute health threshold concentration for the duration of the post-closure period. It can be observed that the mass load contribution to the local drainage system increases to a maximum of >1400.0mg/l, breaking through the SANS 241:2015 acute health threshold concentration after a simulation period of approximately 15 years post-closure. It can be noted that the mass load contribution during the post-closure phase for all borehole receptors have not reached a quasi-state conditions and remains in an upward

xviii. Various alternative management and mitigation scenarios were simulated to evaluate the remedial options available. An active management scenario evaluating the mitigating effect of seepage capturing boreholes i.e. scavenger boreholes on the plume migration via active pumping were simulated. Based on the constraining effect of this mitigation scenario on both the pollution plume migration as well as reduced mass load contribution, this alternative can be viewed as the best remedial option for implementation.

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

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

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

## 19. RECCOMMENDATIONS

The following recommendations are proposed following this investigation:

i. It is recommended that the management and mitigation measures be implemented as part of the integrated groundwater management plan (Section 16 of this Report). The Licensee shall appoint a suitably qualified and responsible person and make all of the necessary and reasonable financial, human and equipment resources available to him/her" to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.

ii. It is recommended that the monitoring network and 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 on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

iii. Additional monitoring boreholes as recommended should be established down-gradient of the existing waste infrastructure footprints in order to evaluate the groundwater drawdown as well as mass load contribution to environmental and sensitive groundwater receptors. 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.

iv. Newly established monitoring boreholes should be subjected to aquifer hydraulic parameters to supplement and verify existing hydraulic parameters interpreted as part of the first phase drilling and testing run.

v. Groundwater abstraction from proposed production boreholes should not exceed recommended sustainable or safe yields and pump duty cycles.

vi. All waste material analysed can be classed as Type 3 waste (low hazardous waste) and should be handled and stored/ disposed as such.

vii. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.

viii. Alternative remedial options, as suggested in this report, should form part of the mine closure and rehabilitation strategy.

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## 21. APPENDIX A: RAINFALL DATA (RAINFALL ZONE C1A)

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

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

## 22. APPENDIX B: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

# 24. APPENDIX C: AQUIFER TESTS DRAWDOWN AND RECOVERY DATA

# 25. APPENDIX D: GEOCHEMICAL ANALYSIS LABORATORY CERTIFICATES

## 26. APPENDIX E: SPECIALIST CURICULUM VITAE