EXM Environmental Advisory (Pty) Ltd

KOLOMELA MINE
HYDROGEOLOGICAL ASSESSMENT
DRAFT REPORT

Report No.: HG-R-21-005

September 2021

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SPECIALIST DECLARATION

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

I, Tobias Loubser, hereby declare that:

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, Regulations and all other applicable legislation;
- I have not, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- All the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of regulation 48 and is punishable in terms of section 24F of the Act.

Tobias Loubser (Pr. Sci. Nat)

SYNOPSIS

Background

The Sishen Iron Ore Company (Pty) Ltd, part of Kumba Iron Ore Limited (hereafter referred to as SIOC), owns and operates the Kolomela mine located approximately 8 km southwest of Postmasburg, Northern Cape Province. SIOC proposes to expand activities at Kolomela mine which will include the amendment of current approved footprints/activities and also the development of new activities, as listed below:

- DMS tailings management infrastructure including;
  - New tailings storage facility (TSF), comprising of four (4) cells, on the existing Leeuwfontein WRD to dispose of slimes originating from the DMS plant;
  - Paddocks and return water dam (RWD).
- Evaporation dams;
- Low grade ore storage areas;
- Kapstevel Waste Rock Dump amendment and establishment of two (2) additional WRD's to the south and east of the Kapstevel WRD respectively;
- Backfilling of opencast pits

Study Objectives

A specialist hydrogeological assessment is required in support of the environmental authorisation (EA) and Water Use Licence (WUL) Application process for the proposed amendments and planned new activities at Kolomela mine. The purpose of the study was to develop a conceptual model of the hydrogeological regime and to provide a regional assessment of the potential cumulative current and predicted future impacts associated with the mine. The results from the desktop assessment and numerical groundwater flow and transport model have been used to conclude on the baseline conditions as well as on predicted groundwater related impacts at Kolomela Mine. Mitigation measures were also investigated. In order to achieve the study objectives, the following activities were undertaken:

- Review of existing information;
- Geochemical characterisation and assessment;
- Development of a numerical groundwater flow and transport model;
- Hydrogeological impact assessment and reporting

Water Hydrochemistry and Geochemistry

Water monitoring data from Aquatico Scientific (Pty) Ltd (Aquatico) has been sourced and utilised in this study. Annual water quality reports (2017 – 2020) have also been made available as well as monitoring results from earlier monitoring periods (2008 to 2017). Water quality is generally good (unimpacted) with natural climate and geological conditions being the main water characterising factors~~-~~.The water overall has neutral to alkaline but hard to very hard profiles with only certain parameters being found in elevated concentrations. Total Dissolved Solids (TDS) concentrations were well below the SANS 2015 screening guidelines with concentrations mostly being below 800 mg/ℓ.

The results from previous geochemical studies largely agree on the mineralogy, Acid-Base Accounting (ABA) and the observed Total Concentration's (TC's) and Leachable Concentrations (LC's). The mineralogy of the waste rock and tailings is dominated by silica (quartz), ferric oxide (hematite), aluminium oxide and dolomite. In terms of acid generating potential all studies agree that the potential is low to zero for the waste rock or tailings material. The TC's are also similar in the studies in that the elements observed to exceed Total Concentration Threshold (TCT) values are mostly barium, copper and manganese. The LC's are observed to be similar as well. The investigations all classed the waste rock and tailings as Type 3 Waste. The impact on water resources from the Mine Residue Facilities (MRF's) will be minimal, one of the reasons being the very low annual TDS load to groundwater (without Class C liner systems).

Geological and Hydrogeological Setting

The study area is located within the Maremane Dome on the western edge of the Kaapvaal Craton. Locally, the Transvaal Supergroup rocks were deposited unconformably on a basement of Ventersdorp Sequence (lavas) within the Griqualand West sub-basin. In Griqualand West basin the Transvaal Supergroup has a gentle dip to the west. The base of the Griqualand West succession, dating from the middle Proterozoic age, comprises of the sedimentary Ghaap Group which is overlain by the clastic Postmasburg Group. Locally, the Kalahari Group sands is characterised by calcretes, clays and pebbles which transition into underlying Dwyka tillites and shales. The study area has also been subjected to a protracted series of deformation events which produced a series of structures i.e. extensive N-S trending/ striking (W dipping) faults.

As no site characterisation work was conducted as part of the Gradient (2021) hydrogeological assessment, the findings were inferred from previous hydrogeological assessments and groundwater models conducted at Kolomela Mine and surrounding areas, more specifically studies completed by Itasca (2015 & 2020/2021), TECT (2016) and Groundwater Complete (2018).

Decreasing water level trends were observed in a number of boreholes in recent years whereas in others water level recovery was observed. This may be attributed to a combination of factors i.e. persevering drought conditions, mine dewatering and aquifer recharge. It is observed that groundwater flow is generally towards the south and southwest. Groundwater flow direction, locally, is impacted by dewatering from mining with flow towards the pits as well as the Groenwaterspruit. Regionally groundwater levels mimics topography (90% correlation) with flow towards the south & southwest. The average depth to groundwater across the entire monitoring network, excluding dewatering and recharge boreholes, were estimated to be 12.97 mbg (2019) and 13.5 mbg (2020). The harmonic mean has been calculated to be 20.8 mbg (2019) and 21.5 mbg (2020).

Based on the hydrogeological map and data obtained from previous studies, two main aquifers are typically present in the project area. These are:

- The first, upper, **unconfined to semi-confined aquifer**, comprising mainly of Kalahari Formation calcareous sand and silt which extends down to the more competent calcretes. The calcretes retards groundwater flow and groundwater recharge because of its low permeability. Yields from calcrete are low, exceptions are around Groenwaterspruit (east) and Lucasdam Vlei (West) both low lying drainage areas with higher recharge due to seepage and increased hydraulic conductivity due to paleo channels comprising of coarse gravels. In certain places, water strikes also occur on the contact between the calcretes and underlying clays.
- A **deeper, unweathered fractured rock (second porosity) aquifer**, is the major aquifer system within Transvaal/Griqualand West sequences where water occurrence is mainly within fissures and fractures in the brecciated Banded Iron Formation (BIFs) where mineralization and preservation of ore bodies occurred through folding, thrusting, fracturing and sinkholes. Yields can vary from 1 – 80 L/s. Inherently, these types of aquifers are heterogeneous and aquifer parameters are variable. The Ongeluk Formation is generally considered to be a low-yielding aquifer. A dolomitic aquifer is also found in which water occurrence is mostly restricted to karstic compact carbonate rock. The dolomitic aquifers also fall under the secondary, fractured rock

aquifer. Exploration in the dolomites indicated yields of 2 – 4 L/sec, however yields of up to 80 L/s have been recorded.

Based on Vegter (1995) the recharge estimated groundwater recharge for the study area is in the order of 2.7% (8 mm/annum) of the MAP. The chloride mass-balance method was used to determine how the recharge values obtained agree with those from the previous investigations at 2.9% (9mm/annum).

Local rivers do not flow regularly and is probably disconnected from the regional aquifer within the vicinity of Kolomela. No water losses occur from the non-perennial rivers into the model domain, but groundwater on either side of the river might discharge into it as a function of the calculated gradients. Where the Kalahari Formation aquifer is predominantly unsaturated, the rivers and streams most likely only yield water after good rainfall events. Boreholes in the Groenwaterspruit and Lucasdam Vlei areas yield water throughout the year. Groundwater seepage and pit inflows may still occur from the intergranular aquifer during the wet season as a result of the recharge of rainwater that equate to river flow. Aquifer classification indicates that the regional aquifers mostly classified as minor-aquifer systems as a result of the low exploitable potential. However, the Kolomela aquifer is a major-aquifer which is classed as a non-degradation level in terms of protection level.

Numerical Groundwater Flow and Transport Model

A numerical groundwater flow and contaminant transport model were developed to quantify and qualify potential impacts and to serve as a tool to evaluate various water management options and scenarios.

- Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Leeuwfontein South Pit is approximately 2.61e^{+04} m^3/d (1088.0 m^3/h) with a maximum groundwater ingress of approximately ~1800.0 m^3/h for the duration of the simulation period. The predicted dewatering rates correlate well to the existing groundwater flow model (Itasca, 2021) simulations, however the maximum dewatering rate expected is higher and can be attributed to different pit dimensions being the main driver of groundwater ingress.
- Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Kapstevel Pit is approximately 1.67e^{+04} m^3/d (~700.0 m^3/h) with a maximum groundwater ingress of approximately ~1600.0 m^3/h for the duration of the simulation period.
- Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Klipbankfontein Pit is approximately 2.77e^{+03} m^3/d (~115.0 m^3/h) with a maximum groundwater ingress of approximately ~240.0 m^3/h for the duration of the simulation period.
- The predicted dewatering rate correlate well to the existing groundwater flow model (Itasca, 2021) simulations, however the maximum dewatering rates expected is higher and can be attributed to different pit dimensions being the main driver of groundwater ingress.
- It is expected that the groundwater drawdown within existing monitoring as well as neighbouring and private boreholes will range between 3.0m to 50.0-100 mbsl within close proximity to the pit footprints.
- The groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of approximately 509.0 km² at the mine end of life period. It should be noted that the simulated groundwater drawdown zone extends beyond the mining right area stretching a maximum distance of ~8.0 km towards the southeast and ~17.0 km in a general north to north-eastern direction. The groundwater drawdown observed in the north-eastern parts of the greater study area can possibly be attributed to existing mine dewatering activities within this area which has been active the last approximately 100 years.

- It should be noted that the majority of properties being intercepted by the drawdown zone are owned by SIOC, however there are privately owned properties being impacted on as well especially towards the northern and eastern perimeters. Furthermore, the zone of impact does reach various boreholes which is current being utilised.
- A mine post-closure scenario was simulated wherein the hydraulic head recovery within the groundwater drawdown zone of influence was evaluated. It can be observed the potential decant elevations for all the planned pit footprints is situated from 20.0 m (Kapstevel Pit) to > 50.0 m (Leeuwfontein and Klipbankfontein Pits) above the pre-mining and calibrated groundwater level and as such it is highly unlikely that decant will occur. It is estimated that the recovery period i.e. time remaining mine voids will take to fill will be >100 years and beyond the simulation period. A mine post-closure scenario was also conducted wherein the pit footprints were not backfilled and acted as permanent sinks due to the high evaporation rate expected. It is evident that the highest groundwater elevation will not extend beyond 1180.0 mamsl and will reach equilibrium between 6 to 50 years from cessation of mining activities.
- Groundwater level recovery within impacted monitoring as well as neighbouring and private boreholes will be a function of the proximity and distance to the dewatering activities.
- Mass transport model simulations predicts that the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 27.3 km^2, consisting of 10.8 km^2 (Kapstevel section) and 16.5 km^2 (Klipbankfontein and Leeuwfontein sections). It is observed that the generated pollution plume does not migrate in the expected down-gradient direction due to the negative hydraulic gradient caused by the operational pit dewatering activities constraining plume propagation. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient and is limited to the mining right area.
- A 50-year post-closure scenario suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 34.4 km^2, consisting of 12.6 km^2 (Kapstevel section) and 21.8 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 500 m (Kapstevel section) to 800 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient, with the Kapstevel pollution plume extending slightly beyond the mining right area.
- The 100-year model simulation suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 41.5 km^2, consisting of 15.2 km^2 (Kapstevel section) and 26.3 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 1000 m (Kapstevel section) to 2000 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated by the Kapstevel operations reaches down-gradient neighbouring boreholes SUN01, SUN02 and SUN03 situated towards the south as well as WKP05 located to the west, with the Kapstevel pollution plume extending slightly beyond the mining right area. The mass load contribution of the source term reaches a maximum concentration of 200 mg/ℓ to 270 mg/ℓ to the west and 600.0 mg/ℓ towards the south.

Groundwater Impact Assesment

The impact assessment (impact ratings) indicates moderate to high impacts on local and regional aquifers as a result of mine dewatering impacts from the Klipbankfontein, Leeuwfontein and Kapstevel opencast pits. Water quality impacts as indicated by the pollution plume models are rated as being mostly low to moderate from the waste rock dumps and planned co-disposal facilities.

The following recommendations are proposed:

i. It is recommended that mitigation and management measures as set out in this report should be implemented as far as practically possible.
ii. It is recommended that the monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system.
iii. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Human Settlements, Water and Sanitation.
iv. It is recommended that the numerical groundwater flow and transport model be updated every two (2) years, also when (if) changes are made to the mine plan (layout and scheduling). Groundwater monitoring should also be conducted as per the current monitoring plan or agreement.

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GLOSSARY

Abstraction: The act of removing water from a groundwater resource.

Act (The): National Environmental Management Act (Act No. 107 of 1998).

Alluvial Aquifer: An aquifer comprising unconsolidated material deposited by water, typically occurring adjacent to rivers and in buried paleochannels.

Aquifer: Aquifer means a geological formation which has structures or textures that hold water or permit appreciable water movement through them.

Aquifer Testing: Aquifer testing involves the withdrawal of measured quantities of water from or the addition of water to, a borehole(s); and the measurement of resulting changes in head in the aquifer both during and after the period of abstraction or addition.

Artesian Borehole: Boreholes that penetrate confined aquifers in which the piezometric surface is above ground level, so that the boreholes spontaneously discharge water without being pumped.

Baseflow: Sustained low flow in a river during dry or fair-weather conditions, but not necessarily all contributed by groundwater; includes contributions from interflow and groundwater discharge.

Borehole: Includes a well, excavation, or any other artificially constructed or improved underground cavity which can be used for the purpose of intercepting, collecting or storing water in or removing water from an aquifer; observing and collecting data and information on water in an aquifer; or recharging an aquifer.

Borehole Log: A record of the geological and hydrogeological conditions encountered in the drilling of a borehole and the construction thereof.

Borehole Yield: The volume of water that can be abstracted from a borehole.

Catchment: Catchment in relation to watercourse or watercourses or part of a watercourse means the area from which any rainfall will drain into the watercourses, or part of a watercourse, through surface flow to a common point or points.

Conceptual Model: A conceptual model includes designing and constructing equivalent but simplified conditions for the real-world problem.

Cone of Depression: The depression of hydraulic head around a pumping borehole caused by the withdrawal of water.

Contamination: The introduction of any substance into groundwater systems by the action of man.

Drawdown: The distance between the static water level and the surface of the cone of depression.

Dyke: A tabular or sheet-like body of igneous rock that cuts through and across the layering of adjacent rocks.

Electrical Conductivity (EC): Electrical conductivity is a measure of how well a material accommodates the transport of electric charge. The more salts dissolved in the water, the higher the EC value. It is used to estimate the amount of total dissolved salts, or the total amount of dissolved ions in the water.

Fault: A zone of displacement in rock formations resulting from forces of tension or compression in the earth’s crust.

Fracture: Any break in a rock including cracks, joints and faults.

Fracture Flow: Water movement that occurs predominantly in fractures and fissures.

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

Hydraulic Gradient: The rate of change in the total hydraulic head per unit distance of flow in a given direction.

Hydraulic Head: Hydraulic head is the height above a datum plane such as sea level of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system.

Monitoring Borehole: A borehole used to measure groundwater trends.

Observation Borehole: A borehole used to measure the response of the groundwater system to an aquifer test.

Porosity: Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.

Quaternary Catchment: A fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit.

Recharge: The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

Remediation: Reduce the concentrations of contaminants in groundwater to some acceptable level.

Static Water Level (SWL): The groundwater level in a borehole not influenced by abstraction or artificial recharge.

Saturated Zone: The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.

Semi-confined Aquifer: An aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur.

Specific Yield (SY): The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium.

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

Unconfined Aquifer: An aquifer where the water table is the upper boundary and with no confining layer between the water table and the ground surface. The water table is free to fluctuate up and down.

Unsaturated Zone: That part of the geological stratum above the water table where interstices and voids contain a combination of air and water, synonymous with zone of aeration or vadose zone.

Water table: The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is equal to that of the atmosphere.

Acronyms and abbreviations

Acronym / abbreviations	Definition
ABA	Acid Base Accounting
ASTM	American Society for Testing Materials
AMD	Acid Mine Drainage
AP	Acid Potential
ARD	Acid Rock Drainage (similar to AMD)
ASLP	Australian Standard Leaching Procedure
BPEO	Best Practice Environmental Option
DEM	Digital Elevation Model
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation (current name)
DWAF	Department of Water Affairs and Forestry (previous name)
EIA	Environmental Impact Assessment
EMPR	Environmental Management Program Report
i	Hydraulic gradient
ℓ	Litre
LC	Leach concentration in mg/ℓ
LCT	Leach concentration threshold in mg/ℓ
LOI	Loss on ignition (percentage)
LOM	Life of Mine
m^3	Cubic metres
M	Molar
ME	Mean Error
mg/kg	Milligram per kilogram
mg/ℓ	Milligram per litre
n	Porosity
NP	Neutralising potential
NPR	Neutralising potential ratio
NRSMD	Normalised Root Mean Square Deviation
NEM:WA	National Environmental Management: Waste Act, Act 59 of 2008, as amended
NWA	National Water Act, Act 39 of 1998, as amended
PAG	Potentially acid generating
REV	Representative Elementary Value
RMSE	Root Mean Square Error
S	Storage coefficient
T	Transmissivity
TC	Total concentration in mg/kg
TCT	Total concentration threshold in mg/kg
TDS	Total dissolved salts
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
µS/cm	Micro Siemens per centimetre

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1. INTRODUCTION

1.1 Background

The Sishen Iron Ore Company (Pty) Ltd, part of Kumba Iron Ore Limited (hereafter referred to as SIOC), owns and operates the Kolomela mine located approximately 8 km near Postmasburg, Northern Cape Province. SIOC proposes to expand activities at Kolomela mine which will include the amendment of current approved footprints/activities and also the development of new activities.

An investigation is required to assess the impact that the current and proposed amended and new mining associated activities may have on the local and regional groundwater regimes, taking into account the current and future predicted dewatering and contamination associated with the proposed mining and associated activities.

The purpose of the study was to develop a conceptual model of the hydrogeological regime and to provide a regional assessment of the potential impacts associated with the mine. The results from the desktop assessment and numerical groundwater flow and transport model have been used to conclude on the baseline conditions as well as on predicted groundwater related impacts at Kolomela Mine. Mitigation measures were also investigated.

2. REGIONAL SETTING

2.1 Site Locality

Kolomela mine is located within quaternary catchment D73A of the Vaal (major) Water Management Area (WMA), approximately 8km southeast of the town of Postmasburg in the Northern Cape Province. The R383 Regional Route runs along the eastern boundary of the mine and connects with the N8 National Route to the south.

The main land uses include stock and game farming as well as mining. Beeshoek mine is located approximately 10 km to the north and Sishen Mine approximately 65km. The location of the mine is shown in **Figure 2.a.**

2.2 Project Description

Iron ore is currently extracted from three (3) opencast pits, namely Klipbankfontein (KB), Leeuwfontein (LF) and Kapstevel North (KSN). Kolomela is also in the process of developing the Kapstevel South pit (KSS) whereas the Heuningkranz and Ploegfontein ore bodies are planned to be mined in future. The Life of Mine is planned to be extended to 2036.

Kolomela mine currently utilises a Modular Dense Media Separation (DMS) Processing Plant for the processing of low-grade ore. The DMS plant produces tailings and discard which is temporarily stockpiled on site, cured and then blended and disposed together with waste rock. At the direct shipping ore (DSO) plant, recovered ore is crushed and screened and stockpiled into lumps and fines for transportation. A product stockpile area has been developed south of the DSO Processing Plant.

Authorised waste rock dumps (WRD's) at Kolomela mine include Kapstevel WRD (833 ha), Leeuwfontein North WRD (608ha), Leeuwfontein South WRD (469ha) and Klipbankfontein WRD (485ha).

SIOC proposes to expand activities at Kolomela mine which will include the amendment of current approved footprints/activities and also the development of new activities, as listed below ((refer to **Figure 2.b**))

- DMS tailings management infrastructure including;
  - New tailings storage facility (TSF), comprising of four (4) cells, on the existing Leeuwfontein WRD to dispose of slimes originating from the DMS plant;
  - Paddocks and return water dam (RWD).
- Evaporation dams;
- Low grade ore storage areas;
- Kapstevel WRD amendment and establishment of two (2) additional WRD's to the south and east of the Kapstevel WRD respectively;
- Backfilling of opencast pits

A specialist hydrogeological assessment is required in support of the environmental authorisation (EA) and Water Use Licence (WUL) Application process for the proposed amendments and planned new activities at Kolomela Mine. The main objectives of this study are to:

- Develop a numerical groundwater flow and mass transport model to be applied to quantify and qualify the proposed impact of mining activities on the groundwater environment;
- Conduct a groundwater impact assessment using a risk-based approach, based on existing site characterisation data, available literature and data from previous specialist studies;
- Recommendations on best practise mitigation and management measures including post-closure alternatives to be implemented.

2.3 Study Methodology

This hydrogeological assessment was undertaken according to the Department of Water Affairs Best Practice Guideline G4 (Impact Prediction) (DWA BPG, 2008).

The main aim of the hydrogeological assessment was to assess the groundwater dynamics at Kolomela mine i.e. groundwater inflow volumes, as well as the current and predicted extent of contamination in groundwater emanating from the site operations.

In order to achieve the study objectives, the following activities were undertaken:

- Review of existing information;
- Geochemical characterisation and assessment;
- Development of a numerical groundwater flow and transport model;
- Hydrogeological impact assessment and reporting

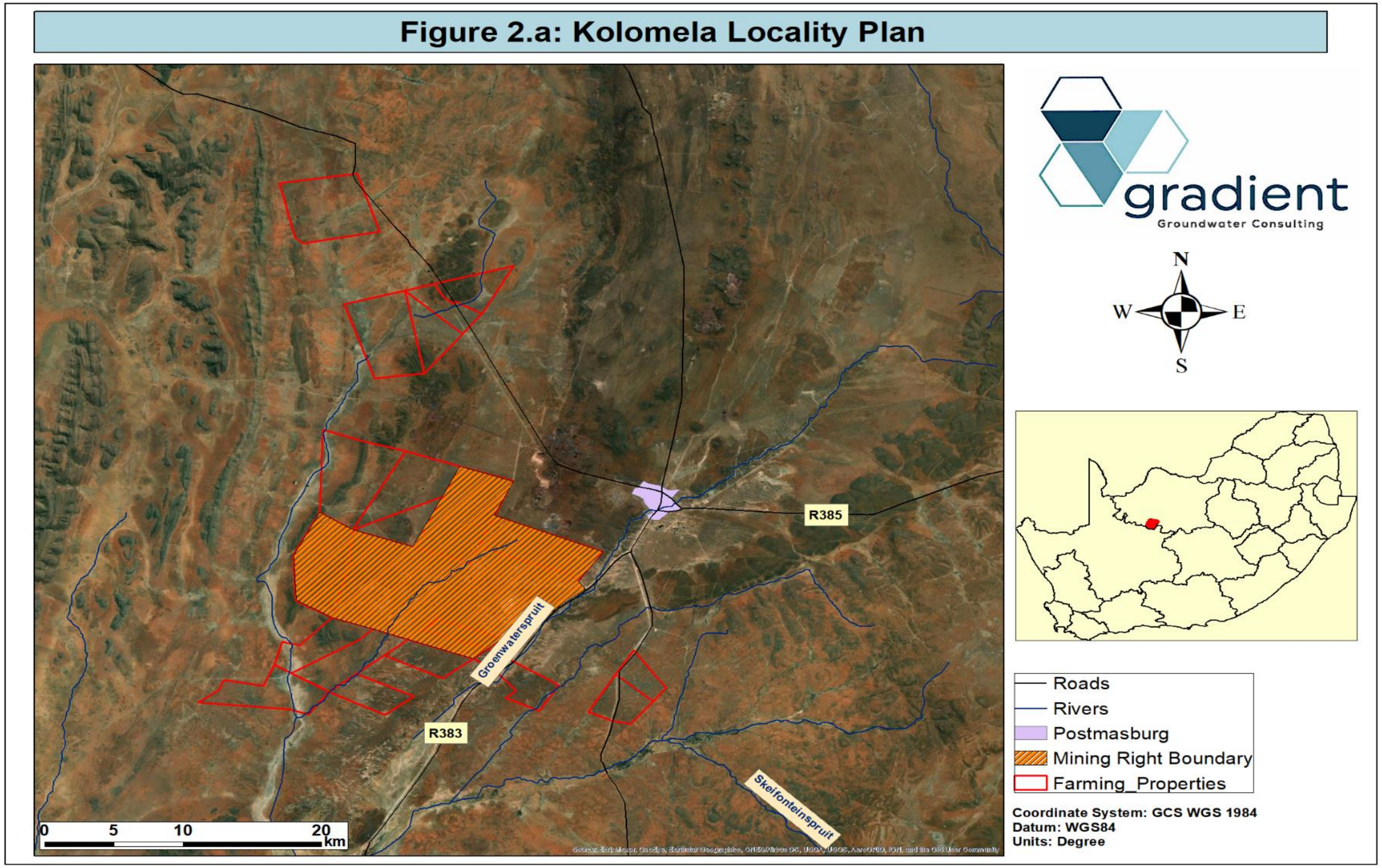


Figure 2.a: Locality Map

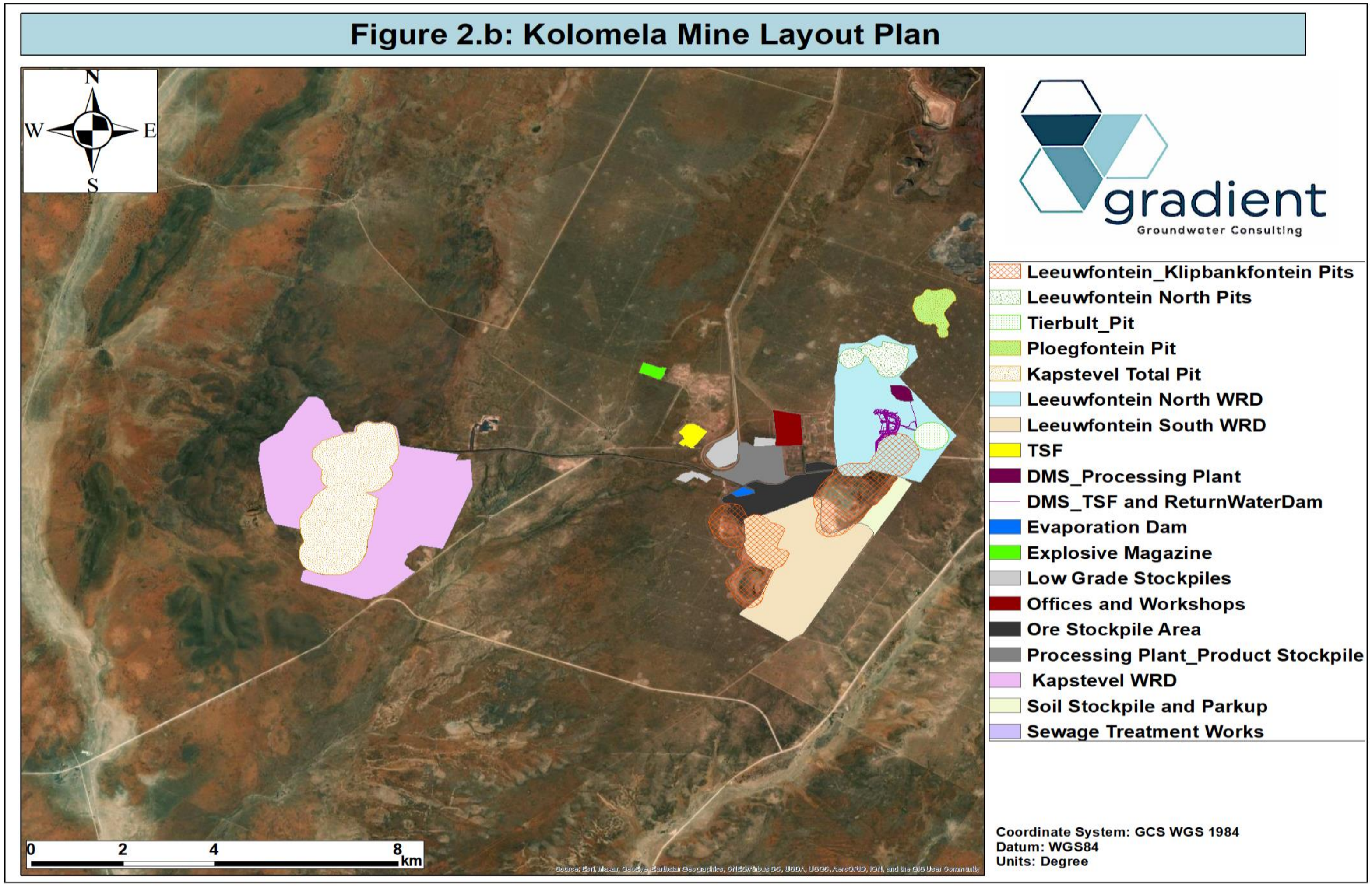


Figure 2.b: Mining activities and infrastructure layout at Kolomela Mine

2.4 Climate

The mine is located within quaternary catchment D73A of the Vaal (major) Water Management Area (WMA). Catchment relevant is included in **Table 2.a**.

Table 2.a: Quaternary catchment D73A summary (DWS, 2016)

Catchment D73A	
Area (km²)	3 235
MAP (mm/annum)	323
MAE (mm/annum)	2 450
Mean Annual Recharge (% MAP)	2.7

It falls within a semi-arid, summer rainfall area with most of the rainfall occurring between November and April. The annual average rainfall for the closest South African Weather Service (SAWS) rainfall station at Postmasburg (0321110_w) is 317 mm whereas WR2012 data for rainfall zone D7C is 323 mm/annum. Site rainfall measurements at Kolomela Mine between 2011 and 2020 indicate an average rainfall of 293 mm over this period. Rainfall is highly variable though and extended droughts have been experienced prior to 2021. **Figure 2.c** summarises the mean monthly rainfall averages mean annual precipitation (MAP) as recorded from 2011 to 2020. The mean annual S-pan evaporation for the area exceeds 2 450 mm per annum (WR 2012).

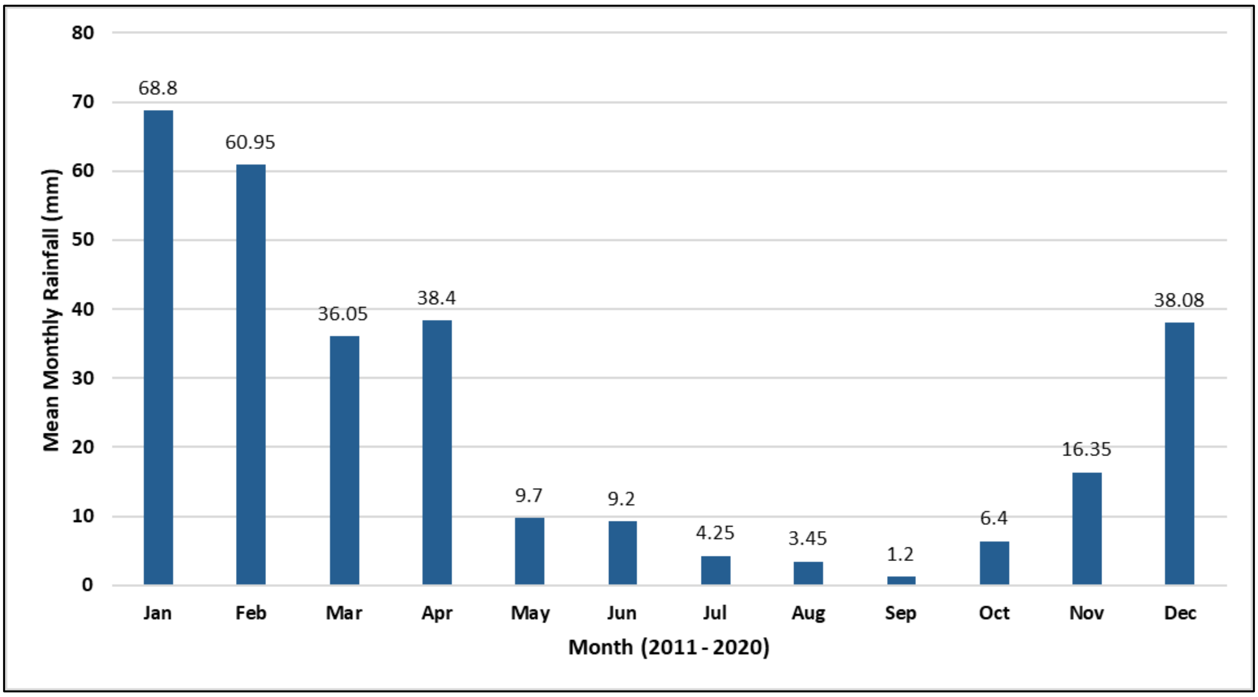


Figure 2.c: Mean monthly rainfall

2.5 Topography and Drainage

The regional topography around Kolomela Mine is comprised of flat to slightly undulating terrain with numerous depressions and pans. Locally the topography has been impacted by mining activities. The terrain slopes gently towards the Groenwaterspruit in the southeast with an elevation range of 1 210 mamsl to 1 300 mamsl. The ephemeral Ga-Groenwaterspruit flows towards the south where it connects with the Skeifonteinspruit before joining the Soutloop drainage channel. There are no other major surface water features in the greater study area. The regional topography is illustrated in **Figure 2.d**.

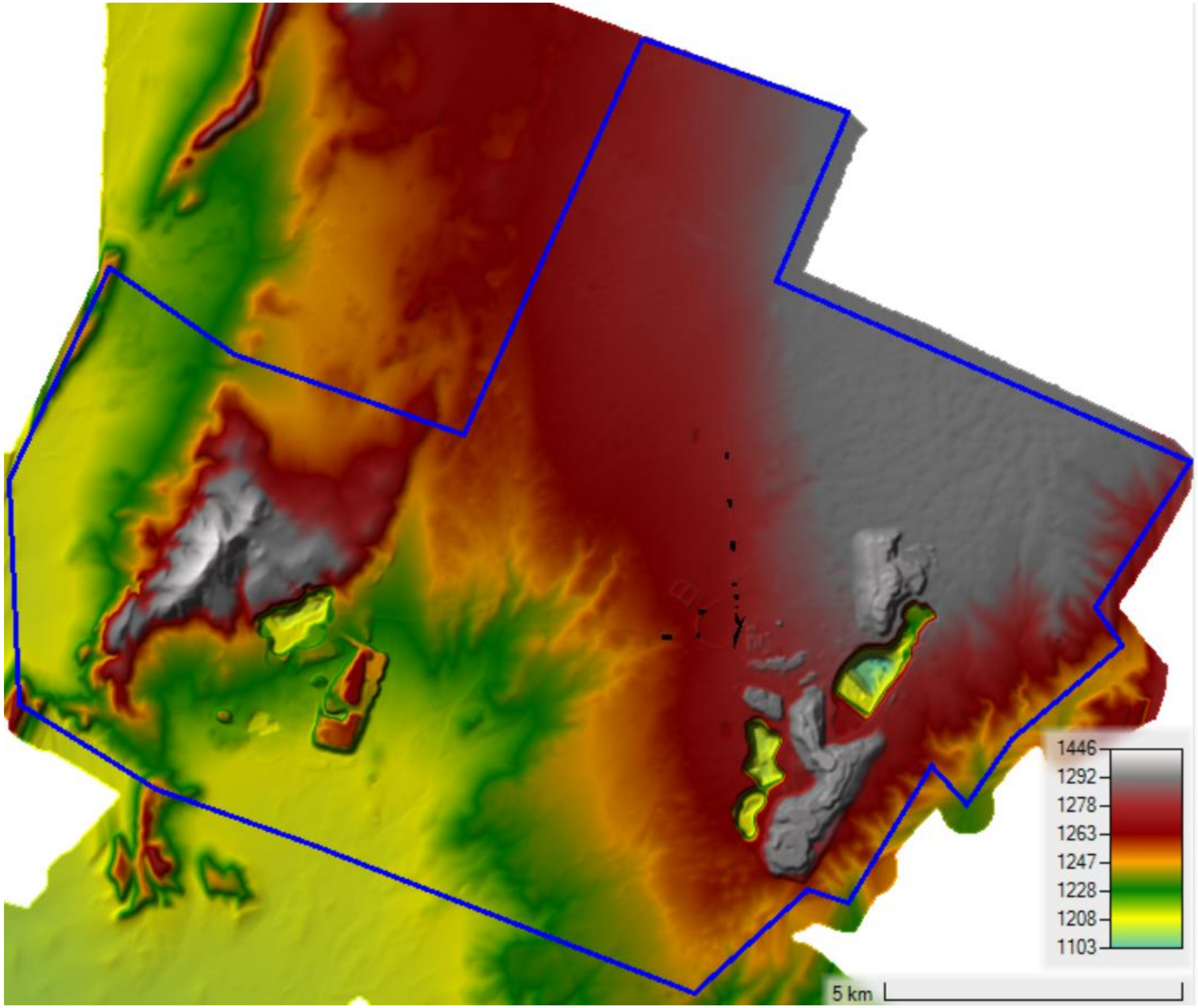


Figure 2.d: Regional topography

2.6 Regional Geology

Since no site characterisation work was performed by Gradient, geological and hydrogeological data was interpreted and assessed on desktop level. Reference is made to various sources.

2.6.1 Lithostratigraphy

The study area is located within the Maremane Dome on the western edge of the Kaapvaal Craton. Locally, the Transvaal Supergroup rocks were deposited unconformably on a basement of Ventersdorp Sequence (lavas) within the Griqualand West sub-basin. In Griqualand West basin the Transvaal Supergroup has a gentle dip to the west (Lurie, 2013). The base of the Griqualand West succession, dating from the middle Proterozoic age, comprises of the sedimentary Ghaap Group which is overlain by the clastic Postmasburg Group (Visser, 1989).

The Ghaap Group is sub-divided into the lower interbedded shales and dolomites of the Schmidtsdrif Subgroup followed by the limestones and dolomites of the Campbellrand Subgroup. This subgroup is locally dominated by the Kogelbeen and Wolhaarkop Formations. The Wolhaarkop chert and chert breccia’s overlie the dolomites and grades upwards into massive, laminated ore and BIFs of the Asbestos Hills Subgroup, which is interlayered by chert and shales (Beukes, 1983). The Asbestos Hills subgroup which overly the Cambellrand rocks, is sub-divided into three (3) formations (Kliphuis, Kuruman & Danielskuil Formations). The Kliphuis Formation chert and shales is overlain by the Kuruman Formation Banded Iron Formation (BIF). Overlying the Kuruman Formation BIF is the Danielskuil Formation, which is probably a reworked Kuruman type BIF (Erkisson et al, 2009). The upper part of the Kuruman Formation includes a lowermost laminated iron ore overlain by clastic-textured iron ore of the Danielskuil Formation.

The Postmasburg Group which unconformably overlie the Ghaap Group, comprise of the lower Koegas and the upper Voëlwater subgroups. From the base up, the Voëlwater sequence comprises of the Makganyene Formation (diamictite), Ongeluk Formation (andesitic lavas), Hotazel Formation (jasper and manganese) and the Mooidraai Formation (dolomite) at the top. The Koegas Subgroup is overlain by diamictite of the Makganyene Formation.

The Transvaal Supergroup sequence in the central and western sections of the Maremane Dome is unconformably overlain by the shales and red-bed clastic Gamagara Formation of the Olifantshoek Supergroup. The Olifantshoek Supergroup is largely covered by Kalahari Group sands, especially towards the north. The lower part comprise mainly of quartzites and shales, followed by u succession of lavas overlain by thick reddish and purple quartzites and schists. Locally, the Kalahari Group sands is characterised by calcretes, clays and pebbles which transition into underlying Dwyka tillites and shales.

The site regional geological setting is illustrated on **Figure 2.e** and **Figure 2.f**.

2.6.2 Geological structures

As interpreted from TECT Geological Consulting (2016).

- N-S Faults

The study area has been subjected to a protracted series of deformation events which produced a series of structures i.e. extensive N-S trending/ striking (W dipping) faults (Thomas & Basson, 2015). The faults underwent numerous phases of reactivation and are more concentrated within the western half of the Maremane Dome. They are tightly spaced within the limits of the Asbestos Hills (dolomites).

Fault drag is associated with the N-S trending faults, where these faults were inverted by a 2nd phase of eastward tectonic vergence, resulting in N-S trending anticlines to the west and N-S trending synclines to the east of the faults (Tinker et al, 2002).

These faults are largely dry at surface but they show clear evidence of past water flow i.e. significant fillings of calcite, sericite, fault gouge, clay, talc epidote and fine grained euhedral quartz.

- NE/ENE and SE/ESE strike-slip faults

These faults cross-cut and offset the N-S trending faults and also N-S trending diabase dykes. Typical spacing between these faults (at Sishen Mine) is 100-500m. The dips are uniformly steep and show variable dip directions. These faults likely originated with the development of the Ventersdorp Rift Basin (2.6Ga – 2.5 Ga) and they were reactivated between 1.73 Ga and 1.4 Ga and a degree of transgression (1.4 – 1.25 Ga). Their aperture is very narrow to narrow (where measurable) and classify as Grade 2 (dry) faults, although their surface mineralogy suggests some degree of fluid paleo-flow.

Where these faults have undergone transgression they are flanked by a zone of BIF and ore breccia.

- Diabase dykes

Thick diabase dykes exploited major N-s trending structures. The dykes also tend to follow NE-SW trending faults and are also clustered in several zones

Regional geological structures and features are indicated on **Figure 2.g.**

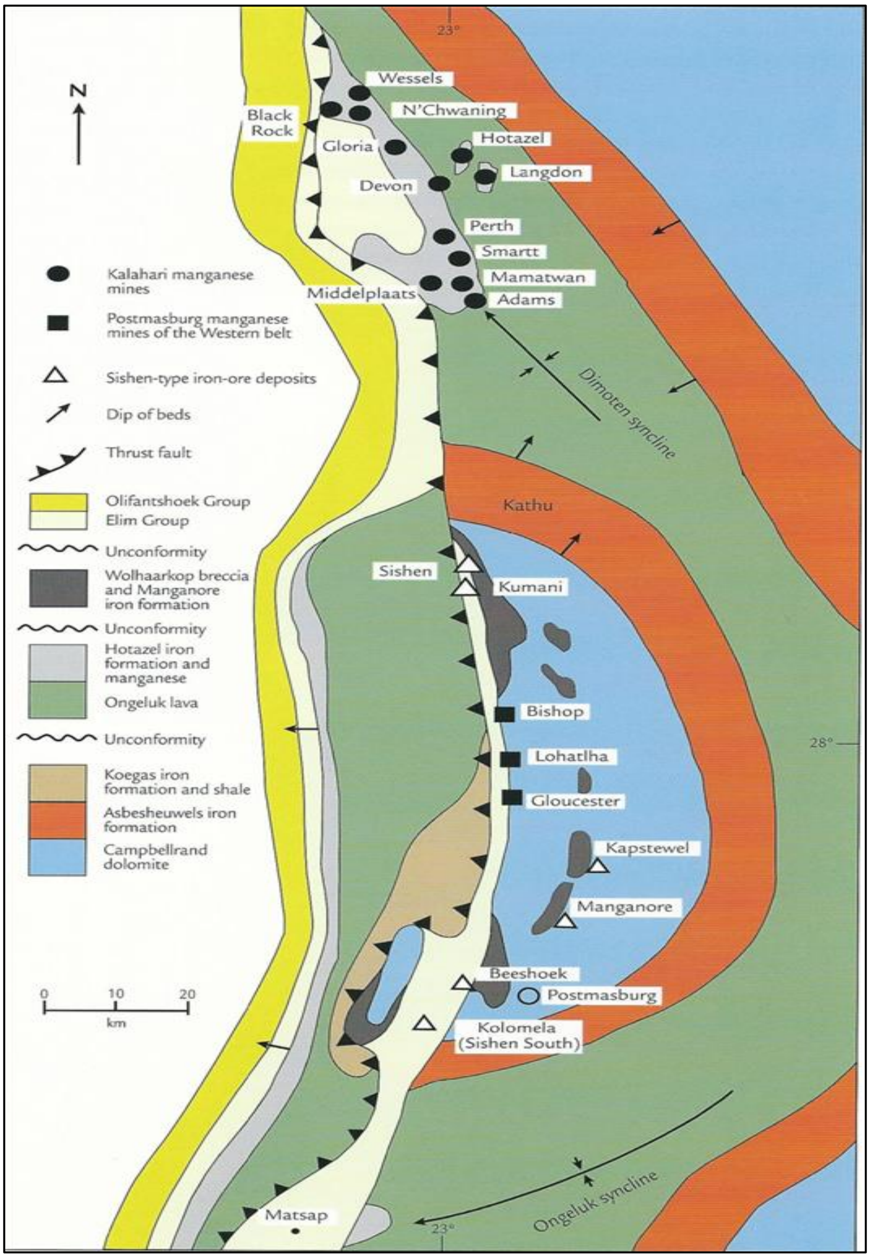


Figure 2.e **Kalahari Manganese and Iron Deposits (Cape Minerals, 2017)**

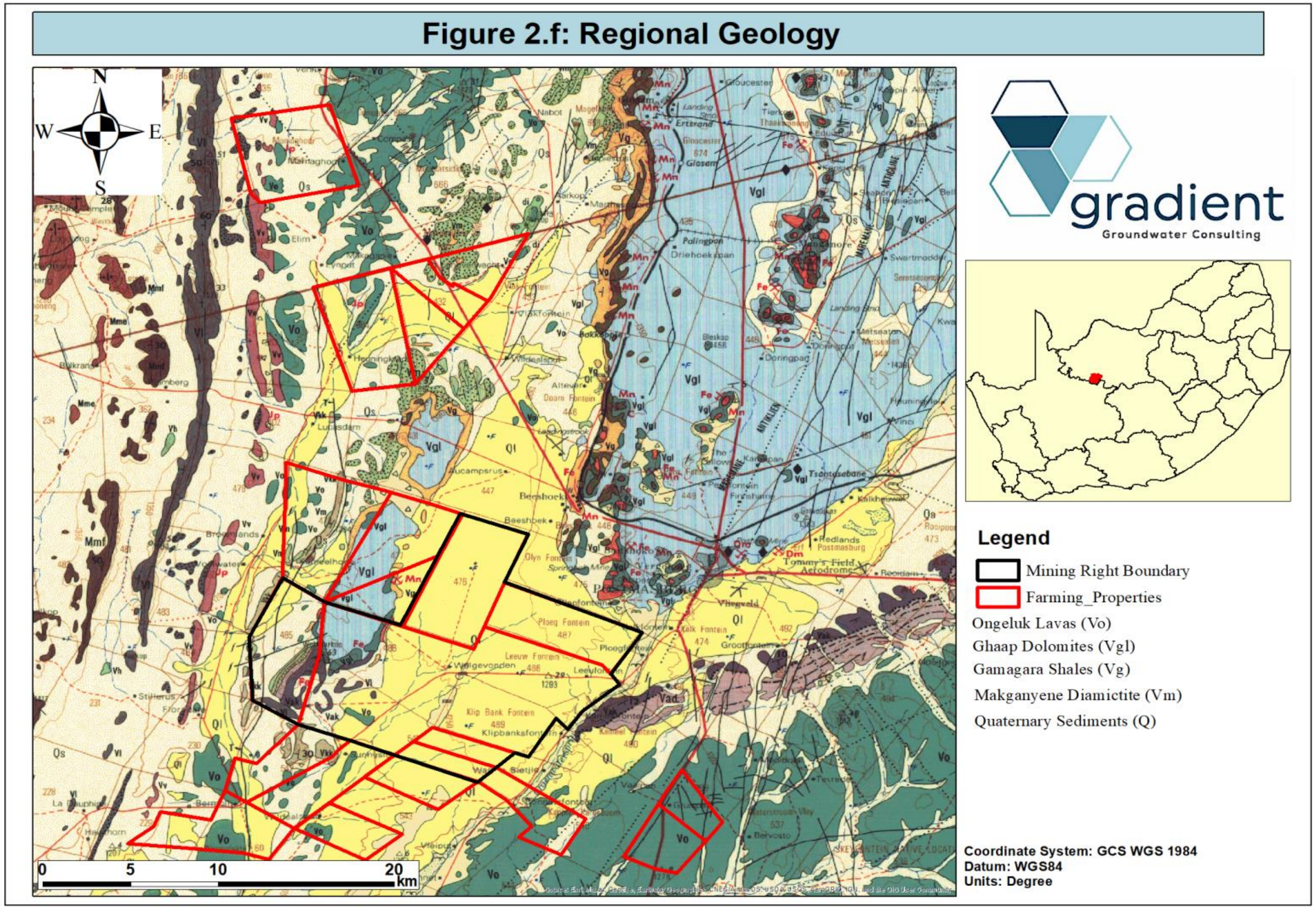


Figure 2.f: Regional Geology

Coordinate System: GCS WGS 1984
Datum: WGS84
Units: Degree

Figure 2.f: Regional geology

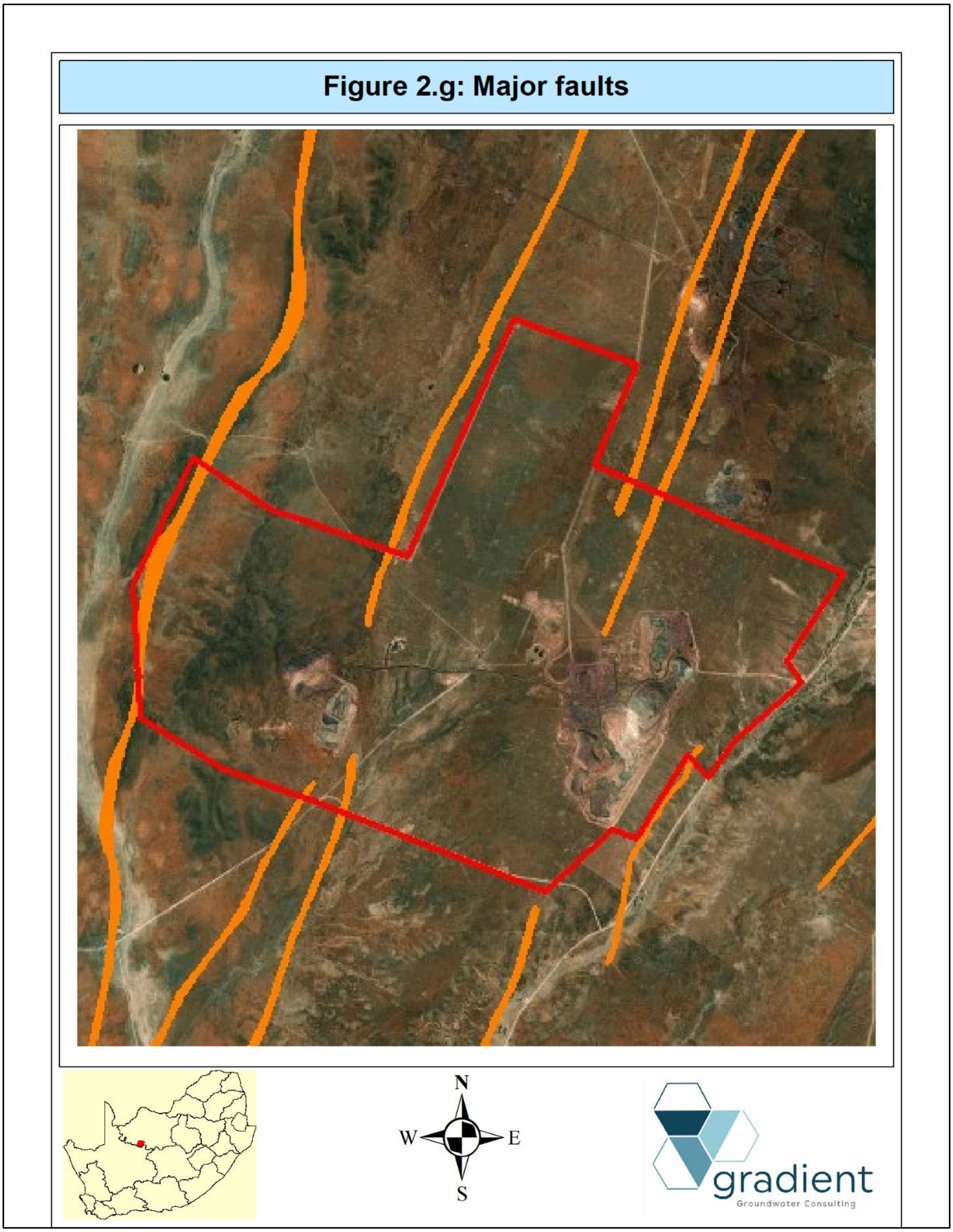


Figure 2.g: Geological structures

3. BASELINE HYDROGEOLOGICAL ASSESSMENT

3.1 Review of Historical Data and Available Information

All the available existing data, including monitoring data and the various reports from previous groundwater and geochemical specialist studies for the study area was collated and scrutinised.

This information was used to obtain an understanding of the conceptual geological and hydrogeological environments in the study area. The desktop study results were used in the calibration of the numerical groundwater flow and transport model.

The following studies were sourced and reviewed for this study:

- Itasca Denver Inc (2021). Technical Memorandum – 2021 Groundwater Model Update. Denver, USA.
- LWRC (2021). Kolomela Geochemical Assessment and Waste Classification. Ref. PRJ21-010, Johannesburg.
- EXM Environmental Advisory (Pty) Ltd (2021). Scoping Report. Expansion of Activities at Kolomela Mine near Postmasburg, Northern Cape. DMRE Ref No. NC069MR. Bryanston.
- Aquatico Scientific (Pty) Ltd (2020). Kolomela Mine Quarterly Surface and Groundwater Quality Assessment Report, October to December 2020. Rep No. KM/QR04/2020/JDS
- Aquatico Scientific (Pty) Ltd (2020). Kolomela Mine Basic Quarterly Salt Balance Monitoring Report, July 2020. Rep No. KM/QR04/2020/JDS
- Aquatico Scientific (Pty) Ltd (2020). Kolomela Mine Annual Surface and Groundwater Quality Assessment Report, January to December 2020. Rep No. KM/AWQR/2020/JDS
- Groundwater Complete cc (2018). Kolomela Mine Mining and Processing at Heuningkranz Project – Report on Geohydrological Investigation as part of the EIA and EMPr. Riversdal.
- Synergistics Environmental Services (Pty) Ltd (2016). Kolomela Mine Amendment: Expansion of Activities at Kolomela Mine – Environmental Impact Assessment Report and Environmental Management Programme Report Part A. Ref No. NC-00039-MR/102
- Synergistics Environmental Services (Pty) Ltd (2016). Kolomela Mine Amendment: Expansion of Activities at Kolomela Mine – Environmental Impact Assessment Report and Environmental Management Programme Report Part B. Ref No. NC-00039-MR/102
- Golder Associates (2016). Kolomela Mineral Waste Streams Assessment and Mining Residue Facilities Impact Report. Rep No. 127024-29903-1. Pretoria.
- Itasca Denver Inc (2015). Updated Three-Dimensional Groundwater Flow Model and Preliminary Predictions of Dewatering Requirements at Kolomela Mine. Ref. 1989
- Synergistics Environmental Services (Pty) Ltd (2010). Kolomela Mine Environmental Impact Assessment Report and Environmental Management Programme. Rep No. S0329. Rivonia.

3.2 Groundwater monitoring results

3.2.1 Groundwater monitoring borehole database

Water monitoring data from Aquatico Scientific (Pty) Ltd (Aquatico) has been sourced and utilised in this study. Annual water quality reports (2017 – 2020) have been made available to LWRC. However, monitoring results from earlier monitoring periods (2008 to 2017) are also included in these reports.

The surrounding farms that have been include as part of their water monitoring programme include Sunnyside, Wildealsput, Kappieskaree, Bonnetsfontein, Kameelfontein, Kameelhoek, Soetfontein, Voelwater, Bermoli, Brand, Klipbankfontein, Grasvlakte, Witboom, Olynfontein, Geelbult, Kalkfontein, Aucampsrus, Floradale, Koeispeen, Heuningkrantz, Broomlands, Lucasdam, Grootpan, Vleiput, Lynput, Aarkop and Putjie.

Boreholes with the most recent available groundwater level data are listed in **Table 3.a.**

3.2.2 Groundwater levels

As inferred from the Aquatico annual hydrocensus and annual monitoring reports;

- The groundwater levels remained relatively constant throughput the monitoring period, with the exception of aquifer recharge and dewatering boreholes;
- Average groundwater levels range from 5.4 to 21.1 mbg;
- Despite the close proximity of some boreholes to the open pits, generally shallow and stable water levels were observed;
- Boreholes at Leeuwfontein have much deeper groundwater levels due to dewatering with average water levels here exceeding 100 mbg;
- Three boreholes from the Kapstevel (KS) cluster are believed to be drilled into the same aquifer, as are those in the Welgevonden (WV). On the other hand, boreholes in the Leeuwfontein (LF) cluster are clearly drilled into different aquifers or fracture systems with three markedly different water levels.

Groundwater level data interpretation for each farm from Gradient (2021) is included in **Table 3.a.** A number of boreholes display decreasing water level trends in recent years with some exceptions where increasing water levels were observed. This may be attributed to a combination of factors i.e. persevering drought conditions, mine dewatering and aquifer recharge.

Groundwater level trends for selected boreholes have also been plotted for boreholes with comprehensive datasets stretching from 2009 (**Figure 3.a**).

Table 3.a: Borehole database (from Aquatico, 2020)

ID	LAT	LONG	SWL2019 (mbg)	SWL 2020 (mbg)	Collar (mamsl)	Notes on water levels from 2008 to 2020
Hydrocensus Boreholes						
Aarkop						
AP01	-28.13168	22.98708	14.32	10.88	1309.29	Groundwater levels between 2016 and 2020 show no clear trends, with the exception of AP 14 (increasing trend)
AP02	-28.13155	22.98722	13.85	10.32	1309.29	
AP03	-28.1315	22.98738	13.16	9.77	1304.19	
AP05	-28.13011	22.98918	12.99	9.23	1304.19	
AP06	-28.13098	22.98724	13.14	9.48	1304.19	
AP07	-28.13091	22.98715	13.35	9.72	1309.29	

AP08	-28.1245	22.99014	16.6	14.56	1309.29	
AP10	-28.12852	22.99106	15.13	12.23	1305.60	
AP11	-28.12958	22.99042	15.05	12.95	1307.92	
AP12	-28.12955	22.9903	13.8	13.36	1306.49	
AP13	-28.11836	22.97113	14.06	14.75	1304.73	
AP14	-28.1309	22.98387	5.91	*	1304.73	
AP15	-28.13141	22.98463	19.56	20.16	1299.47	
AP16	-28.13305	22.98241	20.58	21.5	1318.72	
Aucampsrus						
AU01	-28.27579	22.96335	*	17.25	1292.28	Groundwater levels between 2016 and 2020 show slight decreasing trend
AU02	-28.2757	22.96284	16.88	16.62	1290.13	
AU03	-28.27879	22.96422	11.67	12.25	1292.12	
AU04	-28.2781	22.96376	*	*	1292.12	
AU05	-28.29095	22.96316	15.79	15.94	1290.34	
AU06	-28.30281	22.97322	45.9	46.57	1297.61	
AU07	-28.27938	22.9335	41.3	41.75	1275.56	
AU08	-28.27623	22.93548	42.91	43.36	1276.15	
AU09	-28.26529	22.94259	*	*	1280.00	
AU10	-28.26318	22.93799	48.43	48.88	1281.49	
AU11	-28.23974	22.91798	*	60.61	1300.97	
AU12	-28.24713	22.972	18.74	30.58	1300.00	
AU13	-28.24284	22.95163	*	*	1299.35	
AU14	-28.25706	22.95253	12.98	13.08	1288.36	
AU14A	-28.25707	22.95253	*	13.15	1288.36	
AU15	-28.27036	22.96811	10.86	11.28	1294.45	
Bermoli						
BER01	-28.45262	22.82302	9.9	10.2	1160.03	Groundwater levels between 2008 and 2020 remained relatively constant
BER02	-28.45396	22.82274	10.02	10.31	1160.00	
BER03	-28.4666	22.8277	*	*	1158.98	
BER04	-28.45589	22.8058	17.84	17.43	1169.74	
BER05	-28.44877	22.80688	16.58	18.18	1170.81	
BER06	-28.45463	22.75789	*	*	1208.61	
Broomlands						
BLS02	-28.31088	22.84047	8	7.78	1201.10	Groundwater levels between 2008 and 2020 remained relatively constant with the exception of BLS08 and BLS10 (slight decreasing trend)
BLS03	-28.31098	22.8408	7.61	7.87	1201.10	
BLS04	-28.31069	22.8383	9.21	9.14	1202.83	
BLS05	-28.31018	22.8344	11.3	11.11	1205.94	
BLS06	-28.30974	22.835	11.56	11.4	1205.94	
BLS07	-28.31028	22.83502	11.33	11.13	1205.94	
BLS08	-28.29917	22.81251	37.06	38.06	1228.61	
BLS09	-28.2758	22.81949	*	36.2	1240.01	
BLS10	-28.28726	22.83756	11.05	11.07	1219.73	
BLS11	-28.27542	22.84785	*	*	1220.00	
BLS12	-28.31049	22.83895	9.16	9.16	1201.10	
Bospoort						

BPT01	-28.52359	22.9891	12.78	13.3	1198.73	Groundwater levels between 2019 and 2020 show slight decreasing trend
BPT02	-28.52324	22.98873	13.28	13.98	1198.73	
BPT03	-28.51088	23.00593	12.92	13.19	1213.02	
BPT04	-28.48955	23.01879	8.04	8.27	1231.01	
BPT05	-28.49378	23.02254	*	*	1235.78	
BPT06	-28.52676	23.03508	8.73	9.8	1219.25	
BPT07	-28.52668	23.03516	8.28	9.81	1219.25	
BPT08	-28.52682	23.03489	8.97	10.14	1219.25	
BPT09	-28.53838	23.01058	15.39	15.99	1202.33	
BPT10	-28.52661	22.99626	11.3	13.5	1197.52	
Brand						
BR01	-28.494	22.9776	*	*	1200.88	Groundwater levels between 2019 and 2020 show slight decreasing trend
BR02	-28.50456	22.96702	9.21	9.35	1199.78	
BR03	-28.50462	22.96693	*	*	1199.78	
BR04	-28.50455	22.96713	9.35	9.45	1199.78	
Biesieputs						
BS01	-28.519	22.82158	6.51	6.68	1139.98	Groundwater levels between 2019 and 2020 show slight decreasing trend
BS02	-28.51922	22.81976	2.88	3.18	1140.00	
BS04	-28.55453	22.80977	6.38	6.65	1137.16	
BS05	-28.55454	22.80967	*	*	1137.16	
BS06	-28.55651	22.81765	*	*	1133.34	
BS07	-28.56514	22.80872	2.8	4.8	1127.79	
BS08	-28.5181	22.81998	3.9	4.27	1140.00	
Bonnetfontein						
BT01	-28.48782	22.93108	13.95	13.29	1179.99	Groundwater levels between 2008 and 2020 show slight decreasing trend, with the exception of BT02
BT02	-28.4894	22.92205	*	*	1177.56	
BT03	-28.49219	22.92856	12.71	13.03	1178.87	
Dunhill						
DL01	-28.23194	22.7544	62.35	60.85	1291.06	Groundwater levels between 2019 and 2020 remained constant with the exception of DL05 (decreasing trend) and DL02 (increasing trend)
DL02	-28.26529	22.73618	78.51	71.95	1305.50	
DL03	-28.23743	22.71822	66.9	66.65	1292.73	
DL04	-28.23953	22.71032	59.54	58.1	1337.12	
DL05	-28.21783	22.75302	73.53	80.46	1304.02	
DL06	-28.21376	22.75242	88.3	*	1316.00	
Elim						
EM01	-28.15208	22.86073	13.44	13.87	1263.45	Groundwater levels between 2019 and 2020 show slight decreasing trend with the exception of EM03 (increasing trend)
EM02	-28.14745	22.85574	14.88	15.46	1265.93	
EM03	-28.13424	22.83939	40.2	33.27	1283.64	
EM04	-28.1347	22.85942	91.44	95.5	1278.16	
EM05	-28.13456	22.88093	16.95	17.68	1280.07	
Floradale						
FD01	-28.40647	22.8046	13.13	13.45	1180.36	Groundwater levels between 2008 and 2020 remained relatively constant with the exception of FD09 (increasing trend) and FD05 (decreasing trend)
FD02	-28.40615	22.80622	12.3	12.58	1180.00	
FD03	-28.40634	22.80646	12.2	12.49	1180.00	
FD04	-28.40638	22.80654	12.13	12.42	1180.00	

FD05	-28.40782	22.80491	13.4	14.26	1179.92	
FD06	-28.40784	22.8049	13.82	13.78	1179.92	
FD07	-28.40488	22.80155	19.13	19.51	1193.56	
FD08	-28.39385	22.81995	12.6	12.97	1179.49	
FD09	-28.36281	22.82009	7.99	8.26	1188.26	
FD10	-28.36292	22.8209	7.49	7.76	1190.98	
FD11	-28.37816	22.79458	18.02	18.3	1196.03	
FD12	-28.37095	22.76834	84.8	84.67	1259.67	
FD13	-28.42964	22.81577	11.97	12.16	1176.34	
FD14	-28.42742	22.82968	10.54	10.8	1170.93	
FD19	-28.4299	22.81617	*	12.76	1168.83	
Fletcher						
FR02	-28.05493	22.88409	10.9	9.67	1320.12	An overall increasing trend is observed between 2019 and 2020
FR03	-28.05516	22.88426	11.05	9.63	1320.12	
Fouross						
FS01	-28.045	22.9932	*	22.16	1298.44	Not sufficient time level series data to assess farm as a whole
FS02	-28.04434	22.99381	*	23.31	1297.00	
FS03	-28.04338	22.99404	*	23.48	1293.96	
FS04	-28.05637	22.98404	*	21.15	1299.83	
FS05	-28.0484	23.02393	*	63.11	1335.46	
Geelbult						
GB02	-28.53381	22.93779	12.47	*	1169.48	Groundwater levels in GB02 between 2010 and 2020 show slight decreasing trend, whereas GB05 indicate a relative decrease from 2014 to 2020.
GB05	-28.52955	22.93511	14.2	14.35	1174.26	
Gaston						
GN01	-28.45249	23.04387	48.9	*	1272.79	Not sufficient time level series data to assess farm as a whole
Grootpan						
GR01	-28.44748	22.919	31.64	31.44	1216.89	GR01 indicate strong increasing trend between 2008 and 2020
Grasvlakte						
GV01	-28.50357	22.81612	7.73	8.13	1149.31	Groundwater levels between 2009 and 2020 show increasing trend with the exception of GV19 and GV20 (slight decreasing trend)
GV03	-28.49657	22.81421	*	12.1	1156.74	
GV04	-28.50056	22.82722	*	*	1141.45	
GV05	-28.50116	22.8278	7.05	7.26	1141.45	
GV06	-28.50131	22.82737	6.98	*	1141.45	
GV07	-28.50163	22.82774	6.97	7.2	1140.16	
GV08	-28.50306	22.82885	6.48	6.73	1140.16	
GV09	-28.50384	22.82946	6.8	7.11	1140.16	
GV10	-28.5041	22.82964	6.89	7.16	1140.33	
GV12	-28.50439	22.83033	6.46	6.48	1140.01	
GV13	-28.50446	22.83043	6.23	6.28	1140.01	
GV15	-28.50464	22.83064	*	*	1140.01	
GV16	-28.50506	22.8308	5.51	6.16	1140.01	
GV17	-28.5093	22.8481	*	*	1159.40	
GV18	-28.48087	22.85668	14.33	14.66	1159.31	
GV19	-28.49179	22.85463	13.73	14.67	1159.05	

GV20	-28.49154	22.85362	12.64	13.53	1157.27	
Hilliard						
HD01	-28.01642	22.92928	19.81	16.53	1300.00	Borehole HD01 indicate a relatively strong increasing water level trend between 2019 and 2020, whereas HD03 indicate a slight decrease
HD03	-28.02198	22.90676	18.54	19.23	1295.17	
HD04	-28.02199	22.90674	*	19.23	1295.17	
Heuningkranz						
HK01	-28.19683	22.93164	30.15	30.75	1263.20	Groundwater levels between 2010 and 2020 show decreasing trend, with the exception of HK02 (increasing trend)
HK02	-28.20341	22.9161	9.03	*	1261.19	
HK03	-28.21437	22.91261	63	62.7	1318.51	
HK04	-28.22245	22.89389	18.43	18.76	1249.61	
HK05	-28.21415	22.87935	*	9.95	1238.34	
HK08	-28.21457	22.8803	9.1	*	1238.34	
HK09	-28.21404	22.88145	9	9.33	1238.58	
HK10	-28.21398	22.88158	8.76	9.1	1238.58	
HK11	-28.21158	22.88199	10.12	10.47	1239.79	
HK12	-28.20463	22.88045	*	*	1240.01	
HK13	-28.18744	22.89119	*	18.3	1254.84	
HK14	-28.19464	22.89748	13.14	13.53	1253.35	
HK15	-28.18755	22.90604	15.42	15.6	1257.42	
HK16	-28.21344	22.88139	8.65	9.01	1238.58	
HK17	-28.19682	22.93166	*	*	1263.20	
Hawthorne						
HN01	-28.47195	22.7482	21.01	21.74	1203.39	Groundwater levels between 2019 and 2020 show slight decreasing trend
HN02	-28.4721	22.7482	22.44	21.19	1201.79	
Kalkfontein						
KAL01	-28.34973	23.09336	21.75	23.41	1332.41	Groundwater levels between 2009 and 2020 remained relatively constant, however some decreasing trends are observed between 2019 and 2020.
KAL02	-28.34931	23.09305	22.53	28.59	1328.64	
KAL03	-28.36561	23.07327	16.46	17.83	1322.16	
KAL04	-28.36032	23.04864	1.76	2.05	1290.81	
KAL05	-28.36182	23.0463	9.51	9.48	1282.82	
KAL06	-28.36142	23.04169	8.57	8.85	1279.99	
Klipbankfontein						
KBF01	-28.43405	22.9802	18.32	22.74	1226.94	Groundwater levels between 2009 and 2020 show decreasing trend
KBF02	-28.43405	22.98012	18.05	*	1226.94	
KBF03	-28.43398	22.97985	17.68	*	1226.94	
KBF04	-28.42683	22.98599	*	*	1239.38	
KBF05	-28.42683	22.98598	16.09	17.1	1239.38	
KBF06	-28.41597	22.98957	7.2	7.26	1237.82	
KBF07	-28.416	22.99107	*	*	1232.61	
KBF08	-28.41597	22.99106	*	*	1232.61	
KBF09	-28.41588	22.99091	12.1	13.48	1238.37	
KBF10	-28.41785	22.99311	11.93	13.49	1232.61	
KBF11	-28.4182	22.99248	11	12.45	1232.61	
KBF15	-28.43404	22.98086	19.28	19.52	1226.94	
KBF16	-28.44052	22.97324	21.15	27.79	1220.02	

Kambro						
KBO02	-28.54002	22.90282	14.28	14.82	1159.27	Groundwater levels between 2019 and 2020 show slight decreasing trend
Kameelhoek						
KH01	-28.32399	22.87548	17.2	18.01	1239.98	Groundwater levels between 2009 and 2020 show decreasing trend, with the exception of KH10
KH02	-28.30079	22.89915	30.8	31.2	1271.22	
KH03	-28.30914	22.91946	32.13	32.54	1266.29	
KH04	-28.30741	22.9188	33.38	33.67	1266.93	
KH05	-28.3278	22.90571	30.3	30.57	1261.14	
KH06	-28.32576	22.90744	30.5	*	1261.34	
KH09	-28.33245	22.90334	27.2	*	1260.07	
KH10	-28.33243	22.90332	20.95	15.99	1260.07	
KH11	-28.33401	22.90606	*	*	1260.60	
KH12	-28.35115	22.89334	*	*	1253.93	
KH13	-28.34495	22.88574	9.46	10.98	1249.13	
KH14	-28.32939	22.87928	*	*	1240.39	
KH17	-28.31309	22.87485	23.5	22.5	1240.49	
KH18	-28.30265	22.87873	*	19.3	1254.64	
KH19	-28.2871	22.8567	9.18	9.55	1216.75	
KH20	-28.27956	22.85226	6	6.28	1219.81	
KH21	-28.27776	22.85613	8.18	8.52	1220.00	
KH22	-28.2766	22.8568	8.41	8.77	1220.00	
KH23	-28.27896	22.85659	8.46	8.79	1220.00	
KH24	-28.30063	22.85024	8.77	9.08	1209.53	
KH25	-28.32863	22.85736	11.36	12.17	1220.00	
Kappieskaree						
KK01	-28.45032	22.87929	*	*	1177.06	Groundwater levels between 2008 and 2020 show slight decreasing trend, with the exception of KK02 (increasing trend)
KK02	-28.45098	22.90082	*	*	1199.93	
KK03	-28.45239	22.95242	*	*	1214.83	
KK04	-28.45758	22.95556	12.55	12.59	1200.83	
KK05	-28.47868	22.93786	13.58	14.06	1190.30	
KK07	-28.4552	22.9545	12.38	13.05	1206.96	
Kameelfontein						
KMF01	-28.40284	23.00708	24.54	25.63	1240.08	Groundwater levels between 2008 and 2020 remained relatively constant with the exception of KMF01, KMF02 and KMF08 (decreasing trend)
KMF02	-28.40268	23.00716	*	*	1240.08	
KMF03	-28.40569	23.00774	14.26	14.6	1242.59	
KMF04	-28.41122	23.02693	18.04	18.2	1282.33	
KMF05	-28.41324	23.03211	23.09	23.12	1285.72	
KMF06	-28.41258	23.03294	24.75	23.67	1289.14	
KMF07	-28.43065	23.05283	16.4	15.75	1282.04	
KMF08	-28.40266	23.00697	25.24	26.31	1240.08	
Koeispeen						
KO01	-28.34215	23.04829	11.26	11.55	1282.64	Groundwater levels between 2009 and 2020 show slight increasing trend
KO02	-28.34215	23.04936	*	*	1282.64	
KO03	-28.34243	23.05306	*	*	1290.48	
KO05	-28.33802	23.0505	16.87	16.27	1303.18	

Kouwater						
KR02	-28.1282	22.936	11.99	11.41	1300.12	Groundwater levels between 2019 and 2020 show slight decreasing trend, with the exception of KR02, KR11 and KR12 (increasing trend)
KR07	-28.1205	22.94589	14.12	14.3	1299.01	
KR09	-28.12896	22.95711	19.18	20.25	1300.01	
KR10	-28.09512	22.93381	23.66	23.97	1325.61	
KR11	-28.09503	22.93394	28.32	27.72	1325.61	
KR12	-28.12574	22.9359	12.25	11.2	1295.17	
KR13	-28.11237	22.90869	17.43	18.01	1297.98	
KR14	-28.11249	22.90858	17.39	17.58	1297.98	
KR15	-28.12661	22.88938	27.26	*	1298.89	
KR16	-28.13614	22.904	13.38	13.61	1281.14	
KR17	-28.13619	22.90378	*	13.88	1281.14	
Kapstevel						
KS01	-28.39918	22.87648	13.35	*	1220.47	Not sufficient time level series data to assess farm as a whole
KS02	-28.41335	22.89487	4.73	*	1200.24	
KS03	-28.42837	22.96012	17.01	*	1254.77	
Klein Venn						
KVNN05	-28.01768	22.75784	*	58.31	1298.02	Not sufficient time level series data to assess farm as a whole
Leeuwfontein						
LF723	-28.3973	23.0027	Approximate 150 mbg (Jul2020) – data not available			
LF724	-28.395	23.0012	Approximate 100 mbg (Jul2020) – data not available			
LF725	-28.3974	22.9996	Approximate 50 mbg (Jul2020) – data not available			
Lucasdam						
LD01	-28.2511	22.85919	7.4	7.43	1222.19	Groundwater levels between 2009 and 2020 show slight decreasing trend with the exception of LD06 (increasing trend)
LD02	-28.25214	22.85981	6.2	*	1222.19	
LD03	-28.25096	22.86128	6.03	6.3	1221.08	
LD04	-28.24945	22.86116	6.01	6.35	1222.66	
LD05	-28.24867	22.8584	8.47	8.8	1223.81	
LD06	-28.23889	22.82545	39.34	38.22	1247.83	
LD07	-28.25607	22.83502	22.84	23.05	1240.32	
LD08	-28.24808	22.9049	*	*	1268.41	
LD09	-28.23944	22.87111	7.71	7.9	1230.65	
LD10	-28.2404	22.87302	10.07	10.34	1232.43	
LD11	-28.24568	22.86051	8.24	8.45	1224.13	
LD12	-28.25588	22.86572	7.69	8.08	1222.78	
La-Dau phine						
LE01	-28.46106	22.73838	34.71	34.91	1212.23	Groundwater levels between 2019 and 2020 show decreasing trend
LE04	-28.44531	22.73899	55.5	*	1215.19	
LE07	-28.45791	22.75319	21.22	25.6	1211.99	
Lynput						
LT01	-28.14922	22.89526	*	41.9	1287.03	Groundwater levels between 2013 and 2020 mostly showed a slight decreasing trend
LT02	-28.15544	22.87779	*	23.08	1271.58	
LT03	-28.17108	22.87343	6.51	9.67	1256.95	
LT04	-28.17109	22.87339	*	9.95	1256.95	
LT05	-28.17281	22.87231	9.07	9.54	1256.63	

LT06	-28.1699	22.86854	9.43	9.91	1258.13	
LT07	-28.16477	22.86315	10.96	11.73	1260.00	
LT08	-28.16254	22.8591	11.05	*	1260.07	
LT09	-28.16928	22.82639	45.3	45.4	1289.82	
LT10	-28.15026	22.83308	40.74	41.6	1298.55	
LT11	-28.16721	22.80114	52.13	51.66	1370.48	
LT14	-28.1707	22.83466	28.1	28.41	1279.98	
LT15	-28.16975	22.83136	28.63	29.3	1280.02	
LT17	-28.16497	22.86327	10.49	10.92	1260.00	
LT19	-28.17349	22.8722	8.62	9.07	1256.63	
LT21	-28.15809	22.79046	79.24	87.09	1308.13	
LT22	-28.14519	22.81883	55.67	55.91	1312.74	
LT23	-28.14568	22.80599	100.18	61.42	1379.94	
LT24	-28.15553	22.83458	40.83	41.21	1283.51	
LT25	-28.14977	22.83339	44.68	45.92	1296.70	
LT26	-28.15552	22.83484	43.17	40.01	1283.51	
Mooidraai						
MD01	-28.40687	23.07427	25.53	*	1311.60	Groundwater levels between 2019 and 2020 show slight decreasing trend
MD05	-28.42846	23.08717	20.5	21.09	1319.61	
MD06	-28.42872	23.08723	*	20.77	1319.24	
MD07	-28.42876	23.08737	20.24	*	1319.24	
MD10	-28.43112	23.08628	24.83	28.7	1317.89	
MD16	-28.42338	23.09577	*	21.05	1320.70	
MD17	-28.42311	23.09577	20.44	20.6	1320.70	
MD18	-28.42527	23.10055	24.63	24.94	1332.26	
Makganyene						
ME01	-28.15162	22.92376	27.59	28.02	1282.57	Groundwater levels between 2016 and 2020 show slight decreasing trend
ME03	-28.15481	22.91127	*	9.59	1272.84	
ME04	-28.1574	22.9031	13.54	14.18	1272.39	
ME05	-28.15726	22.90298	14.14	14.36	1272.39	
ME06	-28.16015	22.90364	10.25	10.71	1269.51	
ME07	-28.15197	22.91972	*	*	1278.63	
ME08	-28.16026	22.9032	10.39	10.84	1269.51	
Mierhoop						
MP01	-28.51777	22.80595	7.85	8.12	1140.00	A slight decreasing trend is observed in MP01 between 2019 and 2020.
MP05	-28.51954	22.77836	14.65	*	1154.51	
Mostert						
MT01	-28.03058	22.88567	10.09	5.86	1299.63	An increasing trend is observed in borehole MT01 between 2019 and 2020.
MT02	-28.03064	22.88562	*	5.65	1299.63	
New Castle						
NE01	-28.01892	22.80689	81.66	76.89	1277.95	An increasing trend is observed between 2019 and 2020 with the exception of NE04
NE02	-28.01923	22.80896	89.96	89.9	1277.95	
NE03	-28.01803	22.81488	45.5	45.25	1260.20	
NE04	-27.99512	22.84177	24.96	25.51	*	
Nabot						

NT01	-28.08538	22.97476	32.76	32.48	1317.77	An increasing trend is observed between 2019 and 2020 with the exception of NT02 and NT03
NT02	-28.08439	22.97579	20.9	21.25	1319.25	
NT03	-28.0842	22.97577	21.36	21.55	1319.25	
NT04	-28.08396	22.97605	21.84	21.5	1319.25	
NT05	-28.08314	22.9707	37.2	35.24	1316.47	
NT07	-28.09672	22.96416	17.8	17.22	1306.80	
NT08	-28.09671	22.98104	18.81	17.58	1310.51	
Olynfontein						
OF01	-28.35212	23.04758	7.11	6.15	1279.97	Groundwater levels between 2008 and 2020 show increasing trends in boreholes OF01, OF02, OF05, OF06, OF07
OF02	-28.35198	23.04678	9.47	9.75	1279.97	
OF03	-28.34564	23.04749	*	*	1280.75	
OF04	-28.34522	23.04775	9.74	10.06	1280.75	
OF05	-28.35182	23.04521	7.41	7.69	1279.97	
OF06	-28.352	23.04544	7.71	7.93	1279.97	
OF07	-28.35338	23.04363	7.55	7.88	1278.78	
OF08	-28.35346	23.04648	19.6	17.63	1279.97	
Putjie						
PE01	-28.20515	22.84967	16.9	18.03	1260.00	Groundwater levels between 2016 and 2020 show slight decreasing trend, with the exception of PE02 (increasing trend)
PE02	-28.20563	22.84926	16.15	17.09	1260.00	
PE04	-28.20508	22.85	17.2	18.98	1260.00	
PE05	-28.20629	22.84952	15.42	16.29	1260.00	
PE06	-28.19832	22.84428	26.35	27.22	1273.05	
PE08	-28.20371	22.81158	49.9	50.09	1384.45	
PE09	-28.219	22.84708	24.76	25.29	1260.02	
PE13	-28.19103	22.8407	33.7	33.88	1282.05	
PE14	-28.19534	22.84419	26.65	27.29	1275.62	
Pramberg						
PG01	-28.21667	22.80234	86.69	86.47	1352.77	In general decreasing trends are observed between 2019 and 2020 for PG02, PG05A and PG12 whereas as increasing trends are seen in PG01 and PG10.
PG02	-28.23241	22.78923	53.86	54.85	1311.43	
PG02A	-28.2328	22.78908	*	53.35	1311.43	
PG03	-28.23081	22.78718	*	72.15	1325.99	
PG04	-28.23864	22.78891	*	48.95	1303.94	
PG05A	-28.24141	22.78268	35.88	36.47	1307.38	
PG06	-28.27455	22.77634	*	77.68	1339.99	
PG07	-28.29908	22.76652	*	56.65	1351.87	
PG08	-28.32368	22.77319	*	104	1324.02	
PG09	-28.30134	22.77226	41.8	*	1323.16	
PG10	-28.32352	22.77888	69.78	65.71	1348.20	
PG11	-28.21868	22.75617	*	*	1299.40	
PG12	-28.33328	22.76434	43.85	43.95	1285.34	
Putsfontein						
PN01	-28.54286	22.91831	*	*	1160.00	A decreasing trend is observed between 2019 and 2020
PN02	-28.54207	22.91872	14.21	14.43	1160.00	
PN03	-28.54401	22.91074	18.9	20.07	1158.99	
PN04	-28.55448	22.9036	*	*	1159.67	

PN05	-28.54684	22.91822	11.85	21.36	1160.00	
PN06	-28.56225	22.91962	10.64	10.31	1159.87	
PN07	-28.56836	22.91764	12.57	13.4	1160.00	
Raposa						
RA02	-28.02558	22.87002	20.99	24.99	1274.72	A slight decreasing trend is observed between 2019 and 2020
RA03	-28.02395	22.8391	26.65	28.56	1248.96	
RA04	-28.02446	22.84082	27.06	27.44	1248.92	
Soetfontein						
SF01	-28.37361	23.03662	9.23	9.68	1277.71	Groundwater levels between 2009 and 2020 overall show increasing trend
SF02	-28.37353	23.03634	8	9.43	1277.71	
SF03	-28.37335	23.03619	7.74	8.2	1277.71	
SF04	-28.37396	23.03584	6.41	6.45	1277.71	
SF05	-28.37206	23.03448	4.75	5.13	1269.57	
SF06	-28.372	23.03424	5.09	5.51	1269.57	
SF07	-28.37468	23.03329	2.89	3.1	1268.80	
SF09	-28.39215	23.07139	32.03	31.69	1285.54	
SF10	-28.38756	23.06375	33.9	*	1314.12	
Floradale						
SFE001	-28.3962	22.8047	16.54	16.72	1197.00	Groundwater levels between 2019 and 2020 show slight decreasing trend
SFE002	-28.39632	22.80917	10.54	10.76	1179.83	
SFE003	-28.39632	22.81454	10.11	10.27	1179.68	
SFE004	-28.40101	22.824	23.86	24.13	1193.56	
SFE005	-28.40052	22.82948	46.8	47.46	1212.95	
SFE006	-28.40086	22.82778	32.94	33.28	1212.95	
SFE007	-28.41707	22.82091	8.59	8.77	1179.53	
SFE008	-28.4293	22.80009	24.21	24.59	1190.32	
SFE009	-28.4279	22.79677	37.64	37.86	1197.14	
SFE010	-28.4258	22.7944	45.38	45.51	1200.01	
SFE011	-28.36368	22.8242	11.33	11.6	1194.60	
SFE012	-28.36387	22.82542	15.78	16.16	1194.60	
SFE013	-28.37175	22.81925	17.9	18.17	1184.70	
SFE014	-28.37232	22.82282	14.9	15.17	1187.70	
SFE015	-28.37271	22.82519	15.9	16.17	1190.99	
SFE016	-28.37871	22.81618	12.02	12.95	1180.22	
SFE017	-28.37868	22.8191	14.34	14.53	1181.06	
SFE018	-28.37864	22.82143	14.57	14.76	1183.70	
SFE019	-28.38302	22.81365	12.12	12.48	1180.00	
SFE020	-28.38394	22.81907	13.46	13.65	1180.07	
SFE021	-28.38479	22.82418	18.47	18.65	1190.34	
SFE022	-28.39302	22.81725	11.26	11.45	1178.78	
SFE023	-28.37206	22.82074	16.84	17.12	1187.70	
SFE024	-28.37864	22.82026	14.43	14.63	1181.06	
SFE025	-28.40156	22.8155	10.25	10.53	1180.00	
Aarkop						
SMG003	-28.1045	22.97875	24.48	25.2	1305.42	

SMG005	-28.114	22.95829	24.54	25.47	1300.00	A slight decreasing trend is observed between 2019 and 2020
Stillerust						
ST01	-28.3959	22.7681	44.7	*	1219.82	Water level trends between 2019 and 2020 indicate a slight decrease in ST02.
ST02	-28.39599	22.76807	45.39	45.95	1219.82	
Sunnyside						
SUN01	-28.42358	22.87536	11.71	12.04	1200.05	Groundwater levels between 2008 and 2020 overall show slight decreasing trend with the exception of SUN08 (increasing trend)
SUN02	-28.42322	22.87449	13.89	14.2	1205.21	
SUN03	-28.4234	22.87456	13.2	13.53	1205.21	
SUN04	-28.42345	22.87452	12.2	*	1205.21	
SUN05	-28.42438	22.87466	12.84	13.18	1207.78	
SUN06	-28.42489	22.87426	*	*	1207.78	
SUN07	-28.46025	22.86666	8.7	9.4	1170.11	
SUN08	-28.4596	22.86617	6.63		1170.11	
SUN09	-28.45972	22.86621	7.98	8.61	1170.11	
SUN10	-28.45978	22.86624	*	*	1170.11	
SUN11	-28.46146	22.86479	8.25	8.8	1165.94	
SUN12	-28.46098	22.86468	*	7.62	1166.55	
SUN13	-28.44632	22.86837	*	*	1173.00	
SUN14	-28.43207	22.84842	31.46	*	1187.58	
SUN15	-28.44416	22.82924	9.68	9.8	1160.33	
Vlakfontein						
VN02	-28.15395	22.97452	18.22	18.32	1304.28	A slight decreasing trend is observed between 2019 and 2020
VN03	-28.1494	22.9835	13.18	13.27	1299.98	
VN04	-28.15047	23.00456	27.19	28.34	1317.50	
VN05	-28.16335	22.97502	12.73	13.09	1297.18	
VN06	-28.16646	22.96436	20.73	21.29	1291.42	
VN07	-28.18893	22.96762	6.5	7.03	1280.03	
Venn						
VNN02	-28.06103	22.86844	17.95	18.92	1290.27	A slight decreasing trend is observed between 2019 and 2020
VNN03	-28.06125	22.86823	17.25	18.3	1290.27	
VNN04	-28.06024	22.86467	27.02	29.6	1282.95	
VNN06	-28.06131	22.8595	43.8	*	1276.32	
VNN07	-28.06132	22.85949	56.53	*	1276.32	
Vleiput						
VP01	-28.47564	22.93571	10.98	11.15	1193.04	Groundwater levels between 2011 and 2020 overall show decreasing trend
VP02	-28.47567	22.93556	11.28	11.8	1191.13	
Vlakplaas						
VS01	-28.55157	22.97924	*	16.17	1180.90	Groundwater levels between 2019 and 2020 overall show slight decreasing trend
VS02	-28.55472	22.97971	10.4	10.69	1184.30	
VS03	-28.55312	22.97816	14.67	14.77	1184.30	
VS04	-28.5703	22.99278	19.9	*	1200.00	
VS05	-28.58076	23.0141	17.44	17.97	1218.90	
VS06	-28.56037	23.00973	20.7	*	1206.11	
Voëlwater						
VW01	-28.34854	22.82423	7.61	8.11	1200.00	

VW02	-28.34875	22.79452	*	*	1219.04	Groundwater levels between 2009 and 2020 overall show slight increasing trend with the exception of VW04
VW04	-28.32433	22.79981	62.59	66.17	1238.39	
VW07	-28.32682	22.82648	10.54	10.02	1200.17	
VW08	-28.32696	22.82753	10.34	10.46	1199.47	
Wildealsput						
WAT01	-28.20961	22.96213	41.6	42.2	1280.59	A slight decreasing trend is observed between 2019 and 2020
WAT02	-28.2086	22.9635	7.98	8.18	1282.05	
WAT05	-28.21401	22.96187	9.76	9.85	1280.73	
Watervlakte						
WE01	-28.49015	22.82528	7.81	7.54	1153.61	A slight decreasing trend is observed between 2019 and 2020
Witboom						
WIT01	-28.5529	22.88212	26.96	23.6	1156.57	Groundwater levels between 2009 and 2020 overall show decreasing trend, however between 2019 and 2020 the water levels in WIT01 indicate an increasing trend.
WIT02	-28.55273	22.88619	*	*	1156.27	
Wolhaarkop						
WKP01	-28.39309	22.84051	27.9	*	1219.20	Not sufficient time series data to assess
WKP02	-28.36657	22.83258	17.12	*	1200.17	
WKP05	-28.40124	22.86019	20.65	*	1219.65	
WKP06	-28.3486	22.86585	27.03	*	1232.51	
Welgevonden						
WV114A	-28.36711	22.89706	106.69	*	1263.11	Not sufficient time series data to assess
WV116	-28.35623	22.90349	*	105.46	1260.00	
WV169	-28.37668	22.89429	39.71		1245.46	

*No data / no measurement possible / dry

3.2.3 Previous study results on groundwater levels and dewatering

- Itasca (2015)
  - Dewatering for the mine modelled to vary from 2 235 – 3 990 m³/hr to allow mining;
  - The north – south fault system propagates drawdown;
  - Due to the high evaporation rate in the region, the water levels of the pit lakes will not recover to the pre-mining groundwater table levels by the end of 2070;
  - There is still expected to be a 25 to 95 m difference in pit lake water level vs pre-mining 30 - 40 years post closure;
  - By the end of 2070, the drawdown in the mine vicinity will be less than 50 m, and the areal extent of the 10m drawdown contour line will continue to reduce from the end of mining until 2070;
  - The lack of quality monitoring data the dewatering results were seen as preliminary.
- Synergistics (2016)
  - The increased production rate from 9 Mtpa to 16 Mtpa will require an increase in the current dewatering rate from 1 950 m³/hr to 3 990 m³/hr;
  - Dewatering at a rate of 3 990 m³/hr is expected to result in a drawdown of the natural groundwater levels by up to 50 m outside of the mining area in the years

  2050 and 2060, impacting on the immediately neighbouring farms up to 5 km east of the mine;
  - Mitigation includes confirming spatial extent of cone, update of dewatering requirements (ongoing) and aquifer recharge.

- Itasca (2020/2021)
  - The drawdown cone of 1-10m extends 32 km north and 23 km south. Historical Beeshoek dewatering attributes to north drawdown, drawdown to south mediated by presence of permeable faults and dolomite;
  - 2018 to 2020 water level data indicate continued drawdown in the chert and dolomite as a result of dewatering;
  - For Leeuwfontein, water level data indicated consistent trend between 2018 and 2020 as compared to historical data with slight fluctuation in drawdown per month. The average drawdown at Leeuwfontein was 1.8 meters/month between 2018 and 2020. An increase in dewatering between June 2019 and September 2020 has resulted in these fluctuations;
  - At Klipbankfontein, drawdown has remained fairly consistent from 2018 to 2020 at 1m/month;
  - More variability was observed for Kapstevel South and Kapstevel North. From 2018 to 2020 the drawdown rate was 0.5 m/month but this has accelerated since March 2020 to 1.8 m/month due to an increase in dewatering;
  - The average dewatering rate from 2018 to 2020 for Leeuwfontein was 1 351 m^3/hr and for Kapstevel (north and south), 267 m^3/hr. The peak dewatering rates over this period were in August and September 2020, with 1 080 m^3/hr for Leeuwfontein and 550 m^3/hr for Kapstevel (north and south). Since then the dewatering rates were declining;
  - There was no active dewatering at Klipbankfontein;
  - For Beeshoek Mine it was assumed that dewatering was still occurring at approximately 550 m^3/hr;

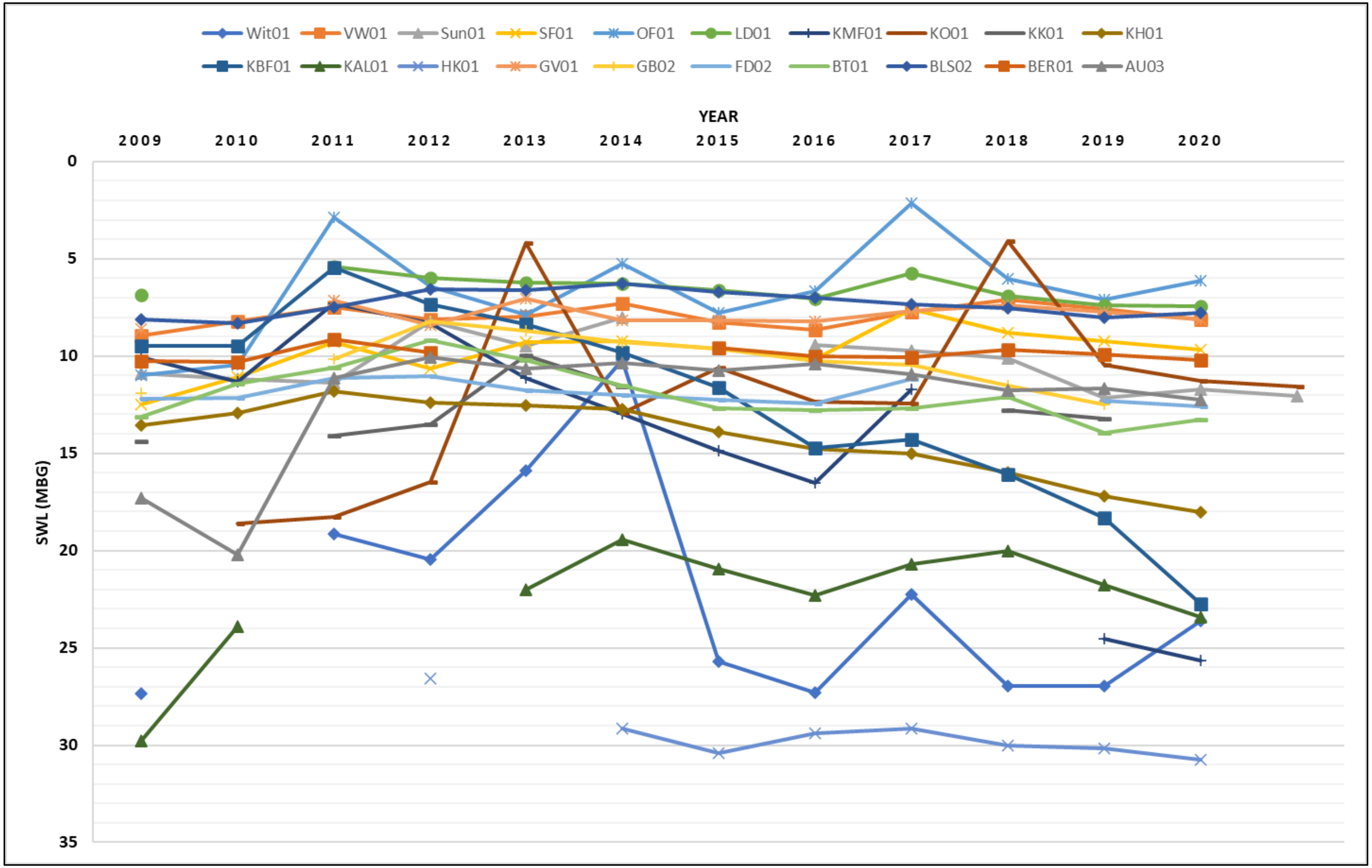


Figure 3.a: **Regional groundwater level trends**

3.2.4 Hydrochemistry

Kolomela has a comprehensive groundwater and surface water monitoring network, on which Aquatico has been conducting comprehensive monitoring dating back to 2008. This data was reviewed and summarised to obtain a better understanding of the historical and current water quality status and trends for Kolomela Mine and the surrounding farms. Sampling and other site characterisation work was not included in the scope of this assessment.

The latest monitoring results were used to conceptualise the site which are summarised below for the 2020 monitoring period include:

- Process water at Kolomela Mine has a neutral to alkaline, very hard profile with pH, total dissolved solids (TDS), calcium, magnesium, sodium and sulphate exceeding the WUL limits;
- The receiving environment has a neutral, very hard profile, also with TDS, calcium, magnesium, sodium and sulphate exceeding the WUL limits in some of the boreholes;
- At Klipbankfontein magnesium exceeded the WUL limits in one (1) borehole and at Leeuwfontein magnesium (two boreboreholes), chloride (one borehole) and total coliforms (one borehole) exceeded the WUL limits;
- At Kapstevel no variables exceeded the WUL limits whereas at Welgevonden only one borehole had elevated levels of total coliforms;
- The boreholes at Kapstevel pit had average magnesium concentrations of 56.8 mg/ℓ, TDS (521.7 mg/ℓ), nitrate (3.6 mg/ℓ) and chloride (22 mg/ℓ);
- Average concentrations for the boreholes located around the plant were 54.4 mg/ℓ (magnesium), 529.8 mg/ℓ (TDS), 3.2 mg/ℓ (nitrate) and 100.3 mg/ℓ (chloride);
- At the slimes dams the average concentrations were 65.2 mg/ℓ (magnesium), 523.3 mg/ℓ (TDS), 1.5 mg/ℓ (nitrate) and 255.3 mg/ℓ (chloride);
- For the Kappieskaree recharge boreholes the average concentrations were 65.6 mg/ℓ (magnesium), 570.8 (TDS), 1.7 mg/ℓ (nitrate) and 79.4 mg/ℓ (chloride);
- The Klipbankfontein recharge boreholes average concentrations were 88.8 mg/ℓ (magnesium), 656.5 mg/ℓ (TDS), 3.5 mg/ℓ (nitrate) and 83.6 mg/ℓ (chloride);
- The Leeuwfontein aquifer recharge boreholes had average magnesium concentrations of 82.8 mg/ℓ, TDS of 592.9 mg/ℓ, nitrate of 3.2 mg/ℓ and chloride of 43.2 mg/ℓ;
- A number of variables in the aquifer recharge boreholes exceeded WUL limits including, pH (most localities), electrical conductivity, alkalinity (many locations), magnesium (most localities) and manganese (certain localities);
- The deep aquifer monitoring boreholes had average magnesium concentrations of 23.2 mg/ℓ, TDS 3205 mg/ℓ, nitrate 1.5 mg/ℓ and chloride 19.8 mg/ℓ. The deep aquifer boreholes that are used to monitoring dewatering impacts all have good water qualities not exceeding any of the guidelines.
- The water fill points (dust suppression) have very high salt and organic contents.

3.2.5 Geochemistry

LWRC (2021) conducted a geochemical assessment and waste classification to determine the chemical nature and character of the waste rock dump (WRD) and tailings storage facility (TSF) material and to determine their pollution generating potential (including AMD / ARD).

Table 3.b below summarises and compares the LWRC (2021) results against relevant previous geochemical assessments and waste classifications conducted at Kolomela Mine. Only samples collected from waste rock or tailings (fines) storage facilities are included in the comparison.

The results from the studies largely agree on the mineralogy, ABA and the observed TC's and LC's. The mineralogy of the waste rock and tailings is dominated by silica (quartz), ferric oxide (hematite), aluminium oxide and dolomite. In terms of acid generating potential all studies agree that the potential is low to zero for the waste rock or tailings material.

The TC's are also similar in the studies in that the elements observed to exceed TCT values are mostly barium, copper and manganese. The LC's are observed to be similar as well. The investigations all classed the waste rock and tailings as Type 3 Waste.

Table 3.b: Previous investigations results comparison (LWRC, 2021)

Investigation	Facility / material	Mineralogy	ABA	TC's Exceeding TCT0	LC's Exceeding LCT0	Waste Classification
LWRC - 2021	Fines & Waste Rock Composite	Silica (quartz) dominant, also hematite & dolomite	Rock Type IV, no potential for AMD	Ba, Mn	None	Type 3 Waste
J&W 2017	Tailings	Quartz & hematite dominant	Not performed	Ba, Cd, F	Fe	Type 3 Waste
	Discard	Quartz & hematite dominant	Not performed	Ba, Cd, F	Fe	Type 3 Waste
Golder 2016	Kapstevel WRD Composite	Silica, iron oxide (ferric oxide) & aluminium oxide dominant	Not Potentially Acid Generating (non-PAG), near neutral-low metal leachate	As, Ba, Cu, Mn	None	Type 3 Waste
	Leeuwfontein South WRD Composite	Silica & iron oxide (ferric oxide) dominant	Not Potentially Acid Generating (non-PAG), near neutral-low metal leachate	As, Ba, Cu, Mn	None	Type 3 Waste
	Leeuwfontein North WRD Composite	Silica & iron oxide (ferric oxide) dominant	Not Potentially Acid Generating (non-PAG), near neutral-low metal leachate	As, Ba, Cu, Mn	None	Type 3 Waste

Golder Associates (2016) assessed the MRF's individually and their results indicated that all material can be classified as Type 3 waste for Leeuwontein WRD (north and south), Kapstevel WRD as well as the TSF.

In addition, Golder Associates (2016) concluded that the impact on water resources from the MRF's will be minimal, one of the reasons being the very low annual TDS load to groundwater (without Class C liner systems). Furthermore, Golder Associates (2016) also indicated manganese seepage loads of 0.07 $kg.a^{-1}$ (Kapstevel), 4.94 $kg.a^{-1}$ (Leeuwfontein North) and 0.06 $kg.a^{-1}$ (Leeuwfontein South).

3.3 Site hydrogeology

As no site characterisation work was conducted as part of the Gradient (2021) hydrogeological assessment, the findings were inferred from previous hydrogeological assessments and groundwater models conducted at Kolomela Mine and surrounding areas, more specifically studies completed by Itasca (2015 & 2020/2021), TECT (2016) and Groundwater Complete (2018).

3.3.1 Groundwater Gradients and Flow

The first important aspect when evaluating the hydrogeological regime and groundwater flow mechanisms is the groundwater gradient. Variations in hydraulic head across the site are used to determine the groundwater gradients which is the driving force behind groundwater flow. At a site where there is a clear differentiation between aquifer systems, in this case as a result of an extensive calcrete & clay horizon that act as an aquitard between the upper (semi-confined to unconfined) Kalahari Formation aquifer and the lower confined (to semi-confined) fractured rocks, it is imperative that the groundwater dynamics be investigated individually for each aquifer. In addition, the dynamics and connectivity between the two aquifer systems also need to be assessed.

However, in the absence of site characterisation data, aquifer characteristics and dynamics have been inferred from Itasca (2016 & 2020) and Groundwater Complete (2018). It is important that the borehole construction of the monitoring boreholes be considered in differentiating between aquifer systems as it determines if aquifers are being monitored and assessed individually or as one system.

With reference to **Table 3.a**, the average depth to groundwater across the entire monitoring network, excluding dewatering and recharge boreholes, were estimated to be 12.97 mbg (2019) and 13.5 mbg (2020). The harmonic mean has been calculated to be 20.8 mbg (2019) and 21.5 mbg (2020).

A 90% correlation between topography and observed groundwater levels was obtained as illustrated in **Figure 3.b.** Correlation above 90% are deemed to be good especially considering the site conditions with water potentially occurring in different fractured formations and under variable pressure the correlation is seen as acceptable to conclude that groundwater flow will mimic the topography.

The groundwater flow directions are indicated on **Figure 3.c**. It is observed that groundwater flow is generally towards the south and southwest. Groundwater flow direction, locally, is impacted by dewatering from mining with flow towards the pits as well as the Groenwaterspruit. Groundwater flow direction generally SSE, impacted by irrigation from Groenwaterspruit & mining. Beeshoek mine to the north of the site does also affect the groundwater flow direction by means of dewatering.

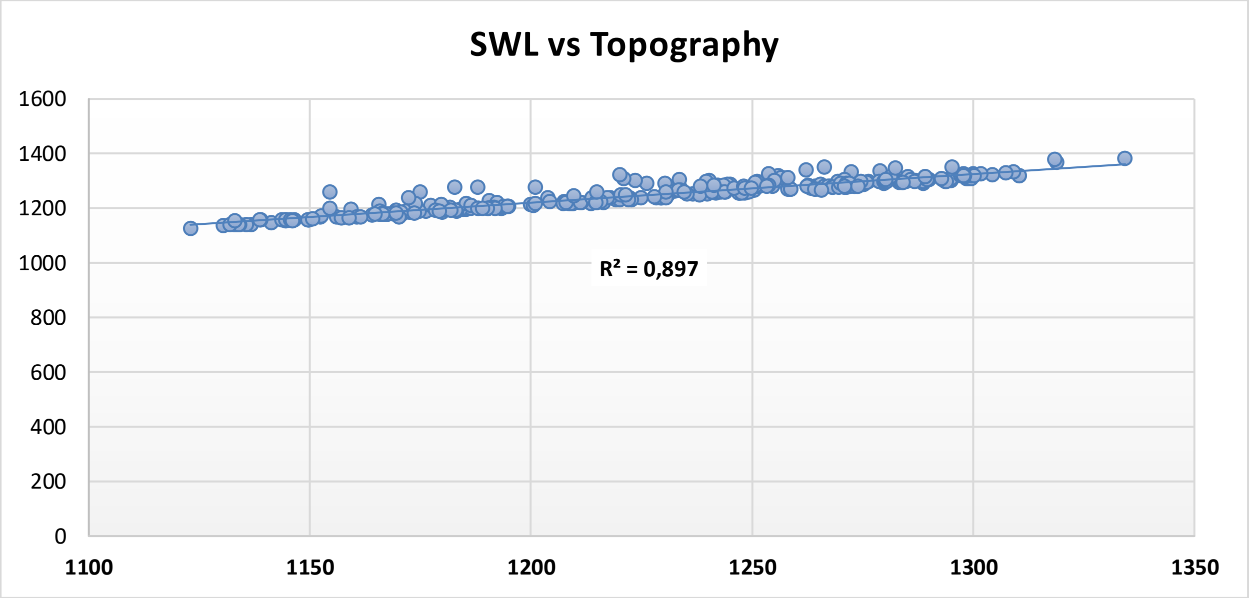


Figure 3.b: Groundwater levels vs topography

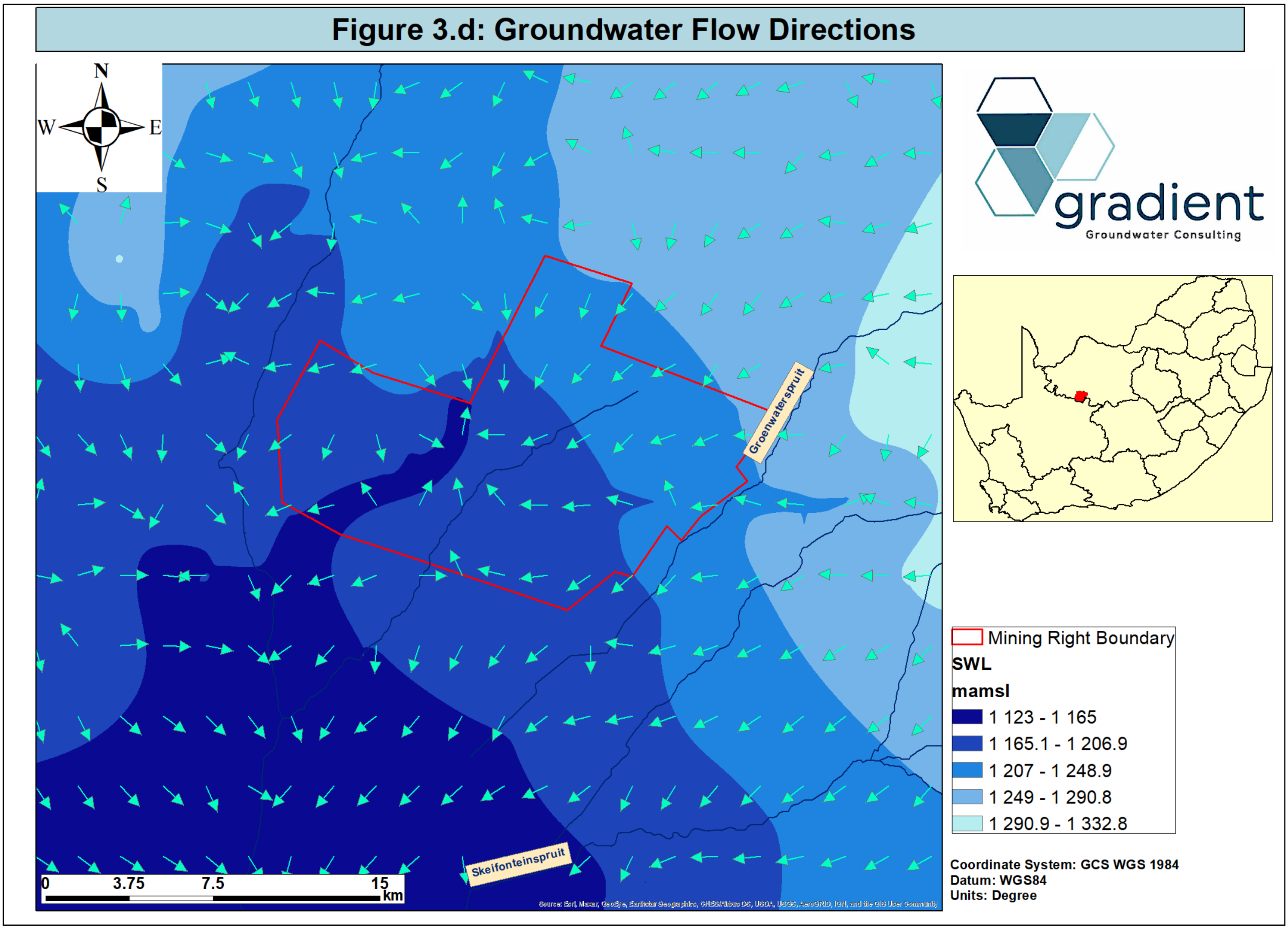


Figure 3.c: **Groundwater flow direction**

3.3.2 Aquifer type

Aquifer properties are primarily determined by the underlying lithologies, which are explained in more detail in **Section 2.6**. In sequence from surface, the typical site lithology at Kolomela Mine comprise of calcretes & clays, tillite (in places), iron ore & BIFs, chert and dolomites. Aquifer boundaries are topographical highs (no-flow boundaries) and rivers / streams (constant head).

According to the Hydrogeological Map Series of the Republic of South Africa (2722 - Kimberley, 1:500 000) the Kolomela study area falls over three main water bearing strata (see **Figure 3.d**) as summarised below:

- An intergranular and fractured aquifer (d2, d3, d4 in map) where the lower fractured bearing strata include basic and intermediate extrusive rocks with yields ranging between 0.1 – 0.5 L/s (d2), 0.5 – 2.0 L/s (d3) and 2.0 – 5.0 L/s (d5).

  The upper intergranular zone comprises predominantly of unconsolidated sediments including sand, calcrete, aeolianite, gravel, clay and silcrete;
- A fractured (confined) aquifer (b2, b3, b5 in map) comprising mainly of BIF's and jaspilite with yields ranging from 0.1 – 0.5 L/s (b2), 0.5 – 2.0 L/s (b3) and >5.0L/s (b5).
- A karst aquifer comprising predominantly of carbonate rocks (dolomite), shale and chert.

Based on the hydrogeological map and data obtained from previous studies, two main aquifers are typically present in the project area. These are:

The first, upper, **<u>unconfined to semi-confined Kalahari Formation aquifer</u>**, comprising mainly of calcareous sand and silt which extends down to the more competent calcretes. The calcretes retards groundwater flow and groundwater recharge because of its low permeability.

Yields from calcrete are low, exceptions are around Groenwaterspruit (east) and Lucasdam Vlei (West) both low lying drainage areas with higher recharge due to seepage and increased hydraulic conductivity due to paleo channels comprising of coarse gravels. The shallow calcrete aquifer is widely used for livestock watering and domestic supply.

Groundwater is generally abstracted near the contact between the calcrete and the underlying clay formations. In multiple areas, there is a perched aquifer at the contact between the calcrete and the tillite.

- A **<u>deeper, unweathered fractured rock (second porosity) aquifer</u>**, is the major aquifer system within the Transvaal/Griqualand West sequences where water occurrence is mainly within fissures and fractures in the brecciated BIFs where mineralization and preservation of ore bodies occurred through folding, thrusting, fracturing and sinkholes. Yields can vary from 1 – 80 L/s. Inherently, these types of aquifers are heterogeneous and aquifer parameters are variable. The Ongeluk Formation is generally considered to be a low-yielding aquifer.

  A dolomitic aquifer is also found in which water occurrence is mostly restricted to karstic compact carbonate rock. The dolomitic aquifers also fall under the secondary, fractured rock aquifer. Exploration in the dolomites indicated yields of 2 – 4 L/sec, however yields of up to 80 L/s have also been recorded.
- In addition to the two main aquifer systems, temporary perched, riverbed aquifers are also found which are located in the riparian zone surrounding the drainage lines and rivers. This primary alluvial sand aquifer is directly recharged during rainfall events and is limited to a zone of variable width and depth, largely determined by the depth and extent of the calcrete and pebble beds. From the local groundwater levels and

subsurface lithology it is assumed that this aquifer only contributes to river flow directly following significant rainfall events. Loss in contribution to baseflow will be minimal as the current groundwater contribution to baseflow is insignificant.

Figure 3.e is a generalised schematic cross section of the Ga-Mogara River between Middelpos and Kuruman and conceptually is similar to drainage features observed in the greater study area. It is observed that the lithology depicted by No.3 (T-Qk) on the map is Kalahari Group Sediments which was laid down in an old glacial valley environment. The Kalahari sediments is underlain by the Dwyka Group (C-Pd) as well as Banded Iron Formation from the Ghaap Group (Va) deeper down. On either side of the paleo-glacial valley, the Postmasburg Group (Vo) andesitic lavas and basal diamictite forms a competent hard rock formation which is largely unweathered with a much shallower Kalahari Formation upper aquifer.

The average depths of the various aquifers within the study area, as based on the existing borehole database, is summarised in **Table 3.c** below.

Table 3.c: Average aquifer depths

Aquifer	Depth (mbg)	Geology
Intergranular Unconfined	0 - 40	Aeolian and calcareous sand underlain by competent calcrete and a pebble marker in places
Fractured confined	40 - 300	Unweathered hard rock Ongeluk Lavas, chert & dolomite (where, Kolomela dolomitic aquifer)

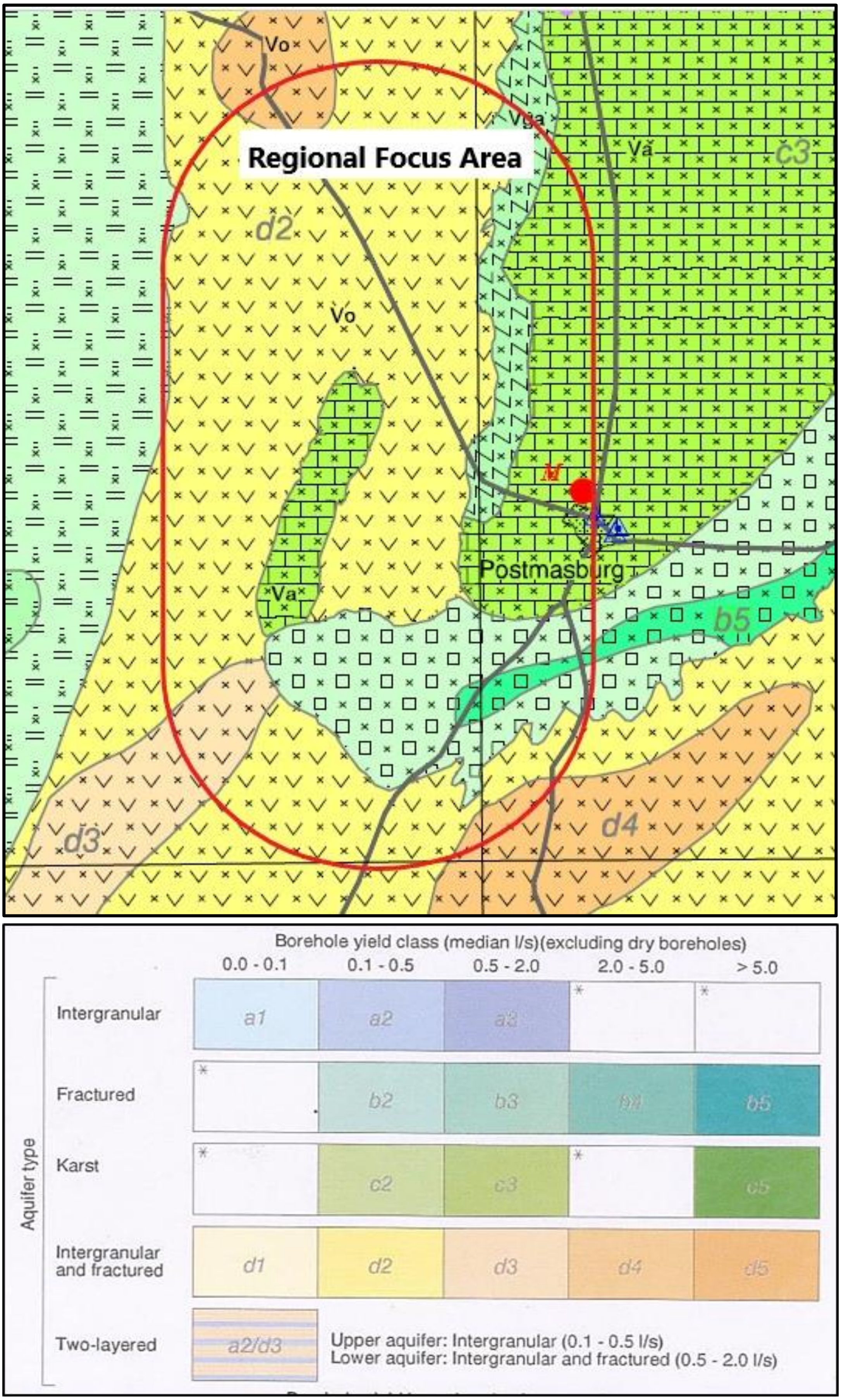


Figure 3.d: **Regional hydrogeological map (2722 Kimberley)**

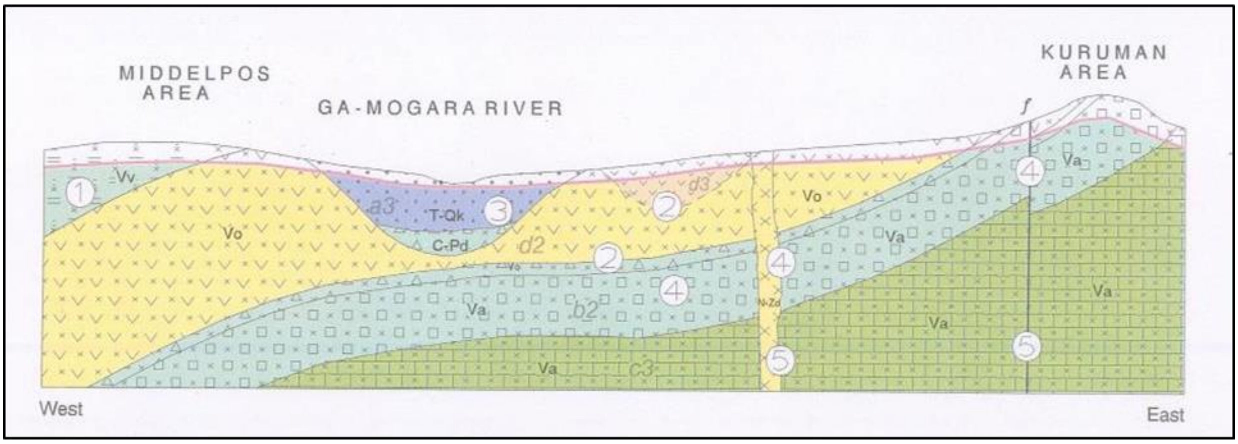
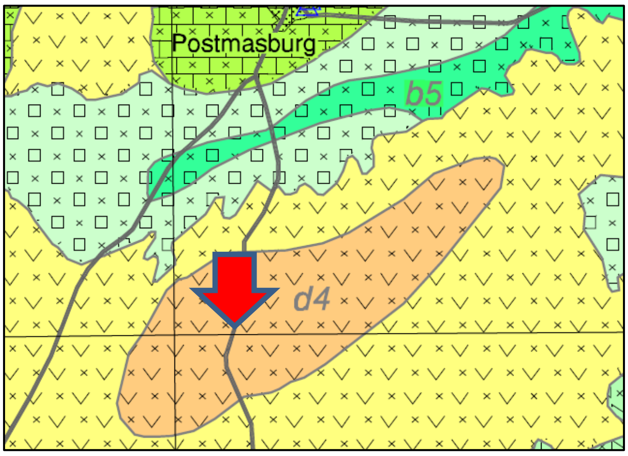


Figure 3.e: Schematic cross section of Ga-Mogara River (Moseki, 1984)

The Kolomela farms have also been plotted against **Groundwater Harvest Potential** (Department of Water Affairs and Forestry, 1996), see **Figure 3.f.** The harvest potential is the maximum amount of groundwater that can be abstracted per square kilometre per annum without depleting the aquifers. It was determined from groundwater recharge and groundwater storage. From this, the aquifers at most farms classify as having a harvest potential ranging from 6 000 to 10 000 m³/km²/annum.

To compliment this map, the geology has been brought into consideration as well (see **Figure 3.g**). The majority of the Kolomela surrounding farms fall under Ongeluk lavas where groundwater occurrence is mostly restricted to fractured igneous (metamorphic) rock. Water bearing fractures are principally restricted to a shallow zone below groundwater level. Exceptions are the farms Kapstevel 541, Grootpan 543 Wildealsput 543 and Kappies Kareeboom 540 which are all also underlaid by Griquatown Group compact sedimentary strata i.e. mudstones, BIFs and jaspilite. In these, water occurrence is mostly in fractured compact rock in fractures. The farm Ploegfontein 487 is underlain also by Campbell Group dolomites, chert and subordinate limestone. Water occurrence is mostly restricted to karstic compact carbonate rock to depths of 50m.

However, considering the hydrogeological map series (1:500 000) (see d4 on insert below) Portion 2 of Gruispan is also considered to have a higher groundwater potential as compared to the farms located to the west. Groundwater is likely to occur in intergranular and fractured aquifers associated with the basic and intermediate extrusive rocks (basalt, andesite). Yields can vary between 2 and 5L/sec.



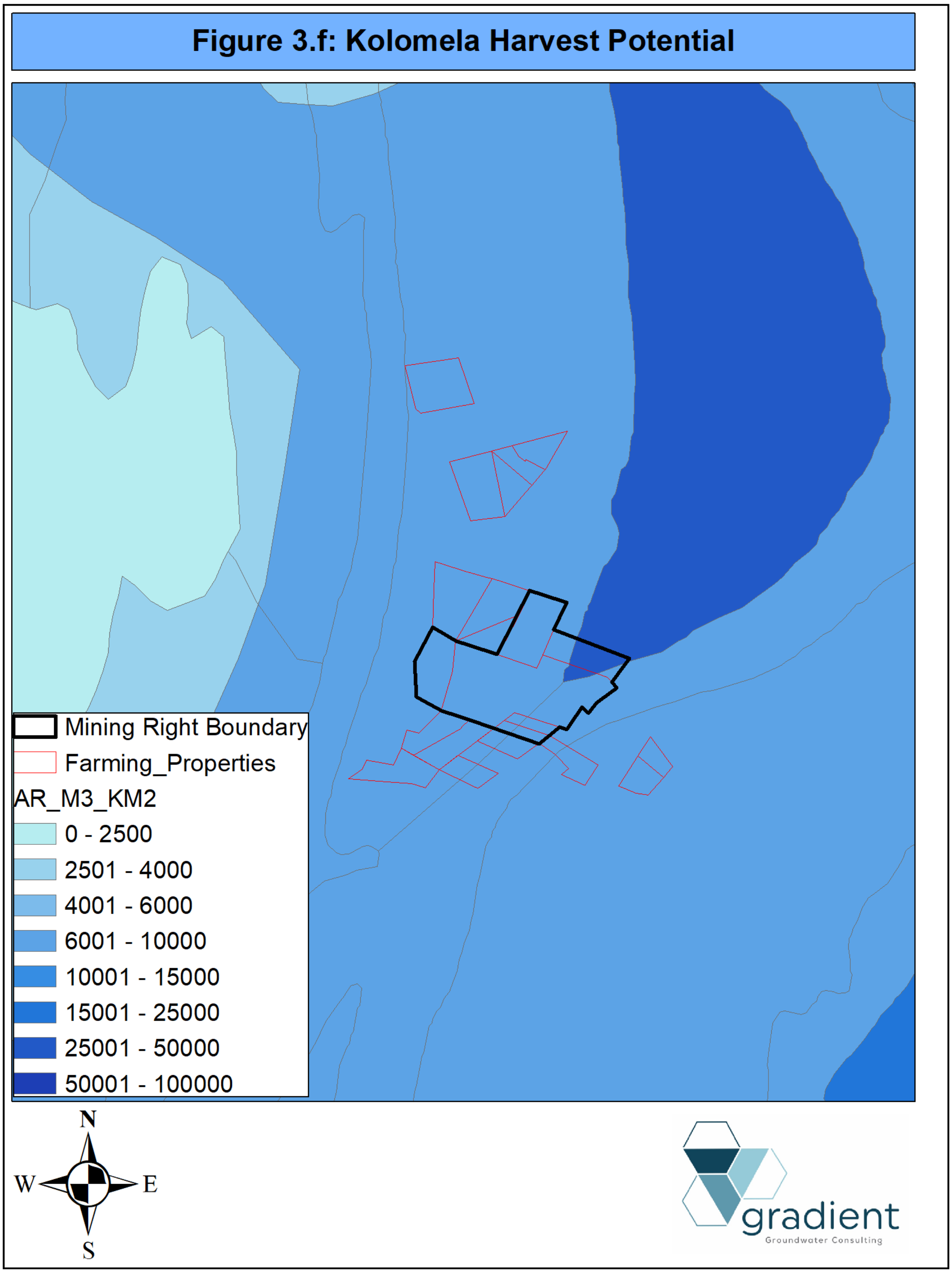


Figure 3.f: **Groundwater harvest potential for Kolomela area**

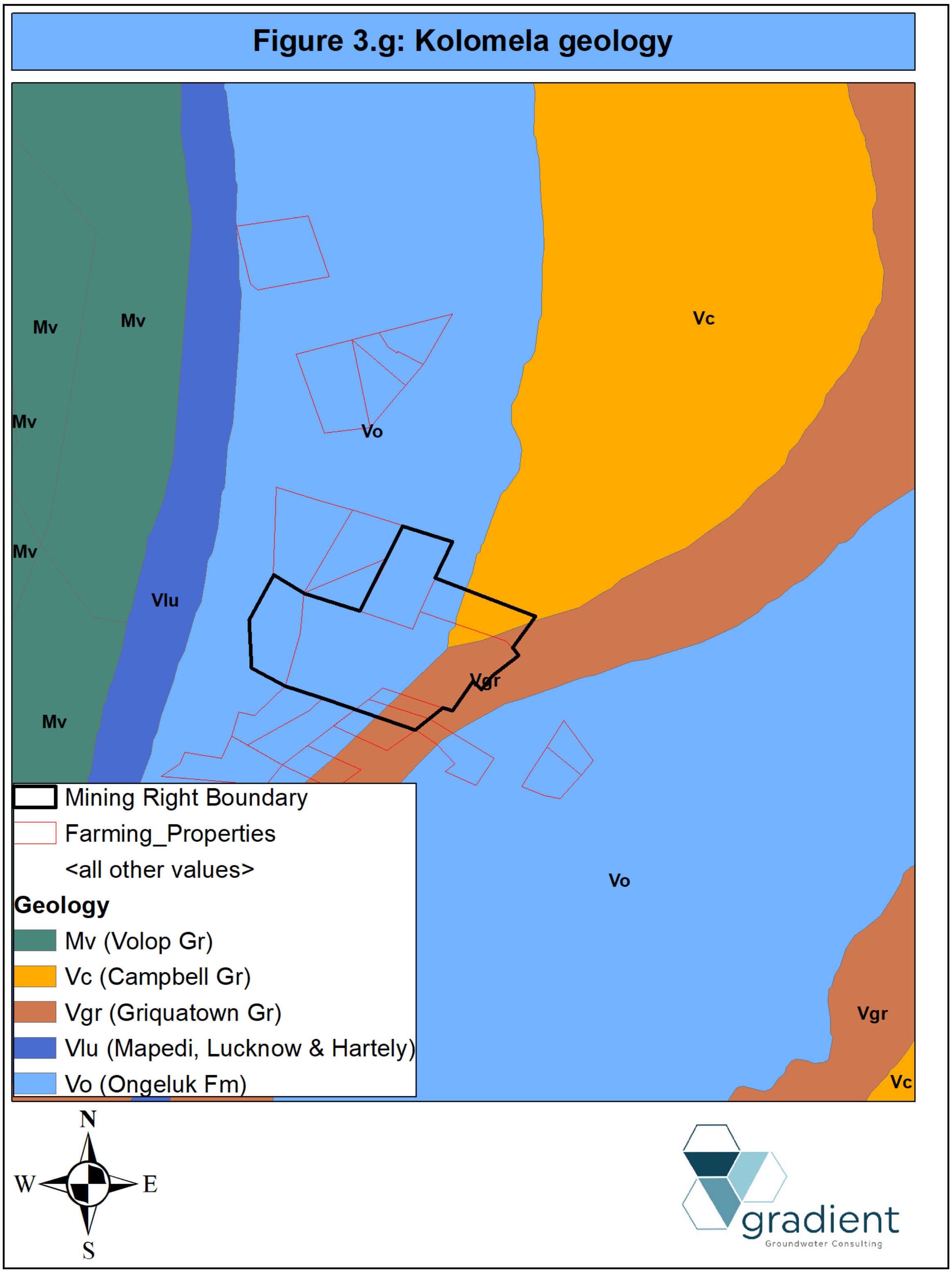


Figure 3.g: **Harvest potential and geology for Kolomela area**

3.3.3 Aquifer parameters

The aquifers parameters below have been obtained from Itasca (2015) and Itasca (2020):

Table 3.d: Itasca (2020) aquifer parameters

Hydrostratigraphic unit	Hydraulic Conductivity (K)	
	Kx,y 1:1 (m/d)	Kz 1:10 (m/d)
Kalahari	1.000E-02	1.000E-02
Tillite	5.000E-04	5.000E-05
Lava	1.000E-04	1.000E-05
Gamagara (1-4)	1.000E-02 to 1.000E-04	1.000E-03 to 1.000E-05
Ore	1.000E-02	1.000E-03
BIF (1-3)	5.000E-03 to 1.000E-04	5.000E-04 to 1.000E-05
Chert	1.9	1.900E-01
Dolomite (1-3 Regional)	1.9	1.9
Dolomite (KS Pit)	7.5	7.5
Dolomite (LF & KB Pit)	5.000E-01 to 5.0	5.000E-01 to 5.000E-02
Fault (Pits)	3.0	3.0
Fault (LF & KB Pit)	2.000E-03 to 1.000E-03	2.000E-03 to 1.000E-03
Fault (regional)	1.0	1.0
Dyke	1.000E-06	1.000E-06

The aquifer parameters below have been calculated for the Gradient (2021) study (**Table 3.e**):

- Layer 1 (upper aquifer)
  - Recharge outcrop areas 15mm/annum, model catchment 10.20 mm/annum
  - Specific storage 1.000E-03
  - Porosity (n) 1.000E-01
- Layer 2 (lower aquifer)
  - Specific storage 1.000E-05
  - Porosity (n) 5.000E-02

Table 3.e: Gradient (2021) aqufier parameters

Model Layer	Hydrostratigraphic unit	Layer thickness (m)	Hydraulic Conductivity (K)	
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)
Layer 01	Kalahari Grp	40.00	1.500E+00	1.500E+00
	Asbestos Hills Sbgrp, Ghaap Grp		3.000E-01	3.000E-02
	Brulsand Sbgrp, Volop Grp		3.000E-01	3.000E-02
	Cambell Rand Sbgrp, Ghaap Grp, Transvaal Spgrp		7.500E-01	7.500E-02
	Gamagara Fm, Olifantshoek Spgrp		1.000E-01	1.000E-02
	Hartley Fm, Olifantshoek Spgrp		7.500E-02	7.500E-03
	Koegas Sbgrp, Ghaap Grp		1.000E+00	1.000E-01
	Makganyene Fm, Postmasburg Grp		7.500E-01	7.500E-02
	Matsap Sbgrp, Volop Grp		7.500E-02	7.500E-03
	Olifantshoek Spgrp		7.500E-01	7.500E-02
	Ongeluk Fm, Postmasburg Grp		7.500E-02	7.500E-03

	Volwater Sbgrp, Postmasburg Grp		7.500E-01	7.500E-02
	Dykes, weathered perimeter		1.000E+00	1.000E-01
	Dykes, matrix		5.000E-02	5.000E-03
Layer 02	Asbestos Hills Sbgrp, Ghaap Grp	300.00	1.500E-01	1.500E-02
	Brulsand Sbgrp, Volop Grp		1.500E-01	1.500E-02
	Cambell Rand Sbgrp, Ghaap Grp, Transvaal Spgrp		1.000E-01	1.000E-02
	Gamagara Fm, Olifantshoek Spgrp		5.000E-02	5.000E-03
	Hartley Fm, Olifantshoek Spgrp		3.750E-02	3.750E-03
	Koegas Sbgrp, Ghaap Grp		5.000E-01	5.000E-02
	Makganyene Fm, Postmasburg Grp		3.750E-01	3.750E-02
	Matsap Sbgrp, Volop Grp		3.750E-02	3.750E-03
	Olifantshoek Spgrp		3.750E-02	3.750E-03
	Ongeluk Fm, Postmasburg Grp		3.750E-02	3.750E-03
	Volwater Sbgrp, Postmasburg Grp		3.750E-02	3.750E-03
	Dykes, weathered perimeter		5.000E-01	5.000E-02
	Dykes, matrix		2.500E-02	2.500E-03

3.3.4 Aquifer recharge

Recharge is defined as the process by which water is added to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation. Any variation in groundwater recharge will depend on the permeability of the strata and the degree of development on site. Based on the historical investigations, it was estimated that the rainfall recharge figure is likely to be in the order of 2.7 –5.0% of MAP.

Based on Vegter (1995) the recharge estimated groundwater recharge for the study area is in the order of 2.7% (8 mm/annum) of MAP (see **Figure 3.h**). The chloride mass-balance method was used to determine how the recharge values obtained agree with those from the previous investigations (**Figure 3.i**)

- where R = (P Clp +D) / Clw:
- P = precipitation (mm/a) = 293mm
- Clp = chloride in rain (mg/l) = 0.78 (Kuruman area)
- D = dry chloride deposition (mg/m2/a) = 0.0598
- Clw = Cl in groundwater (based on unimpacted boreholes) = 30 mg/ℓ

Although some fluctuations are seen, the chloride levels at most, presumed unimpacted, localities ranged between 15 mg/ℓ and 60 mg/ℓ, therefore 30 mg/ℓ has been used in the calculation of recharge.

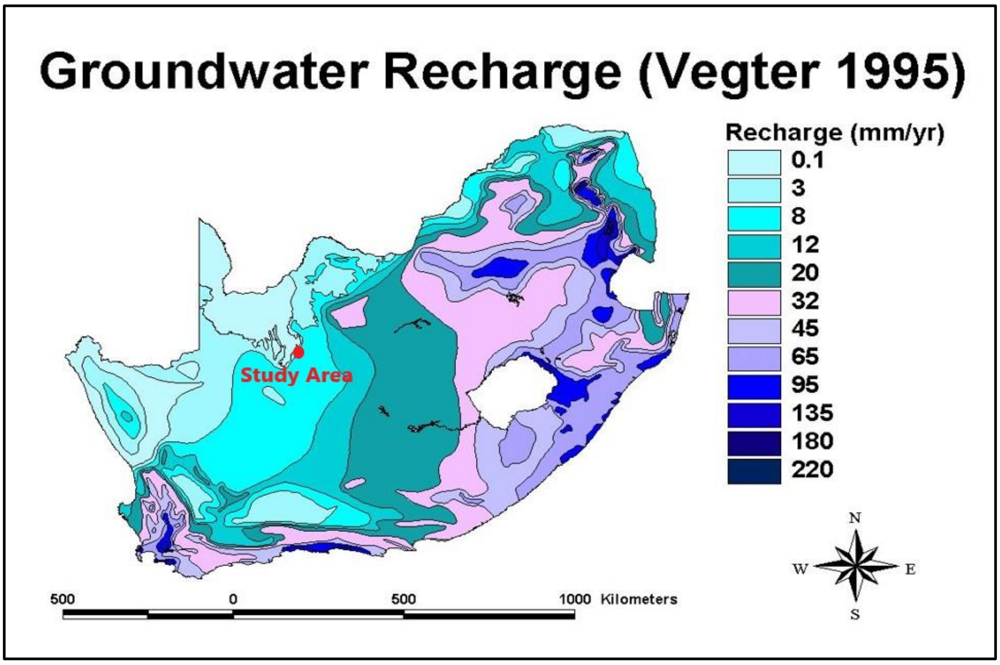
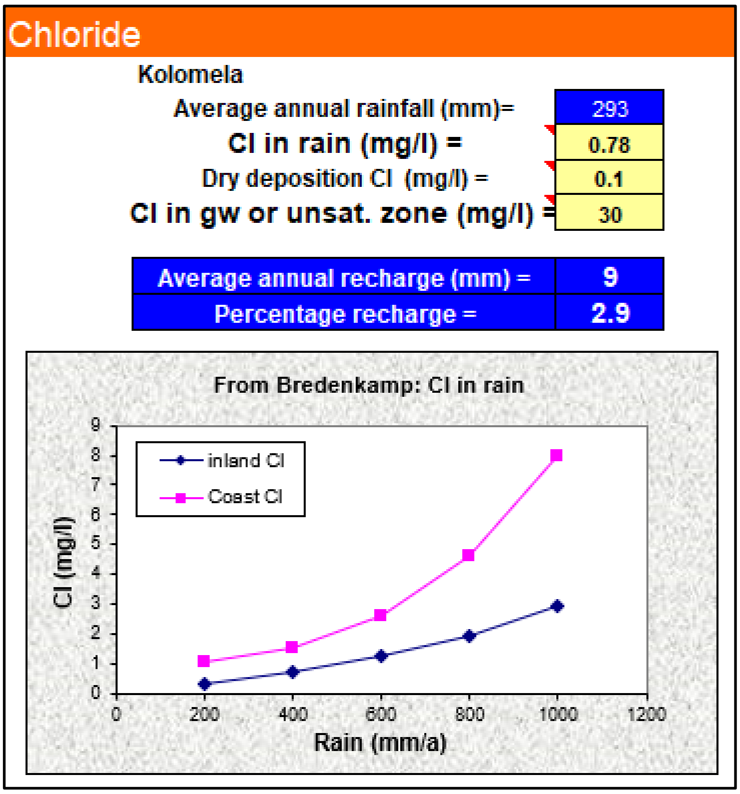


Figure 3.h: Vegter recharge map of South Africa (1995)


Chloride

Kolomela

Average annual rainfall (mm)= 293

Cl in rain (mg/l) = 0.78

Dry deposition Cl (mg/l) = 0.1

Cl in gw or unsat. zone (mg/l) = 30

Average annual recharge (mm) = 9

Percentage recharge = 2.9

Figure 3.i: Chloride method recharge calculations

3.3.5 Groundwater vs surface water interaction

The main findings from the previous investigation with reference to the groundwater vs surface water interaction and the characteristics of the shallow (perched) aquifer system are summarised below:

Jones & Wagener (2015) and Scientific Aquatic Services (2015), Pan Assessment

- Wetlands in the study area are defined as being wetland temporary zones in which the soil is saturated for a short period;
- Hardpan calcrete which underlie much of the study area has a very low permeability and as such, a very shallow, perched (temporary) aquifer may be present. This aquifer only receives water after rainfall events and is mostly sustained by surface water, therefore unlikely to be impacted by mining;
- The functionality of pan is based on the proportion of each that it receives annually and seasonally.

Taking the above into consideration as well as our understanding of the site hydrogeological conditions, it must be emphasised that the local rivers do not flow regularly and is probably disconnected from the regional aquifer within the vicinity of the mine. No water losses occur from the non-perennial rivers into the model domain, but groundwater on either side of the river might discharge into it as a function of the calculated gradients.

With reference to the map in **Figure 3.j**, the groundwater component of baseflow in the Kalahari basin and a large part of the arid to semi-arid western part of South Africa is negligible. The Groenwaterspruit and other minor drainages are seen as a losing river i.e. ephemeral system with groundwater flowing from the river to the underlying aquifer and not vice-versa.

Groundwater seepage and pit inflows may still occur from the intergranular aquifer during the rainy season as a result of the recharge of rainwater that equate to river flow.

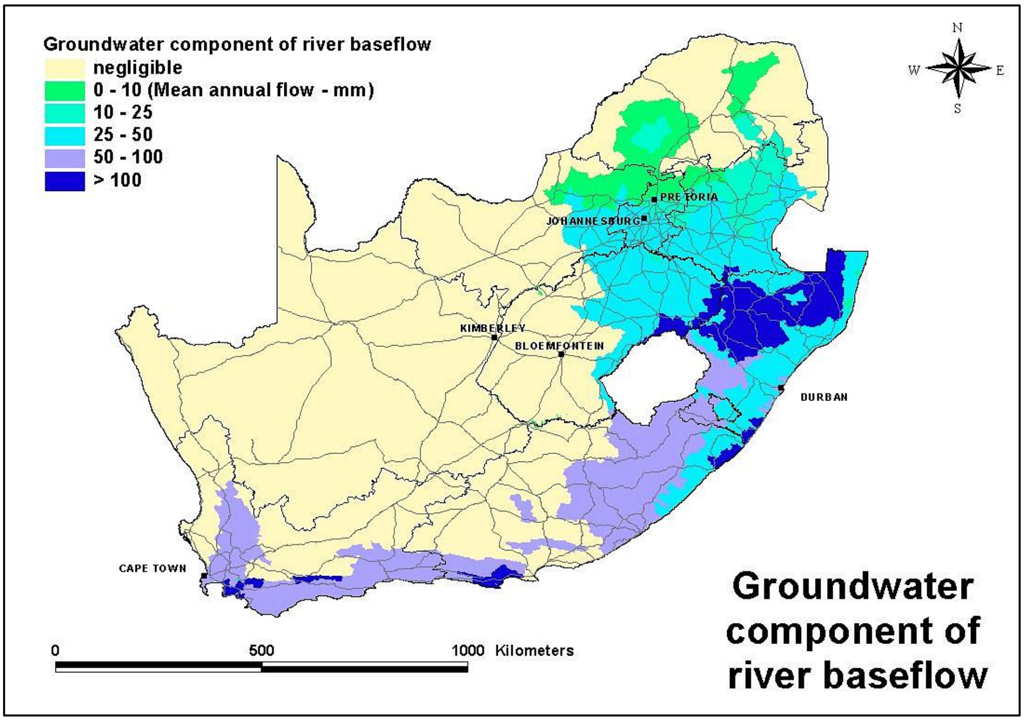


Figure 3.j: Groundwater contribution to baseflow (DWAF, 2006)

4. AQUIFER CLASSIFICATION AND VULNERABILITY

4.1 Classification system

Based on the above assessment, the vulnerability of the aquifers and required protection is addressed.

The aquifer classification system used to classify the aquifers is the National Aquifer Classification System of Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications, such as a vulnerability or usage classification. Parsons suggested that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues. He also suggested that some level of flexibility should be incorporated when using such a classification system.

The South African Aquifer System Management Classification is presented by five major classes:

- Sole Source Aquifer System;
- Major Aquifer System;
- Minor Aquifer System;
- Non-Aquifer System; and
- Special Aquifer System.

Parson’s classification system together with the revised version produced by the Department of Water Affairs and Forestry (DWAF) (now known as the DWS) in 1998 is shown in **Table 4.a.**

Table 4.a: Aquifer classification system (Parsons, 1995)

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Min Requirements (1998)
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 reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (<150 mS/m).	High yielding aquifer (5.0-20 L/s) of acceptable water quality.
Minor Aquifer	These can be fractured or potentially fractured rocks, which do not have a high primary permeability or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying baseflow for rivers.	Moderately yielding aquifer (1.0-5.0 L/s) of acceptable quality or high yielding aquifer (5.0-20 L/s) of poor quality water.
Non-Aquifer	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 need to be considered when assessing the risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1.0 L/s) of good quality water or moderately yielding aquifer (1.0-5.0 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

Based on the aquifer extents and yielding potential of the aquifers the shallow, unconfined (upper) aquifer is regarded as a **minor aquifer system** as well as non-aquifer systems where yield is negligible. Regionally, the lower, fractured aquifer is predominantly regarded as a **minor aquifer system. However, due its exploitation potential the Kolomela dolomitic aquifer is regarded as a major aquifer system.** Generally the groundwater yield vary in places as hydrogeological conditions are variable across the study area.

4.2 Groundwater Vulnerability

An additional variable classification is needed for sound decision making and therefore, the vulnerability of the aquifer to contamination is used as an additional parameter.

Vulnerability of an aquifer is defined as the sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer. Aquifer vulnerability indicates whether the physical and biochemical characteristics of the subsurface prevent or favour the transport of pollutants in and into aquifers. It does not take into account the actual pollutant loading in an area. An area without polluting activities may therefore be very vulnerable to pollution, if for instance the water table is close to the surface and the soil and subsoil is very permeable. Likewise, areas with polluting activities may have low or moderate vulnerability to pollution, if the geological and hydrological settings prevent migration of pollutants. Potentially polluting activities should of course be located in areas with low vulnerability, while areas with high vulnerability should have a higher protection level against pollution.

The vulnerability of an aquifer is to a large extent controlled by the water flow velocity, which again is controlled by the permeability (“hydraulic conductivity”) of the unsaturated and saturated zones, the depth to the water table and the groundwater recharge.

The DRASTIC method is commonly used to assess the aquifer vulnerability, with the following factors having an effect on the vulnerability of the aquifer:

- **_D_**_epth to Groundwater:_ Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- **_R_**_echarge:_ The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- **_A_**_quifer media:_ The rock matrices and fractures which serve as water bearing units.
- **_S_**_oil media:_ The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- **_T_**_opography:_ indicates whether pollutants will run-off or remain on the surface allowing for infiltration to groundwater to occur.
- **_I_**_mpacts of the vadose zone:_ The part of the geological profile beneath the earth’s surface and above the first principal water bearing aquifer. The vadose zone can retard the progress of contamination.
- *Hydraulic* **_C_**_onductivity:_ Describes the ease with which water (and pollutants suspended in water) can move through pore spaces or fractures.

Different ratings are assigned to each of the above factors and then summed together with respective constant weights to obtain a numerical value to quantify the vulnerability:

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

Where D,R,A,S,T,I and C are the parameters, r is the rating value, and w the constant weight assigned to each parameter (Lynch *et al.*, 1997).

The concept of DRASTIC in vulnerability assessments is based on:

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

The higher the DRASTIC index, the greater the vulnerability and possibility of the aquifer to become polluted.

The scores associated with the vulnerability of South African aquifers are shown in **Table 4.b.**

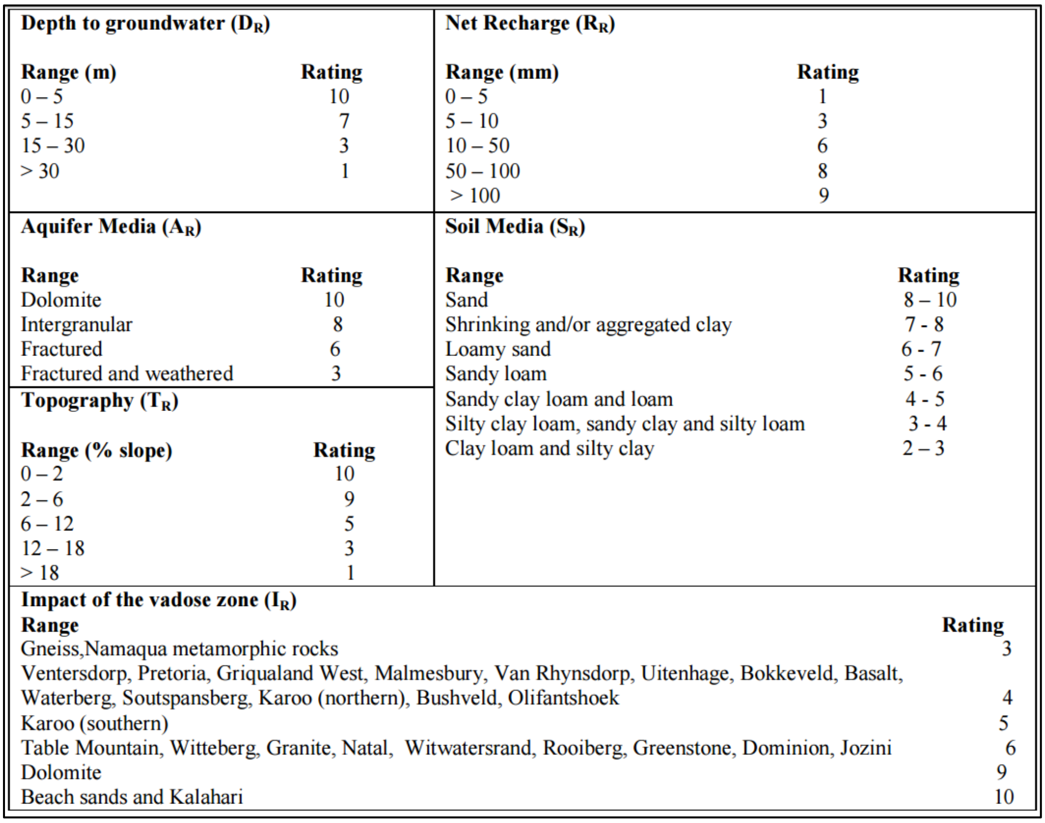
Table 4.b: South African National Groundwater Vulnerability to Pollution (Lynch *et al,* 1997)

Score	Vulnerability
50-87	Least Susceptible
87-109	Moderately Susceptible

109-184	Most Susceptible

The weighting of each parameter used in the DRASTIC assessment remains constant, whereas the ratings assigned to each groundwater vulnerability parameter is indicated in **Table 4.c.**

Table 4.c: 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

From the table above it should be noted that the ratings for Kolomela Mine were undertaken based on data gathered from previous studies. The corresponding weights to each of these parameters are detailed below:

Parameter	***Weight***
Depth to groundwater (D_w)	5
Recharge (R_w)	3
Aquifer media (A_w)	4
Soil media (S_w)	2
Topography (T_w)	1
Impact of vadose zone (I_w)	5
Hydraulic Conductivity (C_w)	3

A summary of the rating and weighting values and final index values for the aquifers present in the study area are illustrated in **Table 4.d** (shallow, unconfined aquifer) and **Table 4.e** (deeper, fractured aquifer). The dolomitic aquifers have also been rated separately from the fractured aquifers (**Table 4.f).**

Table 4.d: Rating and weighting values used in the DRASTIC intrinsic vulnerability model for the shallow intergranular aquifer

Factor	Range/Type	Weight	Rating	Total
D	5 – 15m	5	7	35
R	10 - 50mm	3	6	18
A	Intergranular	4	8	32
S	Sand (and clay)	2	8	16
T	2 - 6% slope	1	9	9
I	Kalahari	5	10	50
C	Intergranular - high	3	8	24
DRASTIC SCORE = 184				

Table 4.e: Rating and weighting values used in the DRASTIC intrinsic vulnerability model for the fractured aquifer

Factor	Range/Type	Weight	Rating	Total
D	>30m	5	1	5
R	0 - 5mm	3	1	3
A	Fractured	4	6	24
S	Clay loam, silty clay	2	3	6
T	2-6% slope	1	9	9
I	Griqualand West	5	4	20
C	Fractured - low	3	6	18
DRASTIC SCORE = 85				

Table 4.f: Rating and weighting values used in the DRASTIC intrinsic vulnerability model for the dolomitic aquifer

Factor	Range/Type	Weight	Rating	Total
D	>30m	5	1	5
R	10 - 50mm	3	6	18
A	Dolomite	4	10	40
S	Clay loam, silty clay	2	3	6
T	2-6% slope	1	9	9
I	Dolomite	5	9	45
C	High	3	8	24
DRASTIC SCORE = 147				

Based on the calculations made above, the intergranular unconfined aquifer has a DRASTIC score of 184, as a result of the higher porosities above the calcretes as well as the shallow groundwater levels (vulnerable to contamination). As such it is deemed as most susceptible to contamination in times that it yields groundwater. The fractured aquifer has a DRASTIC score of 85 and is therefore least susceptible to contamination, mostly as a result of the depth to groundwater level as well as the tight fractured rock formations. The dolomitic aquifers have drastic ratings of 147, thus also most susceptible according to the classification rating system.

4.3 Aquifer Protection Classification

In order to determine the appropriate level of groundwater protection that is required, a combination of the aquifer classification and aquifer vulnerability is used (**Table 4.g).** A weighting and rating approach is then used to decide on the appropriate level of groundwater protection required **(Table 4.h)**.

Table 4.g: Ratings for the aquifer quality management classification system.

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

Table 4.h: Appropriate level of groundwater protection required

GQM Index	Level of Protection
<1	Limited Protection
1 – 3	Low Level Protection
3 – 6	Medium Level Protection
6 – 10	High Level Protection
>10	Strictly Non-degradation

After rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a Groundwater Quality Management (GQM) index. Based on the above, the aquifers at Kolomela operations are classified in **Table 4.i** below.

The above classification indicates that the shallow and deep aquifers at Kolomela Mine classify as minor-aquifer systems as a result of their low exploitable potential. However, with it's high exploitation potential, the dolomitic aquifer at Kolomela is classed as a major aquifer. As such, medium level protection is required for the shallow and in general for the deep aquifers. The Kolomela dolomitic aquifer is classed as being non-degradation level.

Table 4.i: Classification results

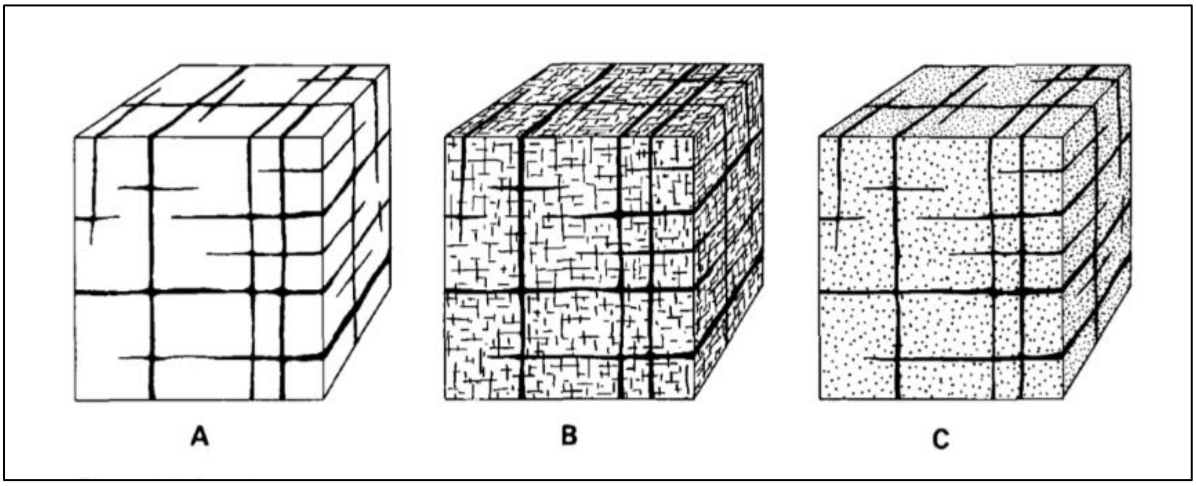
Description	Aquifer	Vulnerability	Rating	Protection
Aquifer Vulnerability				
Intergranular Aquifer	Minor-aquifer (2)	3	6	Medium
Fractured Aquifer	Minor aquifer (2)	2	4	Medium
Dolomitic Aquifer	Major aquifer (4)	3	12	Non-degradation

5. HYDROGEOLOGICAL CONCEPTUAL MODEL

5.1 Site Hydrogeological Conceptualisation

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. Data gathered during the desk study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system. The conceptual model forms the basis for the development of a numerical groundwater model, representing the hydrogeological regime of the delineated model domain. **Figure 5.a** 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 also be classified as double porosity aquifers. **Figure 5.b** depicts an west-east cross section of the study area at the end of mine life with relevant data and information included.



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

Figure 5.a: Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994)

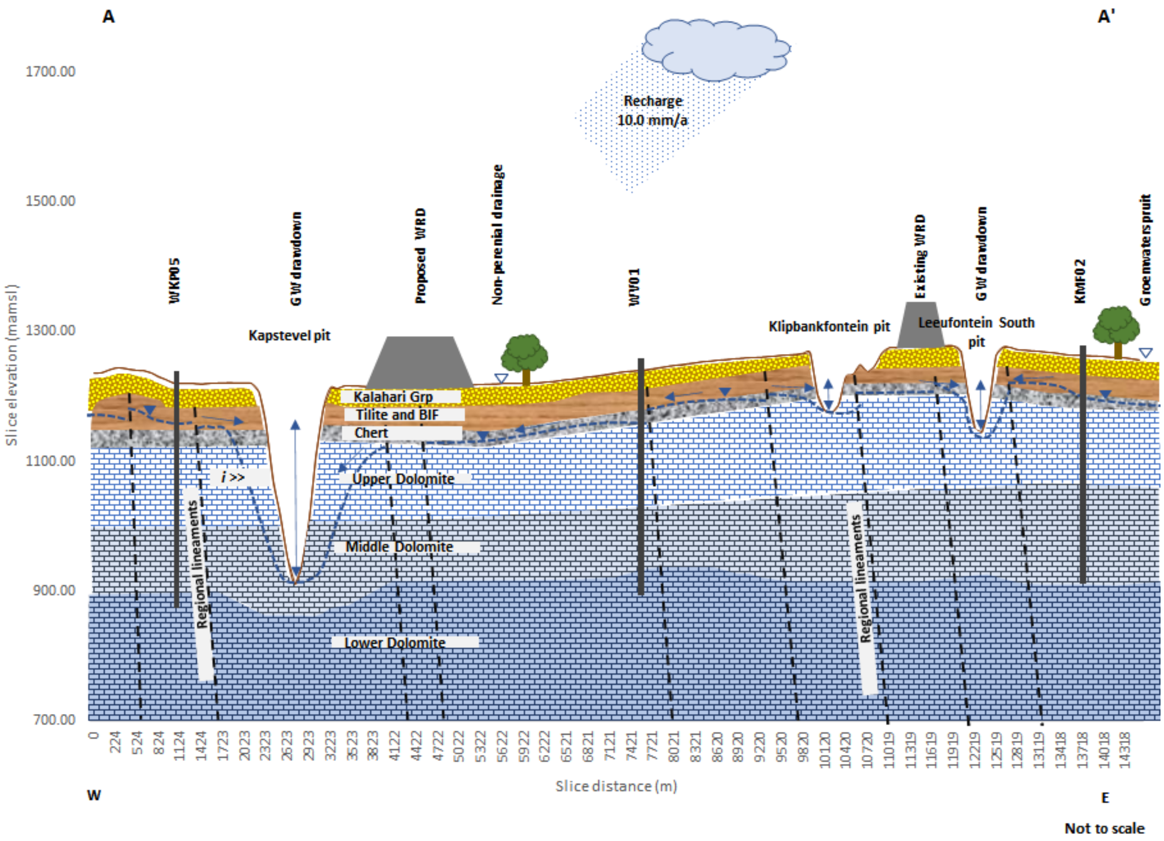


Figure 5.b: Hydrogeological west-east conceptual slice (Figure 6.b)

6. NUMERICAL GROUNDWATER FLOW AND TRANSPORT MODEL

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

6.1 Approach to modelling

The typical workflow and modelling approach employed is summarised in **Figure 6.a:**

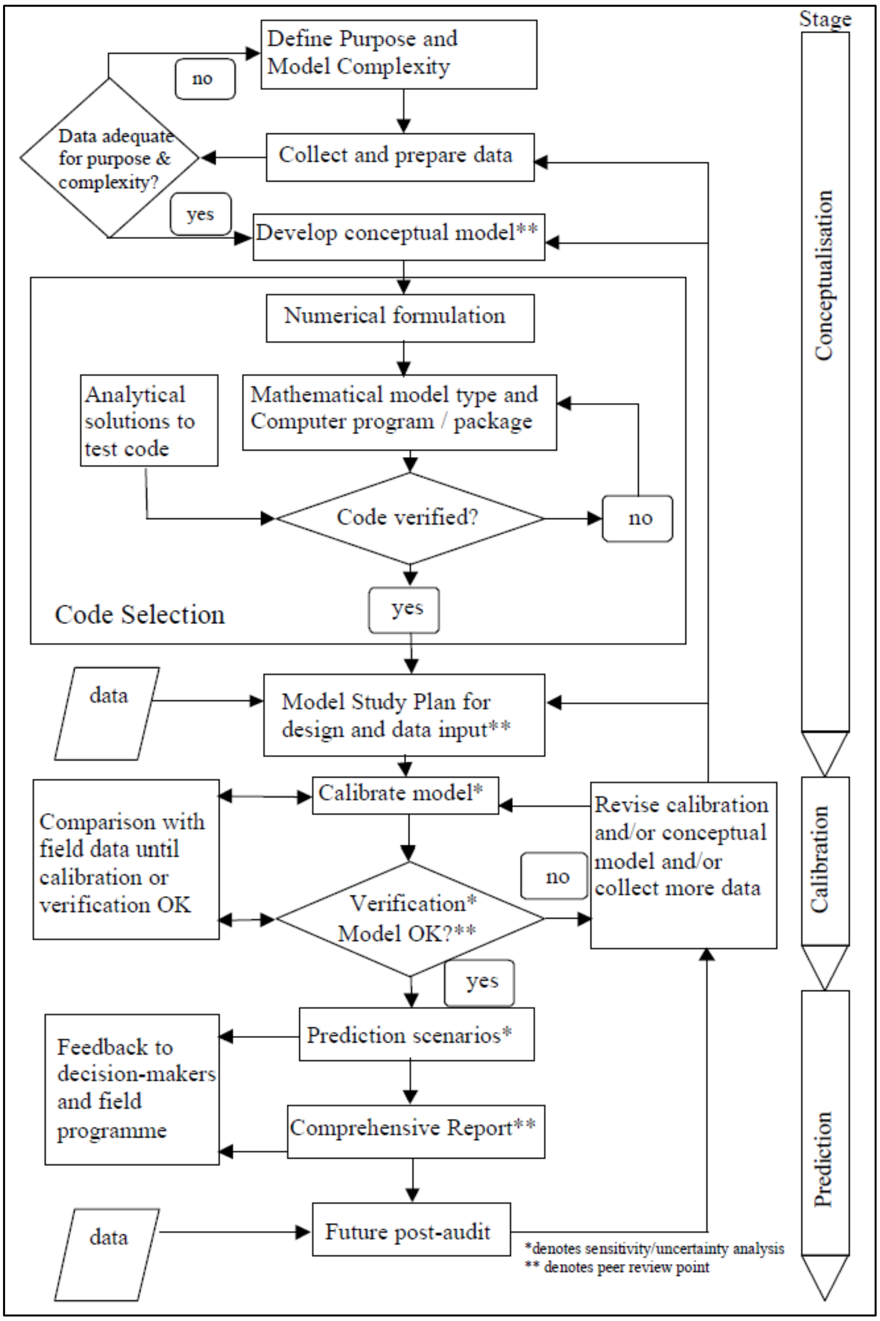


Figure 6.a: **Workflow numerical groundwater flow model development**

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 8.1**:

Equation 8.1 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).

6.2 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.

6.3 Model 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 1:1000 000 scale for geological data and a 1:500 000 scale resolution for hydrogeological information.

ii. The concept of representative elementary volumes (REV) has 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.

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

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

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

vi. 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.

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

ix. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly.

6.4 Model development

6.4.1 Model domain

A model grid was created with global origin X: -7740.87 [m] and Y: -3138912.79 [m] using triangular prism type of elements. The model has a width of 59674.0 [m], height of 53030.6 [m], depth of 784.8 [m] and spans an area of $2.06e^{+9}$ m^2 with a volume of $4.75e^{+11}m^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e. discharge zones and no-flow zones (**Figure 6.b**). **Figure 6.c** shows the model finite element mesh (FEM) construction while **Figure 6.d** depicts a respective cross section on which the hydrogeological conceptual model is based on.

6.4.2 Model construction

The model was constructed from FEM and consist of two layers i.e. three slices, 954 476 triangular prism elements per layer, a total of 1 908 952 elements for the model domain, with 478 369 nodes per slice. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 1.3%.
- Interior holes: 0.
- Obtuse angled triangles: 0.6% > 120°, 9.7% > 90°.

Figure 6.b: Model domain: Aerial extent and conceptual slices

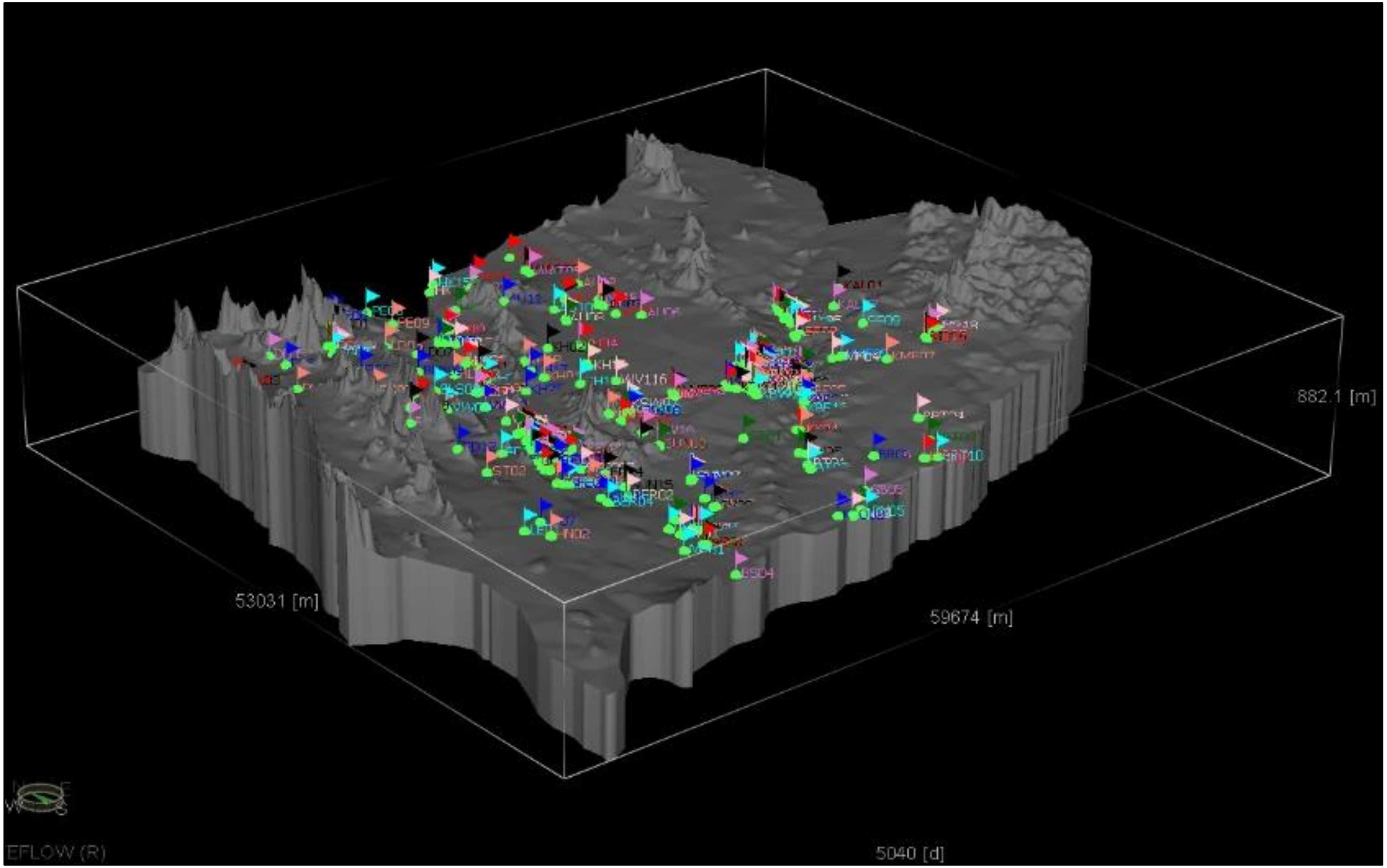


Figure 6.c: **Model domain: 3-D FEM mesh view depicting a plan-view southwest orientation**

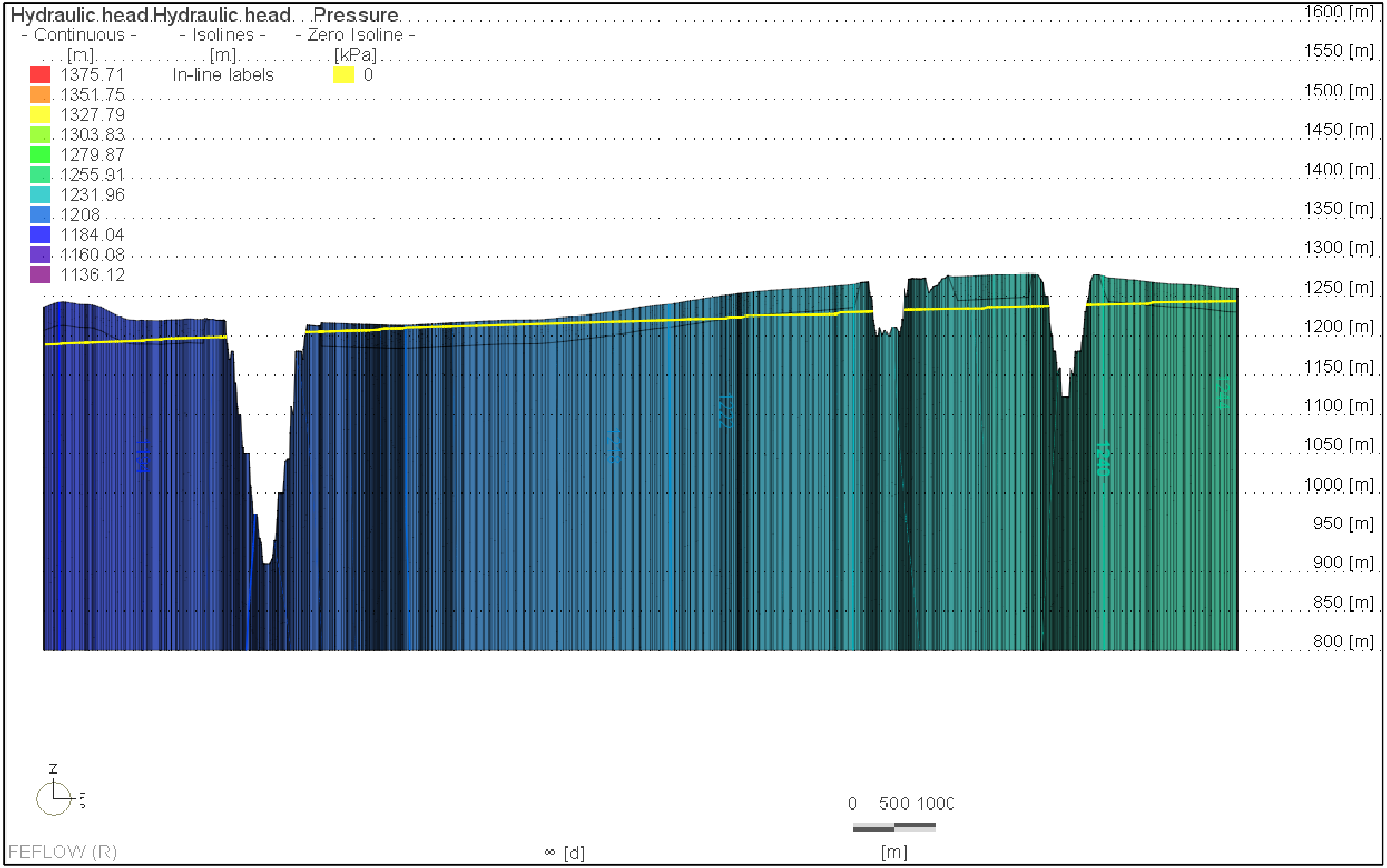


Figure 6.d: **Model domain 3-D FEM mesh view (cross sectional view A-A')**

6.4.3 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. Layer sequence and average thickness are listed below and in **Table 6.a**:

i. Layer 1: Shallow Kalahari Group consisting of quaternary deposits as well as the weathering profile calcrete layer and boulder beds, representing a double porosity aquifer, where groundwater flow occurs through the pores as well as fractures in the formations. Usually, this aquifer is most susceptible to impacts from contaminant sources (Average thickness = 30m).

ii. Layer 2: Deeper fractured aquifer hosted within the Transvaal and Olifantshoek Supergroup rocks representing a secondary porosity aquifer. The latter aquifer is totally consolidated, and porosity is restricted to fractures that have formed after consolidation of the rock (Average thickness = 300m).

Table 6.a: Numerical groundwater flow model development: Aquifer hydraulic parameters

Model	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	Kalahari Grp	40.00	1.500E+00	1.500E+00		1.00E-03	8.00E-02
	Asbestos Hills Sbgrp, Ghaap Grp		3.000E-01	3.000E-02	Outcrop and potential higher recharge zones: 15.0		
	Brulsand Sbgrp, Volop Grp		3.000E-01	3.000E-02			
	Cambell Rand Sbgrp, Ghaap Grp, Transvaal Spgrp		7.500E-01	7.500E-02			
	Gamagara Fm, Olifantshoek Spgrp		1.000E-01	1.000E-02	Remaining model catchment: 10.20		
	Hartley Fm, Olifantshoek Spgrp		7.500E-02	7.500E-03			
	Koegas Sbgrp, Ghaap Grp		1.000E+00	1.000E-01			
	Makganyene Fm, Postmasburg Grp		7.500E-01	7.500E-02			
	Matsap Sbgrp, Volop Grp		7.500E-02	7.500E-03			
	Olifantshoek Spgrp		7.500E-01	7.500E-02			
	Ongeluk Fm, Postmasburg Grp		7.500E-02	7.500E-03			
	Volwater Sbgrp, Postmasburg Grp		7.500E-01	7.500E-02			
	Dykes, weathered perimeter		1.000E+00	1.000E-01			
	Dykes, matrix		5.000E-02	5.000E-03			
Layer 02	Asbestos Hills Sbgrp, Ghaap Grp	300.00	1.500E-01	1.500E-02	0.0	1.00E-05	3.00E-02
	Brulsand Sbgrp, Volop Grp		1.500E-01	1.500E-02			
	Cambell Rand Sbgrp, Ghaap Grp, Transvaal Spgrp		1.000E-01	1.000E-02			
	Gamagara Fm, Olifantshoek Spgrp		5.000E-02	5.000E-03			
	Hartley Fm, Olifantshoek Spgrp		3.750E-02	3.750E-03			
	Koegas Sbgrp, Ghaap Grp		5.000E-01	5.000E-02			
	Makganyene Fm, Postmasburg Grp		3.750E-01	3.750E-02			
	Matsap Sbgrp, Volop Grp		3.750E-02	3.750E-03			
	Olifantshoek Spgrp		3.750E-02	3.750E-03			
	Ongeluk Fm, Postmasburg Grp		3.750E-02	3.750E-03			
	Volwater Sbgrp, Postmasburg Grp		3.750E-02	3.750E-03			
	Dykes, weathered perimeter		5.000E-01	5.000E-02			
	Dykes, matrix		2.500E-02	2.500E-03			

6.4.4 Boundary conditions

For the purposes of this model, it is assumed that the lower perimeter of the model domain i.e. lower dolomite unit has a low permeability and, no significant volume of groundwater will flow across the bottom of the model. Accordingly, this boundary is represented numerically as a "no-flow" boundary condition and was assigned as such. Topographical high perimeters (groundwater divides) were assigned as no-flow boundaries while regional drainages/rivers i.e. Groenwaterspruit, Lucasdamvlei and Skeifonteinspruit were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[1]. **Figure 6.g** indicates different boundary conditions assigned within the model domain.

6.5 Model hydraulic properties

The following sections provide a brief overview of the model hydraulic parameters assigned as part of the model development and calibration phase.

6.5.1 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[2]. Hydraulic conductivity values range from 5.0e^{-03}m/d for dolerite/dyke matrices, to >1.0m/d for the shallow, quaternary deposits as well as regional geological lineament contact zones. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in **Figure 6.e** and **Figure 6.h.** A ratio of 1:1 for hydraulic conductivity (K) in x and y directions have been assigned, with a 1:10 ratio in the z direction i.e. anisotropic aquifer. **Table 6.a** provides a summary of parameter values per layer.

6.5.2 Sources and sinks

The primary source to groundwater is through recharge. Two recharge zones were assigned based on different topographical zones within the model domain. An approximation of recharge for lower lying zones throughout the greater study area is estimated at ~10.0 mm (2.5% of MAP) while higher elevated and potential higher recharge zone(s) have been assigned a 15.0mm (~3.0% of MAP) value as depicted in **Figure 6.f**. Sinks in the model domain include groundwater abstraction from privately owned and community boreholes as well as existing pit dewatering.

6.5.3 Storativity and specific storage

Specific storage values were assigned per layer (Layer01 = 1.00e^{-3}, Layer02 = 1.00e^{-5}) as listed in **Table 6.a.**

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[1] It should be noted that groundwater contribution to baseflow within the study is insignificant and the system is considered as a "losing/effluent stream" or Ephemeral system.

[2] 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.

6.5.4 Porosity

A porosity value of 8.0% was assigned for the matrix of the quaternary deposits and calcrete zones whereas the fractured formations of layer 2 was assigned a porosity value of 3.0% as listed in **Table 6.a.**

6.5.5 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.

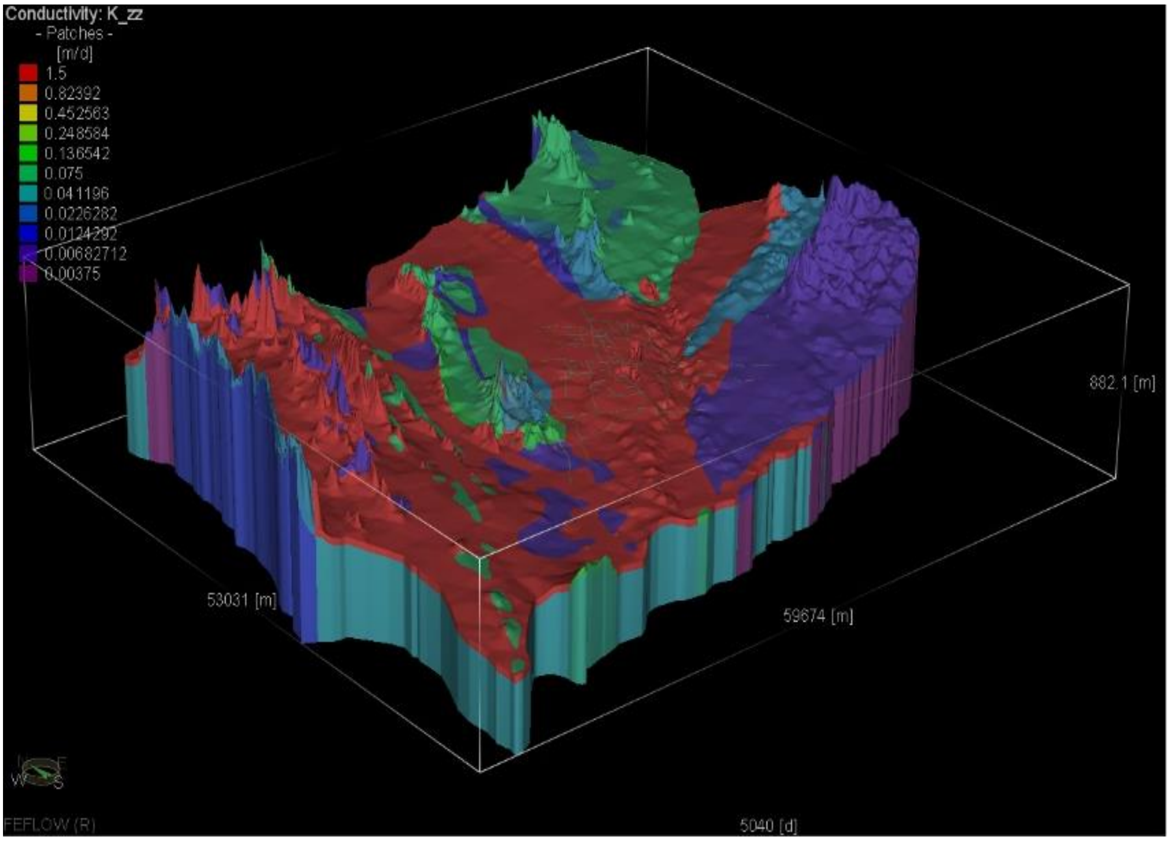

Figure 6.e: Spatial distribution of hydraulic conductivity values per hydrostratigraphical unit

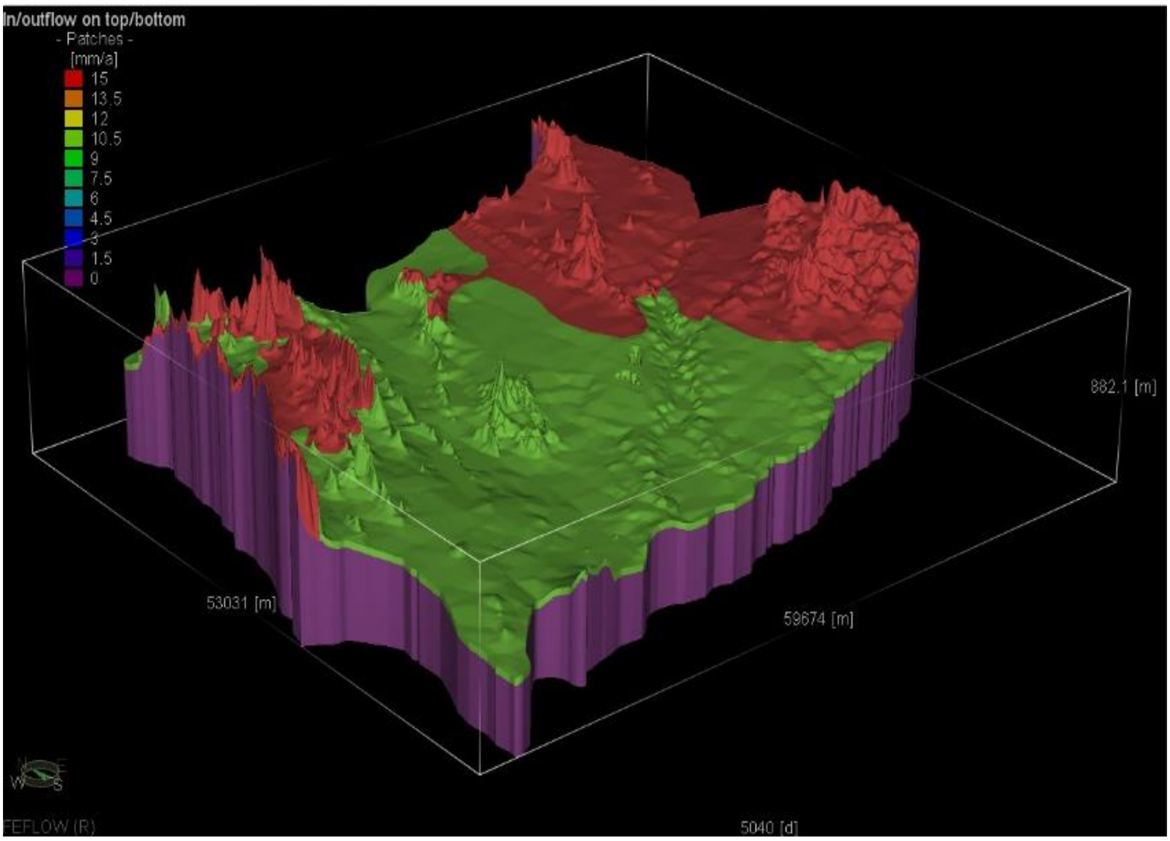

Figure 6.f: Spatial distribution of recharge values per hydrostratigraphical unit

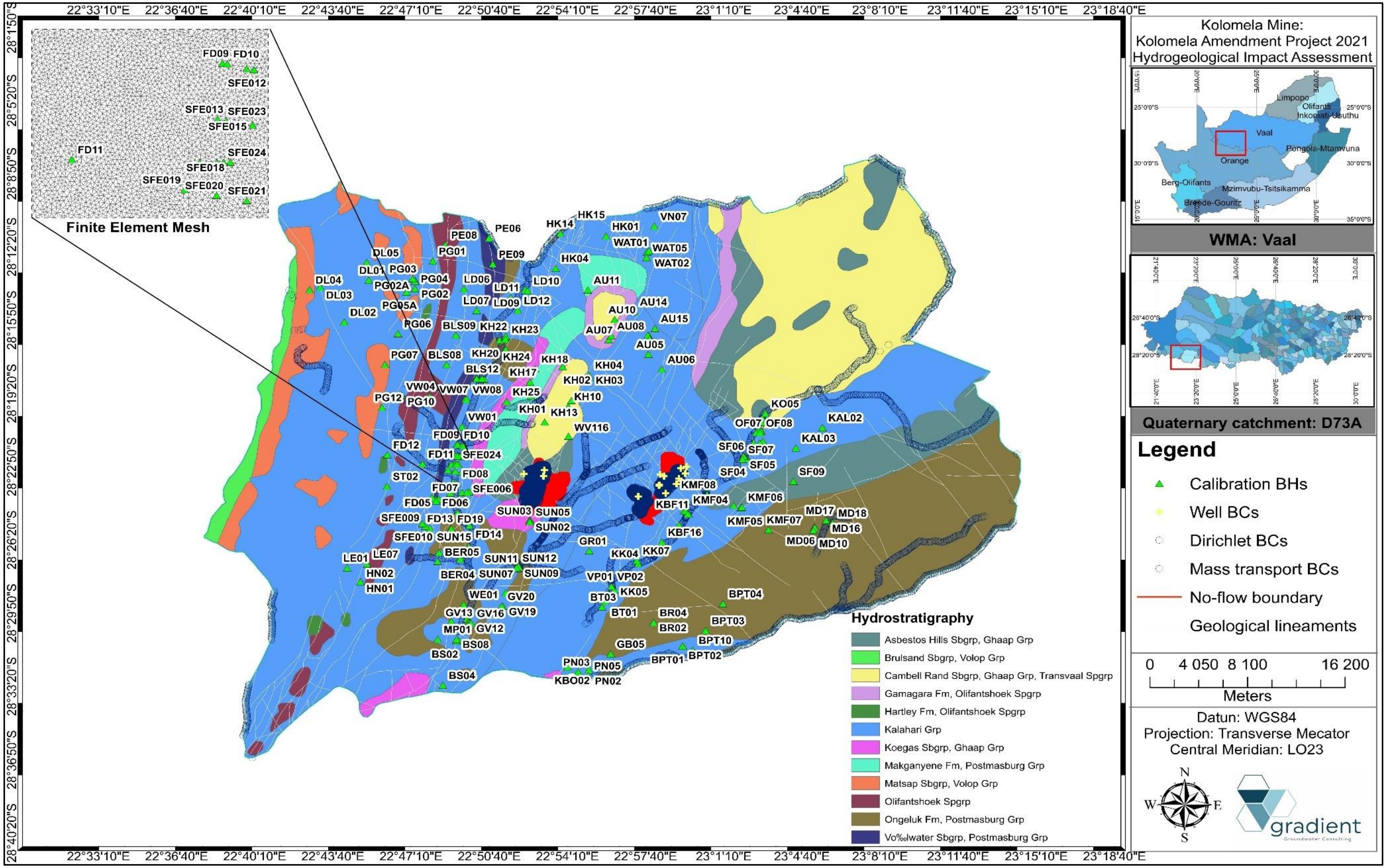

Figure 6.g: Numerical groundwater flow model development: Hydrostratigraphic units and model boundary conditions

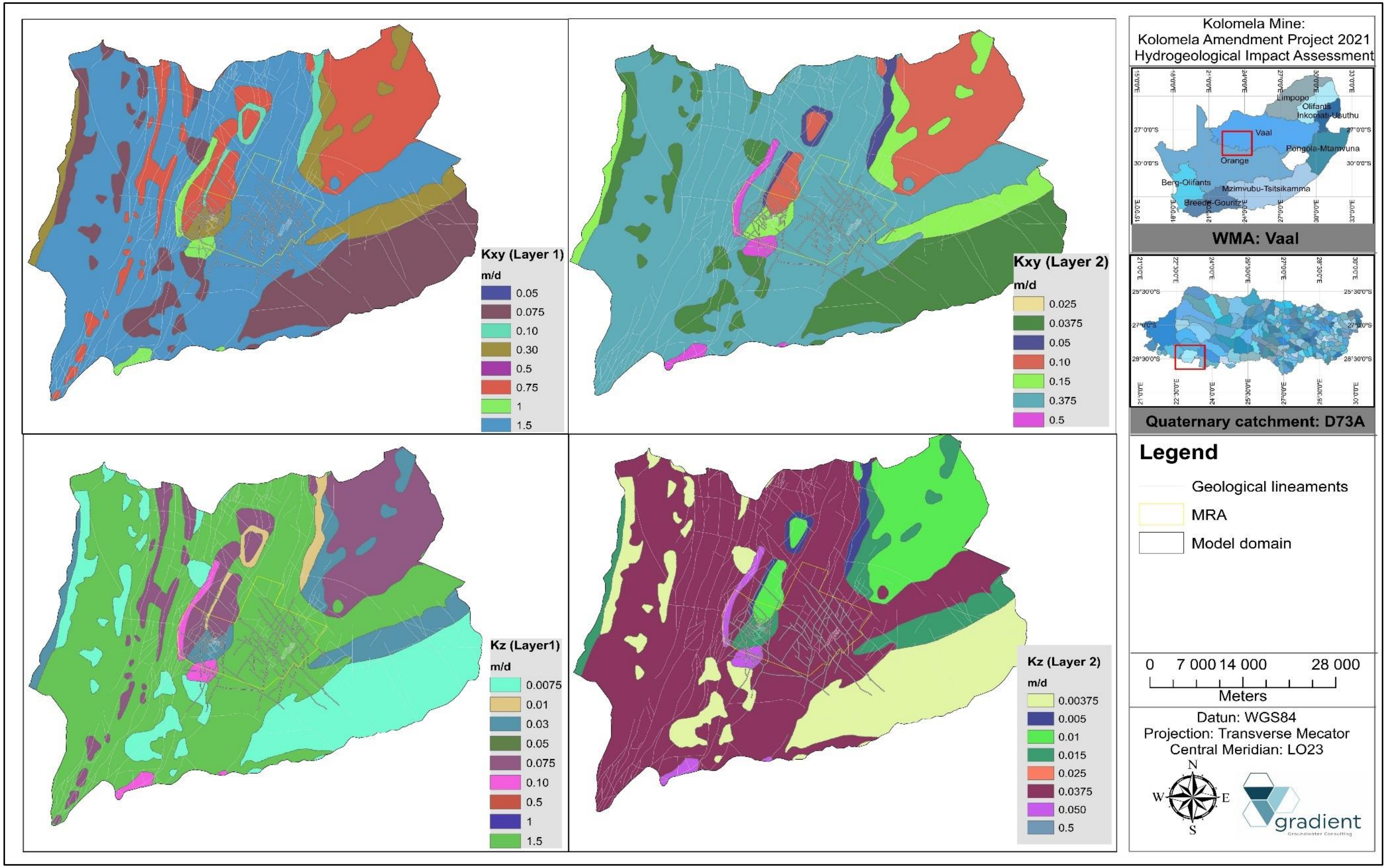

Figure 6.h: **Numerical groundwater flow model development: Aquifer hydraulic properties**

6.6 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 6.a: 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]

6.6.1 Model simulation scenarios

Various management scenarios were modelled for the purposes of planning and decision making with stress periods listed in **Table 6.b**:

i. **Scenario 01a:** Steady state calibration and sensitivity analysis (∞).
ii. **Scenario 01b:** Transient calibration.
iii. **Scenario 02:** Base-case scenario pre-mining water balance.
iv. **Scenario 03:** Operational phase pit dewatering and groundwater capture zone.
v. **Scenario 04:** Post-closure opencast pits re-watering and hydraulic head recovery.
vi. **Scenario 05:** Operational phase pollution plume migration with no mitigation measures implemented.
vii. **Scenario 06:** Post-closure pollution plume migration with no mitigation measures implemented.
viii. **Scenario 07 (mitigation and management):** Evaluating the effect of aquifer artificial recharge by a series of water injection boreholes.

Table 6.b: Summary of model stress-periods

Stress period	Description
Year 01 – Year 14	LOM operational opencast (2022 – 2035)
Year 15 – Year 65	50-years post closure
Year 66 – Year 116	100-years post closure

6.7 Model calibration

6.7.1 Scenario 1a: Steady state calibration (∞)

A steady state groundwater flow model was developed to simulate equilibrium 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 as summarised in **Table 6.c**. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.97 was obtained (refer to **Figure 6.i**, Figure **6.j** and **Figure 6.k**) while **Figure 6.l** indicate calibration error margin per borehole observation locality while **Figure 6.m** depicts steady state hydraulic head contours and groundwater flow directions. 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): -7.03 m.
ii. Mean Absolute Error (MAE): 10.88 m.
iii. Normalised Root Mean Square Deviation (NRMSD): 7.03% i.e. represents the deviation between observed and calibration water levels across the model domain.

Table 6.c: Steady State Model Calibration – Statistical Summary

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
AU01	1297.00	17.25	1279.75	1273.04	6.71	6.71	45.04
AU02	1297.00	16.62	1280.38	1272.86	7.52	7.52	56.49
AU03	1298.00	12.25	1285.75	1272.43	13.32	13.32	177.45
AU05	1295.00	15.94	1279.06	1267.86	11.20	11.20	125.44
AU06	1302.00	46.57	1255.43	1267.25	-11.82	11.82	139.69
AU07	1282.00	41.75	1240.25	1259.67	-19.42	19.42	376.98
AU08	1283.00	43.36	1239.64	1261.32	-21.68	21.68	470.02
AU10	1288.00	48.88	1239.12	1265.26	-26.14	26.14	683.20
AU12	1304.00	30.58	1273.42	1284.21	-10.79	10.79	116.42
AU14	1297.00	13.08	1283.92	1273.84	10.08	10.08	101.63
AU14A	1297.00	13.15	1283.85	1273.84	10.01	10.01	100.28
AU15	1301.00	11.28	1289.72	1276.63	13.09	13.09	171.37
BER01	1175.00	10.20	1164.80	1161.01	3.79	3.79	14.37
BER02	1175.00	10.31	1164.69	1160.72	3.97	3.97	15.75
BER04	1182.00	17.43	1164.57	1171.74	-7.16	7.16	51.34
BER05	1183.00	18.18	1164.82	1169.30	-4.48	4.48	20.08
BLS02	1217.00	7.78	1209.22	1203.18	6.04	6.04	36.49
BLS03	1217.00	7.87	1209.13	1203.44	5.70	5.70	32.43
BLS04	1219.00	9.14	1209.86	1201.57	8.29	8.29	68.77

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
BLS05	1221.00	11.11	1209.89	1204.93	4.97	4.97	24.65
BLS06	1221.00	11.40	1209.60	1204.89	4.71	4.71	22.18
BLS07	1221.00	11.13	1209.87	1204.51	5.36	5.36	28.75
BLS08	1238.00	38.06	1199.94	1220.27	-20.33	20.33	413.15
BLS09	1254.00	36.20	1217.80	1228.56	-10.76	10.76	115.78
BLS10	1223.00	11.07	1211.93	1219.34	-7.40	7.40	54.83
BLS12	1218.00	9.16	1208.84	1201.77	7.07	7.07	49.98
BPT01	1207.00	13.30	1193.70	1196.16	-2.46	2.46	6.07
BPT02	1208.00	13.98	1194.02	1196.11	-2.09	2.09	4.38
BPT03	1225.00	13.19	1211.81	1210.83	0.98	0.98	0.96
BPT04	1246.00	8.27	1237.73	1239.63	-1.90	1.90	3.61
BPT10	1212.00	13.50	1198.50	1197.58	0.92	0.92	0.85
BR02	1199.78	9.35	1190.43	1201.99	-11.56	11.56	133.61
BR04	1199.78	9.45	1190.33	1202.05	-11.72	11.72	137.43
BS01	1139.98	6.68	1133.30	1153.60	-20.30	20.30	411.93
BS02	1140.00	3.18	1136.82	1153.66	-16.84	16.84	283.45
BS08	1142.00	4.27	1137.73	1152.51	-14.78	14.78	218.42
BT01	1184.00	13.29	1170.71	1181.03	-10.32	10.32	106.56
BT03	1182.00	13.03	1168.97	1179.72	-10.75	10.75	115.61
DL02	1307.00	71.95	1235.05	1256.60	-21.55	21.55	464.57
DL04	1329.00	58.10	1270.90	1265.74	5.16	5.16	26.59
FD01	1182.00	13.45	1168.55	1187.86	-19.31	19.31	372.76
FD02	1181.00	12.58	1168.42	1187.14	-18.72	18.72	350.40
FD03	1180.00	12.49	1167.51	1187.05	-19.54	19.54	381.77
FD04	1180.00	12.42	1167.58	1187.01	-19.44	19.44	377.80
FD05	1181.00	14.26	1166.74	1187.75	-21.01	21.01	441.25
FD06	1181.00	13.78	1167.22	1187.75	-20.53	20.53	421.52
FD07	1189.00	19.51	1169.49	1189.43	-19.94	19.94	397.44
FD08	1179.49	12.97	1166.52	1180.51	-13.98	13.98	195.55
FD09	1191.00	8.26	1182.74	1192.32	-9.58	9.58	91.74
FD10	1190.98	7.76	1183.22	1192.28	-9.06	9.06	82.05
FD11	1196.03	18.30	1177.73	1195.77	-18.04	18.04	325.48
FD12	1267.00	84.67	1182.33	1208.82	-26.49	26.49	701.72
FD13	1176.34	12.16	1164.18	1179.78	-15.59	15.59	243.08
FD14	1166.00	10.80	1155.20	1170.45	-15.25	15.25	232.56
FD19	1172.00	12.76	1159.24	1179.24	-19.99	19.99	399.80
GB05	1172.00	14.35	1157.65	1173.78	-16.13	16.13	260.05
GR01	1227.00	31.44	1195.56	1189.24	6.32	6.32	39.93
GV01	1154.00	8.13	1145.87	1147.40	-1.53	1.53	2.35
GV03	1156.74	12.10	1144.64	1153.46	-8.81	8.81	77.70
GV05	1144.00	7.26	1136.74	1145.84	-9.10	9.10	82.79
GV07	1144.00	7.20	1136.80	1145.70	-8.90	8.90	79.17
GV08	1144.00	6.73	1137.27	1146.10	-8.83	8.83	78.02
GV09	1145.00	7.11	1137.89	1146.34	-8.45	8.45	71.37

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
GV10	1144.00	7.16	1136.84	1146.40	-9.56	9.56	91.47
GV12	1144.00	6.48	1137.52	1146.77	-9.25	9.25	85.49
GV13	1144.00	6.28	1137.72	1146.81	-9.09	9.09	82.66
GV16	1143.00	6.16	1136.84	1146.91	-10.07	10.07	101.47
GV18	1163.00	14.66	1148.34	1160.53	-12.19	12.19	148.57
GV19	1159.05	14.67	1144.38	1162.17	-17.79	17.79	316.45
GV20	1157.27	13.53	1143.74	1161.71	-17.97	17.97	322.96
HK01	1271.00	30.75	1240.25	1269.73	-29.48	29.48	869.25
HK03	1310.00	62.70	1247.30	1259.47	-12.17	12.17	148.18
HK04	1249.61	18.76	1230.85	1247.89	-17.03	17.03	290.12
HK14	1253.35	13.53	1239.82	1256.29	-16.47	16.47	271.29
HK15	1257.42	15.60	1241.82	1258.52	-16.71	16.71	279.12
HN01	1210.00	21.74	1188.26	1194.85	-6.59	6.59	43.38
HN02	1210.00	21.19	1188.81	1194.82	-6.01	6.01	36.10
KAL01	1337.00	23.41	1313.59	1314.90	-1.31	1.31	1.72
KAL02	1337.00	28.59	1308.41	1314.76	-6.35	6.35	40.30
KAL03	1327.00	17.83	1309.17	1298.23	10.94	10.94	119.77
KAL04	1290.81	2.05	1288.76	1280.17	8.59	8.59	73.82
KAL05	1287.00	9.48	1277.52	1277.98	-0.46	0.46	0.21
KAL06	1276.00	8.85	1267.15	1274.63	-7.48	7.48	55.91
KBF01	1226.94	22.74	1204.20	1209.70	-5.50	5.50	30.24
KBF05	1232.00	17.10	1214.90	1211.25	3.66	3.66	13.36
KBF06	1241.00	7.26	1233.74	1211.52	22.22	22.22	493.91
KBF09	1238.37	13.48	1224.89	1213.55	11.34	11.34	128.55
KBF10	1235.00	13.49	1221.51	1217.14	4.38	4.38	19.14
KBF11	1234.00	12.45	1221.55	1216.85	4.70	4.70	22.13
KBF15	1226.94	19.52	1207.42	1209.99	-2.56	2.56	6.57
KBF16	1223.00	27.79	1195.21	1207.16	-11.95	11.95	142.78
KH01	1239.98	18.01	1221.97	1221.35	0.62	0.62	0.39
KH02	1269.00	31.20	1237.80	1239.89	-2.09	2.09	4.36
KH03	1268.00	32.54	1235.46	1244.89	-9.43	9.43	88.91
KH04	1268.00	33.67	1234.33	1245.13	-10.80	10.80	116.64
KH05	1265.00	30.57	1234.43	1233.04	1.39	1.39	1.94
KH10	1265.00	15.99	1249.01	1230.39	18.62	18.62	346.56
KH13	1254.00	10.98	1243.02	1219.20	23.82	23.82	567.58
KH17	1240.49	22.50	1217.99	1225.43	-7.44	7.44	55.38
KH18	1244.00	19.30	1224.70	1231.59	-6.88	6.88	47.40
KH19	1216.75	9.55	1207.20	1220.59	-13.38	13.38	179.08
KH20	1213.00	6.28	1206.72	1220.58	-13.86	13.86	192.07
KH21	1217.00	8.52	1208.48	1224.66	-16.18	16.18	261.86
KH22	1220.00	8.77	1211.23	1224.72	-13.48	13.48	181.85
KH23	1220.00	8.79	1211.21	1224.56	-13.35	13.35	178.12
KH24	1209.53	9.08	1200.45	1210.29	-9.84	9.84	96.88
KH25	1220.00	12.17	1207.83	1211.25	-3.42	3.42	11.70

Calibration BH	**Topographical Elevation (mamsl)**	**Water Level (mbgl)**	**Measured head elevation (mamsl)**	**Simulated head elevation (mamsl)**	**Mean Error (m)**	**Mean Absolute Error (m)**	**Root Mean Square Error (m)**
KK04	1205.00	12.59	1192.41	1196.79	-4.38	4.38	19.16
KK05	1190.30	14.06	1176.24	1185.58	-9.34	9.34	87.18
KK07	1206.96	13.05	1193.91	1196.84	-2.93	2.93	8.61
KMF01	1246.00	25.63	1220.37	1231.95	-11.58	11.58	134.14
KMF03	1247.00	14.60	1232.40	1231.44	0.97	0.97	0.93
KMF04	1282.33	18.20	1264.13	1244.66	19.47	19.47	378.93
KMF05	1285.72	23.12	1262.60	1248.00	14.59	14.59	212.98
KMF06	1289.14	23.67	1265.47	1248.76	16.71	16.71	279.12
KMF07	1282.04	15.75	1266.29	1273.29	-7.00	7.00	48.97
KMF08	1247.00	26.31	1220.69	1231.94	-11.25	11.25	126.59
KO01	1282.64	11.55	1271.09	1281.12	-10.02	10.02	100.42
KO05	1286.00	16.27	1269.73	1284.59	-14.86	14.86	220.70
LD01	1225.00	7.43	1217.57	1223.94	-6.37	6.37	40.53
LD03	1225.00	6.30	1218.70	1223.04	-4.34	4.34	18.81
LD04	1222.66	6.35	1216.31	1224.49	-8.18	8.18	66.85
LD05	1225.00	8.80	1216.20	1226.41	-10.21	10.21	104.16
LD07	1240.32	23.05	1217.27	1231.56	-14.29	14.29	204.20
LD09	1230.65	7.90	1222.75	1232.48	-9.73	9.73	94.73
LD10	1234.00	10.34	1223.66	1233.47	-9.81	9.81	96.24
LD11	1227.00	8.45	1218.55	1227.04	-8.49	8.49	72.15
LD12	1224.00	8.08	1215.92	1226.19	-10.27	10.27	105.45
LE01	1214.00	34.91	1179.09	1198.89	-19.80	19.80	391.84
LE07	1211.99	25.60	1186.39	1196.35	-9.97	9.97	99.32
MD05	1319.61	21.09	1298.52	1314.18	-15.66	15.66	245.20
MD06	1319.24	20.77	1298.47	1314.19	-15.72	15.72	247.06
MD10	1317.89	28.70	1289.19	1312.71	-23.52	23.52	553.05
MD16	1320.70	21.05	1299.65	1323.12	-23.47	23.47	551.08
MD17	1320.70	20.60	1300.10	1323.25	-23.15	23.15	536.06
MD18	1332.26	24.94	1307.32	1329.14	-21.82	21.82	475.98
MP01	1141.00	8.12	1132.88	1155.74	-22.86	22.86	522.44
OF01	1279.97	6.15	1273.82	1281.02	-7.20	7.20	51.84
OF02	1279.97	9.75	1270.22	1280.45	-10.23	10.23	104.65
OF04	1280.75	10.06	1270.69	1280.22	-9.54	9.54	90.97
OF05	1279.97	7.69	1272.28	1279.38	-7.10	7.10	50.41
OF06	1279.97	7.93	1272.04	1279.51	-7.46	7.46	55.70
OF07	1278.78	7.88	1270.90	1277.88	-6.98	6.98	48.72
OF08	1279.97	17.63	1262.34	1279.99	-17.64	17.64	311.24
PE06	1273.05	27.22	1245.83	1247.88	-2.05	2.05	4.21
PE09	1260.02	25.29	1234.73	1243.32	-8.59	8.59	73.81
PG01	1352.77	86.47	1266.30	1250.44	15.86	15.86	251.63
PG02	1307.00	54.85	1252.15	1251.48	0.67	0.67	0.45
PG02A	1307.00	53.35	1253.65	1251.48	2.17	2.17	4.72
PG03	1310.00	72.15	1237.85	1252.38	-14.53	14.53	211.24
PG04	1303.94	48.95	1254.99	1250.67	4.32	4.32	18.67

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
PG05A	1307.38	36.47	1270.91	1252.61	18.30	18.30	334.74
PG06	1339.99	77.68	1262.31	1243.21	19.11	19.11	365.04
PG08	1318.00	104.00	1214.00	1221.34	-7.34	7.34	53.90
PG12	1280.00	43.95	1236.05	1218.59	17.46	17.46	304.78
PN02	1160.00	14.43	1145.57	1167.58	-22.01	22.01	484.48
PN05	1160.00	21.36	1138.64	1165.37	-26.73	26.73	714.65
SF01	1277.71	9.68	1268.03	1266.33	1.70	1.70	2.89
SF02	1277.71	9.43	1268.28	1266.10	2.17	2.17	4.72
SF03	1277.71	8.20	1269.51	1266.03	3.48	3.48	12.08
SF04	1277.71	6.45	1271.26	1265.50	5.76	5.76	33.15
SF05	1269.57	5.13	1264.44	1265.09	-0.65	0.65	0.42
SF06	1269.57	5.51	1264.06	1264.92	-0.86	0.86	0.74
SF07	1268.80	3.10	1265.70	1262.31	3.39	3.39	11.51
SF09	1314.12	31.69	1282.43	1292.29	-9.86	9.86	97.18
SFE001	1197.00	16.72	1180.28	1188.49	-8.22	8.22	67.52
SFE002	1179.83	10.76	1169.07	1185.28	-16.21	16.21	262.73
SFE003	1179.68	10.27	1169.41	1182.99	-13.58	13.58	184.39
SFE004	1193.56	24.13	1169.43	1181.76	-12.33	12.33	152.13
SFE005	1220.00	47.46	1172.54	1182.79	-10.25	10.25	105.00
SFE006	1212.95	33.28	1179.67	1182.40	-2.74	2.74	7.49
SFE007	1179.53	8.77	1170.76	1179.23	-8.47	8.47	71.71
SFE008	1195.00	24.59	1170.41	1188.97	-18.56	18.56	344.40
SFE009	1206.00	37.86	1168.14	1190.58	-22.44	22.44	503.64
SFE010	1209.00	45.51	1163.49	1191.27	-27.78	27.78	771.51
SFE011	1194.60	11.60	1183.00	1192.34	-9.33	9.33	87.10
SFE012	1194.60	16.16	1178.44	1192.70	-14.25	14.25	203.18
SFE013	1190.00	18.17	1171.83	1185.51	-13.68	13.68	187.01
SFE014	1196.00	15.17	1180.83	1187.80	-6.97	6.97	48.64
SFE015	1190.99	16.17	1174.82	1188.81	-13.99	13.99	195.80
SFE016	1184.00	12.95	1171.05	1183.10	-12.05	12.05	145.15
SFE017	1184.00	14.53	1169.47	1184.24	-14.77	14.77	218.24
SFE018	1196.00	14.76	1181.24	1185.62	-4.38	4.38	19.21
SFE019	1182.00	12.48	1169.52	1182.00	-12.48	12.48	155.75
SFE020	1183.00	13.65	1169.35	1182.83	-13.48	13.48	181.66
SFE021	1190.34	18.65	1171.69	1184.66	-12.97	12.97	168.12
SFE022	1178.78	11.45	1167.33	1181.51	-14.19	14.19	201.27
SFE023	1187.70	17.12	1170.58	1186.46	-15.88	15.88	252.17
SFE024	1187.00	14.63	1172.37	1184.67	-12.30	12.30	151.22
SFE025	1180.00	10.53	1169.47	1182.90	-13.43	13.43	180.45
ST02	1228.00	45.95	1182.05	1204.77	-22.72	22.72	516.24
SUN01	1200.05	12.04	1188.01	1186.96	1.05	1.05	1.09
SUN02	1205.21	14.20	1191.01	1186.95	4.05	4.05	16.43
SUN03	1205.21	13.53	1191.68	1186.92	4.76	4.76	22.65
SUN05	1196.00	13.18	1182.82	1186.71	-3.89	3.89	15.16

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
SUN07	1172.00	9.40	1162.60	1166.28	-3.68	3.68	13.56
SUN09	1171.00	8.61	1162.39	1166.20	-3.81	3.81	14.55
SUN11	1170.00	8.80	1161.20	1161.70	-0.50	0.50	0.25
SUN12	1170.00	7.62	1162.38	1161.66	0.72	0.72	0.52
SUN15	1163.00	9.80	1153.20	1160.64	-7.44	7.44	55.41
VN07	1280.03	7.03	1273.00	1286.92	-13.93	13.93	193.96
VP01	1193.04	11.15	1181.89	1186.52	-4.63	4.63	21.40
VP02	1191.13	11.80	1179.33	1186.46	-7.13	7.13	50.82
VW01	1200.00	8.11	1191.89	1197.85	-5.96	5.96	35.47
VW07	1203.00	10.02	1192.98	1202.04	-9.06	9.06	82.03
VW08	1202.00	10.46	1191.54	1201.69	-10.15	10.15	103.04
WAT02	1282.05	8.18	1273.87	1285.29	-11.42	11.42	130.44
WAT05	1280.73	9.85	1270.88	1284.38	-13.50	13.50	182.28
WE01	1153.61	7.54	1146.07	1149.33	-3.27	3.27	10.67
Average	**1229.73**	**18.71**	**1211.02**	**1218.05**	**-7.03**	**10.88**	**161.59**
Minimum	**1139.98**	**2.05**	**1132.88**	**1145.70**	**-29.48**	**0.46**	**0.21**
Maximum	**1352.77**	**104.00**	**1313.59**	**1329.14**	**23.82**	**29.48**	**869.25**
Correlation			**0.97**				
∑					**-1470.02**	**2274.41**	**33771.48**
1/n					**-7.03**	**10.88**	**161.59**
Root Mean Square Deviation (RMSD)					**2.65**	**3.30**	**12.71**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**7.03**

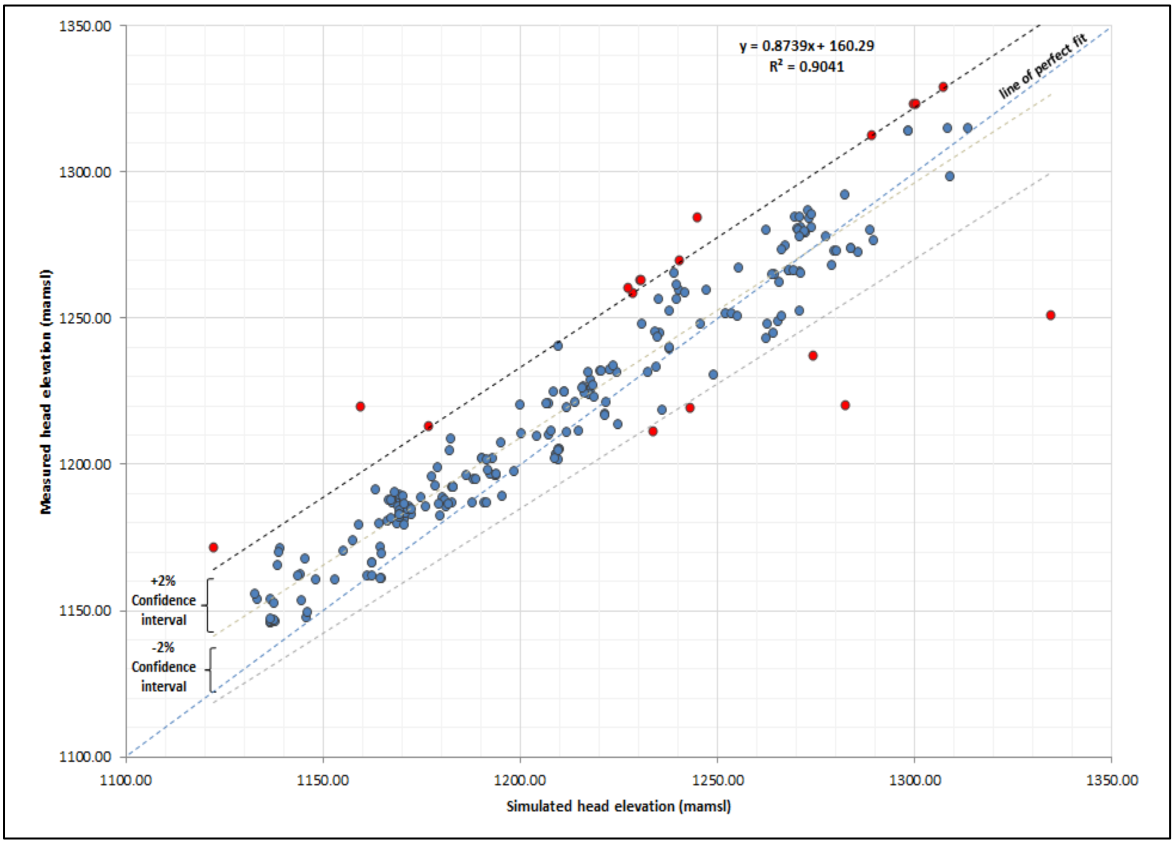

Figure 6.i: Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation

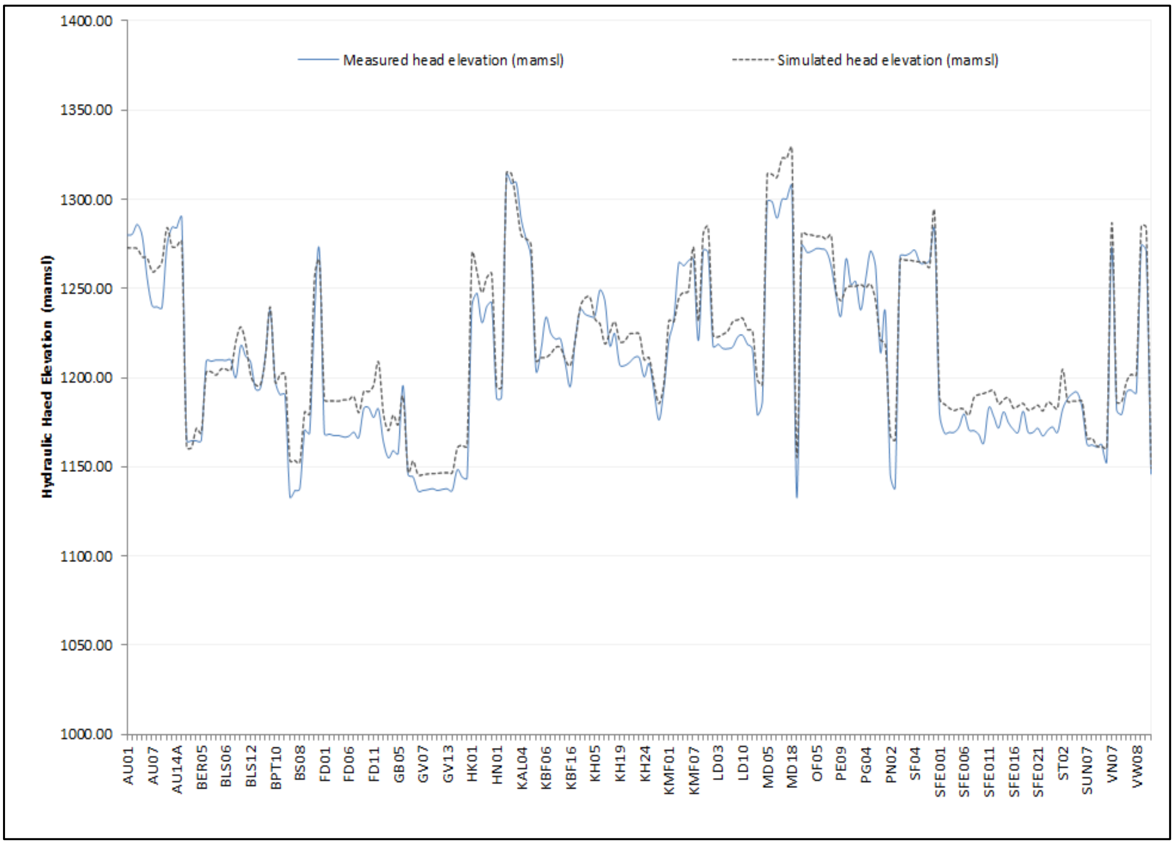

Figure 6.j: Model steady state calibration: Curve of simulated vs. measured hydraulic head elevation

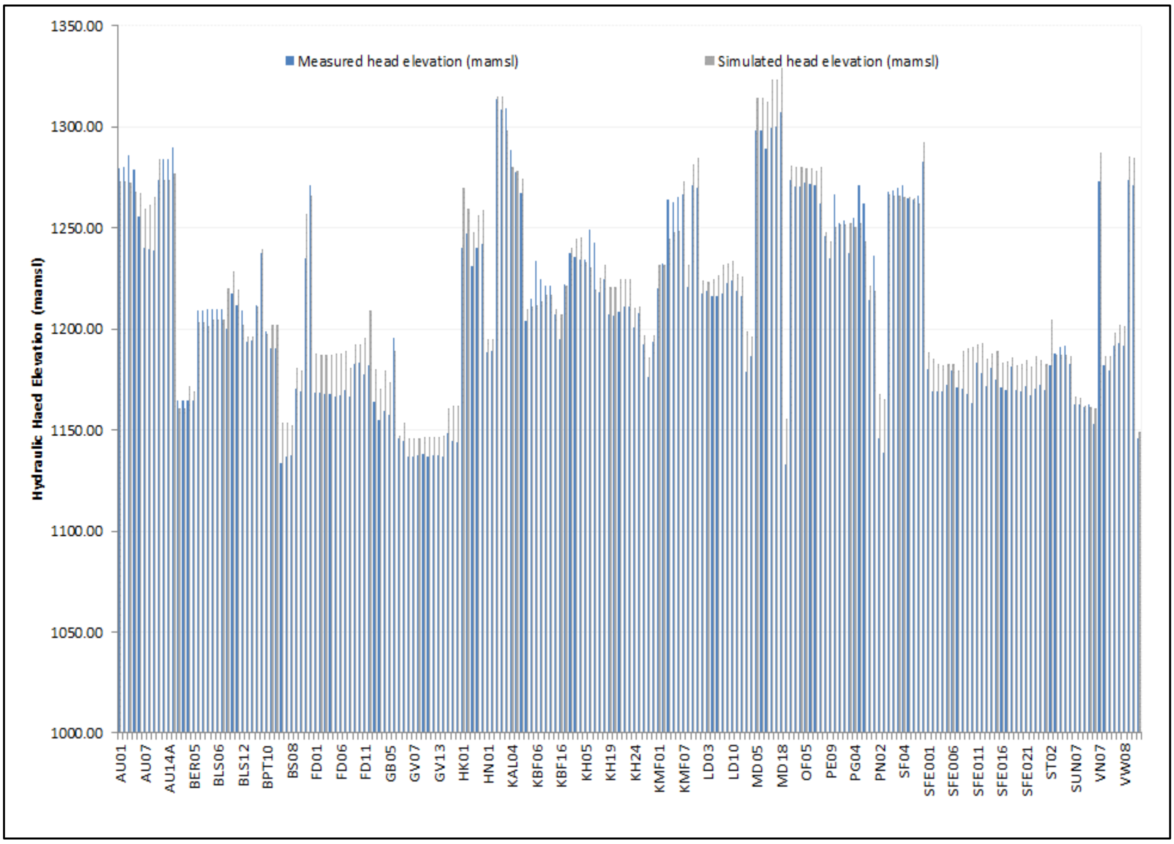

Figure 6.k: Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation

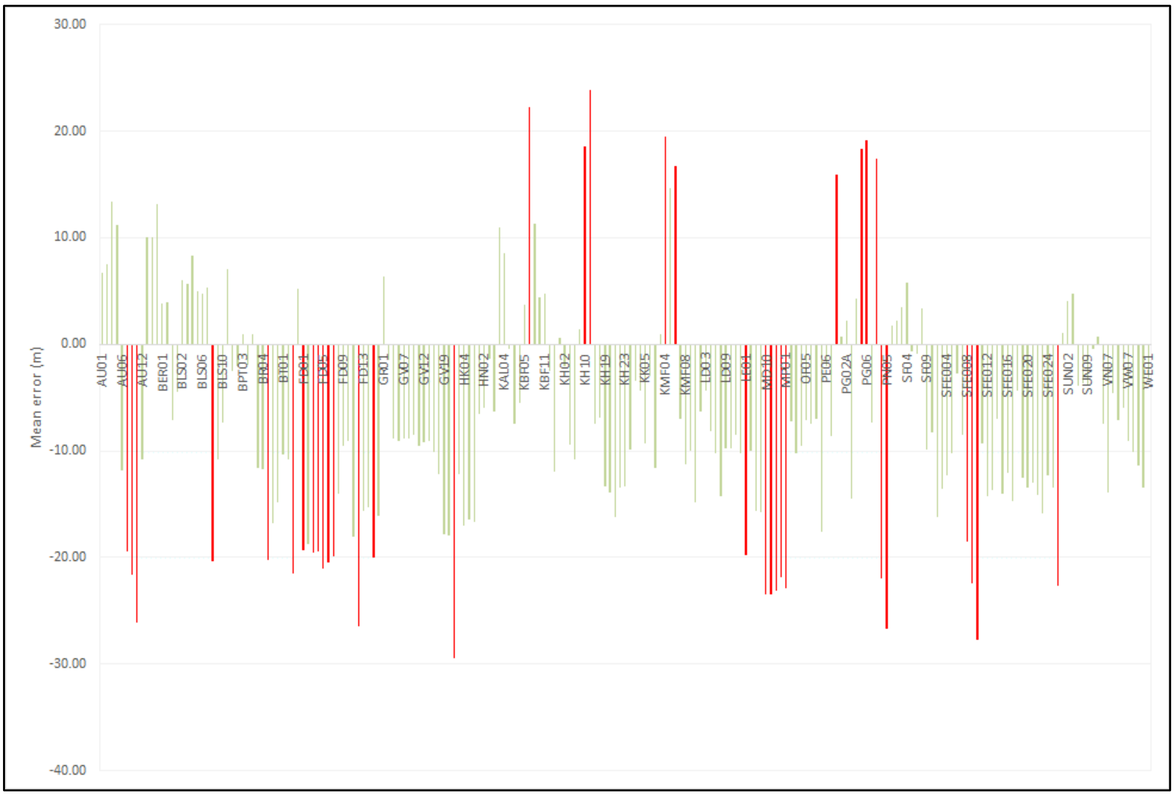

Figure 6.l: Model steady state calibration: Bar-chart of mean error values per calibration borehole

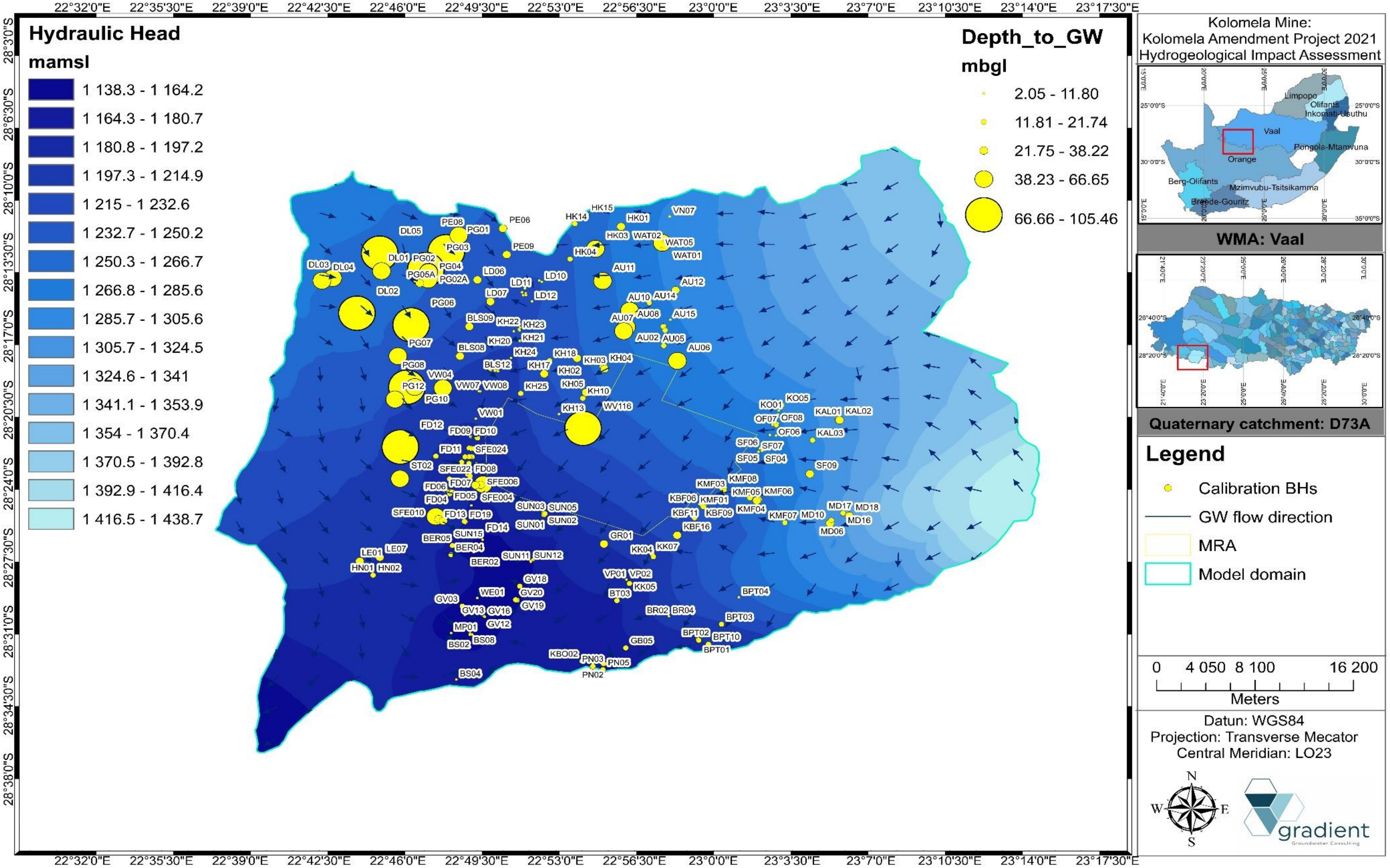

Figure 6.m: Model steady state calibration: Hydraulic head elevation and groundwater flow direction

6.7.2 Scenario 1a: Model sensitivity analysis (∞)

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs (Saltelli, 2002). The process of recalculating outcomes under alternative assumptions to determine the impact of a variable under sensitivity analysis can increase the understanding of the relationships between input and output variables in a system or model as well as reduce the model uncertainty (Pannell, 1997). In order to verify the sensitivity of the calibrated model in terms of hydraulic stresses, aquifer parameters (i.e. recharge and transmissivity) were adjusted while the impact on the hydraulic head elevation evaluated at relevant on-site borehole localities. As summarised in **Table 6.d** it is noted that the model tend to be more sensitive to a downward variation in hydraulic conductivity **(Figure 6.n**, **Figure 6.o** and **Figure 6.p**)[3].

Table 6.d: Steady State Model Calibration – Sensitivity analysis

Parameter	Scenario: Base Case	Scenario: 50% of calibrated K-value	Scenario: 150% of calibrated K-value	Scenario: 50% of calibrated recharge	Scenario: 150% of calibrated recharge
Correlation	0.97	0.97	0.95	0.96	0.97
Mean Error	-7.03	15.25	-7.60	3.09	-11.51
Mean Abs Error	10.88	16.12	12.85	12.76	13.04
RMSD	12.71	19.74	16.67	15.93	15.65
NRMSD	7.03%	10.93%	7.86%	8.81%	8.66%

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[3] 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.

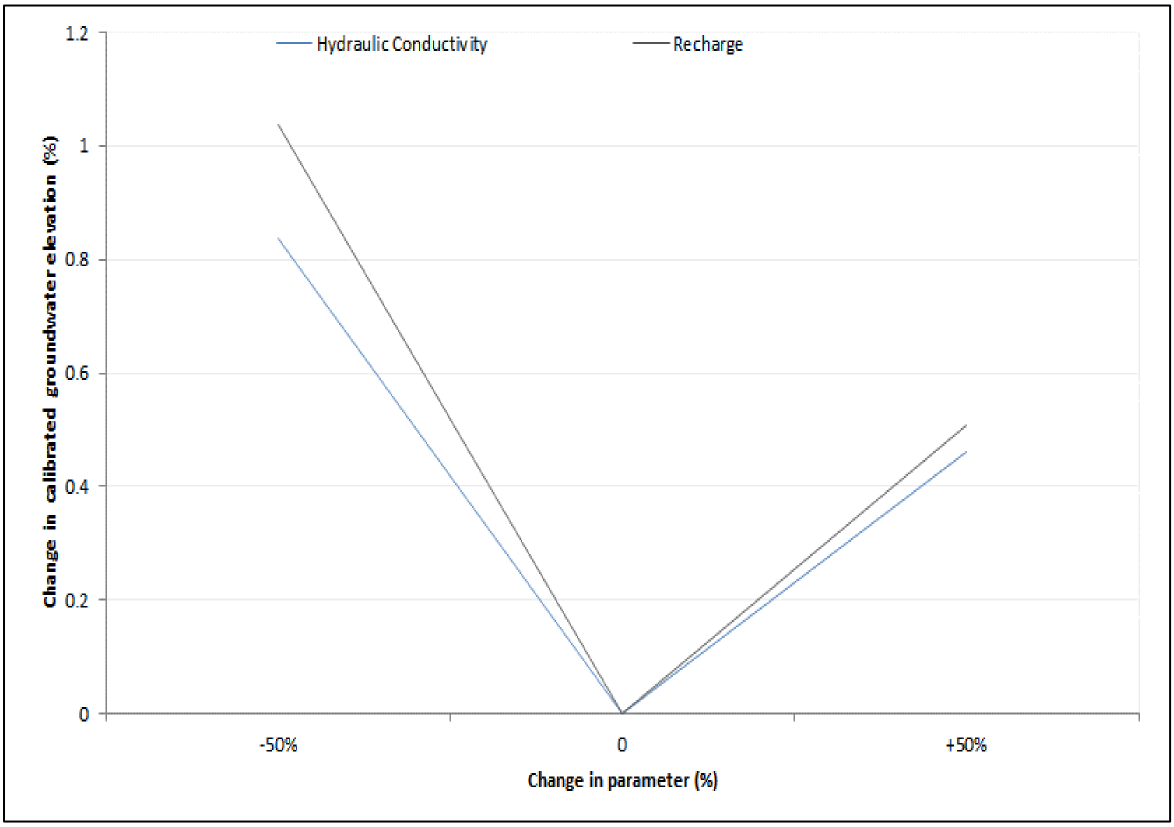

Figure 6.n: Model steady state calibration: Sensitivity analysis for monitoring locality KBF05

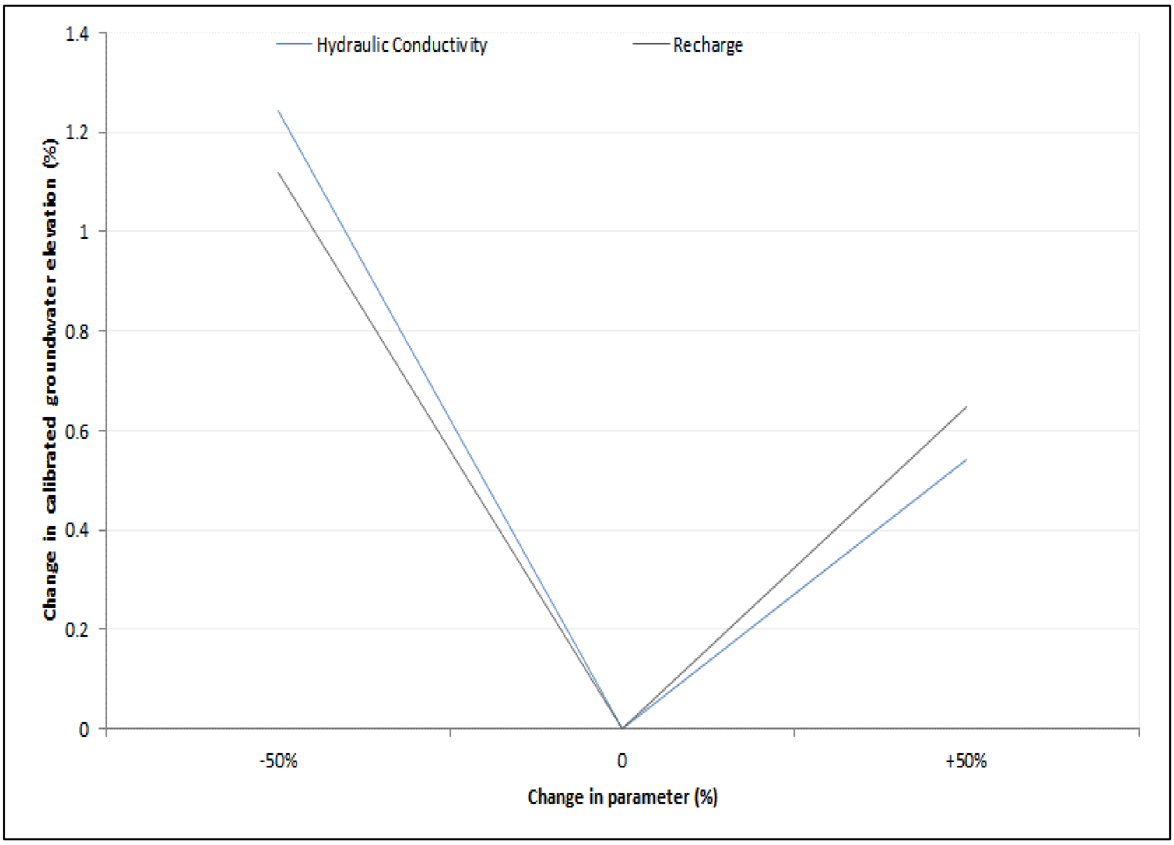

Figure 6.o: Model steady state calibration: Sensitivity analysis for monitoring locality KH05

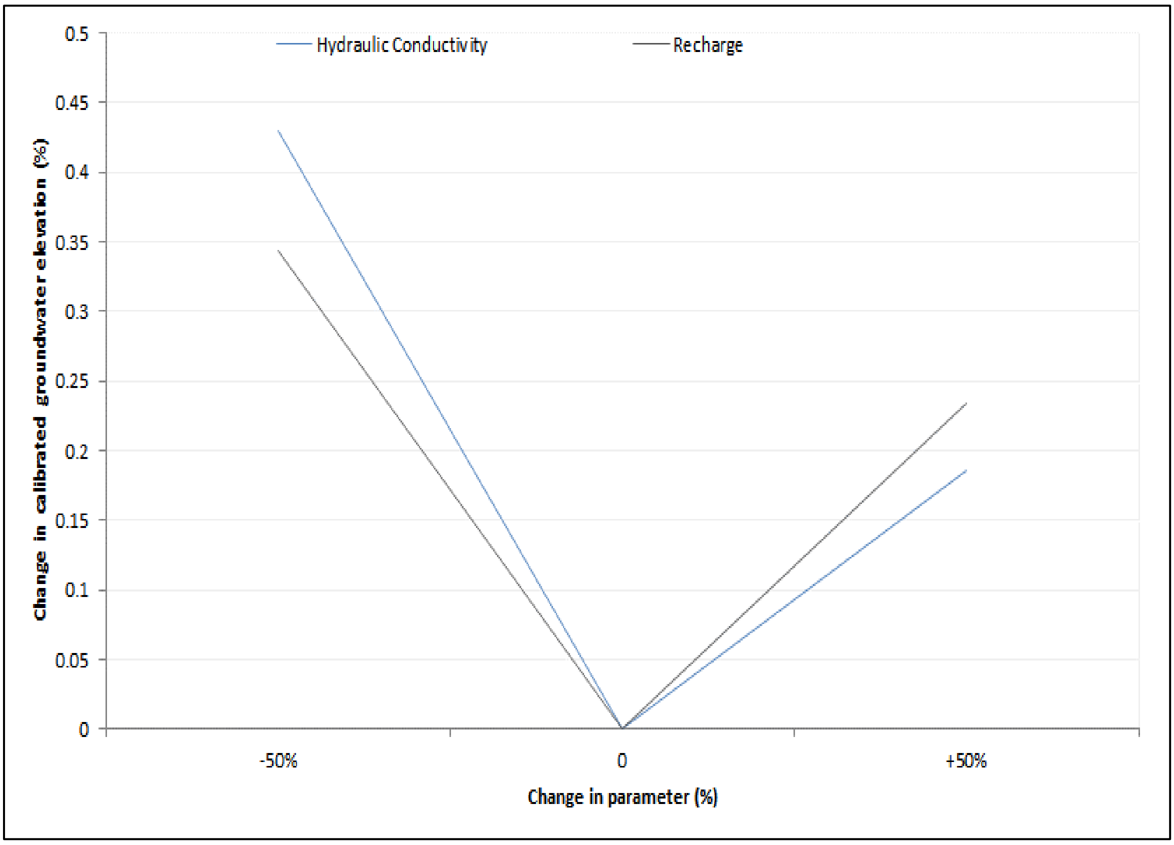

Figure 6.p: Model steady state calibration: Sensitivity analysis for monitoring locality SUN03

6.7.3 Scenario 1b: Transient calibration

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. depicts time-series curves of simulated vs measured hydraulic head elevation of on-site dewatering boreholes[4] while **Figure 6.r** shows the transient hydraulic head contours and groundwater flow directions. It is evident that the current dewatering activities causes a negative hydraulic gradient towards the pit footprints, thus altering groundwater flow directions towards the pit areas.

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[4] It should be noted that dewatering boreholes situated within the existing pit footprints were excluded from the transient calibration.

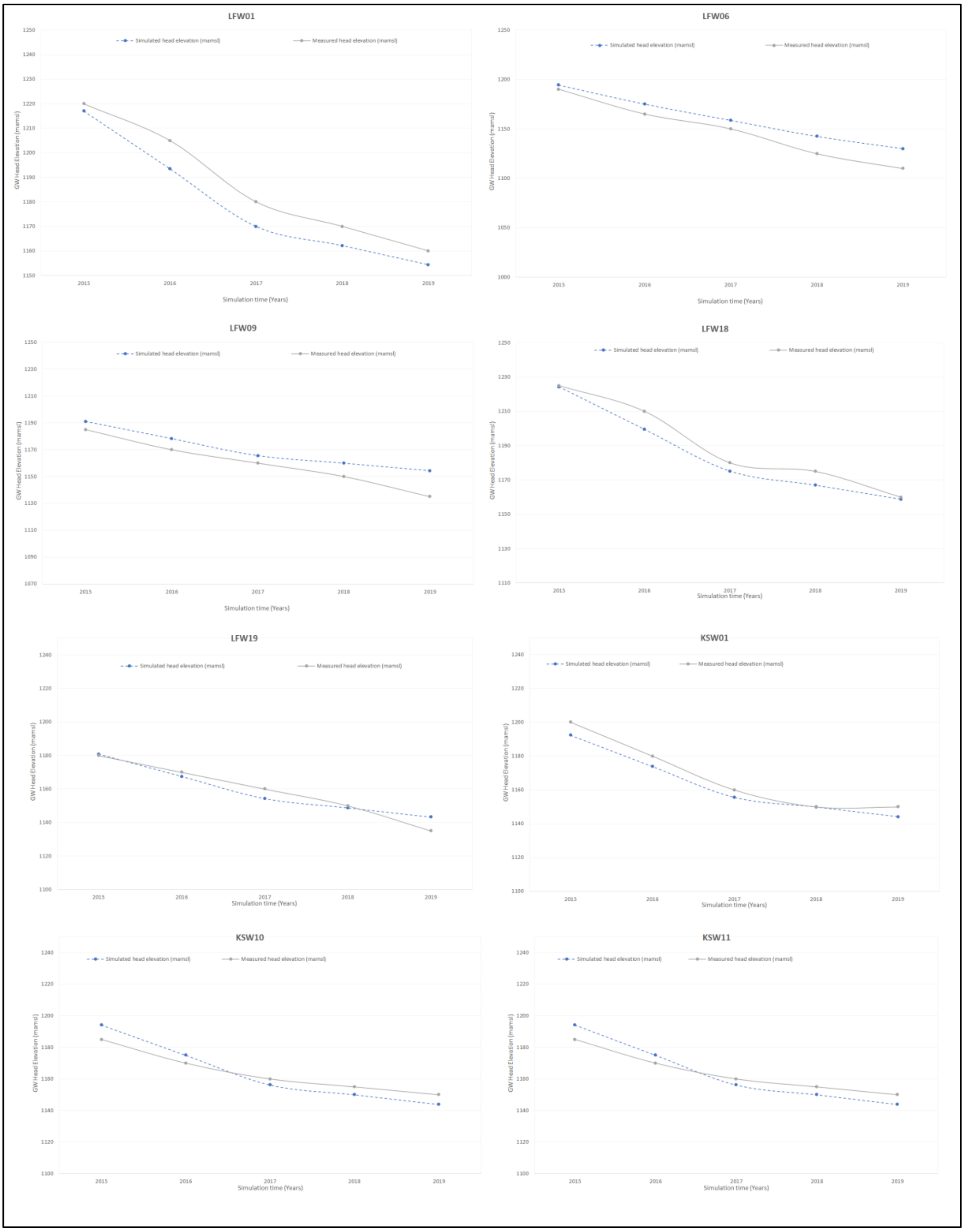

Figure 6.q: Model transient calibration: Time-series groundwater elevation curves of earmarked dewatering boreholes

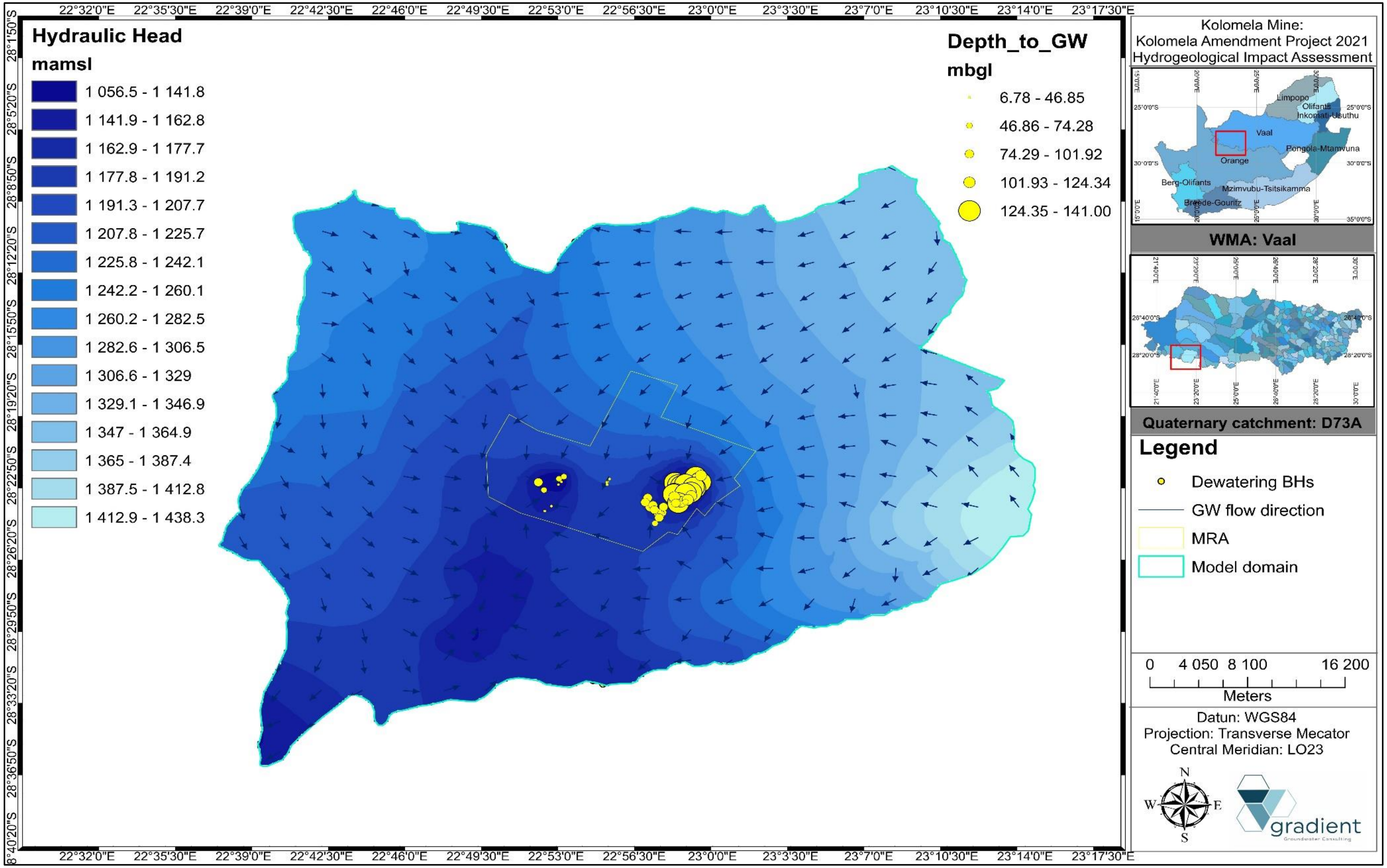

Figure 6.r: Model transient calibration: Hydraulic head elevation and groundwater flow direction

6.7.4 Scenario 02: Baseline pre-mining water balance

Table 6.e summarises the groundwater catchment water balance representing pre-mining conditions. Recharge is assumed the major source of inflow to the system and has been simulated at 6.89e^{+04} m^3/d, while the largest loss to the groundwater system is via Dirichlet boundary conditions (3.38e^{+4} m^3/d) as well as from current water use allocations including mine dewatering activities (3.51e^{+4} m^3/d).

Table 6.e: Catchment water balance: Scenario 02 – Baseline pre-mining

Scenario 02 – Base-case pre-mining conditions			
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	6.89E+04	0.00E+00	6.89E+04
Dirichlet boundary conditions (m^3/d)	0.00E+00	3.38E+04	-3.38E+04
Current catchment water use (m^3/d)*	0.00E+00	3.51E+04	-3.51E+04
Imbalance ignoring internal transfer (m^3/d)	0.00E+00	0.00E+00	0.00E+00
Total (m^3/d)	**6.89E+04**	**6.89E+04**	**0.00E+00**

6.7.5 Scenario 03: Operational phase pit dewatering and groundwater capture zone

Table 6.f summarises the groundwater catchment water balance for stress period(s) representing the LOM phases for the proposed open pit operations. Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Leeuwfontein South Pit is approximately 2.61e^{+04} m^3/d (1088.0 m^3/h) with a maximum groundwater ingress of approximately ~1800.0 m^3/h for the duration of the simulation period as depicted in **Figure 6.s**. The predicted dewatering rates correlate well to the existing groundwater flow model (Itasca, 2021) simulations, however the maximum dewatering rate expected is higher and can be attributed to different pit dimensions being the main driver of groundwater ingress.

Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Kapstevel Pit is approximately 1.67e^{+04} m^3/d (~700.0 m^3/h) with a maximum groundwater ingress of approximately ~1600.0 m^3/h for the duration of the simulation period as depicted in **Figure 6.t.** The predicted dewatering rate correlate well to the existing groundwater flow model (Itasca, 2021) simulations, however the maximum dewatering rates expected is higher and can be attributed to different pit dimensions being the main driver of groundwater ingress.

Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Klipbankfontein Pit is approximately 2.77e^{+03} m^3/d (~115.0 m^3/h) with a maximum groundwater ingress of approximately ~240.0 m^3/h for the duration of the simulation period as depicted in **Figure 6.u.** Although simulated groundwater ingress is low to zero for certain periods it should be noted that the existing groundwater flow model (Itasca, 2021) suggested zero groundwater ingress for the entire simulation period. The latter can be attributed to different pit dimensions being the main driver of groundwater ingress.

It is expected that the groundwater drawdown within the existing monitoring as well as neighbouring and private boreholes will range between 3.0m (regional) to 50.0-100 mbsl (meters below static level) within close proximity to the pit footprints as shown in **Figure 6.v**. It should be noted that the majority of properties being intercepted by the drawdown zone are owned by SIOC, however there are privately owned properties being impacted on as well especially towards the northern and eastern perimeters.

It should be noted that the zone of impact does reach various boreholes which is current being utilised.

The groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of approximately 509.0 km² at the mine end of life period as indicated in **Figure 6.w** and **Figure 6.x**. Figure **6.y** depicts the groundwater capture zones for the various operational phases. It should be noted that the simulated groundwater drawdown zone extends beyond the mining right area stretching a maximum distance of ~8.0 km towards the southeast and ~17.0 km in a general north to north-eastern direction. The groundwater drawdown observed in the north-eastern parts of the greater study area can possibly be attributed to existing mine dewatering activities within this area which has been active the last approximately 100 years.

Table 6.f: Catchment water balance: Scenario 03 - LOM opencast dewatering operational phase(s)

Scenario 03: LOM dewatering operational phase(s)			
Parameter	**Inflow (m³/d)**	**Outflow (m³/d)**	**Balance (m³/d)**
Recharge (m³/d)	6.89E+04	0.00E+00	6.89E+04
Dirichlet boundary conditions (m³/d)	0.00E+00	5.68E+04	-5.68E+04
Kapstevel pit dewatering (m³/d)	0.00E+00	1.67E+04	-1.67E+04
Klipbankfontein pit dewatering (m³/d)	0.00E+00	2.77E+03	-2.77E+03
Leeuwfontein pit dewatering (m³/d)	0.00E+00	2.61E+04	-2.61E+04
Storage Capture(-)/Release(+)(m³/d)	3.34E+04	0.00E+00	3.34E+04
Total (m³/d)	**1.02E+05**	**1.02E+05**	**0.00E+00**

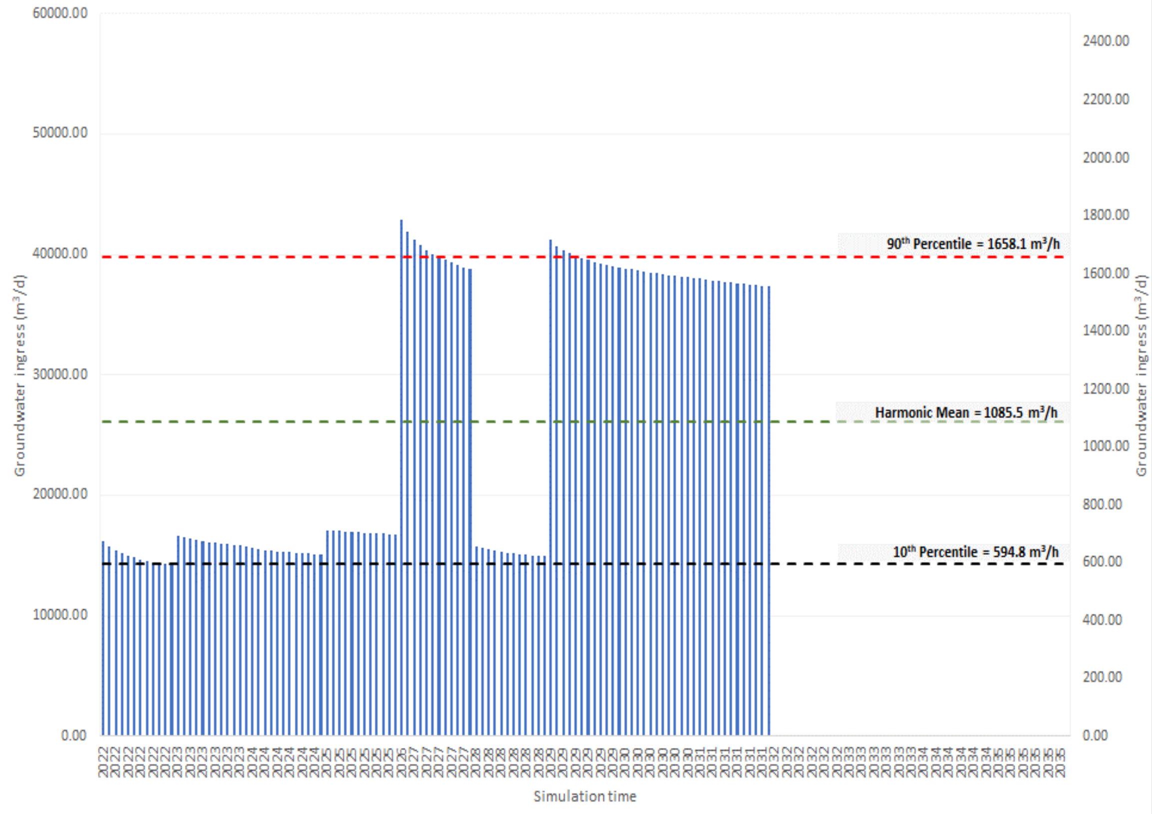

Figure 6.s: Scenario 03: Leeuwfontein pit time-series dewatering/ groundwater ingress curve

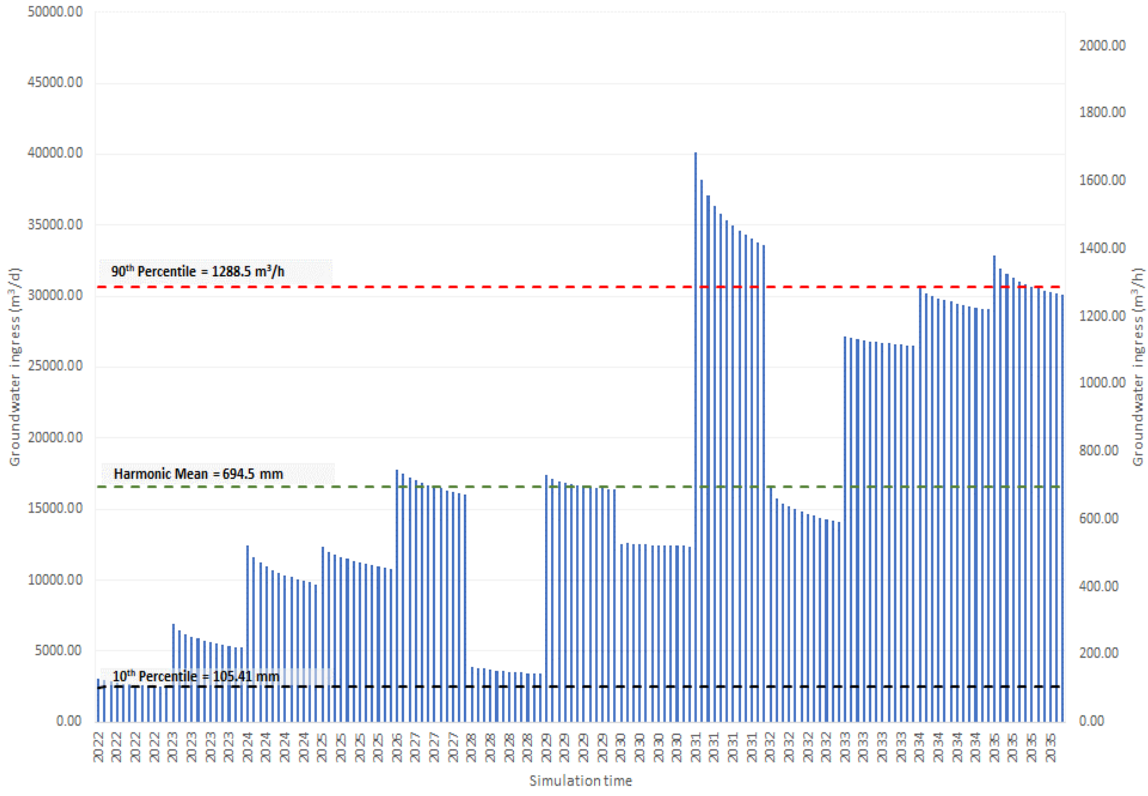

Figure 6.t: Scenario 03: Kapstevel pit time-series dewatering/ groundwater ingress curve

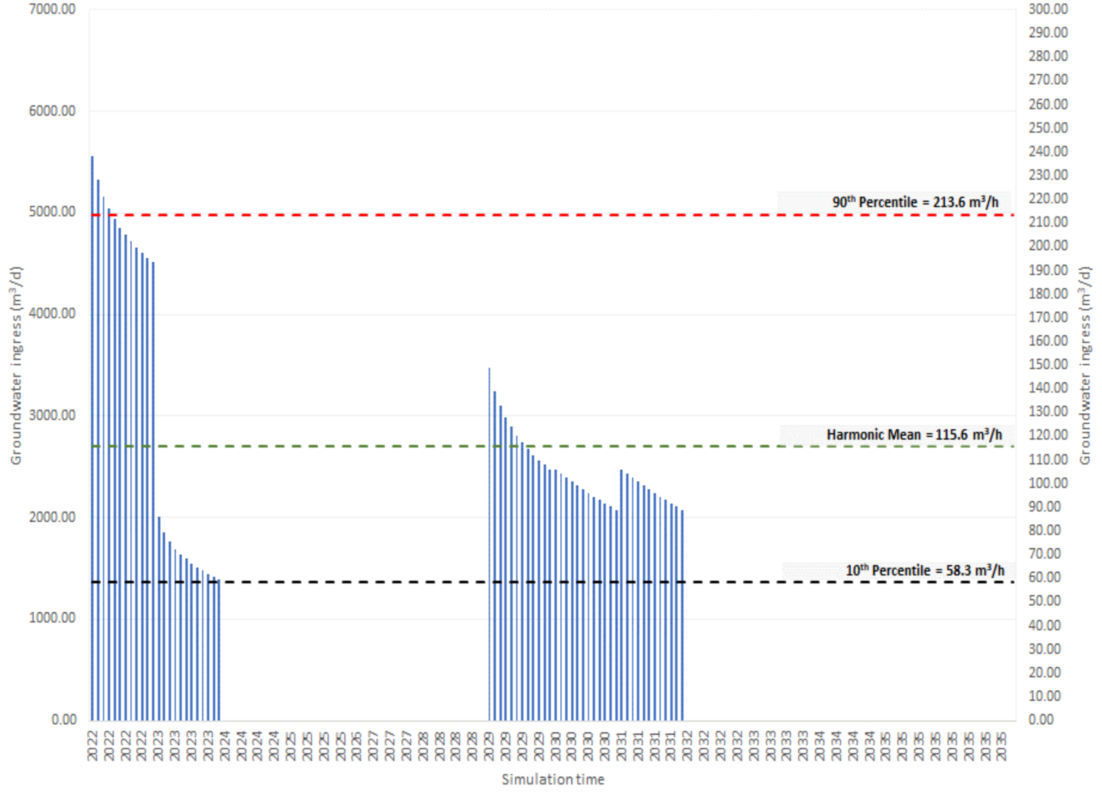

Figure 6.u: Scenario 03: Klipbankfontein pit time-series dewatering/ groundwater ingress curve

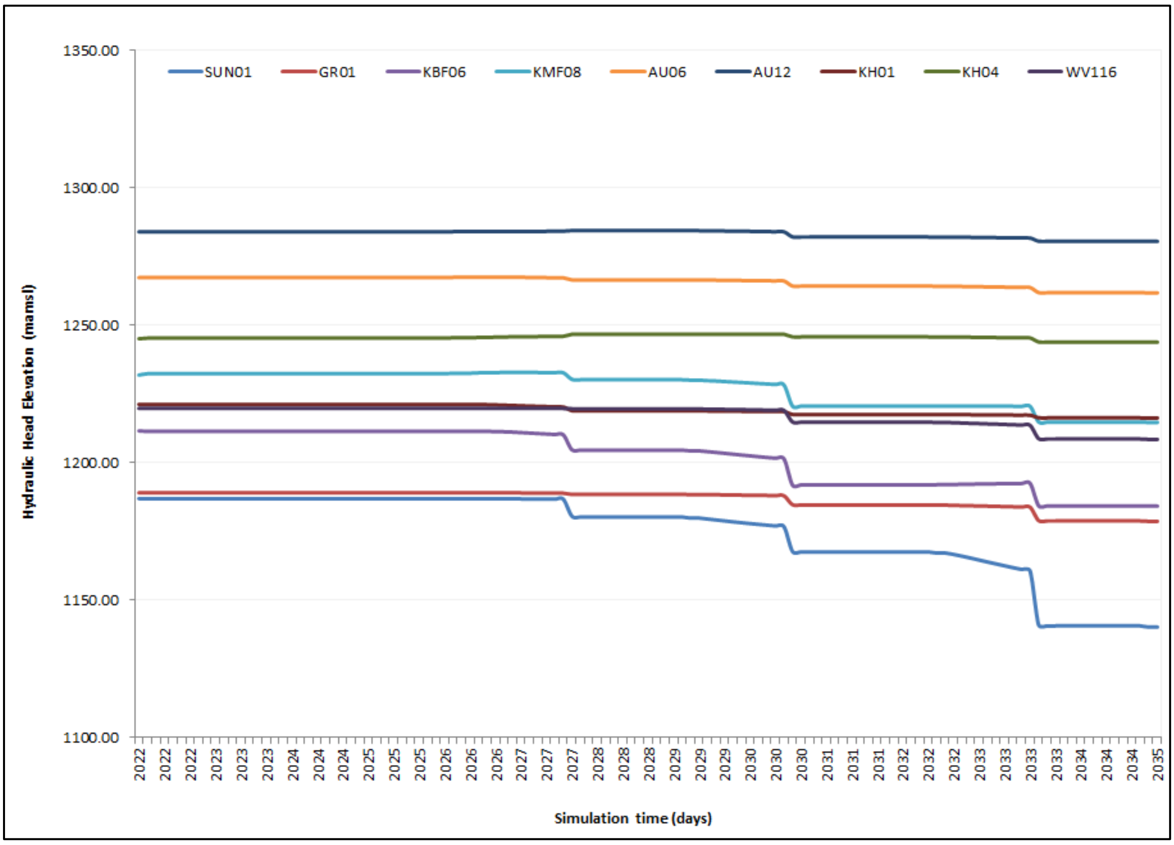

Figure 6.v: Scenario 03: Time-series water level drawdown for certain observation boreholes (LOM)

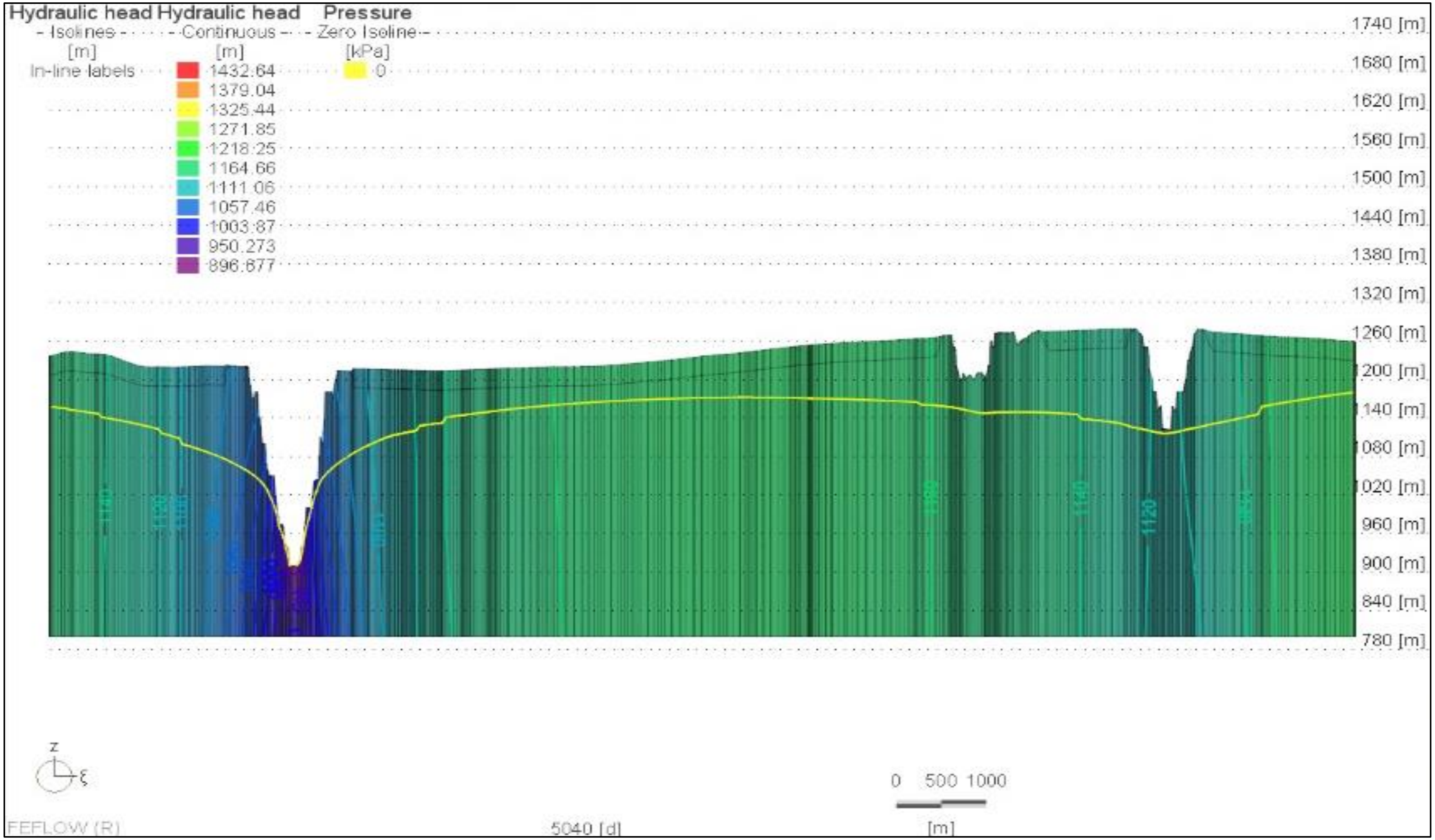

Figure 6.w: Model domain 3-D FEM mesh view (cross sectional view west-east orientation A-A' at the end of mine life) of the predicted hydraulic head drawdown

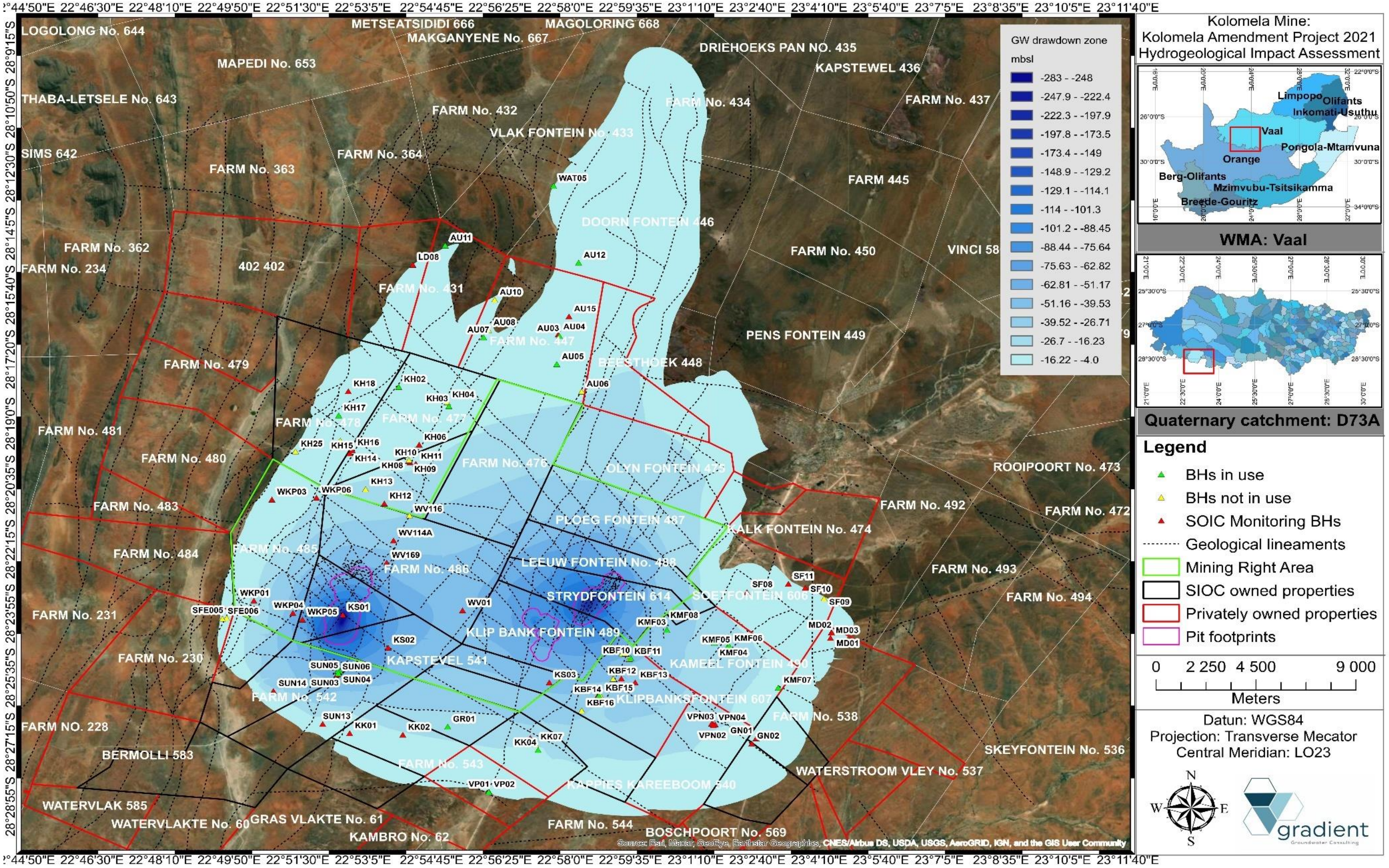

Figure 6.x: Scenario 03: Water level drawdown and groundwater capture zone after the LOM period

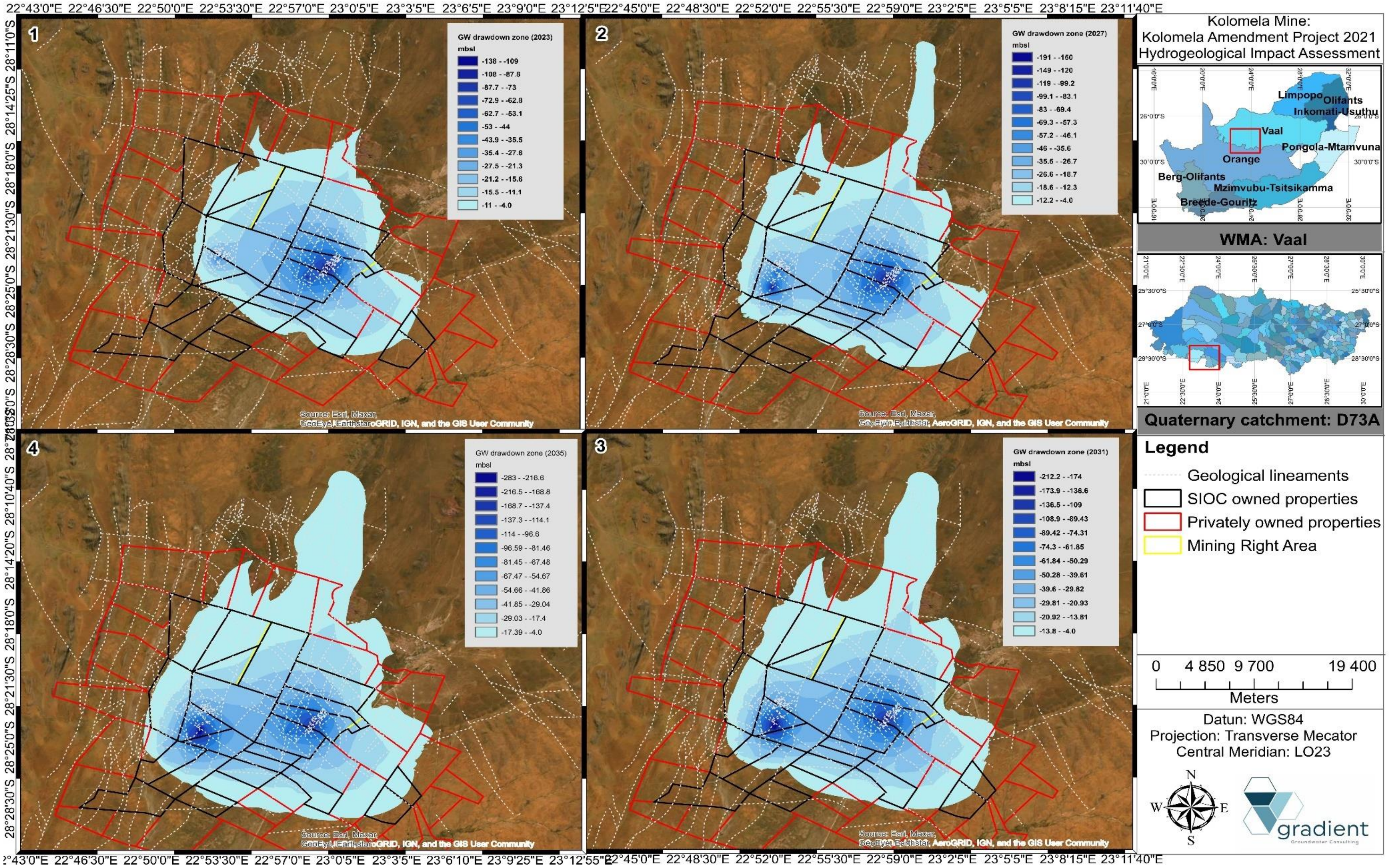

Figure 6.y: Scenario 03: Water level drawdown and groundwater capture zone for various operational phases

6.7.6 Scenario 04: Post-closure opencast pits re-watering, hydraulic head recovery and decant potential

A mine post-closure scenario was simulated wherein the hydraulic head recovery within the groundwater drawdown zone of influence was evaluated. Generally, the decant point/zone is the lowest topographical point of the existing/proposed mining footprint which is in direct connection with surface topography. **Figure 6.z** indicates relevant post-closure rewatering curves simulated for the proposed opencasts. It can be observed the potential decant elevations for all the planned pit footprints is situated from 20.0 m (Kapstevel Pit) to > 50.0 m (Leeuwfontein and Klipbankfontein Pits) above the pre-mining and calibrated groundwater level and as such it is highly unlikely that decant will occur. It is estimated that the recovery period i.e. time remaining mine voids will take to fill will be >100 years and beyond the simulation period. A mine post-closure scenario was also conducted wherein the pit footprints were not backfilled and acted as permanent sinks due to the high evaporation rate expected. It is evident that the highest groundwater elevation will not extend beyond 1180.0 mamsl and will reach equilibrium between 6 to 50 years as summarised in **Figure 6.aa** below.

Groundwater level recovery within impacted monitoring as well as neighbouring and private boreholes will be a function of the proximity and distance to the dewatering activities as shown in

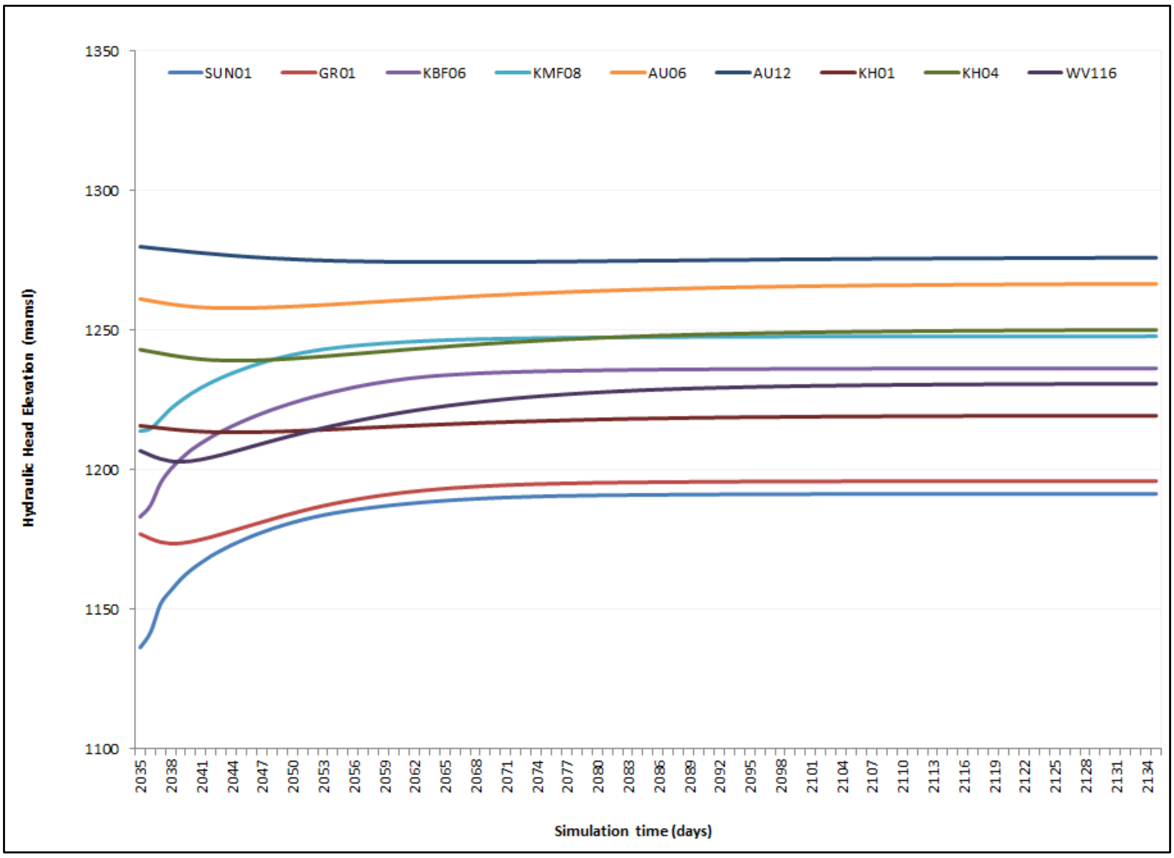

Figure 6.bb and **Figure 6.cc** .

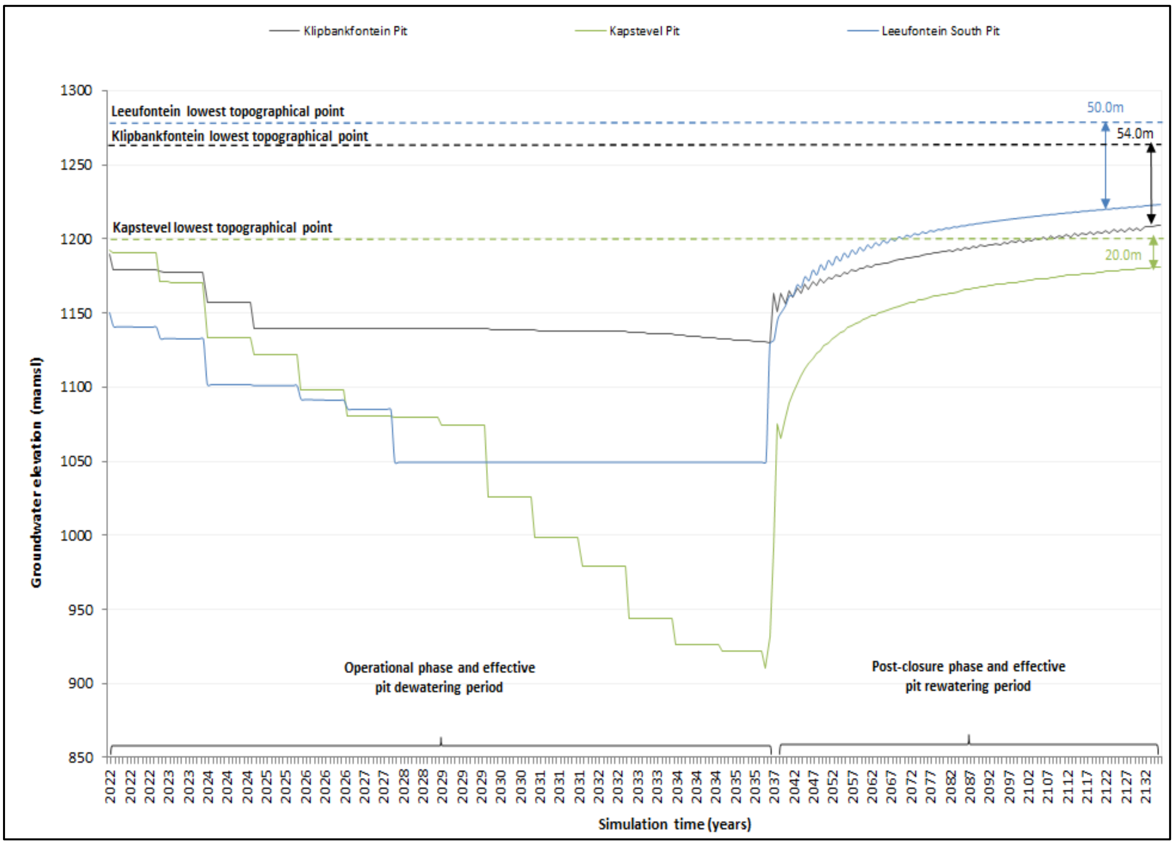

Figure 6.z: Scenario 04: Post-closure void re-watering and hydraulic head recovery within backfilled pits

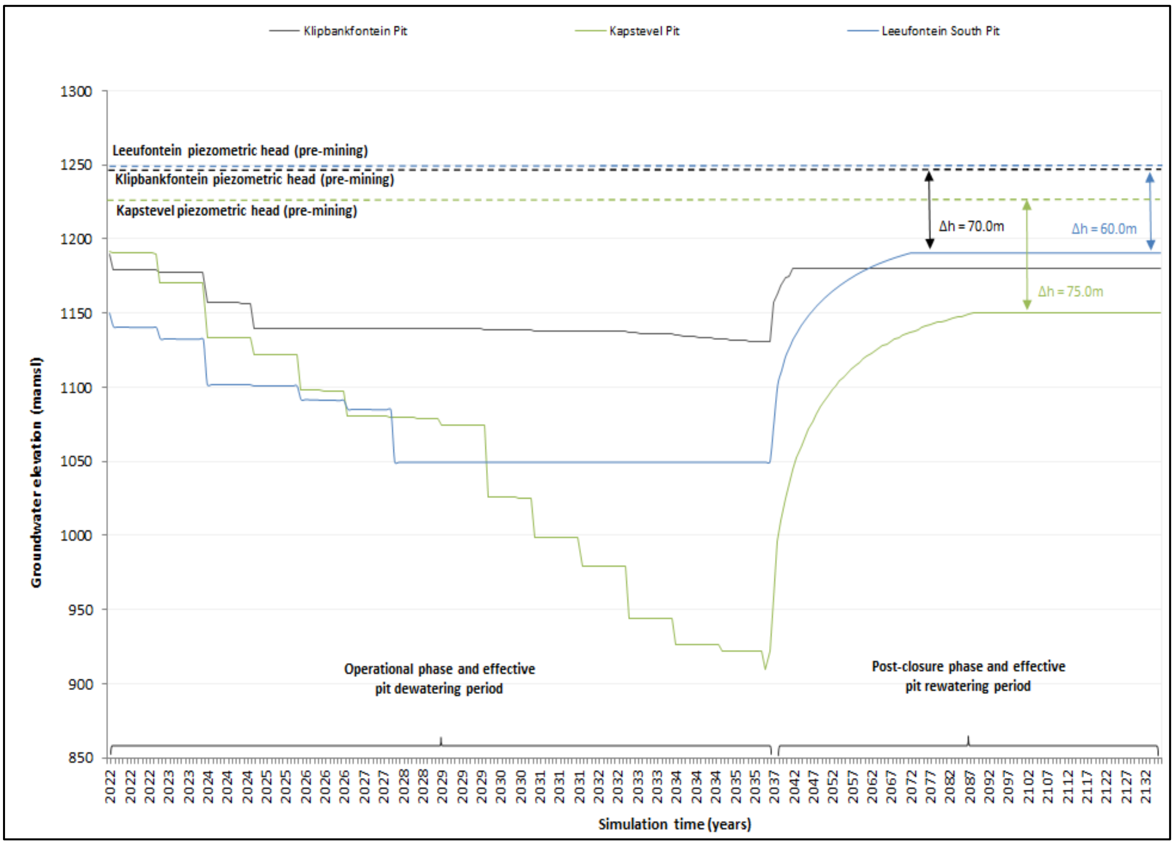

Figure 6.aa: Scenario 04: Post-closure pit flooding and hydraulic head

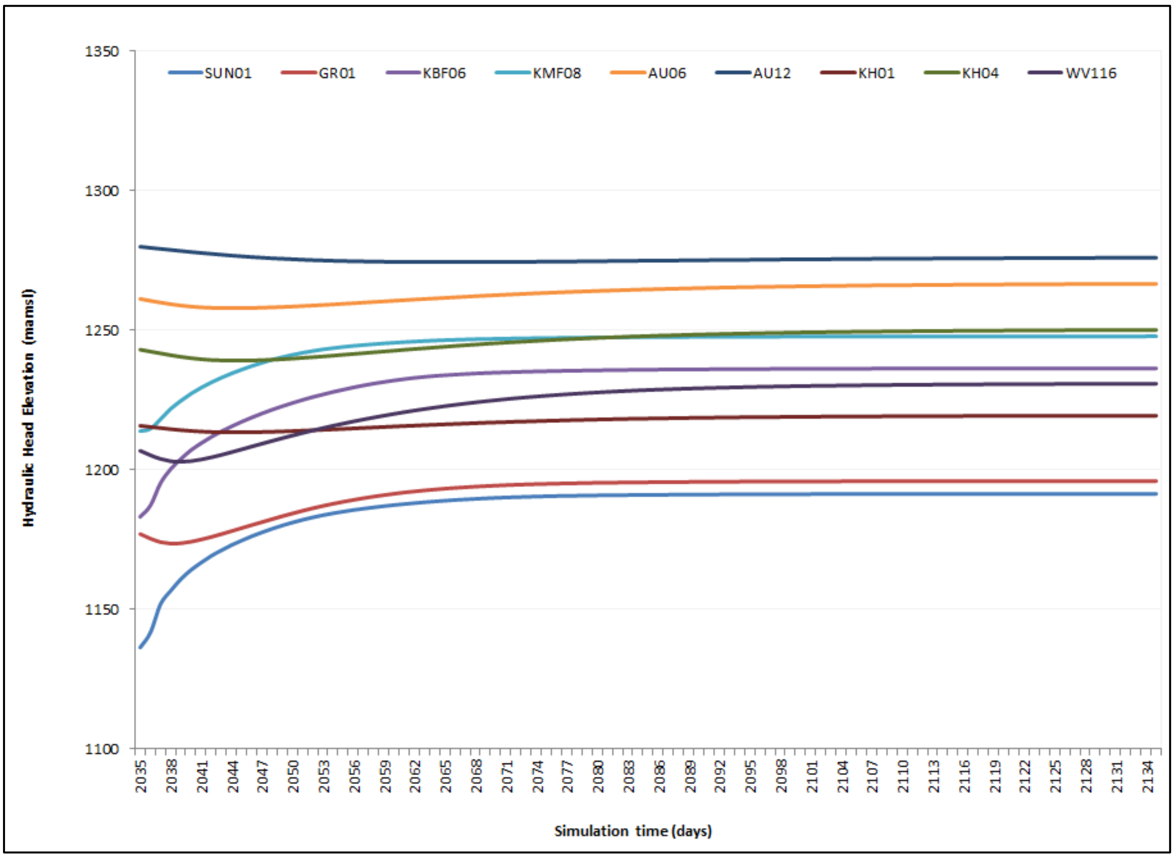

Figure 6.bb: Scenario 04: Time-series water level recovery curves of observation boreholes

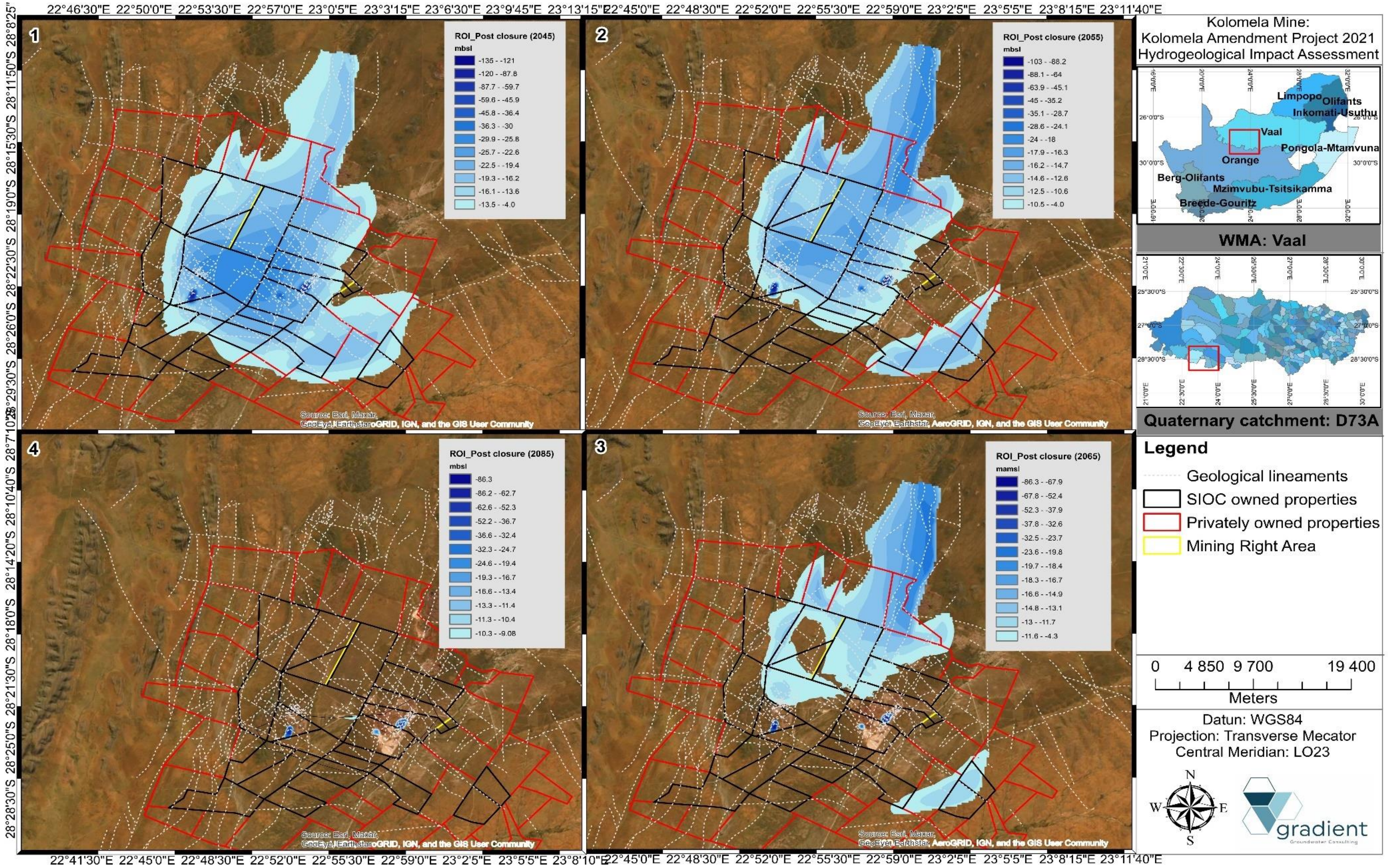

Figure 6.cc: Scenario 04: Water level recovery and groundwater capture zone for various post-closure phases

6.8 Numerical mass transport model

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

Equation 6.8 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 phenomena5;

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

p = density of pollutant;

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

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

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

As the majority of down-gradient observation and monitoring boreholes do not suggest any major signs of inorganic contamination and/or impacts, total dissolved solids (TDS) were applied as source term and contaminant proxy. Although elevated nitrate concentrations were observed at isolated monitoring boreholes, which can be ascribed to mine blasting activities, the latter cannot accurately be applied as source term due to nitrates being actively broken down to produce nitrogen gas. The TDS leach concentration of the waste rock and tailings backfill material as derived from the waste classification and geochemical

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[5] 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. Piezometers situated within the waste rock dumps indicate unsaturated and dry conditions and clay materials in the waste rock material act as impermeable to semi-impermeable barriers to form. Thus the risk of leachate to the host aquifer is low to very low.

assessment, including evaluation of existing monitoring data, suggested a concentration of 800.0 mg/ℓ which were assigned as such.

Figure 6.dd depicts a model cross section of the pollution plume migration within the aquifer. It is evident that the mass transport of the pollution plume is mostly limited to the shallow, weathered aquifer, however, does migrate to the deeper, fractured aquifer as well.

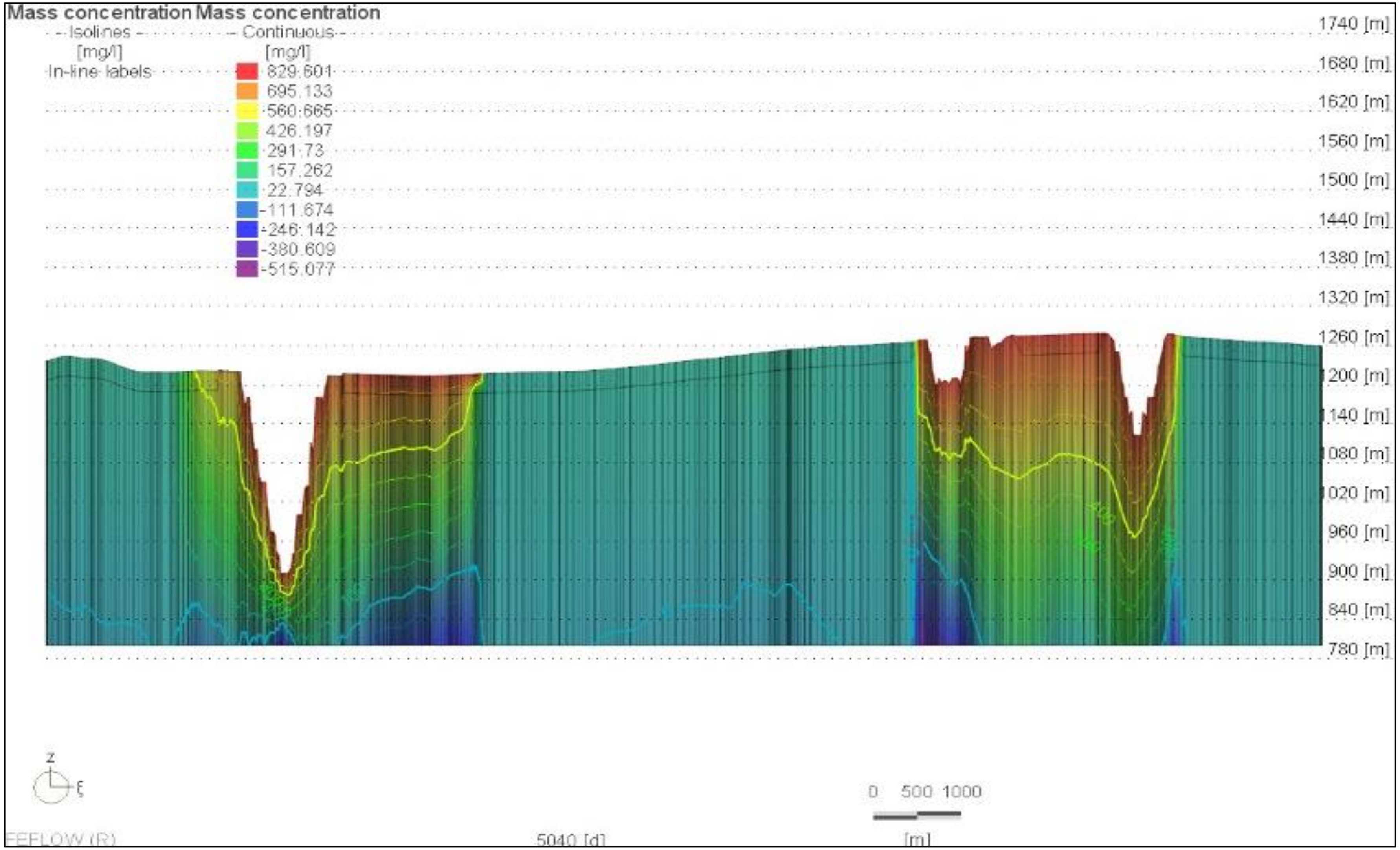


Figure 6.dd: Scenario05: Pollution plume migration cross sectional view west-east orientation A-A' the end of mine life

6.8.1 Scenario 05: Pollution plume migration emanating from backfilling of remaining opencasts for the LOM operational period

Scenario 05 simulated the pollution plume migration from existing as well as proposed waste body footprints i.e. tailings disposal facilities, waste rock dumps, mined out faced etc. for the duration of the operational period. **Figure 6.ee** depicts the expected pollution plume migration within the host aquifer while **Figure 6.ff** show the pollution plume propagation for the various operational phases. The pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 27.3 km^2, consisting of 10.8 km^2 (Kapstevel section) and 16.5 km^2 (Klipbankfontein and Leeuwfontein sections). It is observed that the generated pollution plume does not migrate in the expected down-gradient direction due to the negative hydraulic gradient caused by the operational pit dewatering activities constraining plume propagation. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient and is limited to the mining right area.

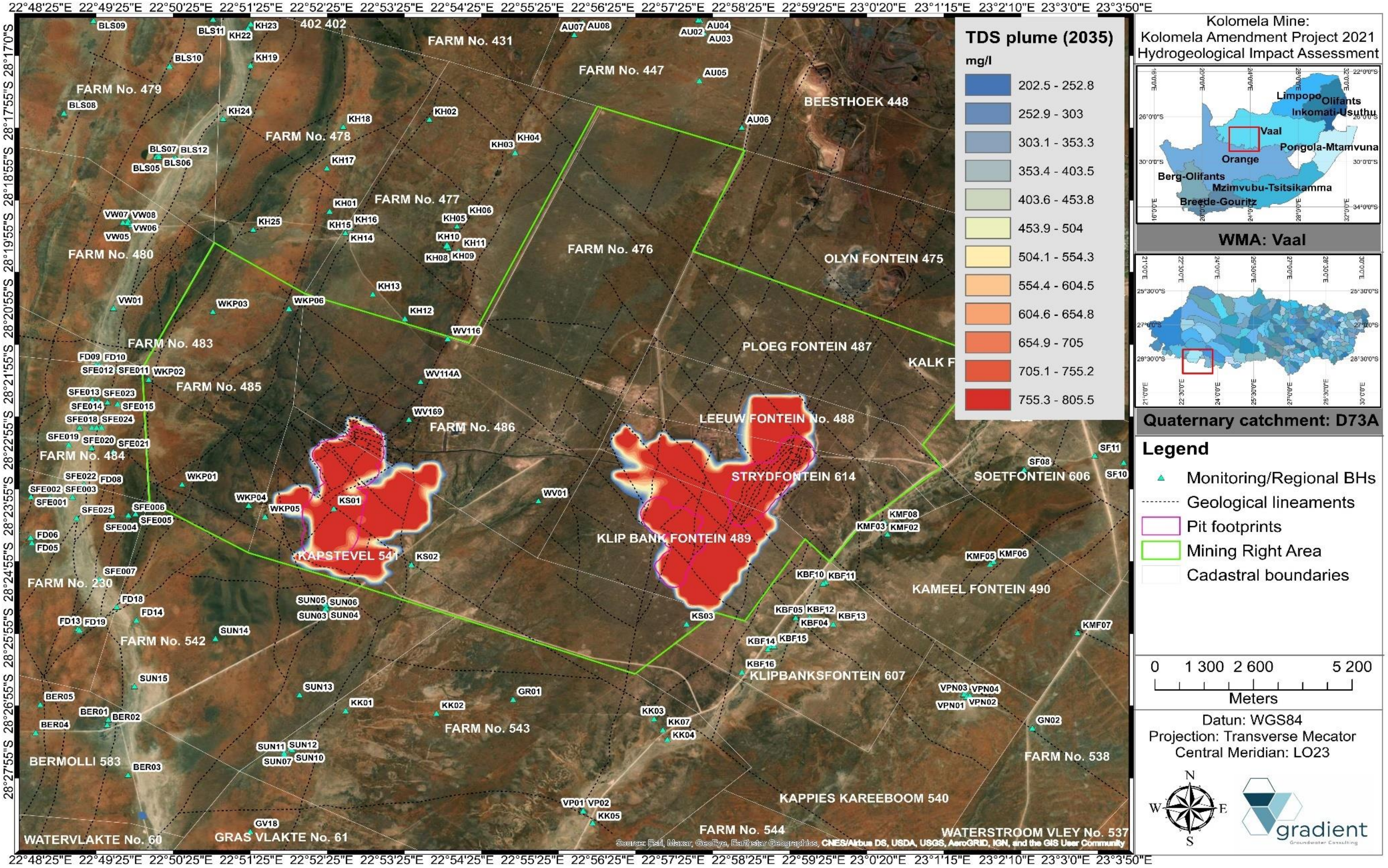


Figure 6.ee: Scenario 05: LOM pollution plume migration within the host aquifer

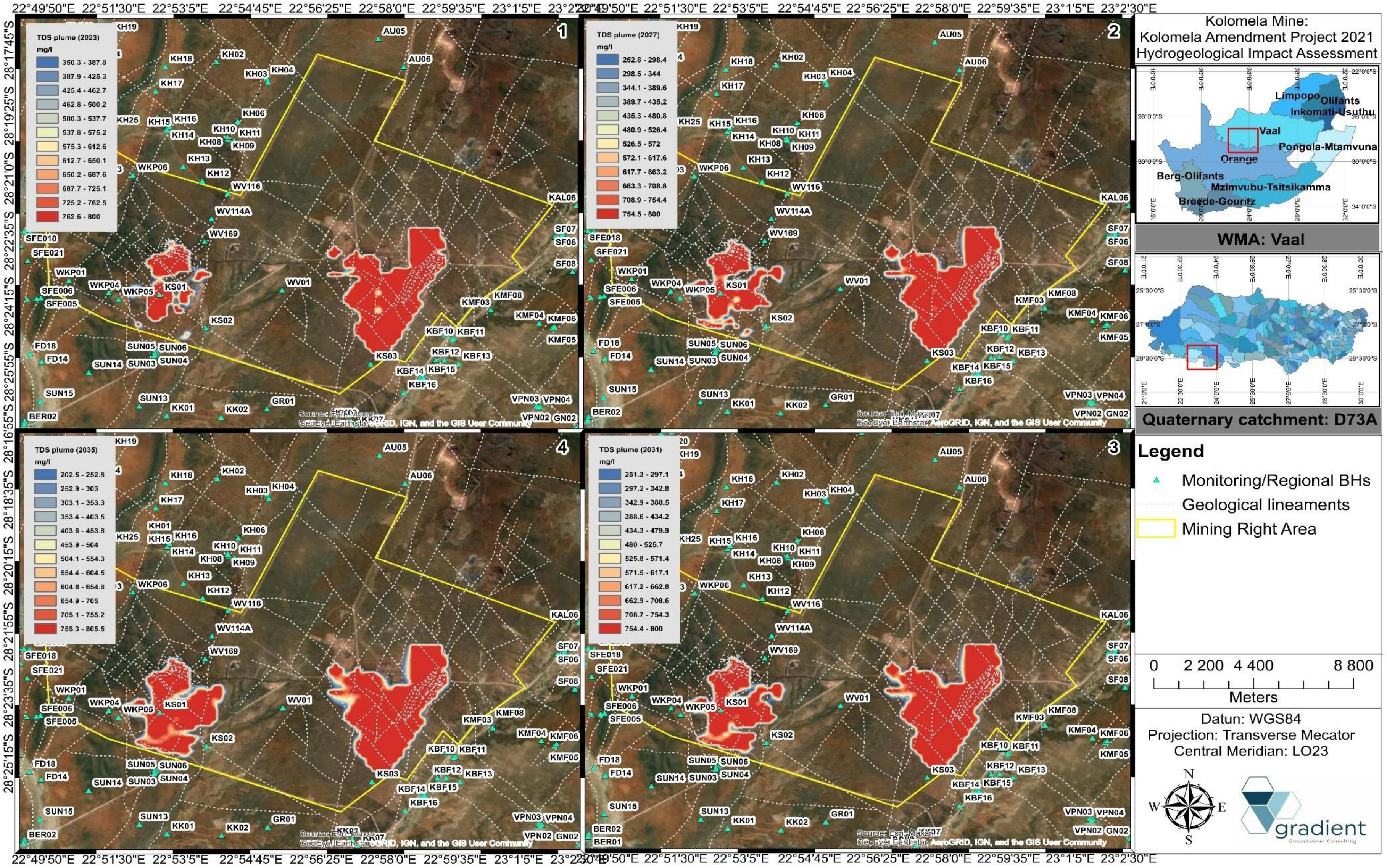


Figure 6.ff: Scenario 05: LOM pollution plume migration within the host aquifer for various operational phases

6.8.2 Scenario 06: Post-closure pollution plume migration

A post-closure scenario was simulated to evaluate the pollution plume migration after discontinuing of mining activities. Figure **6.hh** depicts the simulated pollution plume migration within the host aquifer for both a 50-year as well as 100-year simulation period. The 50-year model simulation suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 34.4 km^2, consisting of 12.6 km^2 (Kapstevel section) and 21.8 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 500 m (Kapstevel section) to 800 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient, with the Kapstevel pollution plume extending slightly beyond the mining right area.

The 100-year model simulation suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 41.5 km^2, consisting of 15.2 km^2 (Kapstevel section) and 26.3 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 1000 m (Kapstevel section) to 2000 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated by the Kapstevel operations reaches down-gradient neighbouring boreholes SUN01, SUN02 and SUN03 situated towards the south as well as WKP05 located to the west, with the Kapstevel pollution plume extending slightly beyond the mining right area.

Figure 6.gg show the mass load contribution of the source term reaches a maximum concentration of 200 mg/ℓ to 270 mg/ℓ to the west and 600.0 mg/ℓ towards the south.

Figure 6.gg: **Time-series graph indicating mass load contribution on down-gradient receptors (Pre-mitigation)**

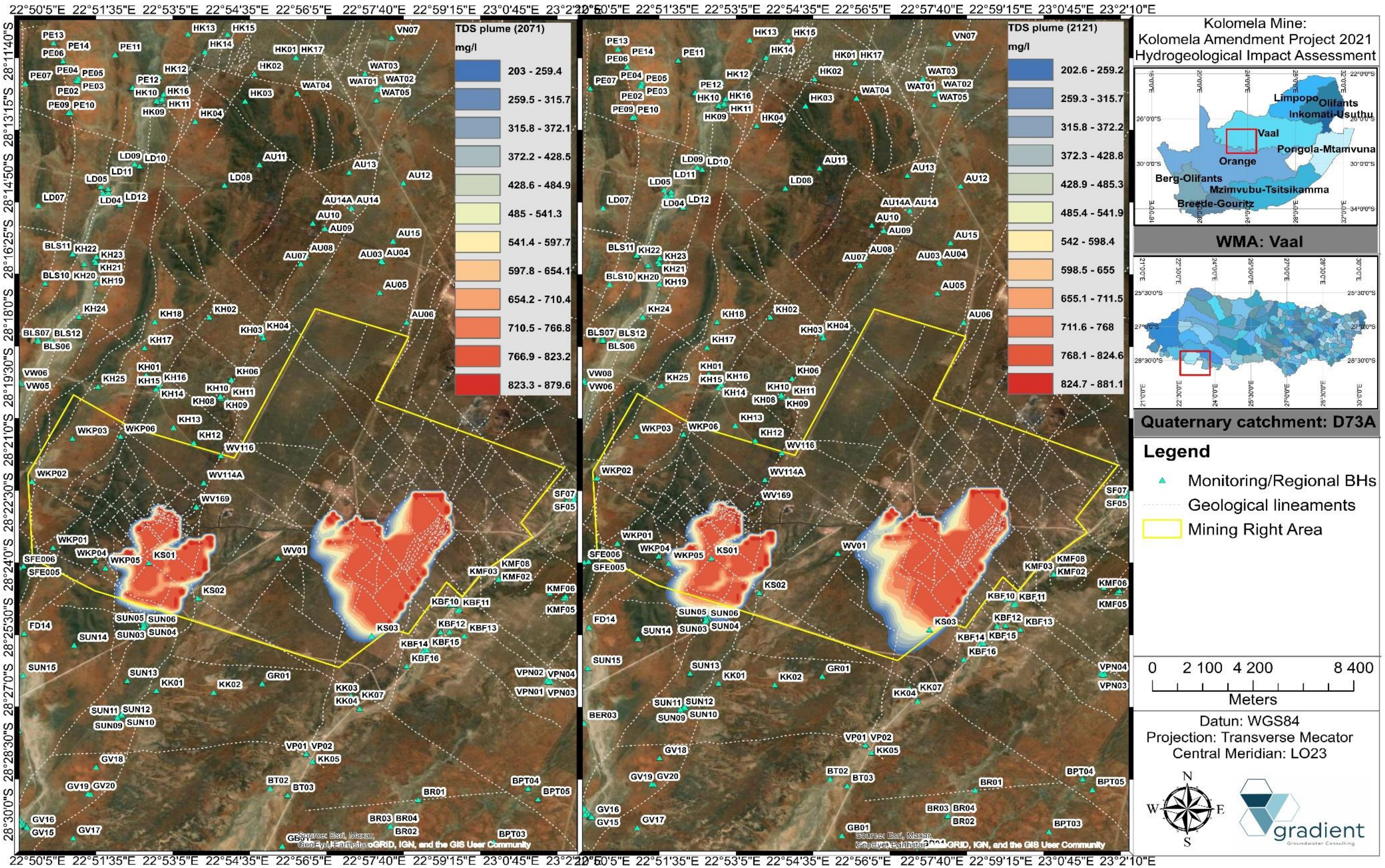


Figure 6.hh: Scenario 06: Post-closure pollution plume migration for a 50-year and 100-year simulation period

6.9 Mitigation and management

Scenario 07 simulated a mitigation alternative which evaluates an existing remedial option to limit and constraint the propagation of the groundwater catchment zone and extent. An active management scenario evaluating the mitigating effect of aquifer artificial recharge which Kolomela Mine is currently undertaking by a series of boreholes was simulated. Model simulations suggest a reduction of between 0 to ~6.0m from the groundwater drawdown within the footprint as depicted in **Figure 6.ii.**

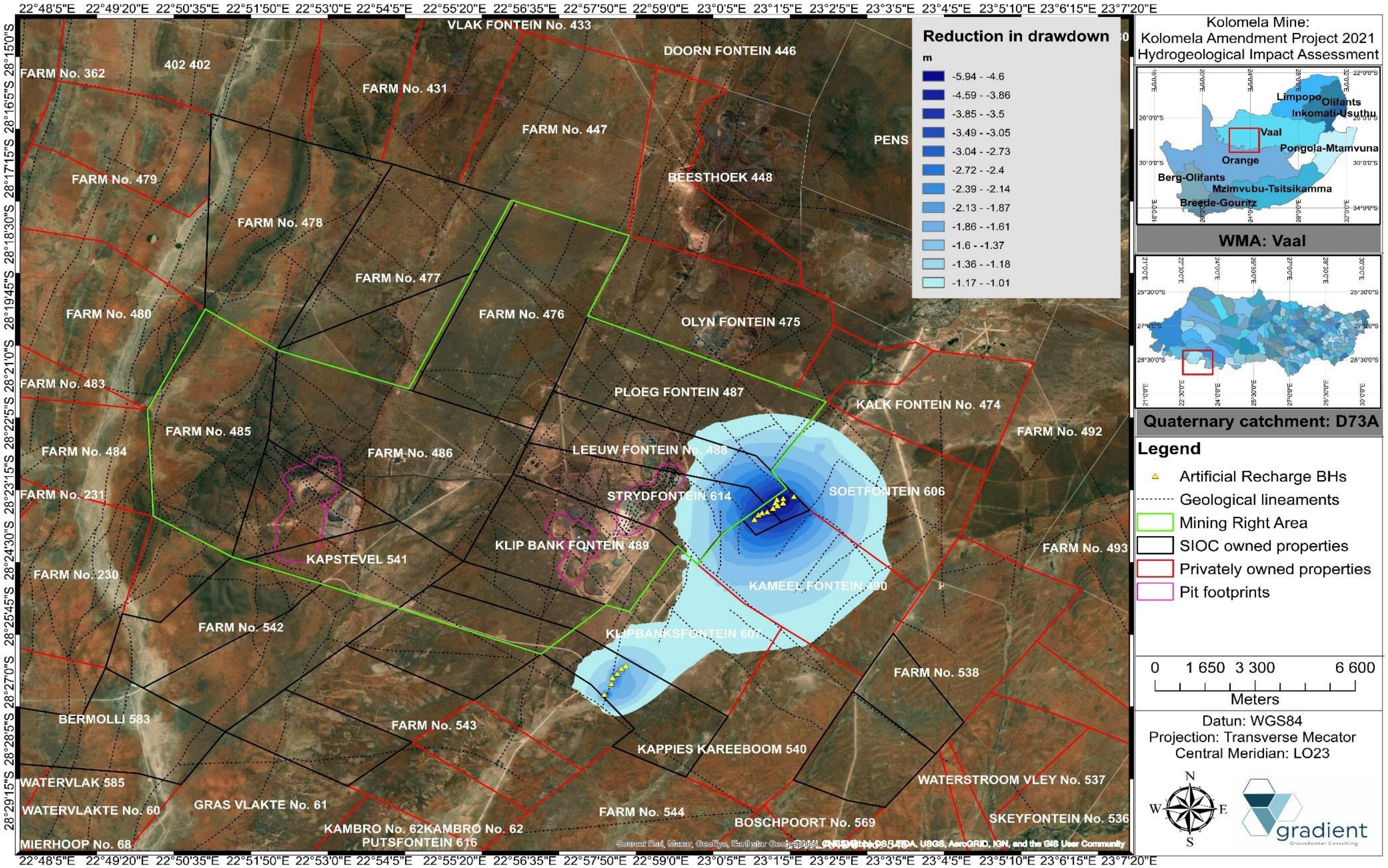


Figure 6.ii: Scenario 07a: Mitigation and management- Evaluating the effect of aquifer artificial recharge by a series of water injection boreholes

7. RISK RATING

7.1 Impact rating method

The numerical groundwater flow and mass transport model was utilised to simulate the potential impacts on groundwater that may result from the simulated scenarios described in **Chapter 6**. There are two primary impacts. These are:

- Dewatering of the aquifer due to inflow of groundwater into the open pits and a regional lowering of the groundwater table; and
- Contamination of the regional groundwater due to seepage of contaminated water from the mine workings and associated infrastructure.

The potential impacts are described for the various mining phases, i.e. construction phase, operational phase, decommissioning and post-closure phases. The final impact of the proposed mining on the groundwater is assessed following the methodology described below.

In order to ensure uniformity, a standard impact assessment methodology has been utilised, so that a wide range of impacts can be compared. The impact assessment methodology makes provision for the assessment of impacts against the following criteria:

- Significance;
- Spatial scale;
- Temporal scale;
- Probability; and
- Degree of certainty.

A combined quantitative and qualitative methodology has been used to describe the impacts for each of the assessment criteria. A summary of each of the qualitative descriptors along with the equivalent quantitative rating scale for each of the criteria is given in **Table 7.a.**

Table 7.a: Quantitative rating and equivalent descriptors for the impact assessment criteria

RATING	SIGNIFICANCE	EXTENT SCALE	TEMPORAL SCALE
1	VERY LOW	*Isolated corridor / proposed corridor*	Incidental
2	LOW	*Study area*	Short-term
3	MODERATE	*Local*	Medium-term
4	HIGH	*Regional / Provincial*	Long-term
5	VERY HIGH	*Global / National*	Permanent

A more detailed description of each of the assessment criteria is given in the following sections.

- **Significance Assessment**

  Significance rating (importance) of the associated impacts embraces the notion of extent and magnitude but does not always clearly define these since their importance in the rating scale is relative. For example, the magnitude (i.e. the size) of area affected by atmospheric pollution may be extremely large (1000km2) but the significance of this effect is dependent on the concentration or level of pollution. If the concentration is great, the significance of the impact would be HIGH or VERY HIGH, but if it is diluted it would be VERY LOW or LOW. Similarly, if 60 ha of a grassland type are destroyed the impact would be VERY HIGH if only 100 ha of that grassland type were known. The impact would be VERY LOW if the grassland type was common. A more detailed description of the impact significance rating scale is given in **Table 7.b** below.

Table 7.b: Description of the significance rating scale

RATING		DESCRIPTION
5	VERY HIGH	Of the highest order possible within the bounds of impacts which could occur. In the case of adverse impacts: there is no possible mitigation and/or remedial activity which could offset the impact. In the case of beneficial impacts, there is no real alternative to achieving this benefit.
4	HIGH	Impact is of substantial order within the bounds of impacts, which could occur. In the case of adverse impacts: mitigation and/or remedial activity is feasible but difficult, expensive, time-consuming or some combination of these. In the case of beneficial impacts, other means of achieving this benefit are feasible but they are more difficult, expensive, time-consuming or some combination of these.
3	MODERATE	Impact is real but not substantial in relation to other impacts, which might take effect within the bounds of those which could occur. In the case of adverse impacts: mitigation and/or remedial activity are both feasible and fairly easily possible. In the case of beneficial impacts: other means of achieving this benefit are about equal in time, cost, effort, etc.
2	LOW	Impact is of a low order and therefore likely to have little real effect. In the case of adverse impacts: mitigation and/or remedial activity is either easily achieved or little will be required, or both. In the case of beneficial impacts, alternative means for achieving this benefit are likely to be easier, cheaper, more effective, less time consuming, or some combination of these.
1	VERY LOW	Impact is negligible within the bounds of impacts which could occur. In the case of adverse impacts, almost no mitigation and/or remedial activity is needed, and any minor steps which might be needed are easy, cheap, and simple. In the case of beneficial impacts, alternative means are almost all likely to be better, in one or a number of ways, than this means of achieving the benefit. Three additional categories should also be used where relevant. They are in addition to the category represented on the scale, and if used, will replace the scale.
0	NO IMPACT	There is no impact at all - not even a very low impact on a party or system.

- **Spatial Scale**

  The spatial scale refers to the extent of the impact i.e. will the impact be felt at the local, regional, or global scale. The spatial assessment scale is described in more detail in **Table 7.c.**

Table 7.c: Description of the spatial rating scale

RATING		DESCRIPTION
5	Global/National	The maximum extent of any impact.
4	Regional/Provincial	The spatial scale is moderate within the bounds of impacts possible, and will be felt at a regional scale (District Municipality to Provincial Level). The impact will affect an area up to 50km from the proposed site / corridor.
3	Local	The impact will affect an area up to 5km from the proposed route corridor / site.
2	Study Area	The impact will affect a route corridor not exceeding the boundary of the corridor / site.
1	Isolated Sites / proposed site	The impact will affect an area no bigger than the corridor / site.

- **Duration Scale**

  In order to accurately describe the impact, it is necessary to understand the duration and persistence of an impact in the environment. The temporal scale is rated according to criteria set out in **Table 7.d.**

Table 7.d: Description of the temporal rating scale

RATING		DESCRIPTION
1	Incidental	The impact will be limited to isolated incidences that are expected to occur very sporadically.
2	Short-term	The environmental impact identified will operate for the duration of the construction phase or a period of less than 5 years, whichever is the greater.
3	Medium term	The environmental impact identified will operate for the duration of life of the project.
4	Long term	The environmental impact identified will operate beyond the life of operation.
5	Permanent	The environmental impact will be permanent.

- **Degree of Probability**

  The probability or likelihood of an impact occurring will be described, as shown in **Table 7.e** below.

Table 7.e: Description of the degree of probability of an impact occurring

RATING	DESCRIPTION
1	Practically impossible
2	Unlikely
3	Could happen
4	Very Likely
5	It’s going to happen / has occurred

- **Degree of Certainty**

  As with all studies it is not possible to be 100% certain of all facts, and for this reason a standard “degree of certainty” scale is used as discussed in **Table 7.f.** The level of detail for specialist studies is determined according to the degree of certainty required for decision-making.

Table 7.f: Description of the degree of certainty rating scale

RATING	DESCRIPTION
Definite	More than 90% sure of a particular fact.
Probable	Between 70 and 90% sure of a particular fact, or of the likelihood of that impact occurring.
Possible	Between 40 and 70% sure of a particular fact, or of the likelihood of an impact occurring.
Unsure	Less than 40% sure of a particular fact or the likelihood of an impact occurring.
Can’t know	The consultant believes an assessment is not possible even with additional research.

- **Quantitative Description of Impacts**

  To allow for impacts to be described in a quantitative manner in addition to the qualitative description given above, a rating scale of between 1 and 5 was used for each of the assessment criteria. Thus, the total value of the impact is described as the function of significance, spatial and temporal scale as described below.

$$\textbf{\textit{Impact Risk}} = \frac{(\text{SIGNIFICANCE} + \textit{Spatial} + \text{Temporal})}{3} \times \frac{\text{Probability}}{5}$$

An example of how this rating scale is applied is shown in **Table 7.g.**

Table 7.g: Example of rating scale

IMPACT	SIGNIFICANCE	SPATIAL SCALE	TEMPORAL SCALE	PROBABILITY	RATING
	LOW	*Local*	Medium Term	*Could Happen*	
Impact to air	2	*3*	3	3	1.6

The impact risk is classified according to 5 classes as described in **Table 7.h.**

Table 7.h: Impact risk classes

RATING	IMPACT CLASS	DESCRIPTION
0.1 – 1.0	1	Very Low
1.1 – 2.0	2	Low
2.1 – 3.0	3	Moderate
3.1 – 4.0	4	High
4.1 – 5.0	5	Very High

7.2 Impact Assessment (sources-pathways-receptors rating)

Sources

Sources considered in the risk rating assessment include the open pits, WRDs as well as the planned co-disposal of fines and waste rock. Due to the inert nature of the material no significant impacts of the mine residues and pit area are expected. Localised impacts are expected on the groundwater levels and flow regime due to the depth of the regional groundwater level in relation to the pit bottom.

Pathways

The groundwater pathways in the aquifers in which the project is situated are typically the contact zones around the calcretes, fractures, faults and bedding planes present in the rocks. Major structures in the Kolomela area trends north to south and follow Maremane Dome trend (anticline). These structures include N-S trending faults, NE/ENE and SE/ESE strike slip faults and dykes.

Receptors

The critical receptors for the project include the shallow and deep aquifers, as such the boreholes (users), identified in the impact zone. Where the upper intergranular aquifer in the Kalahari formations is unsaturated, impacts will be neglible. Since groundwater does not naturally discharge to the ephemeral Groenwaterspruit, it is not considered as a *critical* groundwater (pathway) receptor in this study, neither are the tributaries of the Soutloop drainage channel. However, after significant rainfall events it might be susceptible to contamination via the shallow aquifer overlying the calcrete and will therefore still be assessed as a receptor.

Impact ratings for the different project phases is summarised in **Table 7.i, Table 7.j** and **Table 7.k.**

Table 7.i: Construction phase impact rating

S = severity, SE = spatial extent, D = duration, DP = degree of probability, DC = degree of certainty, IR = impact risk

Potential Environmental Impact	Activity	Environmental Significance score (pm = post mitigation)								Recommended mitigation measures
		Receptor	S	SE	D	DP	DC	IR	IR (pm)	
CONSTRUCTION PHASE										
KAPSTEVEL and KLIPBANKFONTIN OPENCAST PITS										
Change in groundwater levels due to dewatering	During construction, minimal additional impacts in the groundwater system are expected. The main activities that could impact on groundwater in this phase include minor groundwater dewatering during overburden stripping and start of the OC pit. The cone of depression will be localised. The significance of this impact is **very low** for the local streams and aquifers.	**Groenwaterspruit**	1	1	2	3	Pr	0.8	N/A	No mitigation is recommended. Groundwater and surface water levels should be monitored.
		Shallow Intergranular Aquifers	1	1	2	3	Pr	0.8	N/A	
		Deep Fractured Aquifer	1	1	2	2	Pr	0.5	N/A	
Impact of change in groundwater quality	Limited groundwater quality deterioration is expected during the construction phase. Leakages and spillages from machinery might contribute to contamination of the environment. The impact on the streams and aquifers is expected to be **low**.	**Groenwaterspruit**	3	3	3	3	Pr	1.8	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8. Dirty surface run-off should be pumped or transferred passively to dirty water dams. These dams should be lined to ensure no future pollution of groundwater resources.
		Shallow Intergranular Aquifers	1	1	2	3	Pr	0.8	N/A	
		Deep Fractured Aquifer	4	4	4	2	Pr	1.5	N/A	
KAPSTEVEL WRD										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8.

Potential Environmental Impact	**Activity**	**Environmental** **Significance score (pm = post mitigation)**								**Recommended mitigation measures**
		Receptor	**S**	**SE**	**D**	**DP**	**DC**	**IR**	**IR (pm)**	
Change in groundwater quality	Very low impact on groundwater quality from Kapstevel WRD as ore is not yet being mined during the construction phase. Topsoil and overburden storage (stockpiling) only	**All receptors**	1	1	2	2	Pr	0.5	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8.

Table 7.j: Operational phase impact rating

S = severity, SE = spatial extent, D = duration, DP = degree of probability, DC = degree of certainty, IR = impact risk

Potential Environmental Impact	Activity	Environmental Significance score (pm = post mitigation)								Recommended mitigation measures
		Receptor	S	SE	D	DP	DC	IR	IR (pm)	
OPERATIONAL PHASE										
KAPSTEVEL OPENCAST PIT										
Change in groundwater levels due to dewatering	During the operational phase of the mining project, groundwater can seep into the opencast pit. This water will then be pumped out creating a cone of depression which may negatively impact on groundwater yield to the aquifers and the river. It is expected that the groundwater drawdown will range between 1.0m (regional) to >280.0 mbg within the pit footprint There is no groundwater contribution to baseflow and the rivers only flows during extreme rain events, as such neglible (low) impact is expected on the river. The simulated groundwater drawdown zone extends beyond the mining right area stretching a maximum distance of ~8.0km towards the southeast and ~17.0 km in a general north to north-eastern direction. The groundwater drawdown observed in the north-eastern parts of the greater study area can possibly be attributed to existing mine dewatering activities within this area which has been active the last approximately 100 years. The significance of this impact is **low** for the river and **high** for the aquifers	**Groenwaterspruit**	3	3	4	3	Pr	2.0	N/A	Groundwater and surface water levels should be monitored.
		Shallow Intergranular Aquifers	3	3	4	5	D	3.3	N/A	
		Deep Fractured Aquifer	3	3	4	5	D	3.3	N/A	
Impact of groundwater quality changes due to mining	Initially groundwater flowing into the pit should be of good quality.	**Groenwaterspruit**	2	2	3	3	Pr	1.4	N/A	Monitoring is recommended according to the monitoring plan in Chapter 8.

	The total dissolved solids and other constituents in the groundwater can start increasing due to groundwater contact with mining operations. Water quality in the mine can slowly deteriorate. Spillages and the use of explosives may also contribute to contamination. The dewatering cone will tend to limit the spread of any contamination. The significance of this impact is **low** for the streams and shallow aquifer and moderate for the deep aquifers.	**Shallow Intergranular Aquifers**	2	2	3	3	Pr	1.4	N/A	Dirty surface run-off should be pumped or transferred passively to dirty water dams. These dams should be lined to ensure no future pollution of groundwater resources.
		Deep Fractured Aquifer	4	4	3	3	Pr	2.2	N/A	
KAPSTEVEL WRD										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8.
Impact on groundwater quality	Without any remedial measures implemented, the WRD can result in contamination of downstream receptors. However, due to the inert nature of the waste rock and based on existing monitoring data it is unlikely. The pollution plume extent emanating from the WRD covers a total area of approximately 10.8km^2 (Kapstevel section) and the plumes does not reach any private boreholes. Without remedial options, the impact is seen as **low** for the drainages and shallow aquifer and moderate for the deep aquifer. With mitigation it is estimated to be **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	Dirty surface run-off should be pumped to dirty water dams. Monitoring is recommended according to the monitoring plan in Chapter 8.
		Shallow Intergranular Aquifers	3	3	4	3	Pr	2.0	1.0	
		Deep Fractured Aquifer	4	4	4	3	Pr	2.4	1.0	
KLIPBANKFONTEIN and LEEUWFONTEIN OPENCAST PITS										
Change in groundwater levels due to dewatering	During the operational phase of the mining project, groundwater can seep into the opencast pit. This water will then be pumped out creating a cone of depression which may negatively impact on groundwater yield to the aquifers and the river It is expected that the groundwater drawdown will range between 1.0 m (regional) to >180.0 mbg within the pit footprint. There is no groundwater contribution to baseflow and the rivers only flows during extreme rain events, as such neglible (low) impact is expected on the river.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	N/A	Groundwater and surface water levels should be monitored.
		Shallow Intergranular Aquifers	3	3	4	5	D	3.3	N/A	

	The simulated groundwater drawdown zone extends beyond the mining right area stretching a maximum distance of ~8.0km towards the southeast and ~17.0 km in a general north to north-eastern direction. The groundwater drawdown observed in the north-eastern parts of the greater study area can possibly be attributed to existing mine dewatering activities within this area which has been active the last approximately 100 years. The significance of this impact is **low** for the river and **high** for the aquifers	**Deep Fractured Aquifer**	3	3	4	5	D	3.3	N/A	
Impact of groundwater quality changes due to mining	Initially groundwater flowing into the pit should be of good quality. The total dissolved solids and other constituents in the groundwater can start increasing due to groundwater contact with mining operations. Water quality in the mine can slowly deteriorate. Spillages and the use of explosives may also contribute to contamination. The dewatering cone will tend to limit the spread of any contamination. The pollution plume extent emanating from the WRD covers a total area of approximately 16.5 km^2 and the plume does not reach any private boreholes. The significance of this impact is **low** for the river and shallow aquifers and moderate for the deep aquifers.	**Groenwaterspruit**	2	2	3	3	Pr	1.4	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8. Dirty surface run-off should be pumped or transferred passively to dirty water dams
		Shallow Intergranular Aquifers	2	2	3	3	Pr	1.4	N/A	
		Deep Fractured Aquifer	4	4	3	3	Pr	2.2	N/A	
LEEUWFONTEIN NORTH WRD AND CO-DISPOSAL FACILITY										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. Groundwater and surface water levels should be monitored.
Impact on groundwater quality	Without any remedial measures implemented, the WRD and co-disposal facilities can result in contamination of downstream receptors. However, due to the inert nature of the waste rock and based on existing monitoring data it is unlikely. Without remedial options, the impact is seen as **low** for the drainages and shallow aquifer and moderate for the deep aquifers. With mitigation it is estimated to be **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	Dirty surface run-off from the WRD and fines should be pumped to dirty water dams, which should be lined.
		Shallow Intergranular Aquifers	3	3	4	3	Pr	2.0	1.0	
		Deep Fractured Aquifer	4	4	4	3	Pr	2.4	1.0	

LEEUWFONTEIN SOUTH WRD										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. Groundwater and surface water levels should be monitored.
Impact of groundwater quality	Without any remedial measures implemented, the WRD and co-disposal facilities can result in contamination of downstream receptors. However, due to the inert nature of the waste rock and based on existing monitoring data it is unlikely. Without remedial options, the impact is seen as **low** for the drainages and shallow aquifer and moderate for the deep aquifer. With mitigation it is estimated to be **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	Dirty surface run-off from the WRD should be pumped to dirty water dams, which should be lined.
		Shallow Intergranular Aquifers	3	3	4	3	Pr	2.0	1.0	
		Deep Fractured Aquifer	4	4	4	3	Pr	2.4	1.0	

Table 7.k: Post closure phase impact rating

Potential Environmental Impact	**Activity**	**Environmental** **Significance score (pm = post mitigation)**								**Recommended mitigation measures**
		Receptor	**S**	**SE**	**D**	**DP**	**DC**	**IR**	**IR (pm)**	
POST CLOSURE PHASE										
KAPSTEVEL OPENCAST PIT										
Impact of flooding and possible decanting of mine	The flooding of the mine is dependent on a number of factors including permeability and preferential flow zones such as geological lineaments.	**Groenwaterspruit**	3	3	4	2	Pr	1.3	0.8	Increasing groundwater levels and groundwater quality should be monitored.

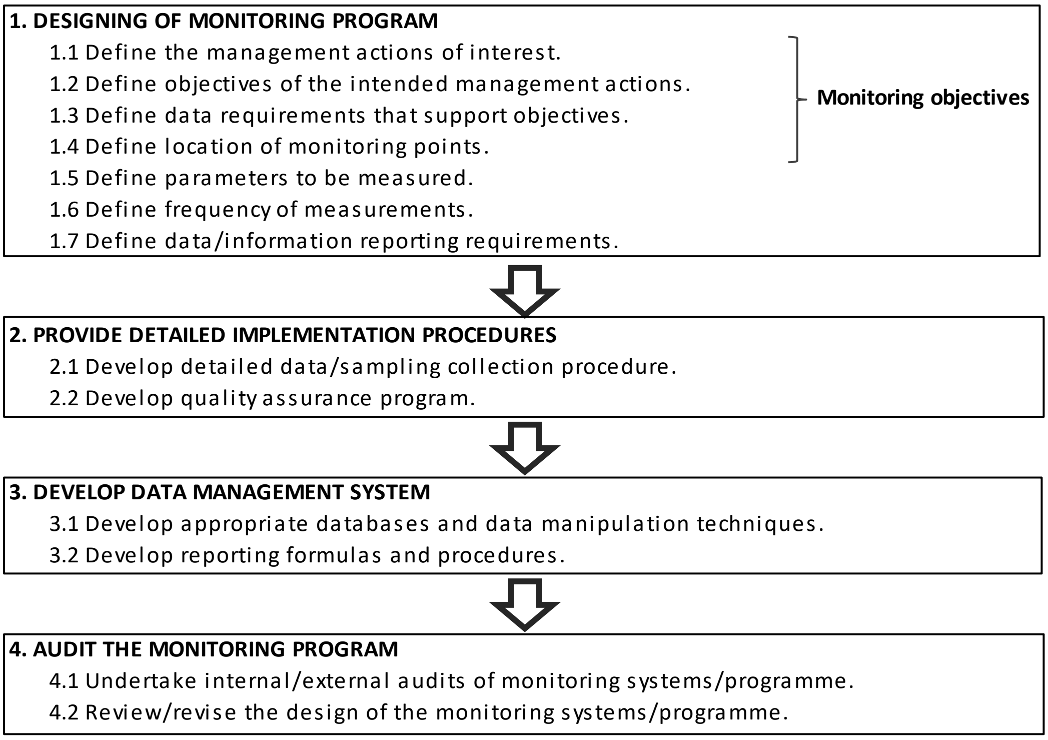
	It is expected that poorer quality groundwater will be present on the mine horizon when total flooding is completed.. It can be observed the potential decant elevations for all the planned pit footprints is situated from 20.0 m (Kapstevel Pit) to > 50.0m (Leeuwfontein and Klipbankfontein Pits) above the pre-mining and calibrated groundwater level and as such it is highly unlikely that decant will occur. It is estimated that the recovery period i.e. time remaining mine voids will take to fill will be >100 years and beyond the simulation period The pre-mitigation rating for the aquifers and river are rated as **low** decant is unlikely to occur. Post mitigation rating for all three are **very low**.	**Shallow Intergranular Aquifers**	3	3	4	2	Pr	1.3	0.8	Rehabilitation alternatives should be such that effective pit infiltration is minimised.
		Deep Fractured Aquifer	3	3	4	2	Pr	1.3	0.8	
KAPSTEVEL WRD										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8
Impact on groundwater quality	The 100-year model simulation suggests the pollution plume extent emanating from the Kapstevel waste body footprint covers a total area of approximately 15.2 km^2 migrating a total distance of approximately 1000m. The mass load contribution of the source term ranges from 25.0 – 35.0 mg/ℓ . The pre-mitigation rating for all receptors is seen as **low** whereas the post-mitigation impact for all three is **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	
		Shallow Aquifer	3	3	4	3	Pr	2.0	1.0	
		Fractured Aquifer	3	3	4	3	Pr	2.0	1.0	
KLIPBANKFONTEIN and LEEUWFONTEIN OPENCAST PITS										
Impact of flooding and possible decanting of mine	The flooding of the mine is dependent on a number of factors including permeability and	**Groenwaterspruit**	3	3	4	2	Pr	1.3	0.8	No mitigation is recommended. Groundwater

	preferential flow zones such as geological lineaments. It is expected that poorer quality groundwater will be present on the mine horizon when total flooding is completed.. It can be observed the potential decant elevations for all the planned pit footprints is situated from 20.0 m (Kapstevel Pit) to > 50.0m (Leeuwfontein and Klipbankfontein Pits) above the pre-mining and calibrated groundwater level and as such it is highly unlikely that decant will occur. It is estimated that the recovery period i.e. time remaining mine voids will take to fill will be >100 years and beyond the simulation period The pre-mitigation rating for the aquifers and river are rated as **low** decant is unlikely to occur. Post mitigation rating for all three are **very low**.	**Shallow Intergranular Aquifers**	3	3	4	2	Pr	1.3	0.8	and surface water levels should be monitored.
		Deep Fractured Aquifer	3	3	4	2	Pr	1.3	0.8	
LEEUWFONTEIN NORTH WRD AND CO-DISPOSAL FACILITY										
Change in groundwater levels due to dewatering	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. Groundwater and surface water levels should be monitored.
Impact on groundwater quality	The 100-year model simulation suggests the pollution plume extent emanating from the existing and proposed Leeuwfontein & Klipbankfontein waste bodies at footprints covers a total area of approximately 26.3 km^2 migrating a total distance of approximately 2000m. The mass load contribution of the source term ranges from 25.0 – 35.0 mg/ℓ. The pre-mitigation rating for all receptors is seen as **low** whereas the post-mitigation impact for all three is **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	No mitigation is recommended. However, monitoring is recommended according to the monitoring plan in Chapter 8.
		Shallow Intergranular Aquifers	3	3	4	3	Pr	2.0	1.0	
		Fractured Aquifer	3	3	4	3	Pr	2.0	1.0	
LEEUWFONTEIN SOUTH WRD										
Change in groundwater	No impact on groundwater yield from WRD	**All receptors**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No mitigation is recommended. However,

levels due to dewatering										monitoring is recommended according to the monitoring plan in Chapter 8
Impact on groundwater quality	The 100-year model simulation suggests the pollution plume extent emanating from the existing and proposed Leeuwfontein & Klipbankfontein waste bodies at footprints covers a total area of approximately 26.3 km^2 migrating a total distance of approximately 2000m. The mass load contribution of the source term ranges from 25.0 – 35.0 mg/ℓ . The pre-mitigation rating for all receptors is seen as **moderate** whereas the post-mitigation impact for all three is **very low**.	**Groenwaterspruit**	3	3	4	3	Pr	2.0	1.0	.
		Shallow Intergranular Aquifers	3	3	4	3	Pr	2.0	1.0	
		Fractured Aquifer	3	3	4	3	Pr	2.0	1.0	

8. GROUNDWATER MONITORING PLAN

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 below used as guideline for the development of this water monitoring program.



1. DESIGNING OF MONITORING PROGRAM

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

Monitoring objectives

2. PROVIDE DETAILED IMPLEMENTATION PROCEDURES

2.1 Develop detailed data/sampling collection procedure.
2.2 Develop quality assurance program.

3. DEVELOP DATA MANAGEMENT SYSTEM

3.1 Develop appropriate databases and data manipulation techniques.
3.2 Develop reporting formulas and procedures.

4. AUDIT THE MONITORING PROGRAM

4.1 Undertake internal/external audits of monitoring systems/programme.
4.2 Review/revise the design of the monitoring systems/programme.

8.1 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:

- To provide reliable groundwater data that can be used for management purposes.
- The early detection of changes in groundwater quality and quantity.
- Provide an on-going performance record on the efficiency of the Water Management Plan.
- Obtain information that can be used to redirect and refocus the Water Management Plan.
- Determine compliance with environmental laws, standards and the water use licence and other environmental authorizations.

8.2 Monitoring network

Kolomela mine already has an extensive monitoring network which covers much of the surrounding area. Newly proposed monitoring localities are conceptual only and should be refined by means of a geophysical survey in order to delineate potential preferential groundwater flow pathways. It is advised that the monitoring programme be reviewed every 2 years as some boreholes may have been damaged or destroyed by surface activities.

8.3 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[6]. Chemical variables to form part of the sampling run are listed below.

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

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).

8.4 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. It is important that the proposed monitoring program be implemented 12 months prior to any construction activities in order to establish a regional background to be used as impact threshold. Water quality reports summarising monitoring results should be submitted to the Regional Head: DWS within timeframes as stipulated in the WUL conditions.

8.5 Pit dewatering volumes

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

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[6] 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.

9. GROUNDWATER MANAGEMENT PLAN

9.1 Groundwater Management Objectives

Construction Phase

Impacts are not foreseen for the construction phase, as it is unlikely that the groundwater table will be intersected during pre-stripping of the Kalahari Sand and calcretes.

Operational Phase

There are no private user boreholes in close proximity to the proposed/existing Kolomela site, as such significant impacts on groundwater users are not expected as a result of dewatering or other operational phase activities. However, to prevent the reduction in groundwater yield in private boreholes the following are recommended:

- Clean and dirty runoff should be separated, and dirty water should be contained in an adequately sized Pollution Control Dam (PCDs) or Return Water Dam as per GN704 regulations.
- Clean runoff should be released back into the catchment.
- Groundwater levels should be monitored on-site as well as on private farms around the mine.
- Results from ongoing groundwater monitoring should be used to update the mine water balance and groundwater model, as required.
- A replacement water supply strategy needs to be prepared for impacted groundwater users.

Closure Phase

- Groundwater monitoring results should be used to plan for mine closure.
- Ongoing groundwater monitoring after mining has ceased for a specific time period to establish post-closure trends.
- The numerical groundwater flow and transport model should be updated prior to closure to confirm predicted impacts.
- Based on results from the model update a post-closure monitoring programme may need to be established.

10. CONCLUSIONS AND RECOMMENDATIONS

The purpose of the study was to provide a regional assessment of the potential future impacts associated with the mine. The results from the baseline hydrogeological assessment and numerical groundwater flow and transport model have been used to conclude on the predicted groundwater related impacts at Kolomela mine. Mitigation measures were also investigated.

Based on the hydrogeological map and data obtained from previous studies, two main aquifers are typically present in the project area. These are:

- The first, upper, **intergranular, unconfined to semi-confined Kalahari formation aquifer**, comprising mainly of calcareous sand and silt which extends down to the more competent calcretes. The calcretes retards groundwater flow and groundwater recharge because of its low permeability. Yields from calcrete are low, exceptions are around Groenwaterspruit (east) and Lucasdam Vlei (West) both low lying drainage areas with higher recharge due to seepage and increased hydraulic conductivity due to paleo channels comprising of coarse gravels.
- A **deeper, unweathered fractured rock (second porosity) aquifer**, is the major aquifer system within Transvaal/Griqualand West sequences where water occurrence is mainly within fissures and fractures in the brecciated BIFs where mineralization and preservation of ore bodies occurred through folding, thrusting, fracturing and sinkholes. Yields can vary from 1 – 80 L/s. Inherently, these types of aquifers are heterogeneous and aquifer parameters are variable. The Ongeluk Formation is generally considered to be a low-yielding aquifer. A dolomitic aquifer is also found in which water occurrence is mostly restricted to karstic compact carbonate rock. The dolomitic aquifers also fall under the secondary, fractured rock aquifer. Exploration in the dolomites indicated yields of 2 – 4 L/sec. However, records also indicate yields in the Kolomela dolomitic aquifer of up to 80 L/s.

Based on Vegter (1995) the recharge estimated groundwater recharge for the study area is in the order of 2.7% (8 mm/annum) of MAP. The chloride mass-balance method was used to determine how the recharge values obtained agree with those from the previous investigations at 2.9% (9mm/annum).

Spruite and drainage channels do not flow regularly and is probably disconnected from the regional aquifer within the vicinity of the proposed Mine. No water losses occur from the non-perennial rivers into the model domain, but groundwater on either side of the drainage channels might discharge into it as a function of the calculated gradients. Where the Kalahari formation aquifer is predominantly unsaturated the regional drainages and discharge channels most likely only yield water episodically after rainfall events. The Groenwaterspruit is known to yield water throughout the year. Groundwater seepage and pit inflows may still occur from the intergranular aquifer during the rainy season as a result of the recharge of rainwater that equate to river flow. Aquifer classification indicates that the aquifers at Kolomela Mine mostly classify as minor-aquifer systems as a result of their low exploitable potential. The Kolomela dolomitic aquifer is the exeption and is classed as a major aquifer system. As such, medium to high level protection is required.

A numerical groundwater flow and contaminant transport model were developed to quantify and qualify potential impacts and to serve as a tool to evaluate various water management options and scenarios.

Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Leeuwfontein South Pit is approximately 2.61e^{+04} m^3/d (1088.0 m^3/h) with a maximum groundwater ingress of approximately ~1800.0 m^3/h for the duration of the simulation period.

Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Kapstevel Pit is approximately 1.67e^{+04} m^3/d (~700.0 m^3/h) with a maximum groundwater ingress of approximately ~1600.0 m^3/h for the duration of the simulation period.

Model simulations suggest the average groundwater ingress and pit dewatering volumes for the proposed Klipbankfontein Pit is approximately 2.77e^{+03} m^3/d (~115.0 m^3/h) with a maximum groundwater ingress of approximately ~240.0 m^3/h for the duration of the simulation period.

It is expected that the groundwater drawdown within existing monitoring as well as neighbouring and private boreholes will range between 3.0m (regional) to 50.0-100 mbsl within close proximity to the pit footprints.

The groundwater capture zone i.e. zone of influence extent will cover an estimated footprint of approximately 509.0 km² at the mine end of life period. It should be noted that the simulated groundwater drawdown zone extends beyond the mining right area stretching a maximum distance of ~8.0 km towards the southeast and ~17.0 km in a general north to north-eastern direction. The groundwater drawdown observed in the north-eastern parts of the greater study area can possibly be attributed to existing mine dewatering activities within this area which has been active the last approximately 100 years.

It should be noted that the majority of properties being intercepted by the drawdown zone are owned by SIOC, however there are privately owned properties being impacted on as well especially towards the northern and eastern perimeters. Furthermore, it should be noted that the zone of impact does reach various boreholes which is current being utilised.

A mine post-closure scenario was simulated wherein the hydraulic head recovery within the groundwater drawdown zone of influence was evaluated. It can be observed the potential decant elevations for all the planned pit footprints is situated from 20.0 m (Kapstevel Pit) to > 50.0 m (Leeuwfontein and Klipbankfontein Pits) above the pre-mining and calibrated groundwater level and as such it is highly unlikely that decant will occur. It is estimated that the recovery period i.e. time remaining mine voids will take to fill will be >100 years and beyond the simulation period. A mine post-closure scenario was also conducted wherein the pit footprints were not backfilled and acted as permanent sinks due to the high evaporation rate expected. It is evident that the highest groundwater elevation will not extend beyond 1180.0 mamsl and will reach equilibrium between 6 to 50 years from cessation of mining activities.

Groundwater level recovery within impacted monitoring as well as neighbouring and private boreholes will be a function of the proximity and distance to the dewatering activities.

Mass transport model simulations predicts that the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 27.3 km^2, consisting of 10.8 km^2 (Kapstevel section) and 16.5 km^2 (Klipbankfontein and Leeuwfontein sections). It is observed that the generated pollution plume does not migrate in the expected down-gradient direction due to the negative hydraulic gradient caused by the operational pit dewatering activities constraining plume propagation. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient and is limited to the mining right area.

A 50-year post-closure scenario suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 34.4 km^2, consisting of 12.6 km^2 (Kapstevel section) and 21.8 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 500 m (Kapstevel section) to 800 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated does not reach any neighbouring and privately owned boreholes or drainages situated down-gradient, with the Kapstevel pollution plume extending slightly beyond the mining right area.

The 100-year model simulation suggests the pollution plume extent emanating from the existing and proposed waste body footprints covers a total area of approximately 41.5 km^2, consisting of 15.2 km^2 (Kapstevel section) and 26.3 km^2 (Klipbankfontein and Leeuwfontein sections) migrating a total distance of approximately 1000 m (Kapstevel section) to 2000 m (Klipbankfontein and Leeuwfontein sections) in a general south to southwestern direction. The simulation indicates that the pollution plume generated by the Kapstevel operations reaches down-gradient neighbouring boreholes SUN01, SUN02 and SUN03 situated towards the south as well as WKP05 located to the west, with the Kapstevel pollution plume extending slightly beyond the mining right area. The mass load contribution of the source term reaches a maximum concentration of 200 mg/ℓ to 270 mg/ℓ to the west and 600.0 mg/ℓ towards the south.

The impact assessment (impact ratings) indicates moderate to high impacts on local and regional aquifers as a result of mine dewatering impacts from the Klipbankfontein, Leeuwfontein and Kapstevel opencast pits. Water quality impacts are rated as being low to moderate from the waste rock dumps and planned co-disposal facilities.

<u>The following recommendations are proposed:</u>

i. It is recommended that mitigation and management measures as set out in this report should be implemented as far as practically possible.
ii. It is recommended that the monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system.
iii. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Human Settlements, Water and Sanitation.
iv. It is recommended that the numerical groundwater flow and transport model be updated every two (2) years, also when (if) changes are made to the mine plan (layout and scheduling). Groundwater monitoring should also be conducted as per the current monitoring plan or agreement.

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