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D3 ENERGY SOUTH AFRICA GAS PRODUCTION RIGHT 16 EIA HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

September 2026

Conducted on behalf of:

Environmental Impact Management Services (Pty) Ltd

Compiled by:

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- I declare that there are no circumstances that may compromise my objectivity in performing such work.
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- All the particulars furnished by me in this form are true and correct.



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Executive summary

Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd to conduct a hydrogeological baseline investigation and groundwater impact assessment in support of an Environmental Impact Assessment authorisation process to be followed for the proposed D3 Energy (Pty) Ltd gas production right.

Study objectives

The objective of this investigation is to determine the status quo of the regional groundwater system and quantify and qualify potential impacts from the proposed gas production and extraction on sensitive environmental receptors.

Regional setting and site locality

The proposed gas production right and greater study area falls within the Matjhabeng and Masilonyana Local Municipalities and the Lejweleputswa District Municipality, covering a total footprint of ~144.40km², stretching over various farms which are situated between the towns of Virginia (~11.0km to the northwest), Ventersburg (~13.0km to the northeast), Winburg (~22.0km to the southeast) and Theunissen (~21.0km to the southwest), Free State Province of South- Africa.

Project description

The proposed production right development will target helium and methane, and will consist of up to 43 production wells, gas gathering pipelines, a helium recovery and gas processing plant including associated infrastructure.

Topography

The topography of the greater study area has a generally flat to gently undulating topography becoming more undulating and hillier towards the east and can be classified as a lowland with hills. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features. Elevations generally increase towards the southern and central parts of the study area, with the highest on-site elevation recorded as 1467.0mamsl also shaping the local water divide. The lowest on-site elevation is recorded as 1320.0mamsl forming part of the drainage system situated on the northern edge of the study area.

Drainage and catchment

The greater study is situated in several quaternary catchments of the Vaal WMA which include C42G, C42H and C42K. The hydrology of the region is characterised by predominately perennial watercourses with primary rivers in and around the study area the Merriespruit, Steenbokspruit and Maselspruit, draining the northern section of the production right area in a general northwestern direction, forming a confluence with the Sand River flowing on the northern perimeter in a general southwestern direction. The southern section of the production right area is drained by the Doringspruit as well as Schoemanspruit flowing in a general western direction.

Climate

The mean annual precipitation for the study area is estimated at approximately 535.98 mm/a, with the 5th percentile of the dataset, which approximately represents a 1:20 year drought, and is calculated as 353.24 mm/a. The 95th percentile of the dataset, which approximately represents the 1:20 year flood, is calculated as 774.02 mm/a. The study area falls within evaporation zone 19C with the mean annual evaporation ranging between 1 560 and 1 600 mm/a.

Regional geology

The regional geology consists of various lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort Group within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes.

A high resolution airborne magnetic survey identified various southwest-northeast as well as southeast-northwest striking magnetic lineaments inferred as dolerite dykes towards the western and central zones of the production right area. Regional fault zones include the known Virginia and Ventersburg fault lines. Structural analysis also suggests a potential east-west striking fault zone towards the central zone of the production right area. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

Regional hydrogeology

The study area is predominantly underlain by a Class d2 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.1 and 0.5 L/s) with host aquifers consisting primarily of arenaceous and argillaceous strata. It should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however, will not only be multi-layered, but also multi-porous with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. According to Vegter's groundwater regions delineated the study area can be classified as falling under the Northeastern Upper Karoo Region. Groundwater Region 30 comprises of mudstone and sandstone (with dolerite dyke and sill intrusions) of the Adelaide and Tarkastad Subgroups within the Beaufort Group of the Karoo Supergroup. The maximum aquifer thickness i.e., shallow, intergranular aquifer system within the Northeastern Upper Karoo

Region is 20 – 30m with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level.

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

- i. **A shallow Quaternary (perched and unconfined) aquifer:** These aquifers consist of recent types of sediments and are characteristically primary porosity aquifers, such that groundwater flow occurs in the pore spaces between soil and sediment particles. These aquifers are formed by alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth. Clay lenses in the soil and unsaturated zones may cause local, perched water tables which occur above the regional water table.
- ii. **A shallow, intergranular aquifer within the Beaufort Group and Karoo Dolerite Suite:** These aquifers occur in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually, these aquifers can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. In secondary porosity aquifers, groundwater flow occurs along fractures, while water is stored within the rock matrix. Due to higher effective porosity (n) this aquifer is more susceptible to impacts from contaminant sources compared to confined aquifers.
- iii. **A deeper, fractured aquifer within Beaufort Group and Karoo Dolerite Suite formations:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured mudstone and siltstone sequences as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

Surface water and groundwater interaction

Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. Regional drainages can be generally classified as influent or gaining stream systems as the groundwater head elevation of the water table in the vicinity of the stream is higher than the altitude of the stream bed and, accordingly, there definitely exists groundwater discharge as baseflow to local drainages. The alluvial associated with the floodplains of major drainages forms a primary aquifer and is directly connected with surface water resources, especially during high flow conditions.

Groundwater recharge

An approximation of recharge for the study area is estimated at ~3.29% of MAP i.e. ~17.65 mm/a.

Site characterization

In order to gather representative on-site aquifer data and relevant information a site characterisation phase was conducted where new monitoring boreholes i.e., site characterisation boreholes were established and subjected to aquifer tests to obtain site representative aquifer parameters and hydraulic properties.

A geophysical survey was conducted wherein the sub-strata in the direct vicinity of the study area was investigated by applying the magnetic and electro-magnetic geophysical exploration techniques which were applied according to traverse array design for delineation of sub-surface lineaments and identification of potential preferential groundwater flow pathways to be targeted for site characterisation and monitoring boreholes.

Following the geophysical survey, four drilling targets were identified and incorporated as part of the drilling program. These boreholes were drilled to a depth of 120.0mbgl targeting the intergranular and fractured aquifer units.

Following the drilling phase, the newly established site characterisation boreholes were subjected to hydraulic testing in order to supplement published aquifer parameter data that was available for the site conditions and setting. The site characterisation phase indicates that the local transmissivity values range between 0.04m²/d to 0.27m²/d with a mean value of 0.11m²/d.

Site investigation

A hydrocensus user survey within the greater study area was conducted where relevant hydrogeological baseline information was gathered. A total of 62 geosites were visited and recorded as part of the hydrocensus user survey which includes surface water and groundwater receptors i.e., boreholes, artesian wells, wind pumps as well as surface water features and are largely applied for livestock watering and domestic water supply purposes.

Groundwater flow evaluation

From evaluation of the hydrocensus and site characterisation data, it can be concluded that the unsaturated zone within the study area is in the order of <1.0m to >25.0m with a mean thickness of approximately ~8.0m. The variation in the vadose zone thickness and extent observed, can potentially be attributed to the variations in topographical elevation as well as sub-surface lithology. It should be noted that due to the argillaceous nature of the host aquifer(s) the shallow water levels observed at some of the borehole localities can be attributed to clay/silt lenses and be indicative of perched aquifer conditions and not necessarily represent the vadose zone.

Depth to groundwater and hydraulic gradients

The minimum water level was recorded at 0.16mbgl (BH03), while the deepest water level was measured at borehole locality BH55 (52.44mbgl). The average water level is calculated at 10.67 mbgl which is much shallower than the regional average water level of between 28.10mbgl. From statistical evaluation the 95th percentile of this data set is calculated at 26.17mbgl with the standard deviation of 9.39m. It is noted that various dynamic water levels were recorded, potentially suggesting a pumped aquifer system. The coefficient of variation

calculated is 87.97%, indicating either a dynamic groundwater system or higher variability in topography.

Analysed data indicates that the surveyed water levels correlate very well to the topographical elevation with the square of correlation (R^2) indicating a linear association of >0.96 . Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by surface water divides and will mimic the topography. The inferred groundwater flow direction within the northern catchment of the project area will be in a general northern direction towards the lower laying drainage system(s) traversing the project area from where groundwater will discharge as baseflow. The groundwater flow direction within the southern catchment of the project area will be in a general west to southwestern direction.

The average groundwater gradient (i) of the shallow, intergranular aquifer in the vicinity of proposed gas production footprints is relatively flat and calculated at a mean 0.003, with a maximum of 0.005 in a north to south orientation and a minimum of 0.001 in a general southeast to northwest orientation.

The expected seepage rate from potential contamination originating at the proposed gas production activities as well as associated infrastructure is estimated at an average of approximately 4.0m/a, with a maximum distance of ~5.93m/a in a general southern direction.

According to the aquifer classification map of South Africa the project area is underlain by a “**Minor aquifer**” with a “**Moderate**” vulnerability rating and a “**Medium**” susceptibility rating. Accordingly, a Groundwater Quality Management (GQM) Index of 4 is calculated and a “**Medium**” level groundwater protection is required. It should however be noted that due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon or depleted, the targeted aquifer in some instances can be classified as a sole source aquifer.

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors.

The following potential sources have been identified:

- i. Seepage of poor-quality water and leachate of waste products including drilling mud sump(s).
- ii. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- iii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- iv. Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.
- v. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.

The following potential aquifer pathways have been identified:

- i. Vertical flow through the unsaturated/vadose zone as well as saturated zone to the underlying intergranular and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.
- ii. Preferential flow-paths include the contact between the depth of weathering and fresh un-weathered rock, fractures, faults, joints and bedding planes. Secondary fractures may also potentially act as transport mechanisms.
- iii. If not adequately sealed and suitably mitigated, gas production wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

The following potential receptors were identified:

- i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.
- ii. Down-gradient drainages and streams including associated riparian zone aquifer system(s) and baseflow contribution.
- iii. Private or neighbouring boreholes associated with relevant fracture zones and/or structures(s) if intercepted by the pollution plume migration footprint.

All site characterization information gathered were evaluated and incorporated into the formulation of a conceptual groundwater model. The conceptual model formed the basis for the numerical groundwater model development. The latter was calibrated to an acceptable error margin and applied as groundwater management tool for simulation of management scenarios.

A scenario was simulated by assigning a point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase. Due to the linear correlation of groundwater elevation and topographical elevation, the simulation indicates that the generated TDS pollution plume will generally mimic topography and will migrate towards the lower laying drainage system. It is evident that regional geological lineaments act as preferred pathways for groundwater flow and contaminant transport mechanisms. It can be noted that conceptual receptors situated within the unconsolidated, riparian zone aquifer, reaches quasi-steady state much quicker than conceptual receptors within the denser Karoo formations. It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~180.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~350.0m during the operational phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted

that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer. The TDS mass load contribution within conceptual receptors in close proximity of the production zone ranges between ~980.0mg/l to approximately 1660.0mg/l, which is slightly above the SANS 241:2015 limits while the TDS mass load contribution to existing boreholes in the vicinity of the proposed gas production zone ranges between 350.0mg/l (current background concentration) to a maximum of approximately 800.0mg/l, which is below the SANS 241:2015 limits. It can be observed the mass load contribution is a function of the distance to the source or gas production borehole.

A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase. The simulation indicates that the generated CH₄ pollution plume will also mimic topography and will migrate towards the lower laying drainage system. It can be observed that the simulated pollution plume migration is also more sluggish within the denser Karoo formations, reaching a maximum distance of ~150.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~300.0m during the operational production phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer. The CH₄ mass load contribution within the conceptual receptors in close proximity of the production zone is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole. It can be observed that the CH₄ mass load contribution ranges between ~0.15mg/l (which is the current background concentration) to a maximum of approximately 0.49mg/l, which is below the EPA safety threshold (2011) of 10.0mg/l.

A scenario summarises the simulated point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated TDS pollution plume will continue to mimic topography during the post-closure phase and will propagate towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~250.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial deposits of the riparian zone is ~450.0m. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems. The TDS mass load contribution within the conceptual receptors in close proximity of the production zone ranges between ~950.0mg/l to approximately >1600.0mg/l, which is slightly above the SANS 241:2015 limits while the TDS mass load contribution to existing boreholes in

the vicinity of the proposed gas production boreholes ranges between 380.0mg/l to a maximum of approximately 480.0mg/l, which is below the SANS 241:2015 limits.

A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised after decommissioning. After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~180.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial deposits of the riparian zone is ~350.0m. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems. The CH₄ mass load contribution within conceptual receptors in close proximity of the production zone is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole. It can be observed that the CH₄ mass load contribution ranges between ~0.15mg/l (which is the current background concentration) to a maximum of approximately 0.65mg/l, which is below the EPA safety threshold (2011) of 10.0mg/l.

A scenario was simulated evaluating the three site alternatives for the proposed processing plant footprint. It can be observed that the TDS mass load contribution ranges between <350.0mg/l (which is the current background) for Plant locality C, to a maximum of approximately 1700.0mg/l for Plant locality B. Furthermore, it can be observed that processing plant locality B suggest the most impact on the riparian zone aquifer with processing plant locality C indicating the least potential impact. It should however be noted that processing plant locality C is situated in close proximity to a geological lineament which can serve as a potential mechanism and preferred pathway for groundwater flow and contaminant transport.

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

During the construction phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. Potential impacts associated with the construction phase activities include the following:

- i. Site clearing and vegetation removal may cause increased turbidity and sediment loads in groundwater.
- ii. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads into recharge areas.
- iii. Poor quality leachate including sewage and domestic wastewater emanating from the construction camp may have a negative impact on groundwater quality.
- iv. Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
- v. Borehole drilling can introduce various potential contaminants including drilling muds/additives and hydrocarbons into host-aquifers which may have a detrimental effect on the water quality.

- vi. Drilling activities can disturb sediments and may result in silt formation in groundwater and can cause siltation within the potable water aquifer.
- vii. Encountering of major water strikes and blow-out during the drilling process may reduce local groundwater levels.
- viii. Groundwater pollution as a result of produced formation water or wastewater spills and seepage from drilling sumps.
- ix. Handling of borehole drilling chips may pose a risk to groundwater contamination.
- x. Borehole construction in terms of casing installation and concrete works might have a negative impact on groundwater quality.
- xi. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
- xii. Anthropogenic activities and movement related to the construction phase can cause potential groundwater pollution.
- xiii. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.
- xiv. Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.
- xv. Unplanned releases of formation water.
- xvi. Unplanned event such as well explosion can release saline formation water and gasses.

During the operational phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. Potential impacts associated with the operational phase activities include the following:

- i. Inadequate casing or cementing can create a vertical flow pathway between different aquifers/hydrostratigraphical units or between the production zone and potable aquifer.
- ii. Migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- iii. Upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- iv. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
- v. Gas production can alter pressure differences and alter hydraulic gradients between different hydrostratigraphical units resulting in modification of local groundwater flow pathways.
- vi. Poor quality leachate may emanate from the gas production zone which may have a negative impact on groundwater quality.
- vii. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
- viii. Operation and maintenance of heavy vehicles as well as associated machinery on-site may cause

hydrocarbon contamination of groundwater resources.

- ix. Leaking pipelines may cause contamination of groundwater resources.

During the decommissioning phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. Potential impacts associated with the post-closure and decommissioning phase activities include the following:

- i. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
- ii. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing an upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
- iii. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
- iv. Poor quality leachate may emanate from production zone footprint areas which may have a negative impact on groundwater quality.
- v. De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
- vi. Site de-establishment and removal of infrastructure can potentially cause increased turbidity and sediment loads in groundwater.

The following recommendations are proposed following this investigation:

- i. Mitigation and management measures as set out in the groundwater management plan must be implemented as far as practically possible. It should be noted that the mitigation and management measures recommended in this report must be incorporated into the measures stipulated in the previously approved D3 Energy ER315EMPr for similar activities within the same area, not to substitute the existing mitigation measures, but rather to supplement them for the current activities.
- ii. It is recommended that the monitoring program and network as set out in this report must be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated on a bi-annual basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.
- iii. Any development and/or drilling which takes place within the primary porosity aquifer associated with alluvium material deposited in flood plains must be avoided where possible and restricted if it cannot be avoided. If there are no other alternatives available and drilling within the riparian zone aquifer is necessary, mitigation and management measures, such as pitiless drilling, should be strictly adhered to.

- iv. The identified hydrogeological sensitive areas and buffer zones delineated as part of this assessment must be adhered to during the construction and operational phase activities. It is recommended that an updated hydrocensus user survey be performed in the vicinity of proposed production boreholes where limited hydrocensus points were identified. The survey should be conducted within a 500.0m radius of each proposed gas production borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas production borehole situated within the Karoo formations in order to verify the presence of other sensitive groundwater receptors and/or private boreholes.
- v. Additional monitoring boreholes should be established within the proposed target areas buffer zone as identified in Section 16 of this report, to evaluate the mass load contribution to sensitive environmental and groundwater receptors. Drilling localities should be determined in consultation with a suitably qualified hydrogeologist and sited means of a geophysical survey to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.
- vi. Newly established monitoring boreholes should be subjected to aquifer hydraulic parameters to supplement and verify existing hydraulic parameters interpreted as part of the first phase drilling and testing run.
- vii. Geological logs and data recording should include major water strikes and depths, water loss or water make volumes and depths as well as blow yields if applicable. Should water from the deeper, fractured aquifer be encountered, a sample should be collected to be subjected for inorganic testing as well as isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.
- viii. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed production borehole drilling be recorded along with associated water levels in order to get a better understanding of the deeper aquifer piezometric head and expected behaviour.
- ix. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial (once every two years) basis as newly gathered site characterisation data and monitoring results become available in order to be applied as a dynamic groundwater management tool for future scenario predictions.
- x. It is recommended that a weather station (i.e., rain gauges) be established at a central collection point on-site (i.e., at the production plant) in order to keep record of all rainfall events and assess potential climatic changes. The latter should be incorporated into the numerical groundwater flow model update accordingly.
- xi. All preferred groundwater flow pathways which are in direct connection with surface topography such as decommissioned gas production boreholes should be sealed off and rehabilitated according to best practise guidelines.

List of Abbreviations

ASTM	American Society for Testing Materials
Avg	Average
AWD	Accelerated Weight Drop Seismic
BH	Borehole
CGS	Council for Geoscience
CMB	Chloride Mass Balance
CNG	Compressed Natural Gas
CV	Coefficient of Variation
b	Saturated Thickness
DMR	Department of Environmental Affairs
DEM	Digital Elevation Model
DRASTIC	DI Index
DWS	Department of Water Affairs
EC	Electrical Conductivity (mS/m)
EA	Environmental Authorisation
EIA	Environmental Impact Assessment
E.N.	Electro Neutrality
EOH	End of Hole
ER	Exploration Right
ERA	Exploration Release Area
EPA	United States Environmental Protection Agency
ha	Hectares
GIS	Geographic Information Systems
GIIP	Good International Industry Practice
GN	Government Notice
GQM	Groundwater Quality Management
i	Hydraulic gradient (dimensionless)
ICP-OES	Inductively coupled plasma optical emission spectrometer
ICP-MS	Inductively coupled plasma mass spectrometry
IWULA	Integrated Water Use License Application
ISP	Internal Strategic Perspective
K	Hydraulic Conductivity (m/d)
LNG	Liquefied natural gas
l/s	Litre per second
m³/d	Cubic meters per day
MAE	Mean Annual Evaporation OR Mean Absolute Error
mamsl	Metres Above Mean Sea Level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	Metres Below Ground Level
mcm	Million Cubic Metres
ME	Mean Error
meq/L	Mili-equivalents per litre
mg/l	Milligrams per litre
mm/a	Millimetre per annum

MPRDA	Minerals and Petroleum Resources Development Act (Act 28 of 2002)
n	Porosity
NAWL	No Access to Water Level
NGA	National Groundwater Archive
NGDB	National Groundwater Database
NRMSD	Normalised Root Mean Square Deviation
NWA	National Water Act (Act 36 of 1998)
PR	Production Right
REV	Representative Elementary Value
RMSE	Root Mean Square Error
S	Storage coefficient
SANAS	South African National Accreditation System
SANS	South African National Standards
Sc	Specific Storage
SoW	Scope of Work
SRTM	Shuttle Radar Topography Mission
T	Transmissivity (m²/d)
TCP	Technical Cooperation Permit
TDS	Total Dissolved Solids
UNESCO	The United Nations Educational, Scientific and Cultural Organisation
USGS	United States Geological Survey
WGS	World Geodetic System
WM	With Mitigation
WOM	Without Mitigation
WRC	Water Research Commission
WUL	Water Use Licence

Table of contents

1. INTRODUCTION.....	27
1.1. PROJECT BACKGROUND	27
1.2. OBJECTIVES.....	27
1.3. TERMS OF REFERENCE	28
1.3.1. PHASE A: DESK STUDY AND GAP ANALYSIS	28
1.3.2. PHASE B: HYDROGEOLOGICAL BASELINE ASSESSMENT - HYDROCENSUS USER SURVEY, HYDROCHEMICAL ANALYSIS AND AQUIFER CLASSIFICATION	28
1.3.3. PHASE C: SITE CHARACTERISATION: SITING, DRILLING AND TESTING OF MONITORING BOREHOLES	29
1.3.4. PHASE D: DEVELOPMENT OF A NUMERICAL GROUNDWATER FLOW AND MASS TRANSPORT MODEL.....	29
1.3.5. PHASE E: HYDROGEOLOGICAL IMPACT ASSESSMENT AND REPORTING	30
1.4. DETAILS AND EXPERTISE OF THE AUTHOR.....	30
1.5. AVAILABLE INFORMATION	31
1.6. PROJECT ASSUMPTIONS AND LIMITATIONS.....	32
2. METHODOLOGY	33
2.1. DESK STUDY AND REVIEW.....	33
2.2. EVALUATION OF POTENTIAL ENVIRONMENTAL RECEPTORS	33
2.3. HYDROGEOLOGICAL BASELINE DESCRIPTION	33
2.4. SITE CHARACTERISATION AND DETERMINATION OF SITE-REPRESENTATIVE HYDRAULIC PARAMETERS.....	33
2.4.1. GEOPHYSICAL SURVEY	33
2.4.2. DRILLING.....	34
2.4.3. AQUIFER TESTING	34
2.5. DEVELOPMENT OF A CONCEPTUAL HYDROGEOLOGICAL MODEL	34
2.6. NUMERICAL GROUNDWATER FLOW AND MASS TRANSPORT MODEL DEVELOPMENT.....	34
2.7. GROUNDWATER IMPACT ASSESSMENT	35
3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS	35
3.1. THE NATIONAL WATER ACT (ACT 36 OF 1998) AS AMENDED	35
3.2. NATIONAL ENVIRONMENTAL MANAGEMENT ACT (ACT 107 OF 1998) AS AMENDED	36
3.3. MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT (ACT 28 OF 2002).....	36
3.4. NATIONAL ENVIRONMENTAL MANAGEMENT: WASTE ACT (ACT 59 OF 2008).....	36
4. STUDY AREA AND LISTED ACTIVITIES.....	37
4.1. REGIONAL SETTING AND SITE LOCALITY	37
4.2. PROJECT DESCRIPTION, LISTED ACTIVITIES AND PROPOSED INFRASTRUCTURE	37
5. PHYSIOGRAPHY.....	42
5.1. TOPOGRAPHY	42
5.2. DRAINAGE AND CATCHMENT	46
5.2.1. CLIMATE	50
5.3. GEOLOGICAL SETTING.....	52
5.3.1. REGIONAL GEOLOGY	52
5.3.2. STRUCTURAL GEOLOGY	52
5.3.3. SOILS.....	53
6. HYDROGEOLOGICAL BASELINE ASSESSMENT	55
6.1. REGIONAL HYDROGEOLOGY	55
6.2. LOCAL HYDROSTRATIGRAPHIC UNITS.....	56
6.3. UNSATURATED ZONE	56
6.4. GROUNDWATER-SURFACE WATER INTERACTION	57
6.5. HYDRAULIC PARAMETERS.....	60
6.5.1. HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY	60
6.5.2. STORATIVITY	61
6.5.3. POROSITY.....	61

6.5.4.	RECHARGE.....	61
7.	SITE INVESTIGATION	66
7.1.	HYDROCENSUS USER SURVEY	66
7.1.1.	GROUNDWATER STATUS.....	66
7.1.2.	GROUNDWATER APPLICATION	66
7.1.3.	BOREHOLE EQUIPMENT.....	66
8.	AQUIFER CHARACTERISATION.....	74
8.1.	GEOPHYSICAL SURVEY	74
8.1.1.	TRAVERSE 08.....	78
8.1.2.	TRAVERSE 10.....	78
8.1.3.	TRAVERSE 15.....	78
8.1.4.	TRAVERSE 18.....	78
8.2.	DRILLING	82
8.2.1.	DRILLING LOCALITY MTBH03	84
8.2.2.	DRILLING LOCALITY MTBH04	84
8.2.3.	DRILLING LOCALITY MTBH05	84
8.2.4.	DRILLING LOCALITY MTBH06	85
8.3.	AQUIFER TESTING.....	85
8.3.1.	CONSTANT RATE TEST BOREHOLE MTBH03	87
8.3.2.	CONSTANT RATE TEST BOREHOLE MTBH04	88
8.3.3.	CONSTANT RATE TEST BOREHOLE MTBH05	90
8.3.4.	CONSTANT RATE TEST BOREHOLE MTBH06	91
9.	GROUNDWATER FLOW EVALUATION	93
9.1.	UNSATURATED ZONE	93
9.2.	DEPTH TO GROUNDWATER.....	93
9.3.	GROUNDWATER FLOW DIRECTION AND HYDRAULIC GRADIENTS	95
9.4.	DARCY FLUX AND GROUNDWATER FLOW VELOCITY	99
10.	HYDROCHEMISTRY	100
10.1.	WATER QUALITY ANALYSIS	100
10.2.	DATA VALIDATION	101
10.3.	WATER QUALITY	103
10.4.	DISSOLVED METHANE AND ETHANE ANALYSIS	112
10.5.	HYDROCHEMICAL SIGNATURE	114
10.5.1.	PIPER DIAGRAMS	114
10.5.2.	STIFF DIAGRAMS	117
10.5.3.	EXPANDED DUROV DIAGRAM	121
11.	AQUIFER CLASSIFICATION AND GROUNDWATER MANAGEMENT INDEX.....	124
11.1.	AQUIFER CLASSIFICATION	124
11.2.	AQUIFER VULNERABILITY.....	125
11.3.	AQUIFER SUSCEPTIBILITY	125
11.4.	GROUNDWATER CONTAMINATION RISK ASSESSMENT.....	125
11.5.	SOURCE-PATHWAY-RECEPTOR EVALUATION.....	132
11.5.1.	POTENTIAL SOURCES.....	132
11.5.2.	POTENTIAL PATHWAYS	133
11.5.3.	POTENTIAL RECEPTORS.....	133
12.	HYDROGEOLOGICAL CONCEPTUAL MODEL	134
13.	NUMERICAL GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL	137
13.1.	APPROACH TO MODELLING.....	137
13.2.	SOFTWARE APPLICATION.....	138
13.3.	MODEL DEVELOPMENT.....	138

13.3.1.	MODEL DOMAIN	138
13.3.2.	MODEL CONSTRUCTION	139
13.3.3.	MODEL LAYERS.....	139
13.3.4.	BOUNDARY CONDITIONS	146
13.4.	MODEL HYDRAULIC PROPERTIES	146
13.4.1.	HYDRAULIC CONDUCTIVITY	146
13.4.2.	SOURCES AND SINKS	147
13.4.3.	STORATIVITY AND SPECIFIC STORAGE	147
13.4.4.	POROSITY	147
13.4.5.	LONGITUDINAL AND TRANSVERSAL DISPERSIVITIES	147
13.4.6.	LONGITUDINAL AND TRANSVERSAL DISPERSIVITIES	147
13.4.7.	MOLECULAR DIFFUSION	147
13.5.	MODEL CALIBRATION	153
13.5.1.	STEADY STATE CALIBRATION (∞).....	153
13.5.2.	MODEL SENSITIVITY ANALYSIS.....	159
13.6.	NUMERICAL GROUNDWATER FLOW MODEL	161
13.7.	NUMERICAL MASS TRANSPORT MODEL	161
13.7.1.	SCENARIO 01: STEADY STATE BASELINE WATER BALANCE (∞).....	163
13.7.2.	SCENARIO 02: MIGRATION OF SALINE GROUNDWATER FROM THE DEEP, FRACTURED AQUIFER TO THE OVERLYING, POTABLE AQUIFER(S) DURING THE OPERATIONAL GAS PRODUCTION PHASE	164
13.7.3.	SCENARIO 03: MIGRATION OF STRAY METHANE (CH ₄) GAS EMANATING FROM THE PRODUCTION ZONE TO THE OVERLYING, POTABLE AQUIFER(S) DURING THE OPERATIONS GAS PRODUCTION PHASE	171
13.7.4.	SCENARIO 04: MIGRATION OF SALINE GROUNDWATER FROM THE DEEP, FRACTURED AQUIFER TO THE OVERLYING, POTABLE AQUIFER(S) DURING THE POST-CLOSURE AND DECOMMISSIONING PHASE (50-YEAR AND 100-YEAR SCENARIOS)	175
13.7.5.	SCENARIO 05: MIGRATION OF STRAY METHANE (CH ₄) GAS EMANATING FROM THE PRODUCTION ZONE TO THE OVERLYING, POTABLE AQUIFER(S) DURING THE POST-CLOSURE AND DECOMMISSIONING PHASE (50-YEAR AND 100-YEAR SCENARIOS)	179
13.7.6.	SCENARIO 06: GAS PROCESSING PLANT ALTERNATIVE EVALUATION AND SITE SELECTION.....	183
14.	ENVIRONMENTAL IMPACT ASSESSMENT.....	185
14.1.	METHODOLOGY.....	185
14.2.	DETERMINATION OF ENVIRONMENTAL RISK	185
14.3.	IMPACT PRIORITIZATION	188
14.4.	IMPACT IDENTIFICATION AND SIGNIFICANCE RATINGS.....	190
14.4.1.	CONSTRUCTION PHASE: ASSOCIATED ACTIVITIES AND IMPACTS.....	190
14.4.2.	OPERATIONAL PHASE: ASSOCIATED ACTIVITIES AND IMPACTS.....	207
14.4.3.	POST-OPERATIONAL AND DECOMMISSIONING PHASE: ASSOCIATED ACTIVITIES AND IMPACTS.....	217
14.4.4.	ASSOCIATED ACTIVITIES AND CUMULATIVE IMPACTS.....	224
15.	GROUNDWATER MANAGEMENT PLAN	226
15.1.	POTENTIAL IMPACTS AND ASSOCIATED RISKS	226
15.2.	KEY RESPONSIBILITIES.....	227
15.3.	MITIGATION AND MANAGEMENT	227
15.3.1.	CONSTRUCTION PHASE: MANAGEMENT AND MITIGATION MEASURES	227
15.4.	OPERATIONAL PHASE: MANAGEMENT AND MITIGATION MEASURES	229
15.5.	POST-OPERATIONAL AND DECOMMISSIONING PHASE: MANAGEMENT AND MITIGATION MEASURES	231
16.	MONITORING	234
16.1.	MONITORING OBJECTIVES	234
16.2.	MONITORING NETWORK.....	235
16.3.	DETERMINANTS FOR ANALYSIS	235
16.4.	WATER LEVELS.....	236
16.5.	MONITORING FREQUENCY	236
16.6.	SAMPLING PROCEDURE.....	237
17.	CONCLUSIONS	241
18.	RECOMMENDATIONS.....	249

19.	SPECIALIST PROFESSIONAL OPINION	251
20.	REFERENCES	252
21.	APPENDIX A: RAINFALL DATA (RAINFALL ZONES C4C)	254
22.	APPENDIX B: GEOPHYSICAL SURVEY FIELD MEASUREMENTS AND PROFILES	255
23.	APPENDIX C: BOREHOLE GEOLOGICAL LOGS AND CONSTRUCTION	256
24.	APPENDIX D: AQUIFER TESTING DATASHEETS	257
25.	APPENDIX E: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES	258
26.	APPENDIX F: D3 ENERGY HENNENMAN EXPLORATION AREA EMPR (ER315).....	259
27.	APPENDIX G: SPECIALIST DECLARATION FORM	260
28.	APPENDIX H: SPECIALIST CURRICULUM VITAE	261

List of figures

Figure 4-1	Aerial extent indicating the production right area as well as greater study area.....	39
Figure 4-2	Production right area and greater study area (1:50 000 topographical mapsheet 2826 and 2827). 40	
Figure 4-3	General site layout and proposed infrastructure map.	41
Figure 5-1	West-East Elevation Profile (refer to Figure 5-4 Slice A-A').	43
Figure 5-2	North-South Elevation Profile (refer to Figure 5-4 Slice B-B').	43
Figure 5-3	Topographical cross-sections of the greater project area.	44
Figure 5-4	Regional topography and conceptual slice (Refer to Figure 5-1 and Figure 5-2).....	45
Figure 5-5	Quaternary catchments, water management area and regional drainage map.	49
Figure 5-6	Mean Yearly Temperature Distribution of the greater study area, 1991 – 2024 (Climate-Data, 2021). 50	
Figure 5-7	Bar chart indicating monthly rainfall distribution for rainfall zone C4C (WRC, 2016).	51
Figure 5-8	Bar chart indicating yearly rainfall distribution for rainfall zone C4C (WRC, 2016).	51
Figure 5-9	Regional geology and stratigraphy (Geological map sheet 2826: Winburg)(1:250 000 scale).	54
Figure 6-1	Illustration of the Unsaturated Zone (Fetter and Kremer, 2023).	57
Figure 6-2	Typical aquifer hosts and groundwater occurrence for the study region (2726 Kroonstad).....	58
Figure 6-3	Hydrogeological map of the greater study region (2726 Kroonstad).	59
Figure 6-4	Typical hydraulic conductivity values for on-site hydrostratigraphical units.	61
Figure 6-5	Chloride Mass Balance (CMB) method recharge summary: Adelaide Sbrp, Beaufort Group Aquifer. 62	
Figure 6-6	Chloride Mass Balance (CMB) method recharge summary: Karoo Dolerite Formation.	63
Figure 6-7	Chloride Mass Balance (CMB) method recharge summary: Riparian zonw/ Alluvial Aquifer.	64
Figure 6-8	Groundwater recharge distribution in South Africa (After Vegter, 1995).	65
Figure 6-9	Harvest potential distribution in South Africa (DWS, 2013).	65
Figure 7-1	Hydrocensus user survey: Geosite type.....	67
Figure 7-2	Hydrocensus user survey: Geosite status.	67
Figure 7-3	Hydrocensus user survey: Groundwater application.....	68
Figure 7-4	Hydrocensus user survey: Equipment type.	68
Figure 7-5	Spatial distribution map of of the hydrocensus geosites surveyed.	72
Figure 7-6	Spatial distribution map indicating groundwater status and application.....	73
Figure 8-1	Map indicating potential reginal geological lineaments in relations to proposed infrastructure and activities.	76
Figure 8-2	Geophysical traverse array in relation to regioanl geology as well as potential geological lineaments.	77
Figure 8-3	Geophysical traverse 08: Magnetic curve as well as electro-magnetic profile with relevant information.	79
Figure 8-4	Geophysical traverse 10: Magnetic curve as well as electro-magnetic profile with relevant information.	80
Figure 8-5	Geophysical traverse 15: Magnetic curve as well as electro-magnetic profile with relevant information.	80
Figure 8-6	Geophysical traverse 18: Magnetic curve as well as electro-magnetic profile with relevant information.	81
Figure 8-7	Map depicting new drilled site characterisation borehole positions in relation to regional geology and inferred geological lineaments.	83
Figure 8-8	Aquifer tests: MTBH03 water level drawdown and recovery scattered plot.	87
Figure 8-9	Aquifer tests: Cooper-Jacob method displacement time curve for MTBH03.	88
Figure 8-10	Aquifer tests: MTBH04 water level drawdown and recovery scattered plot.	89
Figure 8-11	Aquifer tests: Theis method displacement time curve for MTBH04.	89
Figure 8-12	Aquifer tests: MTBH05 water level drawdown and recovery scattered plot.	90
Figure 8-13	Aquifer tests: Theis method displacement time curve for MTBH05.	91
Figure 8-14	Aquifer tests: MTBH06 water level drawdown and recovery scattered plot.	92
Figure 8-15	Aquifer tests: Theiss method displacement time curve for MTBH06.	92
Figure 9-1	Bar chart indicating regional water level summar.	95
Figure 9-2	Topographical elevation vs. groundwater elevation correlation graph.	96
Figure 9-3	Regional groundwater flow direction and depth to groundwater.	97

Figure 10-1	Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of hydrocensus samples analysed.	104
Figure 10-2	Total hydrochemical analysis spatial distribution map.	110
Figure 10-3	Spatial distribution map for the Nitrate (NO ₃) concentrations.	111
Figure 10-4	Spatial distribution map of boreholes analysed for dissolved methane.	113
Figure 10-5	Piper diagram indicating classification for anion and cation facies in terms of ion percentages	115
Figure 10-6	Piper diagram indicating major anions and cations of groundwater samples analysed.	115
Figure 10-7	Piper diagram indicating major anions and cations of groundwater samples analysed.	116
Figure 10-8	Piper diagram indicating major anions and cations of surface water samples analysed.	116
Figure 10-9	Stiff diagrams representing the groundwater samples analysed.	118
Figure 10-10	Stiff diagrams representing the groundwater samples analysed (cont.).	119
Figure 10-11	Stiff diagrams representing the surface water samples analysed.	120
Figure 10-12	Extended Durov diagram indicating major anions and cations.	122
Figure 10-13	Extended Durov diagram of groundwater samples analysed.	122
Figure 10-14	Extended Durov diagram of groundwater samples analysed (cont.).	123
Figure 10-15	Extended Durov diagram of surface water samples analysed.	123
Figure 11-1	Aquifer classification of South Africa (DWS, 2013).	129
Figure 11-2	Aquifer vulnerability of South Africa (DWS, 2013).	130
Figure 11-3	Aquifer Susceptibility of South Africa (DWS, 2013).	131
Figure 11-4	Source pathway receptor principle.	132
Figure 12-1	Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).	134
Figure 12-2	Hydrogeological conceptual model: West- East cross section (A-A')(Pre-operational) (Refer to	135
Figure 13-2).		
Figure 12-3	Hydrogeological conceptual model: South- North cross section (A'-A')(Post-operational) (Refer	136
to Figure 13-2).		
Figure 13-1	Workflow numerical groundwater flow model development.	137
Figure 13-2	Model domain: Aerial extent.	140
Figure 13-3	Model domain: Supermesh view.	141
Figure 13-4	Model domain 3-D FEM mesh in a plan view depicting a plan-view orientation.	142
Figure 13-5	Model domain 3-D FEM mesh depicting a plan view and cross sectional view in a west-east	143
orientation.		
Figure 13-6	Model domain 3-D FEM mesh view depicting a cross sectional view in a south-north orientation.	144
Figure 13-7	Model domain 3-D FEM mesh view (cross sectional view west-east orientation of conceptual	145
slice A-A').		
Figure 13-8	Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.	148
Figure 13-9	Model development: Numerical groundwater flow model: Recharge distribution.	148
Figure 13-10	Model development: Numerical groundwater flow model: Specific storage distribution.	149
Figure 13-11	Model development: Numerical groundwater flow model: Porosity distribution.	149
Figure 13-12	Hydrostratigraphic units and model boundary conditions.	151
Figure 13-13	Numerical groundwater flow model: Hydraulic properties.	152
Figure 13-14	Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.	155
Figure 13-15	Model steady state calibration: curve of simulated vs. measured hydraulic head elevation. .	155
Figure 13-16	Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.	156
Figure 13-17	Model steady state calibration: Bar-chart of simulated vs. measured hydraulic head elevation.	156
Figure 13-18	Model calibration: steady state hydraulic heads and groundwater flow direction.	157
Figure 13-19	Model calibration: steady state hydraulic head distribution.	158
Figure 13-20	Model steady state calibration: sensitivity analysis for monitoring locality BH03.	159
Figure 13-21	Model steady state calibration: sensitivity analysis for monitoring locality BH23.	160
Figure 13-22	Model steady state calibration: sensitivity analysis for monitoring locality BH56.	160
Figure 13-23	Scenario 02: Time-series graph indicating the TDS mass load contribution of deeper, fractured	
	(saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers	

(Operational phase).....	165
Figure 13-24 Scenario 02: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on existing regional boreholes (Operational phase).	166
Figure 13-25 Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).....	167
Figure 13-26 Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).	168
Figure 13-27 Scenario 02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).....	169
Figure 13-28 Scenario 02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).....	170
Figure 13-29 Scenario 03: Time-series graph indicating the CH ₄ mass load contribution of the production zone on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Operational phase).	172
Figure 13-30 Scenario 03: Scenario 02: Time-series graph indicating the CH ₄ mass load contribution of deeper, fractured (saline) aquifer on existing boreholes (Operational phase).	172
Figure 13-31 Scenario 03: CH ₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).....	173
Figure 13-32 Scenario 03: CH ₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).....	174
Figure 13-33 Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).	176
Figure 13-34 Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targetting the potable shallow, intergranular aquifer (Post-closure phase).	176
Figure 13-35 Scenario 04: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Post-closure phase).....	177
Figure 13-36 Scenario 04: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Post-closure phase).....	178
Figure 13-37 Scenario 05: Time-series graph indicating the CH ₄ mass load contribution of deeper, fractured and saline aquifer on observation boreholes targetting the potable shallow, intergranular aquifer (Post-closure phase).	180
Figure 13-38 Scenario 05: Time-series graph indicating the CH ₄ mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).	180
Figure 13-39 Scenario 05: CH ₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Post-closure phase).....	181
Figure 13-40 Scenario 05: CH ₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Post-closure phase).....	182
Figure 13-41 Scenario 06: Time-series graph indicating the TDS mass load contribution of the processing plant waste infrastructure to observation boreholes targetting the potable shallow, intergranular aquifer (Operational phase).	183
Figure 13-42 Scenario 06: Simulated particle tracking of contaminants originating from potential waste infrastructure associated with the proposed gas processing plant for alterantives footprints (Operational phase).	184
Figure 14-1 Hydrogeological sensitivity map.....	225

Figure 16-1	Monitoring programme (DWA, 2006).	234
Figure 16-2	Integrated groundwater monitoring network.....	240

DRAFT

List of tables

Table 1-1	Details of the authors.	30
Table 4-1	General site coordinates (Coordinate System: Geographic, Datum: WGS84).	37
Table 5-1	Study Area Catchment and Hydrological Properties.	46
Table 5-2	Quaternary catchment information: C42G.	47
Table 5-3	Quaternary catchment information: C42H.	47
Table 5-4	Quaternary catchment information: C42K.	48
Table 5-5	Simplified lithostratigraphy of the greater study area.	53
Table 6-1	Recharge estimation (after van Tonder and Xu, 2000).	62
Table 7-1	Hydrocensus user survey: relevant information for geosites visited.	69
Table 8-1	Geophysical traverse summary (Datum: WGS84).	75
Table 8-2	Drilling targets and objectives.	82
Table 8-3	Relevant borehole information summary.	82
Table 8-4	Constant discharge aquifer tests summary.	86
Table 8-5	Aquifer tests: Hydraulic parameter estimation.	86
Table 9-1	Regional water level summary.	94
Table 9-2	Inferred groundwater gradient and seepage direction.	98
Table 9-3	Darcy flux and seepage rates.	99
Table 10-1	SANS 241:2015 risks associated with constituents occurring in water.	100
Table 10-2	SANS 241:2015 physical aesthetic, operational and chemical parameters.	101
Table 10-3	Laboratory precision and data validity.	102
Table 10-4	Hydrochemical classification according to pH-values.	103
Table 10-5	Hydrochemical classification according to salinity.	103
Table 10-6	Hydrochemical classification according to hardness.	103
Table 10-7	Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed.	105
Table 10-8	Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).	106
Table 10-9	Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).	107
Table 10-10	Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).	108
Table 10-11	Hydrochemistry: Surface water quality evaluation of hydrocensus samples analysed.	109
Table 10-12	Hydrochemistry: Site characterisation borehole dissolved methane and ethane compared to U.S. Department of the Interior guidelines.	112
Table 11-1	Aquifer System Management Classes (After Parsons , 1995).	124
Table 11-2	Groundwater Quality Management Index.	125
Table 11-3	DRASTIC Index.	126
Table 11-4	Ratings assigned to groundwater vulnerability parameters (Lynch et al, 1994).	126
Table 11-5	DRASTIC weighting factors: Shallow, intergranular aquifer.	127
Table 11-6	DRASTIC weighting factors: Alluvial, riparian zone aquifer.	128
Table 13-1	Model set-up: Hydraulic Parameters.	150
Table 13-2	Steady State Model Calibration – Statistical Summary.	154
Table 13-3	Steady State Model Calibration – Sensitivity analysis.	159
Table 13-4	Summary of model stress-periods.	163
Table 13-5	Catchment water balance: Scenario 01 – Steady state baseline water balance.	163
Table 14-1	Criteria for Determining Impact Consequence.	186
Table 14-2	Probability scoring.	187
Table 14-3	Determination of Environmental Risk.	187
Table 14-4	Significance classes.	188
Table 14-5	Criteria for Determining Prioritisation.	189
Table 14-6	Determination of Prioritisation Factor.	189
Table 14-7	Final Environmental Significance Rating.	190
Table 14-8	Impact assessment and significance rating: Construction phase summary.	192
Table 14-9	Impact assessment and significance rating: Operational phase summary.	208
Table 14-10	Impact assessment and significance rating: Decommissioning phase summary.	218
Table 16-1	Current background water quality.	236
Table 16-2	Integrated monitoring network and programme.	238

List of equations

Equation 6-1	Hydraulic Conductivity (Darcy's Law).....	60
Equation 6-2	Transmissivity.....	60
Equation 8-1	Transmissivity (Cooper-Jacob).....	85
Equation 9-1	Hydraulic gradient.....	98
Equation 9-2	Darcy flux.....	99
Equation 9-3	Seepage velocity.....	99
Equation 10-1	Electro-neutrality.....	101
Equation 11-1	GMQ Index.....	124
Equation 11-2	DRASTIC Index (Di).....	126
Equation 13-1	Simplified groundwater balance.....	138
Equation 13-2	Diffusion coefficient.....	147
Equation 13-3	Groundwater flow.....	161
Equation 13-4	Advection-dispersion.....	161
Equation 14-1	Impact Consequence.....	185
Equation 14-2	Significance.....	187
Equation 14-3	Priority.....	189

1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment in support of an Environmental Impact Assessment (EIA) authorisation process to be followed for the proposed D3 Energy gas production right. D3 Energy South Africa (Pty) Ltd (D3 Energy) (hereafter referred to as the applicant) wishes to convert a portion of their existing and previously assessed Exploration Right area (ER315) into a Production Right (PR). The investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts from the proposed gas production on potential sensitive environmental receptors. This report summarises the main conclusions and recommendations derived from the study.

1.2. Objectives

The objective of this investigation is to:

- i. Establish site baseline and background conditions and identify sensitive environmental receptors in the vicinity of each proposed gas production corridors as well as seismic transects.
- ii. Determine the current status quo of the regional groundwater system including aquifer classification, aquifer unit delineation and vulnerability.
- iii. Site characterisation i.e. siting, drilling and testing of on-site boreholes to inform the conceptual model, determine site-specific hydraulic parameters for calibration and input to the numerical groundwater flow model.
- iv. Evaluation and interpretation of site-specific geological, hydrogeological and hydraulic parameters for input and refinement of the conceptual understanding of the greater study area as well as input to the numerical groundwater flow and pollution plume migration model.
- v. Formulation of a conceptual groundwater flow model.
- vi. Development of a numerical groundwater flow and mass transport model in order to quantify and qualify the potential impact of the gas extraction as well as simulate potential saline water migration towards the shallow aquifer.
- vii. Hydrogeological impact assessment and risk matrix.
- viii. Recommendations on best practise mitigation and management measures to be implemented.
- ix. Compilation of an integrated groundwater monitoring network and protocol.

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-25-017-V2, submitted in May 2025. This project plan and scope of work was compiled based on the following guidelines and regulations:

- i. Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications.
- ii. 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).
- iii. Best Practice Guidelines (G4 – Impact Prediction) as published by the former Department of Water Affairs and Sanitation (DWS, 2004).

1.3.1. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

- i. Information gathering and data acquisition.
- ii. Desk study and review of historical groundwater baseline information, existing specialist reports as well as DWS supported groundwater databases i.e. national groundwater archive (NGA).
- iii. Fatal flaw and gap analysis.

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

Phase B will entail the following activities¹:

- i. Hydrocensus user survey to evaluate and verify existing surface and groundwater uses, local and neighbouring borehole locations and depths, spring localities and seepage zones, regional water levels, abstraction volumes, groundwater application as well as environmental receptors in the vicinity of the proposed gas production corridors.
- ii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).
- iii. Assess the structural geology and geometry of the aquifer systems with respect to hydraulic interactions and compartmentalisation.
- iv. Data interpretation aiding in aquifer classification, delineation and vulnerability ratings. Development of a scientifically defensible hydrogeological baseline.
- v. Compilation of geological, hydrogeological and hydrochemical thematic maps summarising the aquifer

¹ It should be noted that Phase B and Phase C scope of work will be performed as part of the follow-up EIA investigation.

system(s), indicating aquifer delineation, groundwater piezometric map, depth to groundwater, groundwater flow directions as well as regional geology.

1.3.3. Phase C: Site characterisation: Siting, drilling and testing of monitoring boreholes

Phase C will entail the following activities:

- i. Geophysical survey: Ground-magnetics (Proton G5 Magnetometer) as well as electro-magnetic survey (EM-34) according to traverse array design for delineation of sub-surface lineaments and identification of potential preferential groundwater flow pathways.
- ii. Air-percussion drilling of site characterisation boreholes i.e. targeting various lithologies and aquifer units. All drilling will be carried out under supervision and according to SANS 10299-4:2003 standards: Development, maintenance and management of groundwater resources.
- iii. Short duration pump test i.e., constant hour constant rate and recovery measurements on newly drilled boreholes to determine aquifer parameters as well as inter-connectivity. All pump-tests will be carried out under test supervision and according to SANS 10299-4:2003 standards. Interpretation of drawdown and recovery data for input into the numerical groundwater flow model.
- iv. Sampling of newly drilled boreholes according to best practise guidelines and analyses of water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

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

Phase D will entail the following activities:

- i. Development of a conceptual hydrogeological model in conjunction with interpreted geology data and gathered site characterisation information.
- ii. Development of a regional numerical groundwater flow model by applying the Finite Element Flow (FEFLOW) modelling software. Model domain to include proposed infrastructure and gas production footprint as well as associated activities.
- iii. Calibration of groundwater flow model using site specific data including hydrocensus geosites information.
- iv. Development of a numerical mass transport model utilizing the calibrated groundwater flow model as basis.
- v. The calibrated model will be used to simulate management scenario's as follows:
 - a. Steady state groundwater flow directions, hydraulic gradient and flow velocities.
 - b. Seepage potential from waste facilities and mass transport plume migration with time.
 - c. Hydrochemical migration of deeper, saline water towards the shallow aquifer and plume propagation

with time.

d. Migration of dissolved gas within the aquifer units and plume migration with time.

e. Post-closure scenarios.

f. Water management alternatives and best practice mitigation measures.

1.3.5. Phase E: Hydrogeological impact assessment and reporting

Phase E will entail the following activities:

- i. Compilation of a detailed hydrogeological specialist investigation report with conclusions and recommendations on the following aspects:
 - a. Fatal flaw and gap analyses.
 - b. Site baseline characterisation.
 - c. Field work summary and interpretation.
 - d. Aquifer classification and vulnerability.
 - e. Numerical groundwater flow and mass transport model development, calibration and simulations.
 - f. Formulation of an impact assessment and risk matrix of proposed activities.
 - g. Recommendation on best practise mitigation and management measures to be implemented.
- ii. Development of an integrated surface water and groundwater monitoring program for implementation.

1.4. Details and expertise of the author

The details of the author(s) who prepared this report are summarised in **Table 1-1** below.

Table 1-1 Details of the authors.

Author	Ferdinand Mostert
Highest qualification	M.Sc. Hydrogeology
Years' experience	18+
Professional registration	SACNASP Member (Reg. No 40057/14 – Water Resource Science). Member of the Groundwater Division of the Geological Society of South Africa (MGSSA).

1.5. Available information

The following information was available and used in this investigation:

- i. Aqiuworx software. 2016. Version 2.5.2.0. Centre for Water Sciences and Management at the North-West University.
- ii. Barnard, H. C., 2000. An explanation of the 1:500 000 general Hydrogeological Map. Kroonstad 2726.
- iii. Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2826 and 2827[Map]. Edition 9. Scale 1:50,000. Mowbray, South Africa: Chief Directorate of Surveys and Mapping.
- iv. Council of Geoscience geological map sheet 2726: Kroonstad and 2826: Winburg (1:250 000).
- v. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer classification of South Africa.
- vi. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer susceptibility of South Africa.
- vii. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer vulnerability of South Africa.
- viii. Department of Water Affairs and Forestry, South Africa. 2004. Internal Strategic Perspective: Middle Vaal Water Management Area. Prepared by PDNA, WMB and WRP on behalf of the Directorate National Water Resources Planning. Report no. 09/000/00/0304.
- ix. ESRI basemaps, 2025.
- x. Google Earth, 2025. 6.0.12032 Beta.
- xi. JR Vegter, DWS and WRC, 1995. Groundwater Resources of the Republic of South Africa.
- xii. Parsons, R, 1995. A South African Aquifer System Management Classification, Water Research Commission, WRC Report No KV 77/95.
- xiii. van Tonder and Xu, 2000. Program to estimate groundwater recharge and the Groundwater Reserve.
- xiv. Water Research Commission (WRC), 2012. Water Resources of South Africa.

1.6. Project assumptions and limitations

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

- i. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic and spatial data, a lower resolution of 1:250 000 scale for geological data and a 1: 500 000 scale resolution for hydrogeological information.
- ii. The Digital Elevation Model (DEM) data was interpolated with a USGS grid spacing of 25.0m intervals.
- iii. Rainfall data and other climatic data was sourced from the WR2012 database.
- iv. Water management and catchment-based information was sourced from the GRDM and Aquiworx databases.
- v. The concept of representative elementary volumes (REV) 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 boreholes².
- vi. The investigation relied on data collected as a snapshot of field surveys and existing data. Further trends should be verified by continued monitoring as set out in the monitoring program.
- vii. 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.
- viii. The geological structures (fault zones and dyke contact zones) were modelled as permeable linear zones³.
- ix. Groundwater divides have been assumed to align with surface water divides and it is assumed that groundwater cannot flow across this type of boundaries.⁴
- x. Where data was absent or insufficient, values were assumed based on relevant and recent literature studies and referenced accordingly⁵.

² Please note that all faults, dykes and fractures identified have been incorporated into this investigation and groundwater model, however this refers to the regional scale of data used i.e., DEM spacings have been used from SRTM data-set at a 30m spacing, regional geological maps used is based on a 1:250 000 scale whereas groundwater maps is based on a 1:500 000 scale.

³ This is to accommodate a worst-case approach. Thus, modelling fault zones as more permeable zones will represent and over-estimation of the expected plume migration patterns, however it will also represent the worst possible case. Accordingly, mitigation and management measures were formulated as such. This approach is usually required by the competent authorities.

⁴ Groundwater usually mimics topography, as the field-data confirmed, however groundwater can cross catchment boundaries via more transmissive fault zones under a hydraulic gradient. However, the model catchment has been delineated taking regional structural behaviour as well as topography into consideration.

⁵ Where model assumptions were made or reference values used, a conservative approach was followed. Data gaps identified should be addressed as part of the model update.

2. METHODOLOGY

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

2.1. Desk study and review

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

2.2. Evaluation of potential environmental receptors

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors.

2.3. Hydrogeological baseline description

Based on the gathered desktop groundwater and site characterisation data a baseline description of the current status quo of the regional groundwater system including aquifer classification, aquifer unit delineation and vulnerability is formulated.

2.4. Site characterisation and determination of site-representative hydraulic parameters

Site characterisation i.e. siting, drilling and testing of on-site monitoring boreholes to inform the conceptual model, determine site-specific hydraulic parameters for calibration and input to the numerical groundwater flow model.

2.4.1. Geophysical survey

Site characterisation and monitoring boreholes will be sited by means of a geophysical survey. The magnetic and electro-magnetic (EM) geophysical exploration techniques will be applied according to traverse array design for delineation of sub-surface lineaments and identification of potential preferential groundwater flow pathways to be targeted for monitoring boreholes.

The magnetic method attempts to differentiate between lateral differences in the earth's magnetic field. These differences or anomalies indicate different types of underlying rock formations and/or variations in depth and weathered profiles. A Proton-G5 ground-magnetometer will be used to conduct measurements at a magnetic field strength of 28 000 nT (nanotesla).

Electro-magnetic conductivity surveys measure ground conductivity by the process of electromagnetic induction. An EM34 system will be utilized and consist of a transmitter and receiver coil spaced at a fixed configuration and then use different operating frequencies to provide a range of depth penetration and resolution for different applications. EM methods make use of the fact that time-varying electromagnetic radiation of the subsurface will cause electric currents to flow.

2.4.2. Drilling

The drilling technique applied entailed percussion drilling whereby a drill-bit, driven by air compression, is hammered into sub-surface formations. The latter technique is a down-hole air hammer system that is designed to advance casing during drilling. Once the desired depth is reached the eccentric bit can be retrieved leaving the casing in place for installations and is often used in soft, unconsolidated sediments. Boreholes were sealed off with solid steel casing while water-bearing formations were cased-off with screened intervals. The annulus of each borehole was filled with a silica gravel-pack and sealed-off with a sanitary seal. All drilling will be carried out under supervision and according to SANS 10299-4:2003 standards: Development, maintenance and management of groundwater resources.

2.4.3. Aquifer testing

Newly established site characterization boreholes were subjected to aquifer tests i.e., pump tests to determine hydraulic parameters. Pump tests comprised the following phases:

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

All pump-tests will be carried out under test supervision and according to SANS 10299-4:2003 standards. Interpretation of drawdown and recovery data for input into the numerical groundwater flow model.

2.5. Development of a conceptual hydrogeological model

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. Data gathered during the desktop study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system.

2.6. Numerical groundwater flow and mass transport model development

A numerical groundwater flow and mass transport model was developed based on the defined groundwater conceptual model. The latter will serve as a tool to evaluate various water management options and different scenarios will be applied to quantify and qualify potential groundwater impacts. It should be noted that modelling scenarios will be based on the worst-case approach to identify the most severe potential outcomes, ensuring preparedness for low-likelihood but high-impact events.

2.7. Groundwater impact assessment

Identification of preliminary and potential impacts and ratings related to new developments and/or listed activities are defined based on outcomes of the investigation. An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human and/or other related activities. Risk assessment involves the calculation of the magnitude of potential consequences (levels of impacts) and the likelihood (levels of probability) of these consequences to occur. Mitigation measures were recommended in order to render the significance of impacts identified.

3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS

The following water management legislation should be adhered to:

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

The purpose of the National Water Act, 36 of 1998 ("NWA") as set out in Section 2, is to ensure that the country's water resources are protected, used, developed, conserved, managed, and controlled, in a way which inter alia considers the reduction, prevention and degradation of water resources. The NWA states in Section 3 that the National Government is the public trustee of the Nation's water resources. The National Government must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons and in accordance with its constitutional mandate. Section 22 of the NWA states that a person may only use water without a license if such water use is: permissible under Schedule 1, if that water use constitutes as a continuation of an existing lawful water use, or if that water use is permissible in terms of a general authorization issued under Section 39. Permissible water use furthermore includes water use authorised by a license issued in terms of the NWA or alternatively without a license if the responsible authority dispensed with a license requirement under subsection 3. Section 21 of the National Water Act indicates that water use includes the following:

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

3.2. National Environmental Management Act (Act 107 of 1998) as amended

The National Environmental Management Act 107 of 1998 intends:

- i. to provide for co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state; and
- ii. to provide for matters connected therewith.

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

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

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

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

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

The classification and definitions herein considered the following documents⁶:

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

⁶ It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable, the Total Concentration (TC) and Leachable Concentration (LC) thresholds as stipulated in GNR635 standards are still applied as part of the waste assessment because guidelines and limits are based on Environmental Protection Agency (EPA) of the Australian State of Victoria and still bears reference.

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

The proposed gas production right and greater study area falls within the Matjhabeng and Masilonyana Local Municipalities and the Lejweleputswa District Municipality, covering a total footprint of ~144.40km², stretching over various farms which are situated between the towns of Virginia (~11.0km to the northwest), Ventersburg (~13.0km to the northeast), Winburg (~22.0km to the southeast) and Theunissen (~21.0km to the southwest), Free State Province of South- Africa.

Fixed coordinates representing the boundaries of production right area are -28.176285°S; 26.963445°E in the northwest, -28.177167°S; 27.049734°E in the northeast, -28.308304°S; 27.000575°E in the southeast and -28.277793°S; 26.876093°E in the southwest, the central coordinates are approximately -28.242956°S; 26.966824°E. The site is accessible via the R73 secondary route traversing the greater study area in a general north south direction. General site coordinates are listed in **Table 4-1** and a map indicating an aerial extent of the greater study area is indicated in **Figure 4-1** with the project boundary and topo-cadastral map depicted in **Figure 4-2**.

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

Latitude	28.242956°S
Longitude	26.966824°E

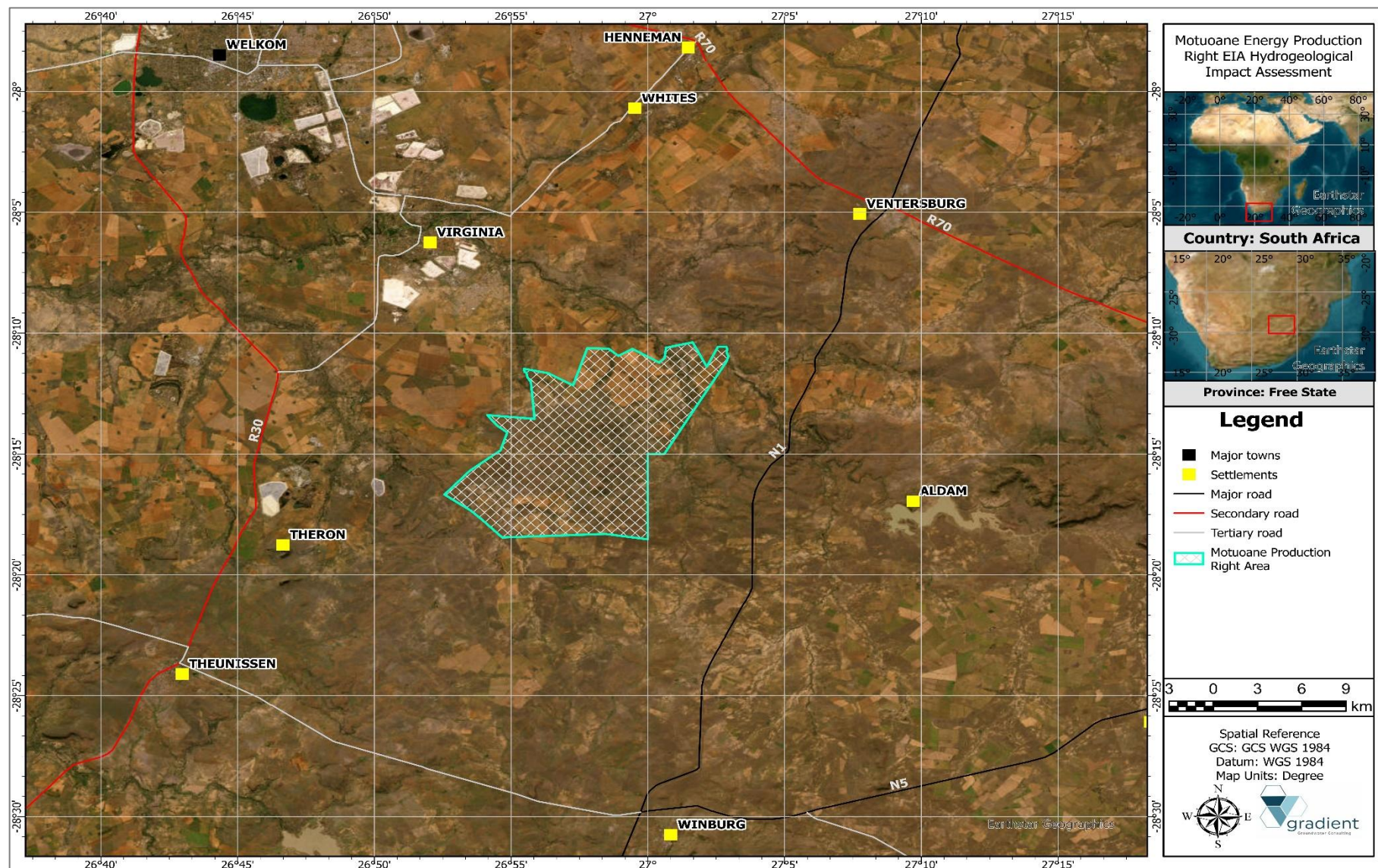
4.2. Project description, listed activities and proposed infrastructure

The proposed PR development will target helium and methane, and will consist of up to 43 production wells, gas gathering pipelines, a helium recovery and gas processing plant (CNG or LNG) and associated infrastructure. Other proposed activities include conducting seismic and/or audio magnetotelluric surveys and clearing vegetation for the proposed infrastructure development. The proposed development of the Production Right area will involve the following activities:

- Pre-drilling seismic and/or audio magnetotelluric surveys to optimize well locations for maximum deliverability;
- Drilling and completion of wells;
- Maintenance workovers of wells;
- Construction of gas gathering pipeline systems;
- Installation of gas compression and processing facilities;
- Construction of a helium recovery facility (gas or liquid helium) and gas (methane) processing plant (CNG or LNG); and
- Construction of associated infrastructure including roads, borrow pits, communications facilities and temporary accommodation facilities if necessary.

The proposed wells will be located along known fault lines (Virginia and Ventersburg fault lines) and close to either existing blowers or exploration wells previously drilled by D3 Energy. All well locations, gas gathering pipelines and processing plant infrastructure will be located in consultation with the landowner and any other stakeholders and be located to minimize damage to existing infrastructure, vegetation and land. Facilities and wells will be located close to existing fence lines and tracks where practical and not be located within close proximity to housing and major structures. A development spacing of 500 m has been chosen for the wells to be drilled. This spacing has been chosen following a review of geological and reservoir properties including well interference testing. The wells will be drilled to a total depth of approximately 500-600m (EIMS, 2025). Refer to **Figure 4-3** for a general site layout and infrastructure map.

DRAFT



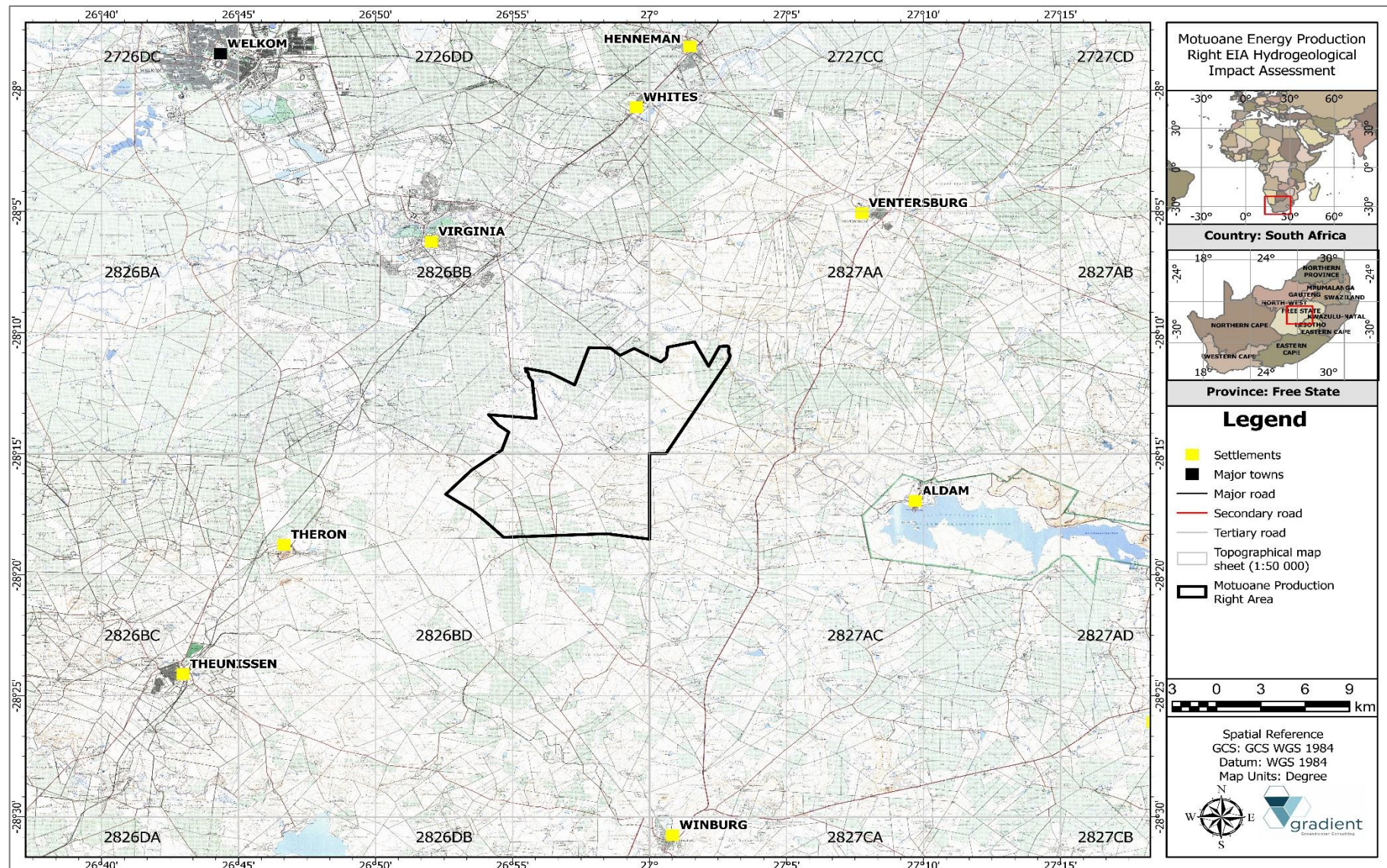


Figure 4-2 Production right area and greater study area (1:50 000 topographical mapsheet 2826 and 2827).

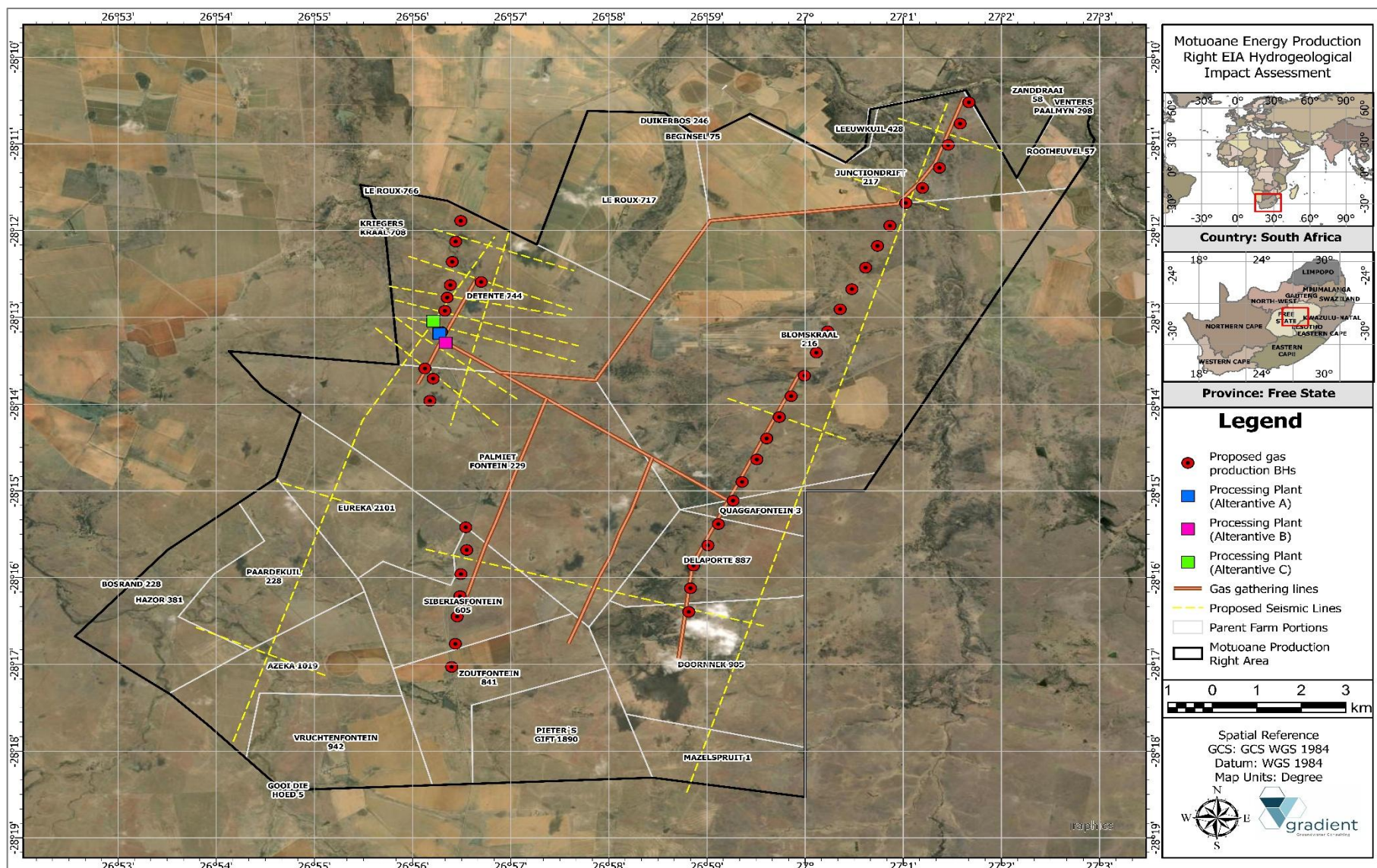


Figure 4-3 General site layout and proposed infrastructure map.

5. PHYSIOGRAPHY

The following sub-sections evaluate the physiography of the greater study area.

5.1. Topography

The topography of the greater study area has a generally flat to gently undulating topography becoming more undulating and hillier towards the east and can be classified as a lowland with hills. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features (DWAF, 2004). The relief of the area varies between 0 – 130.0m towards the far northern and western perimeters and 30 – 450.0m to the south and east.

The landscape gradually flattens out towards the lower laying drainage system towards the northwest (approximate elevation low of 1260.0mamsl), while the southern and southwestern perimeters are shaped by ridges also forming the surface water catchment water divide (approximate elevation high of 1695.0mamsl)(based on elevations extracted from the SRTM DEM raster interpolation).

Elevations generally increase towards the southern and central parts of the study area, with the highest on-site elevation recorded as 1467.0mamsl also shaping the local water divide. The lowest on-site elevation is recorded as 1320.0mamsl forming part of the drainage system situated on the northern edge of the study area.

On-site gradients are variable, especially towards the south zone of the study area, however the gradient is gentle to moderate. The average slope is calculated at ~-2.50% to +3.50% with an elevation loss of approximately 140.0m over a lateral distance of 7.0km in a general northeastern orientation.

Figure 5-1 and **Figure 5-2** indicates elevation profiles for various profiles (refer to **Figure 5-4** for the respective orientations) and it is observed that the greater study flattens out towards the northeast and west which also correlates to the general drainage direction. **Figure 5-3** depicts a topographical cross-section (northwestern aspect) of the greater study area while **Figure 5-4** shows the regional topographical contours and setting.

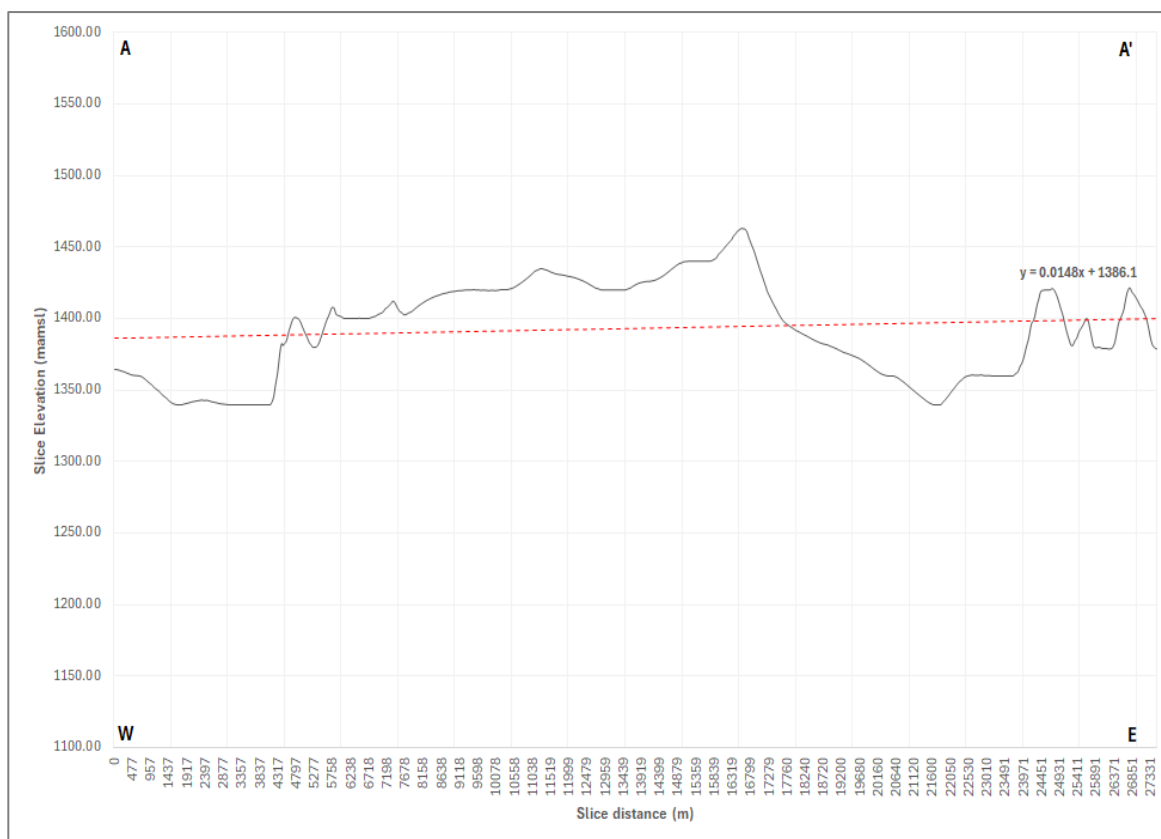


Figure 5-1 West-East Elevation Profile (refer to Figure 5-4 Slice A-A').

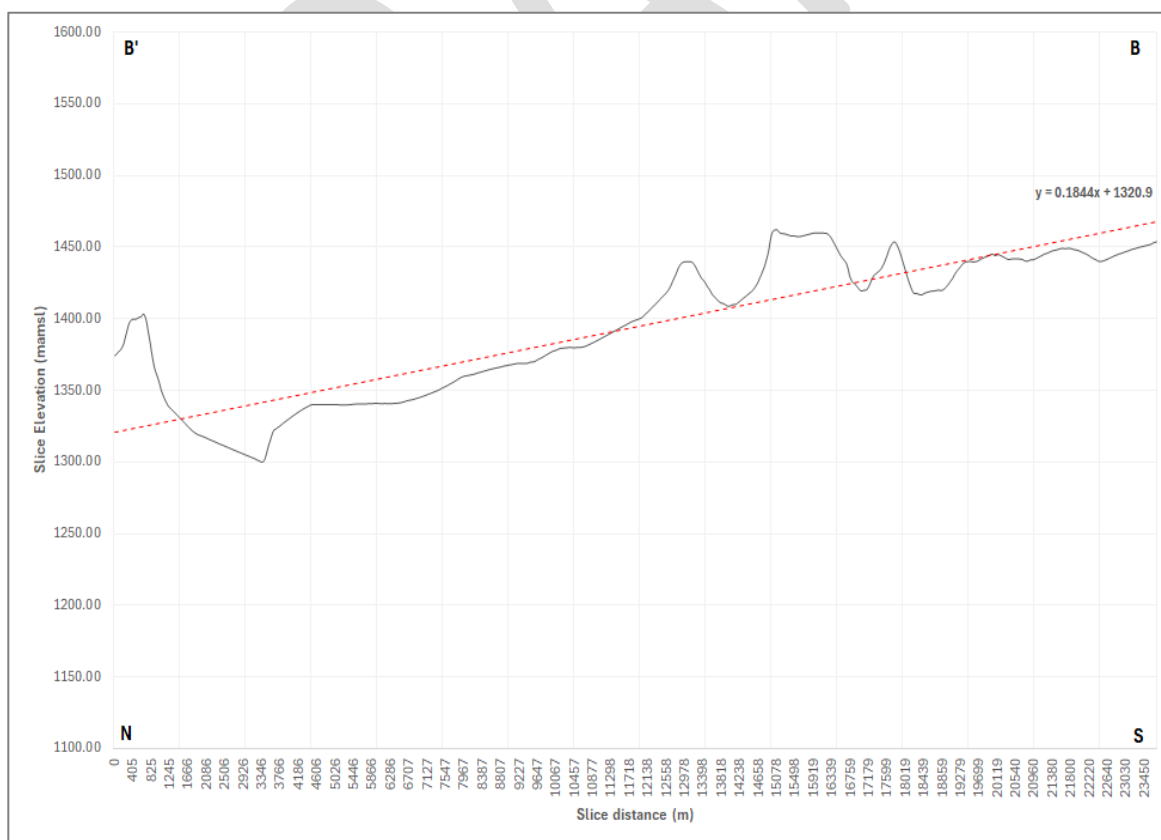


Figure 5-2 North-South Elevation Profile (refer to Figure 5-4 Slice B-B').

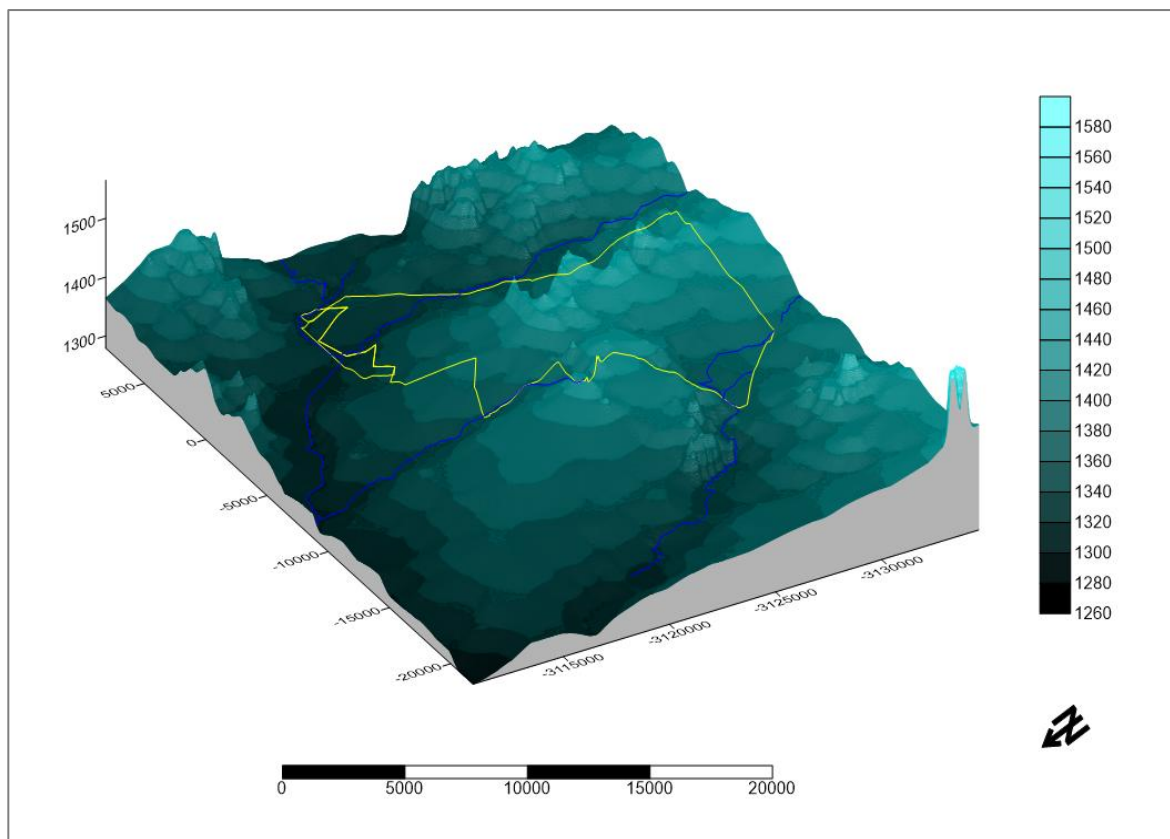


Figure 5-3 Topographical cross-sections of the greater project area.

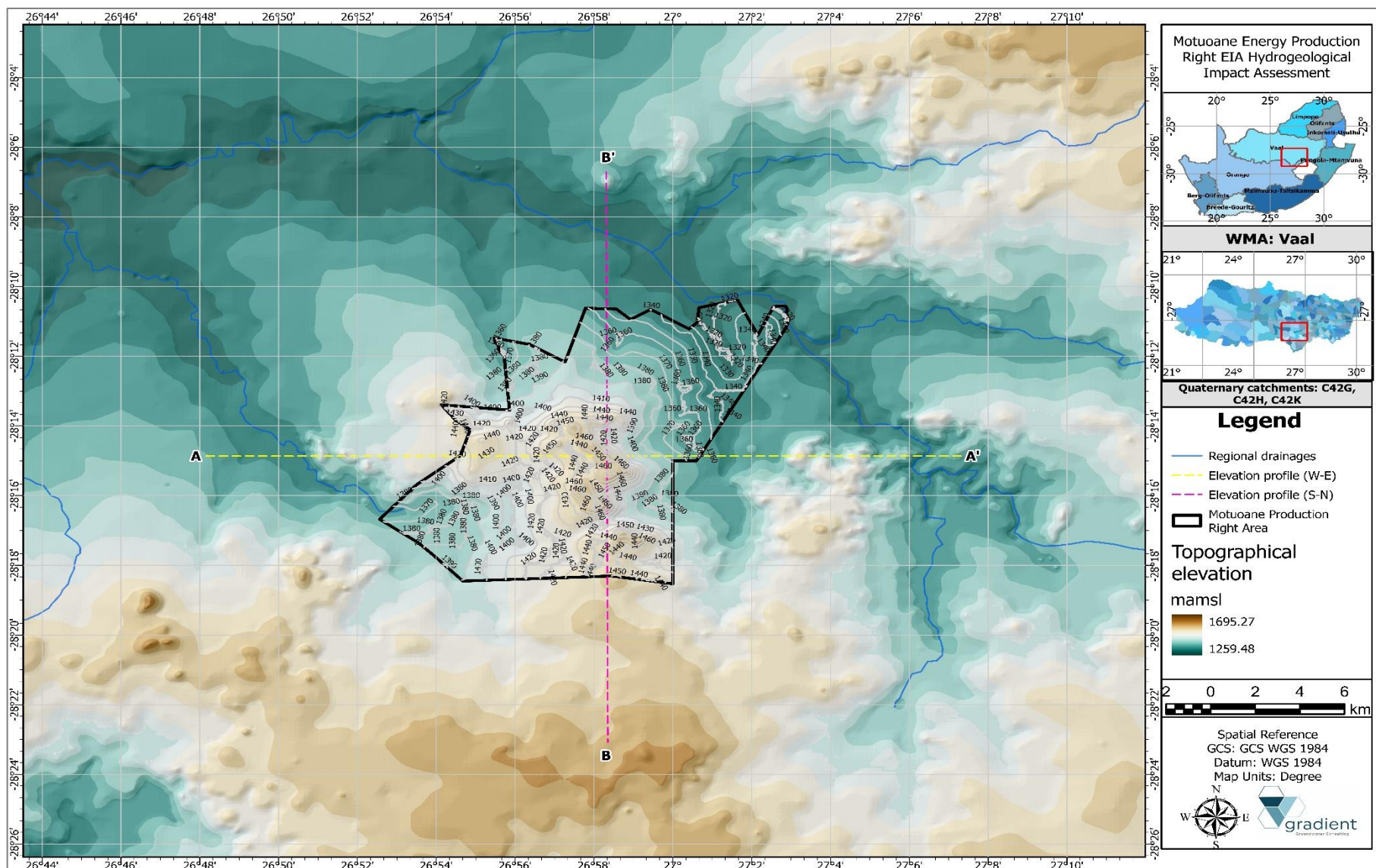


Figure 5-4 Regional topography and conceptual slice (Refer to Figure 5-1 and Figure 5-2).

5.2. Drainage and catchment

The greater study area is situated in primary catchment (C) of the Vaal River drainage system which covers a total area of approximately 598.0km². The resource management falls under the Vaal Water Management Area (WMA5) (previously Middle Vaal WMA⁷) which spans portions of the North West Province, northern Free State as well northern sections of the Northern Cape. The study area encompasses several quaternary catchments of the Vaal WMA which include C42G, C42H and C42K. The main watercourses within the Middle Vaal WMA are the perennial Mooi, Vet, Sand and Vaal Rivers (WRC, 2016). The Vaal River is a major tributary of the Orange River, which generally drains in an eastern direction towards the Atlantic Ocean.

The hydrology of the region is characterised by predominately perennial watercourses with primary rivers in and around the study area the Merriespruit, Steenbokspruit and Maselspruit, draining the northern section of the production right area in a general northwestern direction, forming a confluence with the Sand River flowing on the northern perimeter in a general southwestern direction. The southern section of the production right area is drained by the Doringspruit as well as Schoemanspruit flowing in a general western direction.

Major surface water bodies in close proximity to the greater study area include the Allemanskraal Dam (a surface area of approximately 28.64 km²), which is situated approximately 13.0 km due east and located within the Sand River. The mean annual runoff (MAR) for the study area is estimated at approximately 12.34 Mm³/a, based on MAR data obtained from WR2012 (WRC, 2016). **Table 5-1** provides a summary of relevant climatological information for the relevant quaternary catchments while **Table 5-2** to **Table 5-4** tabulates hydrological and hydrogeological information for the relevant quaternary catchments.

Table 5-1 Study Area Catchment and Hydrological Properties.

Quaternary Catchment	Area (km ²)	% Covered by Study Area	MAP (mm/a)	MAE (mm/a)	MAR (Mm ³ /a)	Rainfall Zone	Evaporation Zone
C42G	555.01	38.92	549.39	1560	13.83	C4C	19C
C42H	445	25.24	540	1 590	10.16	C4C	19C
C42K	668.01	35.66	521.15	1 600	13.02	C4C	19C

⁷ It should be noted that the Department of Water Affairs (DWA), now the Department of Water and Sanitation (DWS), replaced the original 19 WMAs established in 2004 by 9 new WMAs as defined in Government Gazette No. 35517, July 2012. This resulted in the grouping of the Upper, Middle, and Lower Vaal WMAs into the single Vaal WMA.

Table 5-2 Quaternary catchment information: C42G.

Attribute	Quaternary catchment C42G
Water Management Area (WMA)	Vaal
Primary catchment	C
Secondary catchment	C2
Tertiary catchment	C42
Quaternary catchment	C42G
Major rivers	Sand
Hydro-zone	E
Rainfall zone	C4C
Area (km ²)	555.0
Mean annual rainfall (mm)	549.4
Mean annual evaporation (mm)	1560.0
Mean annual runoff (mm)	23.8
Baseflow (mm)	3.4
Population	200.0
Total groundwater use (l/s)	7.0
Present Eco Status Category	Category C
Recharge (mm)	23.0
Average water level (mbgl)	24.2
Soil type	SaClIm - SaCl 100
Groundwater General Authorization	75.0 m ³ /ha/a

Note: Catchment based information sourced from Aqwiworx 2016

Table 5-3 Quaternary catchment information: C42H.

Attribute	Quaternary catchment C42H
Water Management Area (WMA)	Vaal
Primary catchment	C
Secondary catchment	C2
Tertiary catchment	C42
Quaternary catchment	C42H
Major rivers	Sand and Erasmusspruit
Hydro-zone	E
Rainfall zone	C4C
Area (km ²)	445.0
Mean annual rainfall (mm)	540.0
Mean annual evaporation (mm)	1590.0
Mean annual runoff (mm)	27.1
Baseflow (mm)	3.2
Population	7675.0
Total groundwater use (l/s)	34.0
Present Eco Status Category	Category C
Recharge (mm)	23.0
Average water level (mbgl)	32.9
Soil type	SaClIm - SaCl 100
Groundwater General Authorization	75.0 m ³ /ha/a

Note: Catchment based information sourced from Aqwiworx 2016

Table 5-4 Quaternary catchment information: C42K.

Attribute	Quaternary catchment C42K
Water Management Area (WMA)	Vaal
Primary catchment	C
Secondary catchment	C2
Tertiary catchment	C42
Quaternary catchment	C42K
Major rivers	Sand and Doringrivier
Hydro-zone	E
Rainfall zone	C4C
Area (km ²)	668.0
Mean annual rainfall (mm)	521.2
Mean annual evaporation (mm)	1600.0
Mean annual runoff (mm)	23.8
Baseflow (mm)	2.9
Population	350.0
Total groundwater use (l/s)	27.9
Present Eco Status Category	Category C
Recharge (mm)	22.0
Average water level (mbgl)	39.3
Soil type	Sa - LmSa 25 SaLm - SaCLm 70
Groundwater General Authorization	75.0 m ³ /ha/a

Note: Catchment based information sourced from Aqwiworx 2016

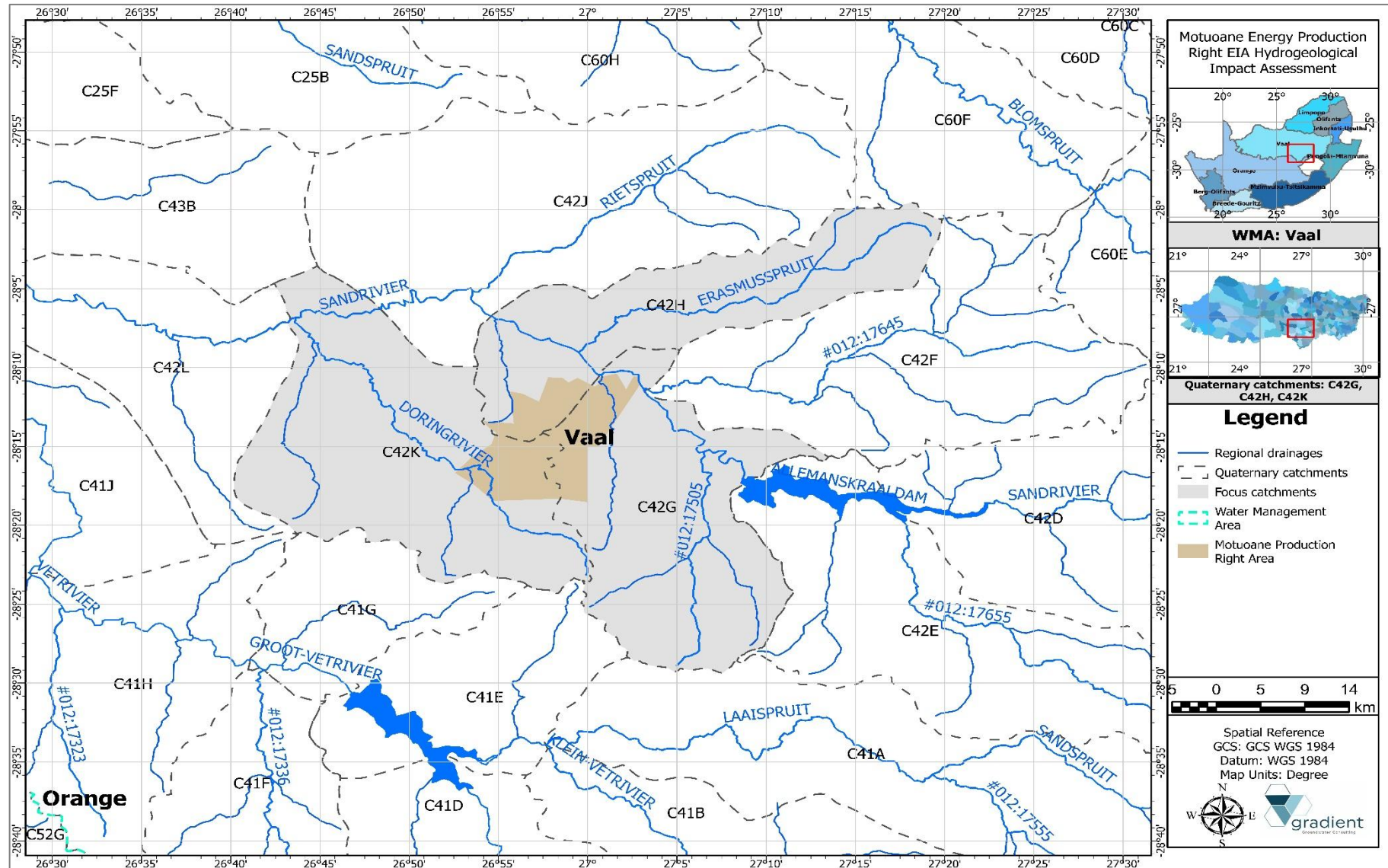


Figure 5-5 Quaternary catchments, water management area and regional drainage map.

5.2.1. Climate

According to the Koppen-Geiger climate classification system, the climate of the study area is classified as BSk (Climate Change & Infectious Diseases Group, 2023). This classification indicates that the study area has a cold, semi-arid climate characterized by cold, dry winters and warm summers. The average temperature in the greater study area ranges between 11.5 °C in the winter (July) and 24.4 °C in the summer (January), while the mean annual temperature is 18.8 °C (Climate-Data, 2021). Climate change and future climatic conditions might lead to hotter temperatures and prolonged drought conditions. The latter will cause higher evapotranspiration rates, increased rainfall runoff due to more intense rainfall events as well as decreasing of effective groundwater recharge. Consequently, a prolonged drought could potentially produce significant groundwater-level declines with climate-change-induced changes in rainfall patterns negatively affecting groundwater availability. Refer to **Figure 5-6** for the Mean Yearly Temperature Distribution of the greater study area.

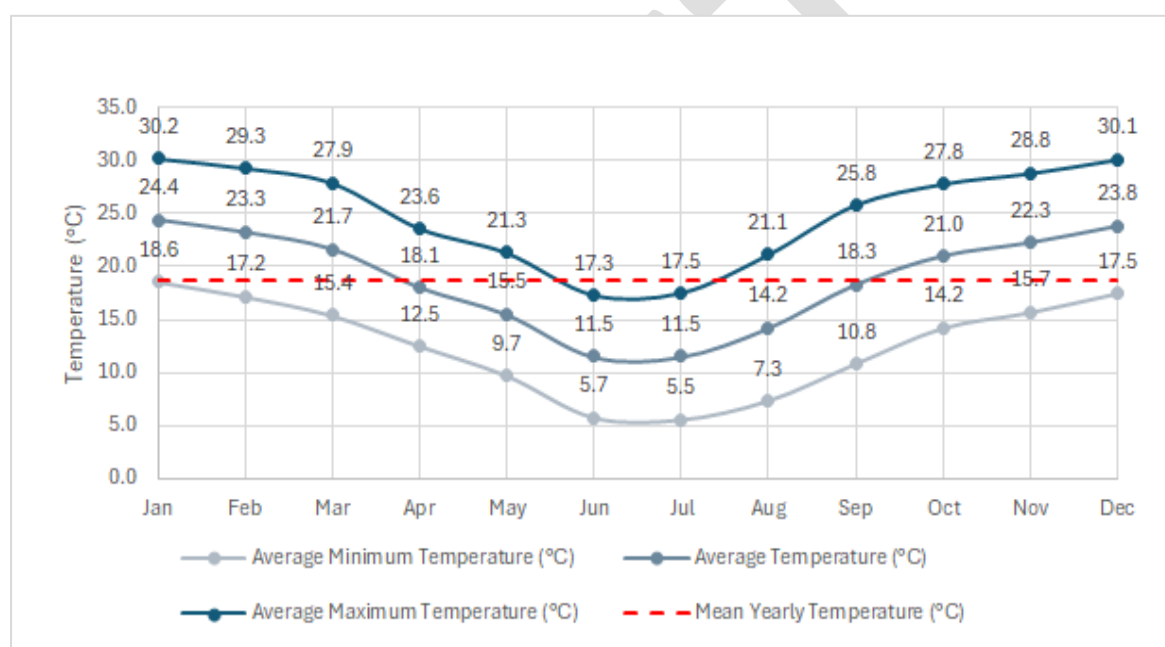


Figure 5-6 Mean Yearly Temperature Distribution of the greater study area, 1991 – 2024 (Climate-Data, 2021).

The mean annual precipitation (MAP) for the study area is estimated at approximately 535.98 mm/a, based on patched monthly precipitation data (ranging from 1920 to 2009), obtained from the WR2012 database (WRC, 2016). The 5th percentile of the dataset, which approximately represents a 1:20 year drought, is calculated as 353.24 mm/a. The 95th percentile of the dataset, which approximately represents the 1:20 year flood, is calculated as 774.02 mm/a.

The results from the analysis of the WR2012 datasets indicate that the study area has a summer rainfall regime, with the majority of the precipitation occurring from October to March (~80.0%) as high intensity thunderstorms, while the winter months, June to August, are particularly dry. Refer to **Figure 5-7** and **Figure 5-8** for graphical representations of the monthly and annual precipitation distributions for the study area. The study area falls within evaporation zone 19C with the mean annual evaporation (MAE), measured by Symons Pan, ranging between 1 560 and 1 600 mm/a (WRC, 2016).

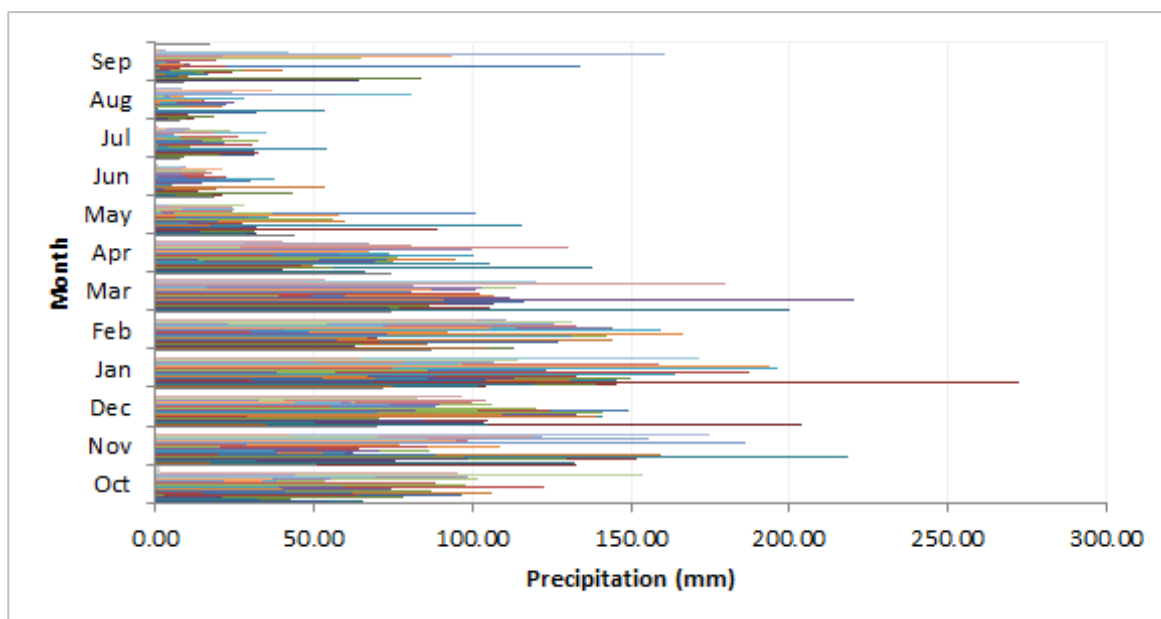


Figure 5-7 Bar chart indicating monthly rainfall distribution for rainfall zone C4C (WRC, 2016).

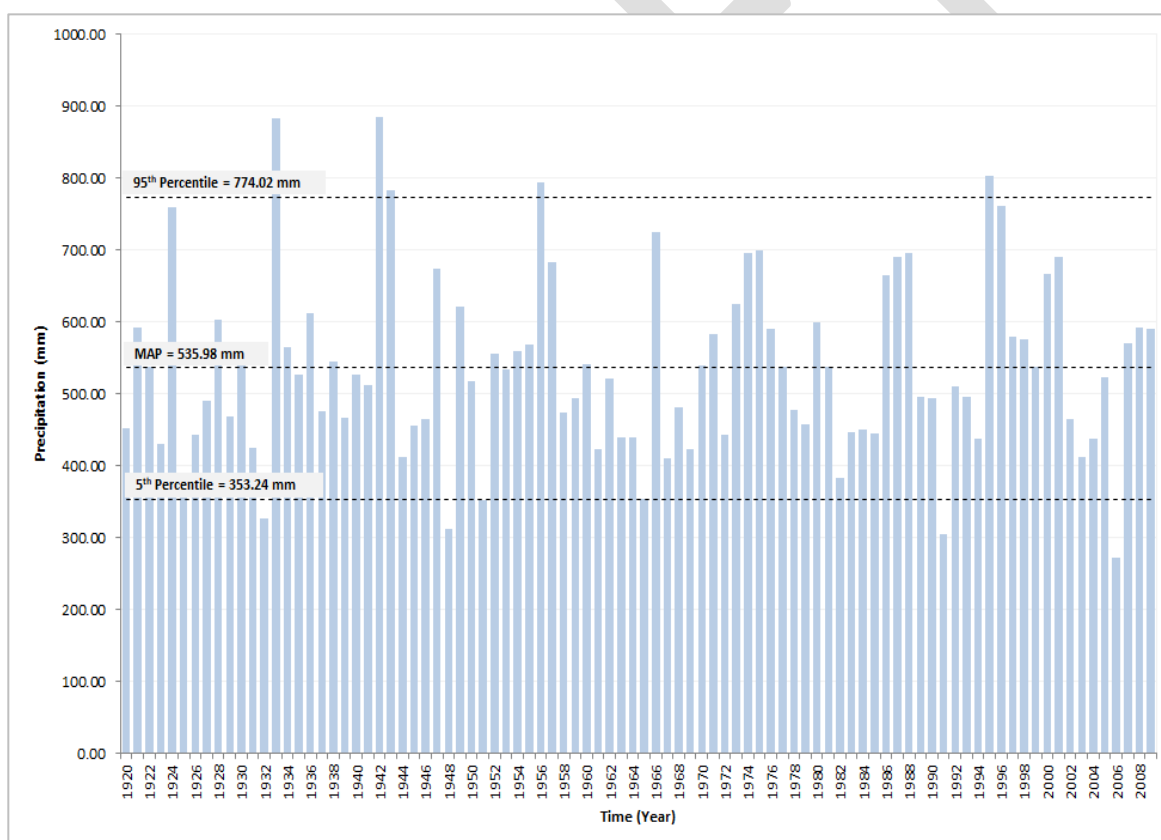


Figure 5-8 Bar chart indicating yearly rainfall distribution for rainfall zone C4C (WRC, 2016).

5.3. Geological setting

The following sections summarises the regional and local geology.

5.3.1. Regional geology

According to the Council for Geoscience (CGS) 1:250 000 geological maps (Geological Map Sheet 2826 Winburg) the surface geology of the study area is characterized by a variety of lithologies, formations, and intrusions. These include geologically recent Quaternary deposits as well as sediments of the Beaufort Group within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. Refer to **Table 5-5** for a summary of the lithostratigraphy of the study area while **Figure 5-9** depicts the regional geology and stratigraphy.

The Quaternary deposits, which were deposited less than 0.01 million years ago (DWA, 2012), cover most of the northern and central parts of the study area, while also being present in the southern parts of the study area. These deposits include aeolian (wind-blown) dune sand in the northern and central parts of the study area; alluvium, including calcified alluvium and river gravel, in the northern, northeastern, central, and southern parts of the study area along the banks and floodplains of surface water drainage features; and patches of calcrete and surface limestone in the western and northwestern parts of the study area.

The sediments of the Beaufort Group, which are primarily of fluvial and deltaic origin (Baran, 2003), were deposited during the late Permian Period between approximately 248 and 239 million years ago and are associated with the orogeny and tectonic paroxysm of the Cape Fold Belt (Woodford and Chevallier, 2002). The Adelaide Subgroup within the Beaufort Group occurs toward the northeastern parts of the study area, while also being present in the central and southern parts of the study area. Specifically, the Normandien Formation within the Adelaide Subgroup occurs towards the northeast of the study area and comprises of greenish grey (bottom of formation) to red (top of formation) mudstone and siltstone, grey shale and rhythmite, and sandstone. The Adelaide Subgroup covering the central and southern parts of the study area is not differentiated into specific formations and comprises of mudstone with subordinate sandstone.

A vast network of dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite occurs throughout the study area and is especially prominent in the southern and central parts of the study area. The Karoo Dolerite Suite intruded into the Karoo Supergroup approximately 180 million years ago during the early stages of the break-up of Gondwanaland (Woodford and Chevallier, 2002).

5.3.2. Structural geology

According to the CGS 1:250 000 geological maps (Geological Map Sheet 2826 Winburg) large dolerite intrusions in the form of dykes and sills are observed throughout the study area. The Karoo sediments in this portion of the WMA are much intruded by sub accordant sheets, and to a lesser extent by near-vertical dykes of Karoo dolerite (DWAF, 2004). The Karoo Basin is characterised by a vast network of post-Karoo intrusive dolerite (Jd) sills and dykes that rapidly intruded at 183.0 to 182.3Ma (Svensen et al., 2012). The intrusive Karoo dolerite suite represents a shallow feeder system which occurs as an interconnected network of dykes, sills as well as sheets which typically form resistant caps of hills compromising softer sedimentary strata (Chevallier and Woodford,

1999). A high resolution airborne magnetic survey identified various southwest-northeast as well as southeast-northwest striking magnetic lineaments inferred as dolerite dykes towards the western and central zones of the production right area. Regional fault zones include the known fault Virginia and Ventersburg fault lines. Structural analysis also suggests a potential east-west striking fault zone towards the central zone of the production right area. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

Table 5-5 Simplified lithostratigraphy of the greater study area.

Age (Mya)	Supergroup	Group	Subgroup	Formation	Intrusions	Lithology
< 0.01	-	-	-	Quaternary Deposits	-	Aeolian sand, alluvium, calcrete and surface limestone
130 to 70	-	-	-	-	Kimberlite	-
180	-	-	-	-	Karoo Dolerite Suite	-
248 to 239	Karoo	Beaufort	Adelaide	-	-	Mudstone with subordinate sandstone
				Normandien	-	Mudstone, siltstone, shale, rhythmite, sandstone
290 to 248		Ecca	-	Volsrust	-	Mudstone, siltstone, shale
300 - 280		Dwyka	-	-	-	Mudstone, shale
Unconformity						
~2.7 Ga	Ventersdorp Supergroup	Klipriviersberg Group	-	-	-	Lavas and volcaniclastics
Unconformity						
2.9–2.7 Ga	Witwatersrand Supergroup	Central Rand Group	-	Virginia Formation	-	Quartzite and conglomerate

5.3.3. Soils

Soils in the study area were identified using GIS data obtained from WR2012 (WRC, 2016). The data indicates that the majority of soils throughout the study area is classified as Sandy-Clay-Loam to Sandy-Clay (SaClIm – SaCl 100) with an average depth of <450.0mm in the higher elevated southern area while the depth increases (450.0 – 750.0mm) towards the lower laying drainage system in the north and northwest.

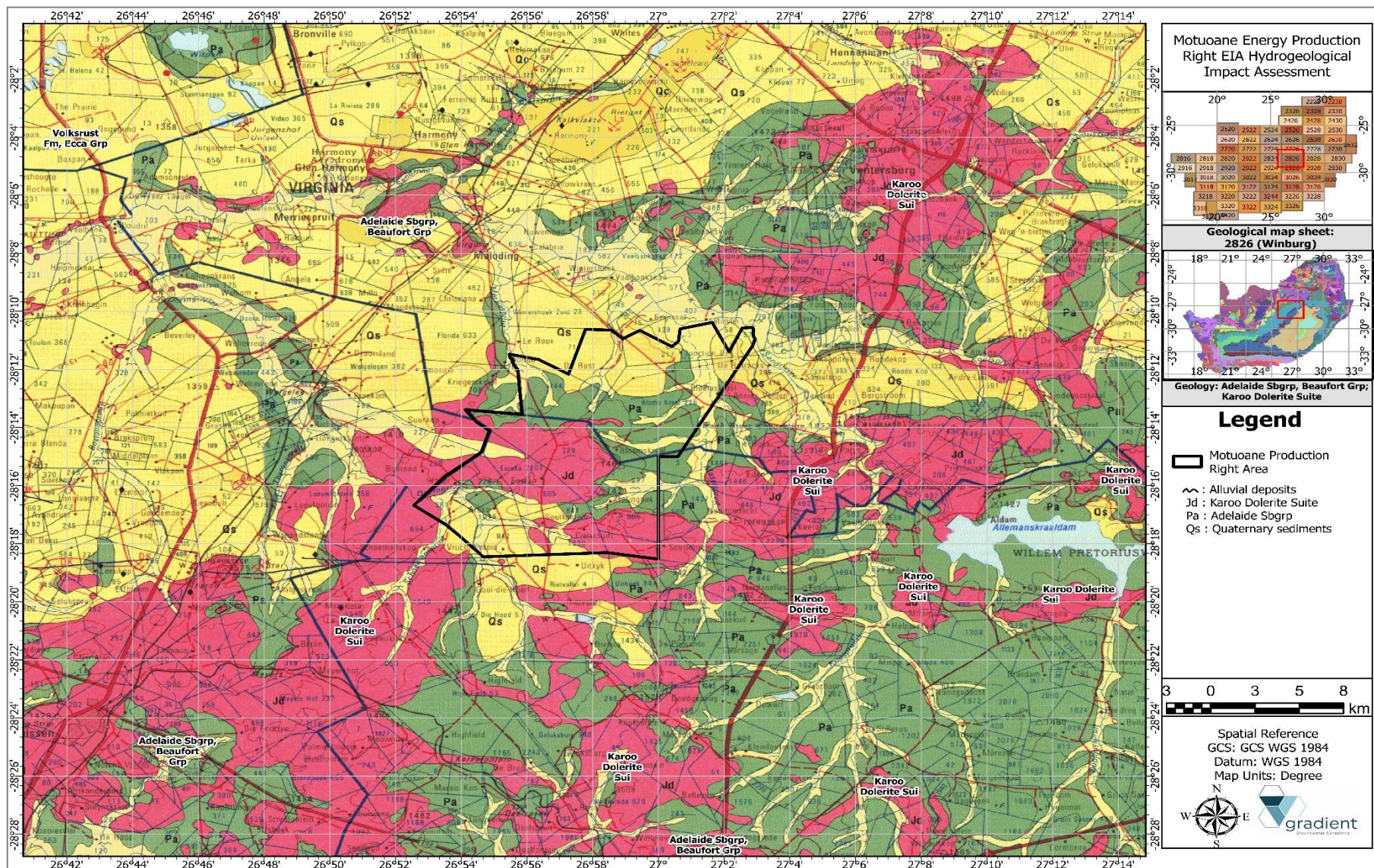


Figure 5-9 Regional geology and stratigraphy (Geological map sheet 2826: Winburg)(1:250 000 scale).

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

The following sections summarise the regional and site-specific hydrogeology.

6.1. Regional hydrogeology

The Department have characterised South African aquifers based on host-rock formations in which it occurs together with its capacity to transmit water to boreholes drilled into relative formations. The water bearing properties of respective formations can be classified into four aquifer classes defined below. Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields:

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

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2726 Kroonstad) the study area is predominantly underlain by a Class d2 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.1 and 0.5 L/s) with host aquifers consisting primarily of arenaceous and argillaceous strata. It should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. (Barnard, 2000). Most hard-rock aquifers are secondary in nature with groundwater associated with fracturing, fault zones as well as contact zones of the dolerite intrusions. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however will not only be multi-layered, but also multi-porous with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer.

According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the Northeastern Upper Karoo Region (Region 30). Groundwater Region 30 comprises of mudstone and sandstone (with dolerite dyke and sill intrusions) of the Adelaide and Tarkastad Subgroups within the Beaufort Group of the Karoo Supergroup (WRC, 2016). The maximum aquifer thickness i.e., shallow, intergranular aquifer system within the Northeastern Upper Karoo Region is 20 – 30m with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level. Refer to **Figure 6-2** for a map illustrating the typical groundwater occurrence for the greater study area while **Figure 6-3** depicts the hydrogeological map of the greater study area.

6.2. Local hydrostratigraphic units

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

- i. **A shallow Quaternary (perched and unconfined) aquifer:** These aquifers consist of recent types of sediments and are characteristically primary porosity aquifers, such that groundwater flow occurs in the pore spaces between soil and sediment particles. These aquifers are formed by alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth. Clay lenses in the soil and unsaturated zones may cause local, perched water tables which occur above the regional water table.
- ii. **A shallow, intergranular aquifer within the Beaufort Group and Karoo Dolerite Suite:** These aquifers occur in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually, these aquifers can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. In secondary porosity aquifers, groundwater flow occurs along fractures, while water is stored within the rock matrix. Due to higher effective porosity (n) this aquifer is more susceptible to impacts from contaminant sources compared to confined aquifers.
- iii. **A deeper, fractured aquifer within Beaufort Group and Karoo Dolerite Suite formations:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured mudstone and siltstone sequences as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

6.3. Unsaturated zone

The unsaturated (vadose) zone is defined as the subsurface zone between the ground surface and the main water table where pores are filled with both air and water as depicted in **Figure 6-1** (Fetter and Kreamer, 2023). According to the 1.0×1.0 km groundwater level grid obtained from WR2012 (WRC, 2016), the thickness of the unsaturated zone i.e., depth to groundwater ranges between ~30.0 m to >55.0 m.

6.4. Groundwater-surface water interaction

Groundwater and surface water interaction is an essential component of the hydrological cycle. The hyporheic zone (stream bed) is the zone of most interaction (Adams et. al.,2012) (**Figure 6-1**). According to records documented by Van Tonder and Dennis (2003), under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. The two regimes are therefore well-linked and should be integrated to manage any water-related issues in these catchments. Regional drainages can be generally classified as influent or gaining stream systems as the groundwater head elevation of the water table in the vicinity of the stream is higher than the altitude of the stream bed and, accordingly, there definitely exists groundwater discharge as baseflow to local drainages. The alluvial associated with the floodplains within the greater study area forms a primary aquifer and may potentially be directly connected with surface water resources, especially during high flow conditions.

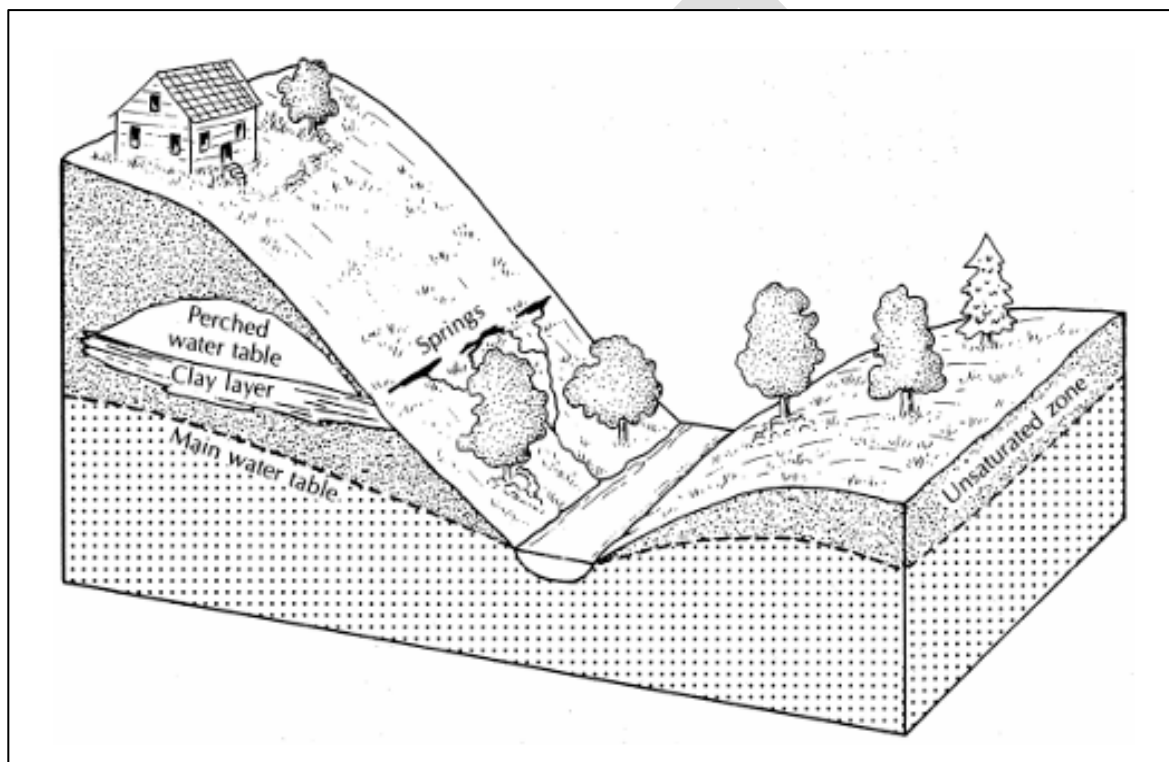


Figure 6-1 Illustration of the Unsaturated Zone (Fetter and Kreamer, 2023).

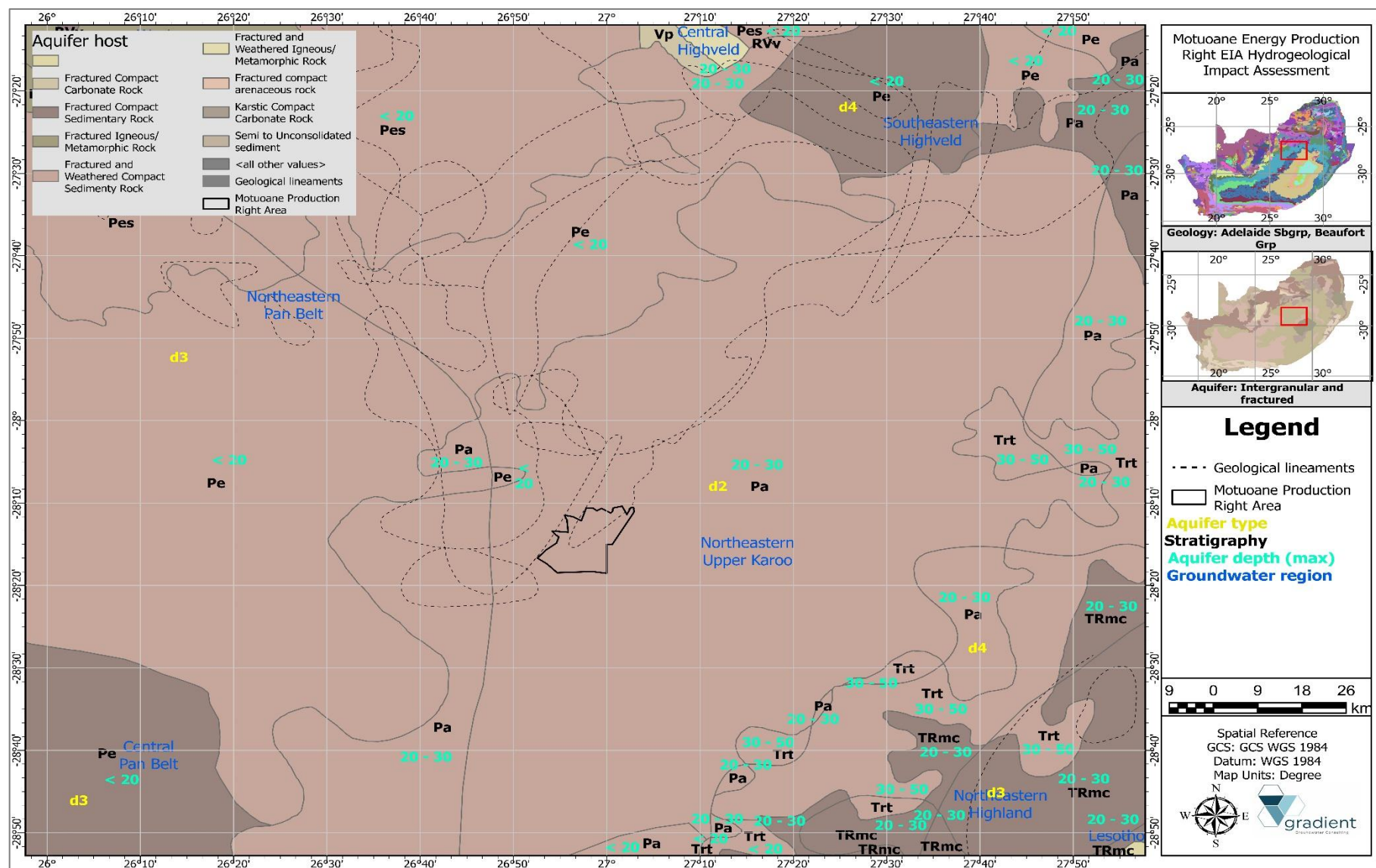


Figure 6-2 Typical aquifer hosts and groundwater occurrence for the study region (2726 Kroonstad).

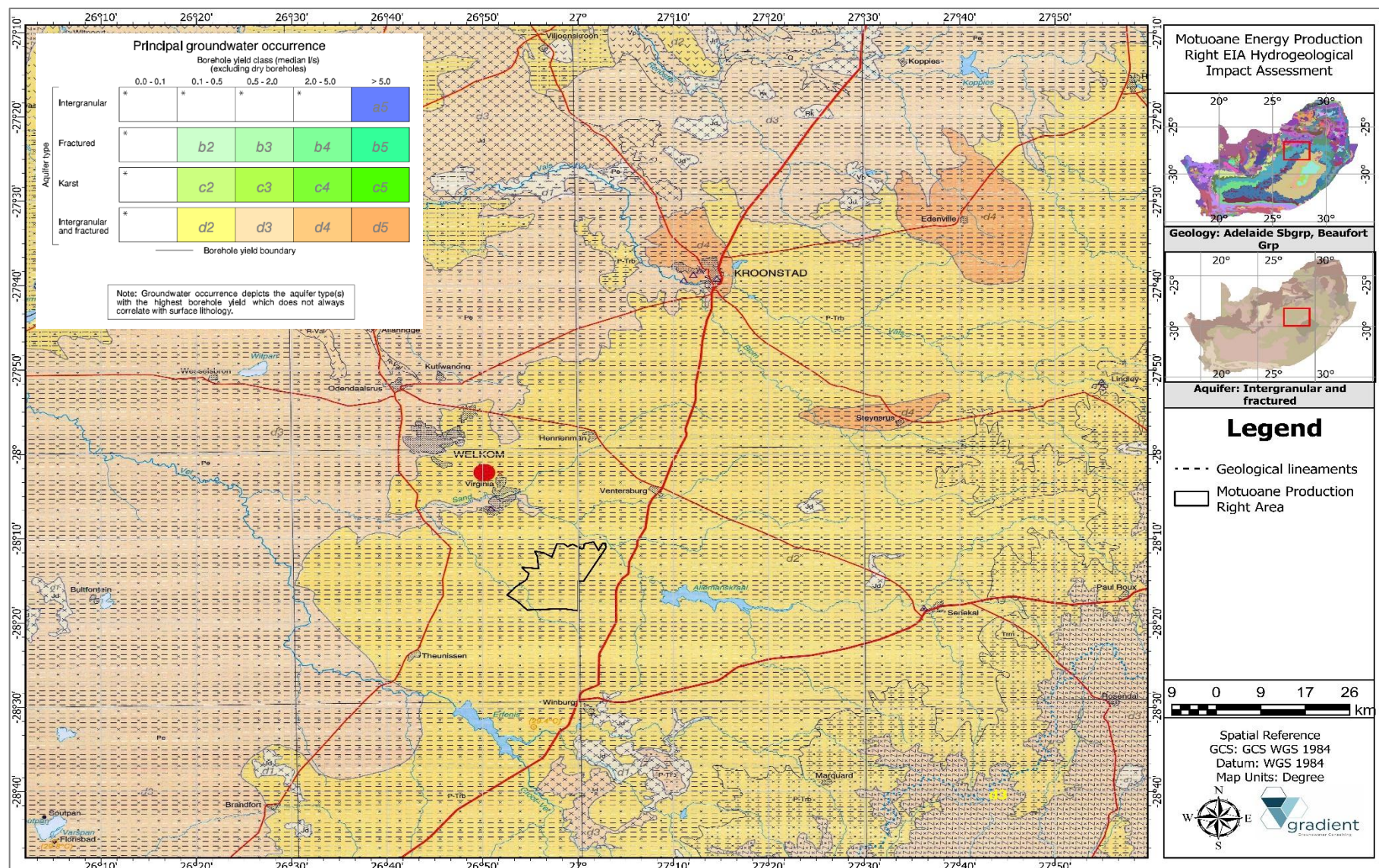


Figure 6-3 Hydrogeological map of the greater study region (2726 Kroonstad).

6.5. Hydraulic parameters

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

6.5.1. Hydraulic conductivity and Transmissivity

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

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

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

where:

K = Hydraulic Conductivity (m/d).

Q = Flow of water per unit of time (m³/d).

dh/dl = Hydraulic gradient.

A = is the cross-sectional area, at a right angle to the flow direction, through which the flow occurs (m²)

The hydraulic conductivity of sedimentary Beaufort Group formations such as evident on site can range from 10E⁻⁰⁶ – 10E⁻⁰² m/d. The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between 10E⁻⁰⁶ – 10E⁻⁰¹ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between 10E⁻⁰⁹ – 10E⁻⁶ m/d. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e., riverbed aquifers can be orders higher and can vary between 10E⁻⁰² – 10E⁰¹ m/d (Freeze and Cherry, 1979). Refer to **Figure 6-4** for the typical hydraulic conductivity values for on-site hydrostratigraphical units.

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

Equation 6-2 Transmissivity.

$$T = Kb$$

where:

T = Transmissivity (m²/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

The site characterisation phase indicates that the local transmissivity values range between 0.04m²/d to 0.27m²/d with a mean value of 0.11m²/d.

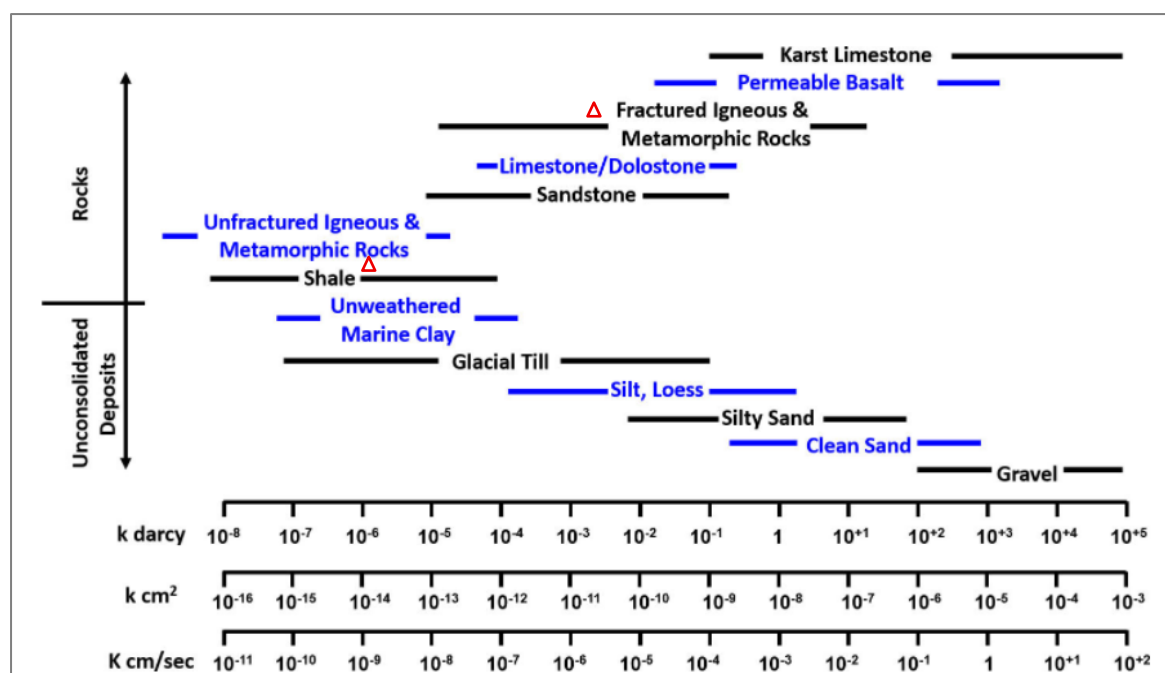


Figure 6-4 Typical hydraulic conductivity values for on-site hydrostratigraphical units.

6.5.2. Storativity

Storativity refers to the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. Typical storativity values for fractured rock systems is in the order of $10E^{-05} - 10E^{-03}$ (Freeze and Cherry, 1979). Storativity values of the shallow, weathered aquifer will be slightly higher i.e., $10E^{-02}$.

6.5.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. The porosity of fractured sedimentary formations ranges between 3% – 10%, while porosity of weathered formations can range between 10% to 15% depending on the nature and state of weathering. The intrinsic porosity of primary aquifers i.e., alluvial deposits can be as high as 20% depending on the nature of sorting (Freeze and Cherry, 1979).

6.5.4. Recharge

An approximation of recharge for the study area is estimated at ~3.29% of MAP i.e. ~17.65 mm/a as summarised in **Table 6-1**. According to the 1 × 1 km recharge grid obtained from WR2012, the lower limit recharge in the greater study area is approximately 1.0% (5.0mm/a) whereas the upper limit is approximately 5.0% (26.50mm/a) (WRC, 2016). Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride Mass Balance (**Figure 6-5**, **Figure 6-6** and **Figure 6-7**) (ii) Geology (iii) Vegter Groundwater Recharge Map (**Figure 6-8**) (iv) Harvest Potential (**Figure 6-9**) (v) Baseflow as a minimum of recharge (vi) Qualified opinion and, (vii) Literature review.

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

Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Chloride	20.89	3.90	3.00
Geology	22.00	4.10	1.00
Vegter	20.00	3.73	3.00
Harvest Potential	15.00	2.80	4.00
Baseflow	15.00	2.80	4.00
Qualified opinion	17.50	3.27	2.00
Literature (Botha et al., 1998)	17.80	3.32	3.00
Weighted average	17.65	3.29	20.00

Notes: Recharge per annum were calculated using a MAP of 535 mm/a.

CMB Method: Beaufort aquifer

Average annual rainfall (mm) =	535.98
Cl in rain (mg/l) =	1.240125
Dry deposition Cl (mg/l) =	0.124012
Cl in gw or unsat. zone (mg/l) =	55

Average annual recharge (mm) =	13.29
Percentage recharge =	2.48

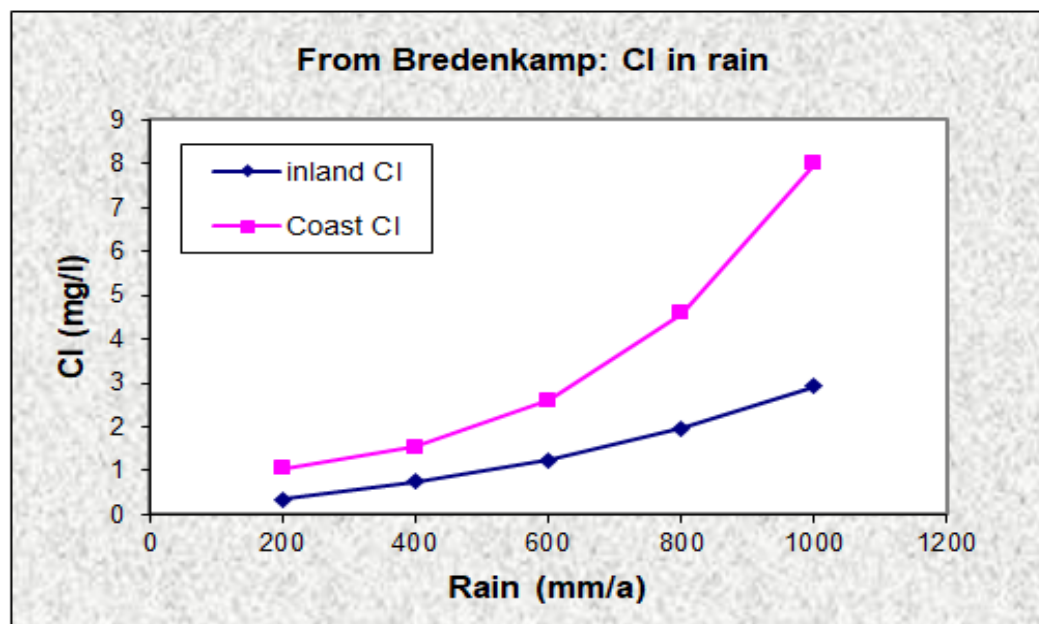


Figure 6-5 Chloride Mass Balance (CMB) method recharge summary: Adelaide Sbgp, Beaufort Group Aquifer.

CMB Method: Dolerite

Average annual rainfall (mm)=	535.98
Cl in rain (mg/l) =	1.240125
Dry deposition Cl (mg/l) =	0.124012
Cl in gw or unsat. zone (mg/l) =	91.2

Average annual recharge (mm) =	8.02
Percentage recharge =	1.50

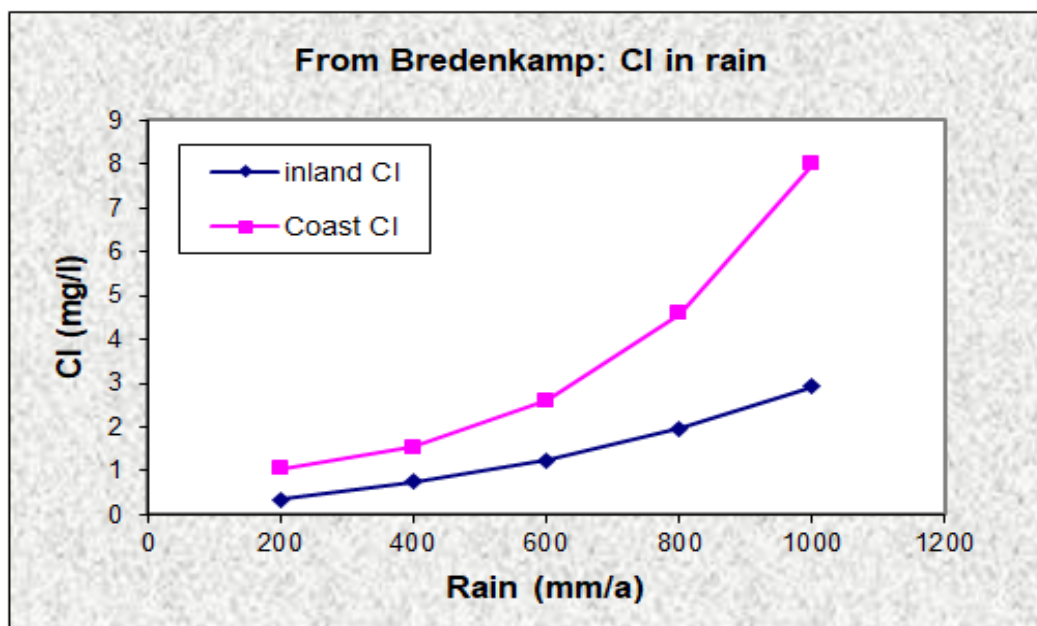


Figure 6-6 Chloride Mass Balance (CMB) method recharge summary: Karoo Dolerite Formation.

CMB Method: Alluvial aquifer

Average annual rainfall (mm)=	535.98
Cl in rain (mg/l) =	1.240125
Dry deposition Cl (mg/l) =	0.124012
Cl in gw or unsat. zone (mg/l) =	24.1

Average annual recharge (mm) =	30.34
Percentage recharge =	5.66

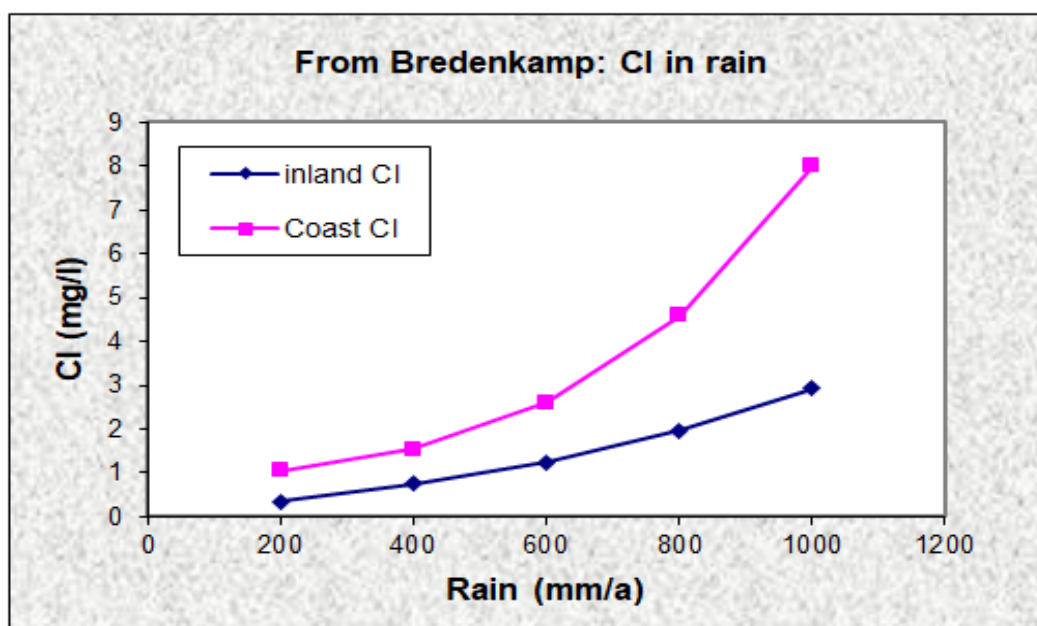


Figure 6-7 Chloride Mass Balance (CMB) method recharge summary: Riparian zonw/ Alluvial Aquifer.

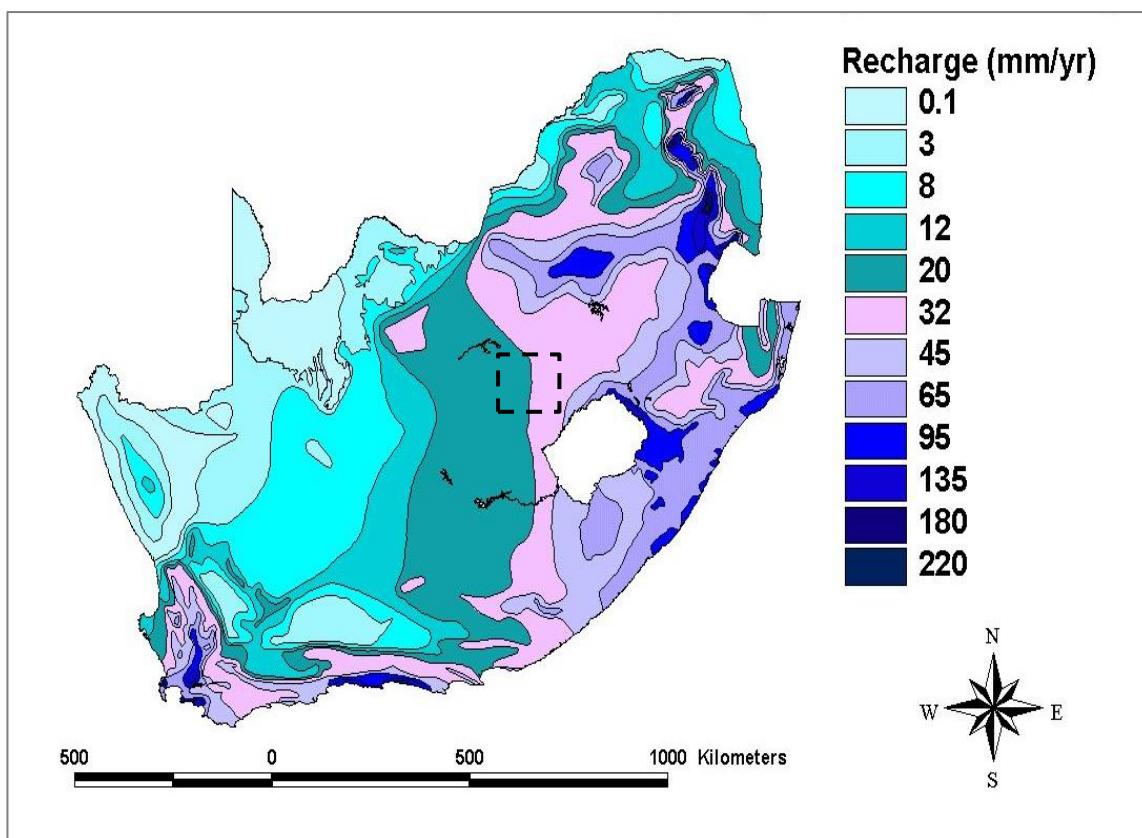


Figure 6-8 Groundwater recharge distribution in South Africa (After Vegter, 1995).

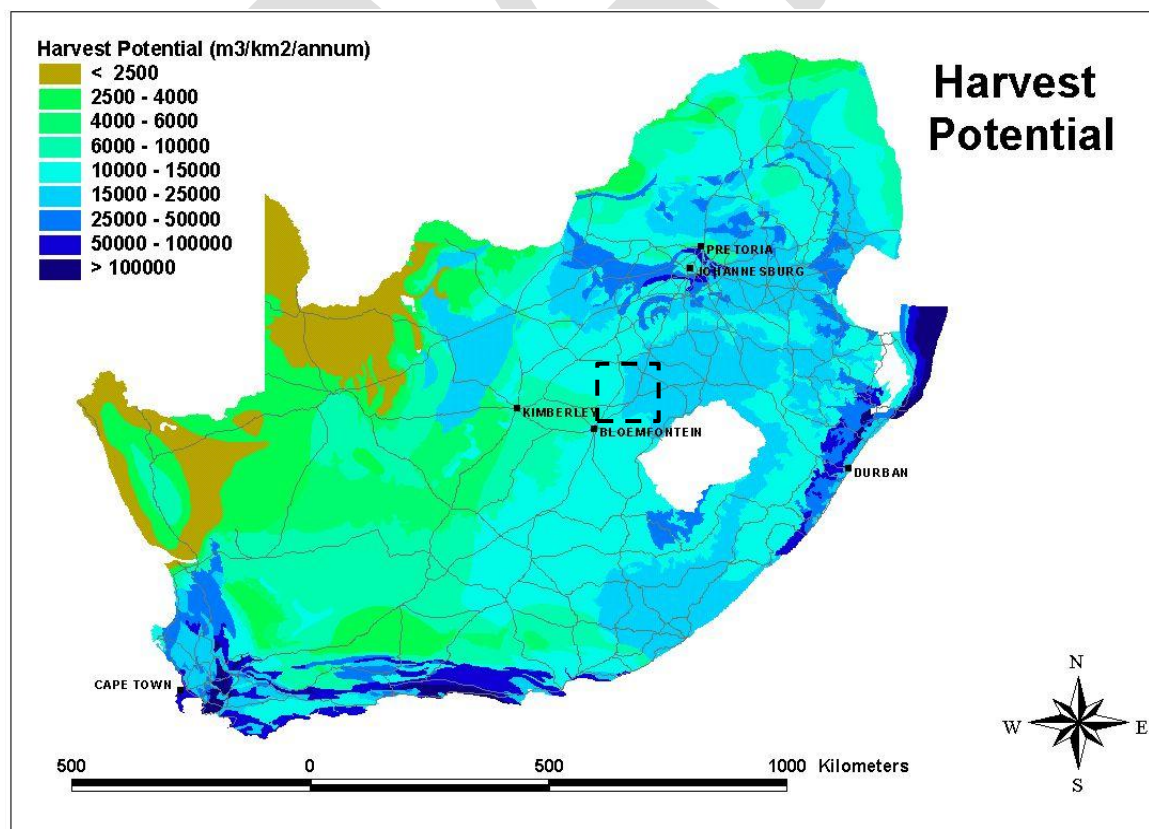


Figure 6-9 Harvest potential distribution in South Africa (DWS, 2013).

7. SITE INVESTIGATION

7.1. Hydrocensus user survey

A hydrocensus user survey within the greater study area was conducted during November and December 2025⁸ where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater conditions and applications and to identify potential sensitive environmental receptors, i.e., groundwater users in the direct vicinity of the proposed gas production activities. A total of 62 geosites were visited and recorded as part of the hydrocensus user survey which includes surface water and groundwater receptors i.e., boreholes, artesian wells, wind pumps as well as surface water features and are largely applied for livestock watering and domestic water supply purposes. Relevant hydrocensus information is summarised in **Table 7-1** while **Figure 7-5** depicts a spatial distribution map of geosites visited as part of the hydrocensus user survey with **Figure 7-6** indicating the various groundwater status and applications.

7.1.1. Groundwater status

Of the boreholes recorded, the majority are in use (74.14%) while 25.86% are not currently being utilized. Refer to **Figure 7-2** for a summary of the groundwater status quo.

7.1.2. Groundwater application

Most boreholes recorded are being applied for livestock watering purposes (34.25%) while water being applied for either domestic and household or domestic and livestock purposes account for 42.47%. A small number of boreholes are also being applied for wildlife watering (1.37%) or monitoring purposes (1.37%). Boreholes which do not have an application and are not currently being utilized account for 20.55% of the total geosites visited. Refer to **Figure 7-3** for summary of groundwater applications. According to the Middle Vaal ISP (DWAF, 2004), most boreholes are being applied for irrigation and small-town water supply.

7.1.3. Borehole equipment

Most boreholes visited are equipped with submersible pumps and account for 42.86%, while 37.50% of boreholes were fitted with a wind pump. An average of 19.64% of boreholes are not equipped as indicated in **Figure 7-4**.

⁸ It should be noted that relevant site information gathered will be representative of wet season contribution and conditions.

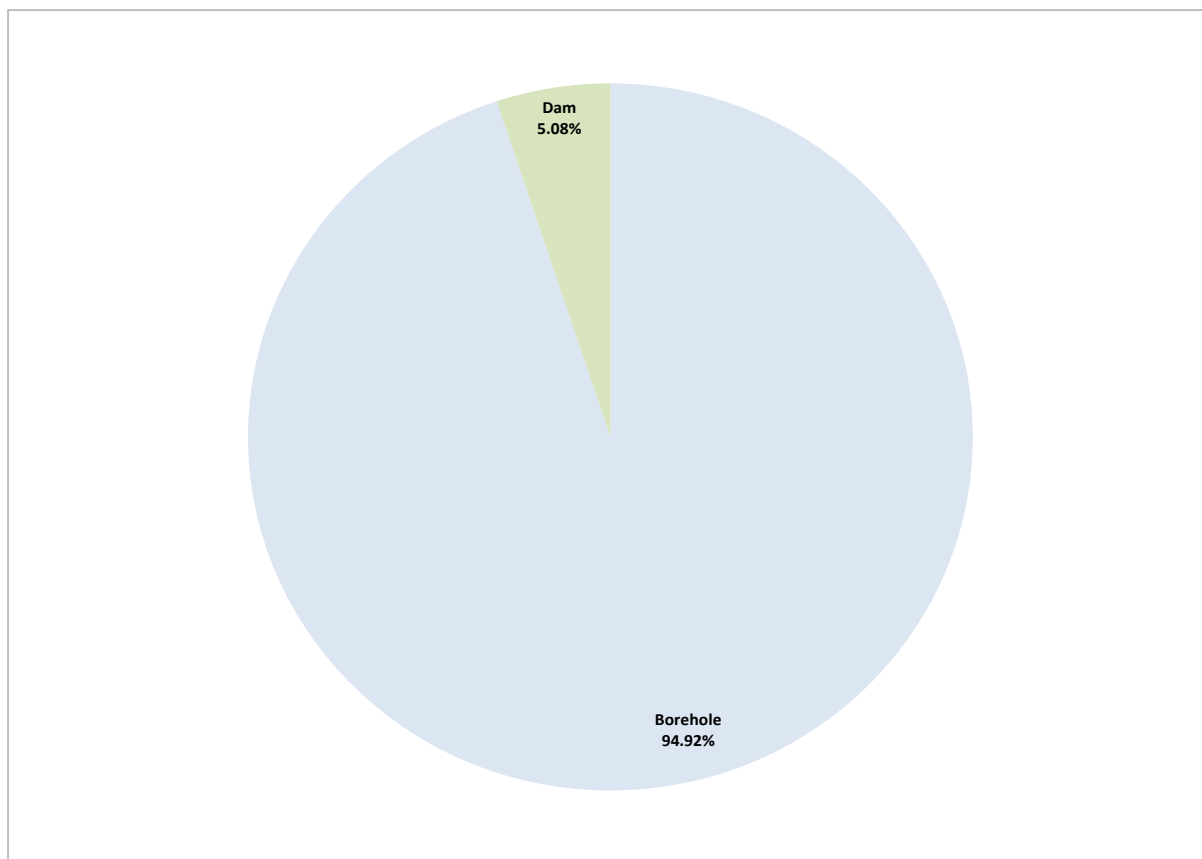


Figure 7-1 Hydrocensus user survey: Geosite type.

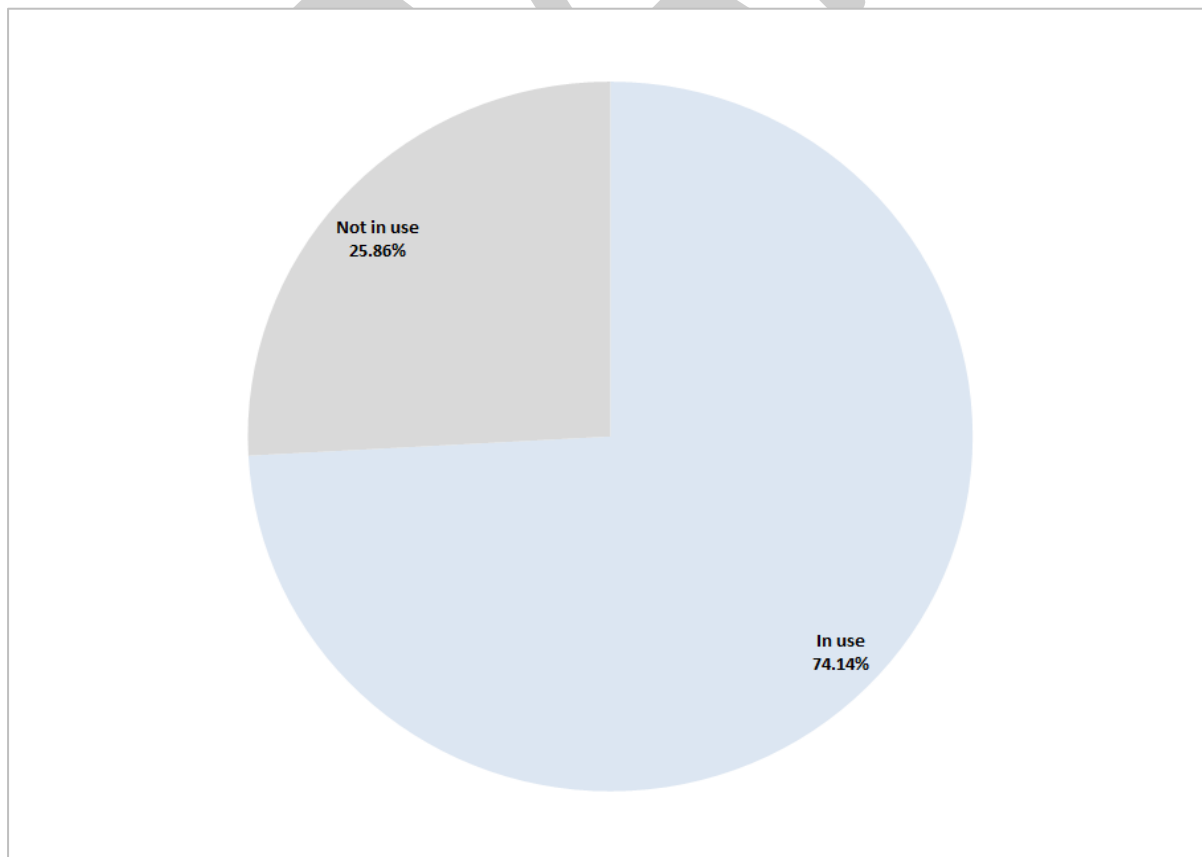


Figure 7-2 Hydrocensus user survey: Geosite status.

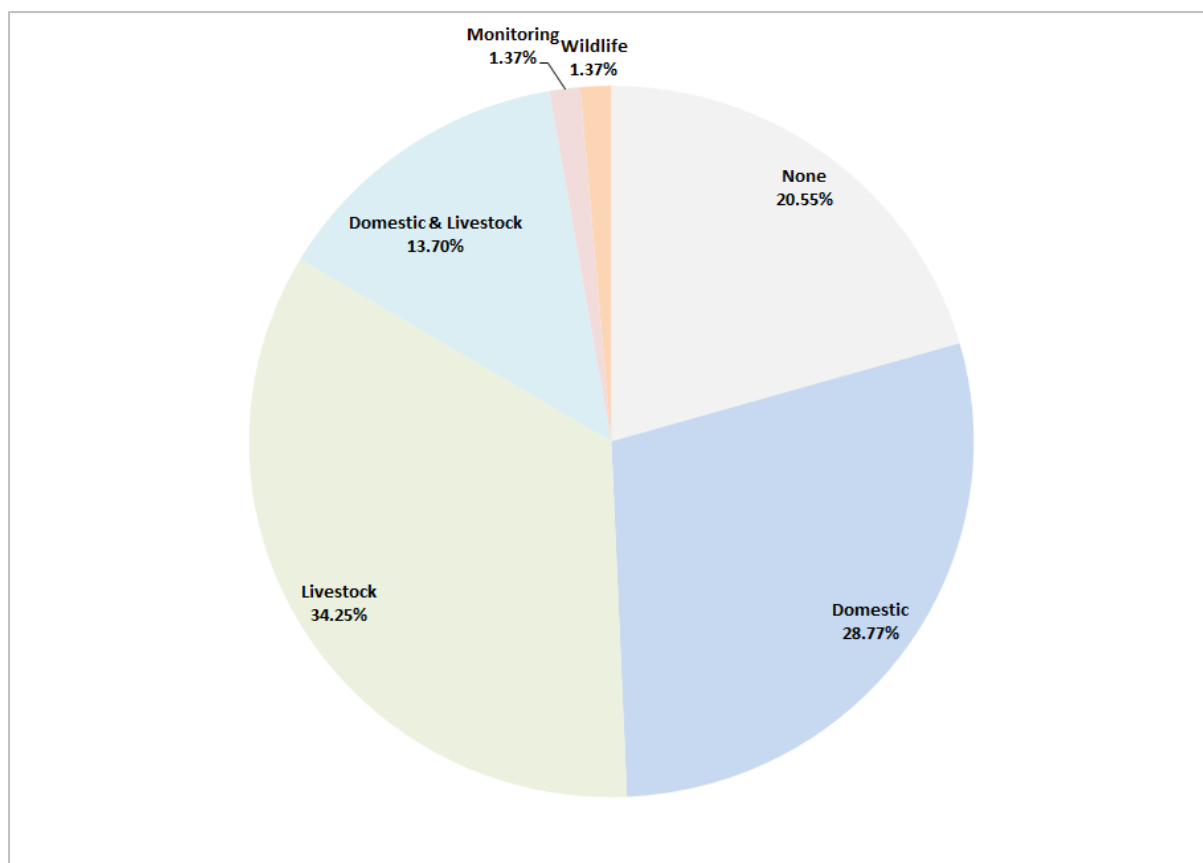


Figure 7-3 Hydrocensus user survey: Groundwater application.

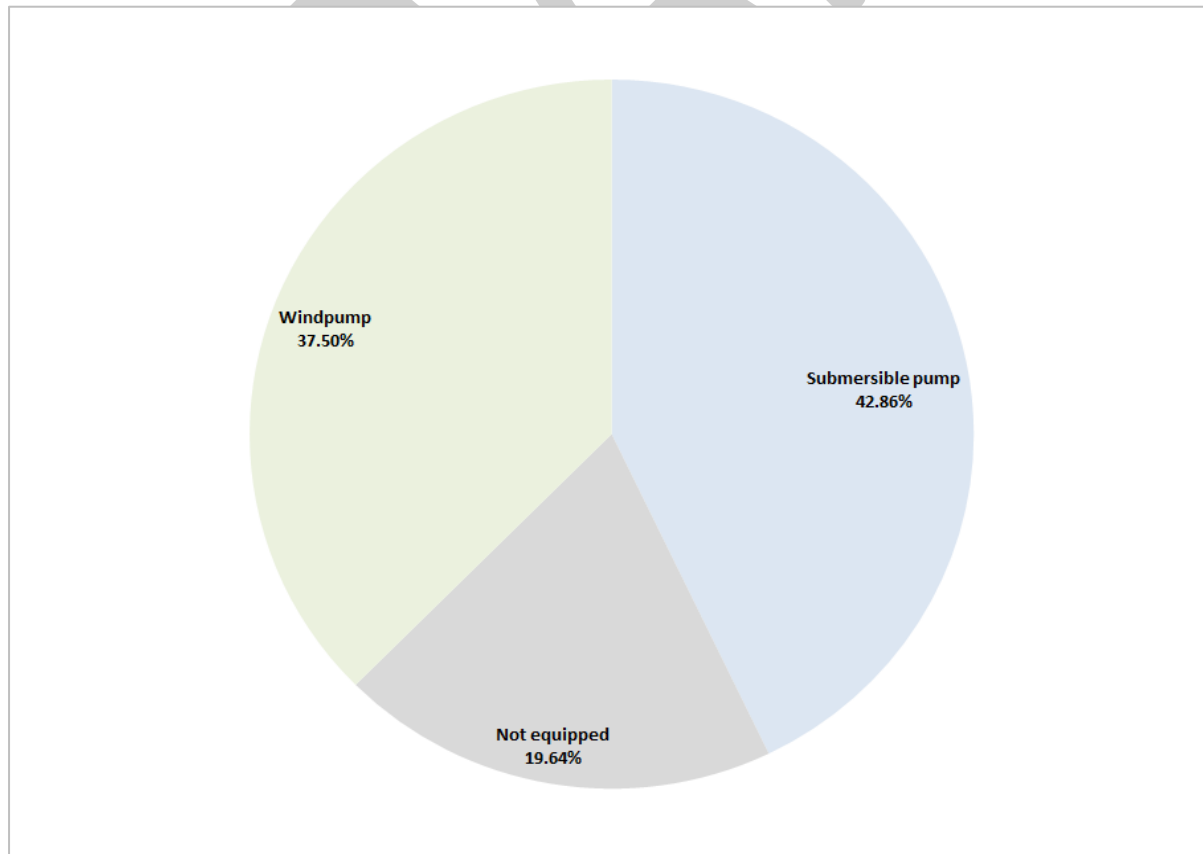


Figure 7-4 Hydrocensus user survey: Equipment type.

Table 7-1 Hydrocensus user survey: relevant information for geosites visited.

Geosite ID	Latitude	Longitude	Measured water level (mbch)	Collar height (m)	Water level (mbgl)	Borehole depth (mbgl)	Water level status	Site type	Site status	Equipment	Water application
BH 01	-28.1961	26.9720	3.48	0.00	3.48		Static	Borehole	In Use	Submersible pump	Domestic
BH 02	-28.1962	26.9723	3.00	0.42	2.58		Static	Borehole	Not in use	Not Equipped	None
BH 03	-28.1592	26.9787	0.16	0.00	0.16	24.22	Static	Borehole	Not in use	Not Equipped	None
BH 04	-28.2030	26.9670	3.13	0.00	3.13	48.07	Static	Borehole	Not in use	Not Equipped	None
BH 05	-28.2088	26.9761			NAWL		Obstructed	Borehole	Not in use	Windpump	None
BH 06	-28.1917	26.9654	1.77	0.25	1.52	18	Static	Borehole	Not in use	Not Equipped	None
BH 07	-28.1918	26.9460	5.07	0.37	4.70		Static	Borehole	In Use	Submersible pump	Livestock
BH 08	-28.1795	26.9402	4.44	0.00	4.44		Static	Borehole	Not in use	Windpump	None
BH 09	-28.2056	26.9120	5.00	0.29	4.71		Recovering	Borehole	In Use	Submersible pump	Domestic
BH 10	-28.2055	26.9139	7.00	0.32	6.68	7.22	Static	Borehole	Not in use	Not Equipped	None
BH 11	-28.2071	26.9137	1.23	0.00	1.23		Static	Borehole	Not in use	Windpump	None
BH 12	-28.2233	26.9175	4.69	0.00	4.69	4.82	Static	Borehole	Not in use	Not Equipped	None
BH 13	-28.1928	26.9117	12.25	0.00	12.25		Pumping	Borehole	In Use	Windpump	Livestock
BH 14	-28.1749	26.9037	10.77	0.00	10.77		Static	Borehole	In Use	Submersible pump	Domestic
BH 15	-28.1913	27.0083	10.65	0.26	10.39		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 16	-28.1915	27.0086	5.04	0.00	5.04		Static	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 17	-28.1908	27.0088	6.83	0.00	6.83		Static	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 18	-28.1924	27.0070	11.01	0.00	11.01		Recovering	Borehole	In Use	Submersible pump	Domestic
BH 19	-28.1721	26.9940	2.70	0.00	2.70		Static	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 20	-28.2882	26.9404			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock
BH 21	-28.2883	26.9397	5.70	0.00	5.70		Pumping	Borehole	In Use	Windpump	Domestic & Livestock
BH 22	-28.2907	26.9444	9.43	0.00	9.43		Pumping	Borehole	In Use	Windpump	Livestock
BH 23	-28.2956	26.9415	4.78	0.00	4.78	29.03	Static	Borehole	Not in use	Not Equipped	None

Geosite ID	Latitude	Longitude	Measured water level (mbch)	Collar height (m)	Water level (mbgl)	Borehole depth (mbgl)	Water level status	Site type	Site status	Equipment	Water application
BH 24	-28.2996	26.9185	9.37	0.00	9.37		Static	Borehole	In Use	Windpump	Domestic & Livestock
BH 25	-28.3035	26.9199	5.83	0.00	5.83		Static	Borehole	In Use	Submersible pump	Domestic
BH 26	-28.3066	26.9258		0.00	NAWL		Obstructed	Borehole	In Use	Windpump	Livestock
BH 27	-28.2896	26.9261	9.19	0.00	9.19		Pumping	Borehole	In Use	Windpump	Domestic & Livestock
BH 28	-28.2702	26.9550	15.88	0.21	15.67		Static	Borehole	In Use	Windpump	Livestock
BH 29	-28.2759	26.9733	27.59	0.00	27.59		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 30	-28.2787	26.9749	3.97	0.23	3.74		Static	Borehole	In Use	Windpump	Livestock
BH 31	-28.2811	26.9768	13.41	0.22	13.19		Static	Borehole	In Use	Windpump	Livestock
BH 32	-28.2899	26.9719	13.94	0.25	13.69		Static	Borehole	In Use	Windpump	Livestock
BH 33	-28.2749	26.9802	10.36	0.23	10.13		Static	Borehole	In Use	Windpump	Wildlife
BH 34	-28.2927	26.9631	9.71	0.12	9.59		Pumping	Borehole	In Use	Windpump	Domestic & Livestock
BH 35	-28.2923	26.9618	25.94	0.24	25.70		Static	Borehole	In Use	Submersible pump	Domestic
BH 36	-28.2840	26.9882	13.13	0.36	12.77	38.2	Static	Borehole	Not in use	Not Equipped	None
BH 37	-28.2837	26.9961	12.50	0.20	12.30		Pumping	Borehole	In Use	Windpump	Livestock
BH 38	-28.2788	26.9998			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock
BH 39	-28.2755	26.9885	13.49		13.49		Static	Borehole	Not in use	Windpump	None
BH 40	-28.2341	26.9748	9.10	0.18	8.92		Static	Borehole	In Use	Submersible pump	Livestock
BH 41	-28.2277	26.9581	19.97	0.26	19.71		Static	Borehole	In Use	Submersible pump	Livestock
BH 42	-28.2304	26.9462	13.00	0.14	12.86		Static	Borehole	In Use	Submersible pump	Domestic & Livestock
BH 43	-28.2114	26.9459			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock
BH 44	-28.2171	26.9405	10.54	1.01	9.53	37.24	Static	Borehole	In Use	Not Equipped	Monitoring
BH 45	-28.2481	26.9496			NAWL		Obstructed	Borehole	In Use	Submersible pump	Livestock
BH 46	-28.2457	26.9612	14.20	0.00	14.20		Potentially affected by Pumping	Borehole	In Use	Submersible pump	Livestock

Geosite ID	Latitude	Longitude	Measured water level (mbch)	Collar height (m)	Water level (mbgl)	Borehole depth (mbgl)	Water level status	Site type	Site status	Equipment	Water application
BH 47	-28.2454	26.9612			NAWL		Obstructed	Borehole	In Use	Submersible pump	Livestock
BH 48	-28.2466	26.9670	5.77	0.40	5.37		Static	Borehole	Not in use	Submersible pump	None
BH 49	-28.2529	26.9630	1.46	0.10	1.36		Static	Borehole	In Use	Submersible pump	Livestock
BH 50	-28.2529	26.9645	1.16	0.31	0.85		Static	Borehole	In Use	Submersible pump	Livestock
BH 51	-28.2697	26.9781	13.30	0.30	13.00		Static	Borehole	Not in use	Not Equipped	None
BH 52	-28.2669	26.9781	10.85	0.22	10.63		Static	Borehole	In Use	Windpump	Livestock
BH 53	-28.2658	26.9884	11.89	0.21	11.68	11.89	Static	Borehole	Not in use	Not Equipped	None
BH 54	-28.2531	26.9908	20.29	0.18	20.11		Static	Borehole	In Use	Submersible pump	Livestock
BH 55	-28.2523	26.9912	52.79	0.35	52.44		Recovering	Borehole	In Use	Submersible pump	Livestock
BH 56	-28.2403	26.9833	10.46	0.10	10.36		Pumping	Borehole	In Use	Submersible pump	Livestock
MTBH03	-28.2411	26.9738	13.08	0.20	1.05	120	Static	Borehole	In Use	Not Equipped	Monitoring
MTBH04	-28.2110	26.9577	8.14	0.20	12.88	120	Static	Borehole	In Use	Not Equipped	Monitoring
MTBH05	-28.2863	26.9701	13.29	0.20	7.94	120	Static	Borehole	In Use	Not Equipped	Monitoring
MTBH06	-28.2244	26.9389	4.86	0.20	13.09	120	Static	Borehole	In Use	Not Equipped	Monitoring
SW 01	-28.2072	26.9173	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock
SW 02	-28.2901	26.9397	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock
SW 03	-28.2785	26.9750	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock

N/A: Not applicable

NAWL: No access to water level

**Contact details for relevant landowners have been recorded, however this information will be made available on request as it is protected by the Protection of Personal Information Act, 2013 (POPIA)

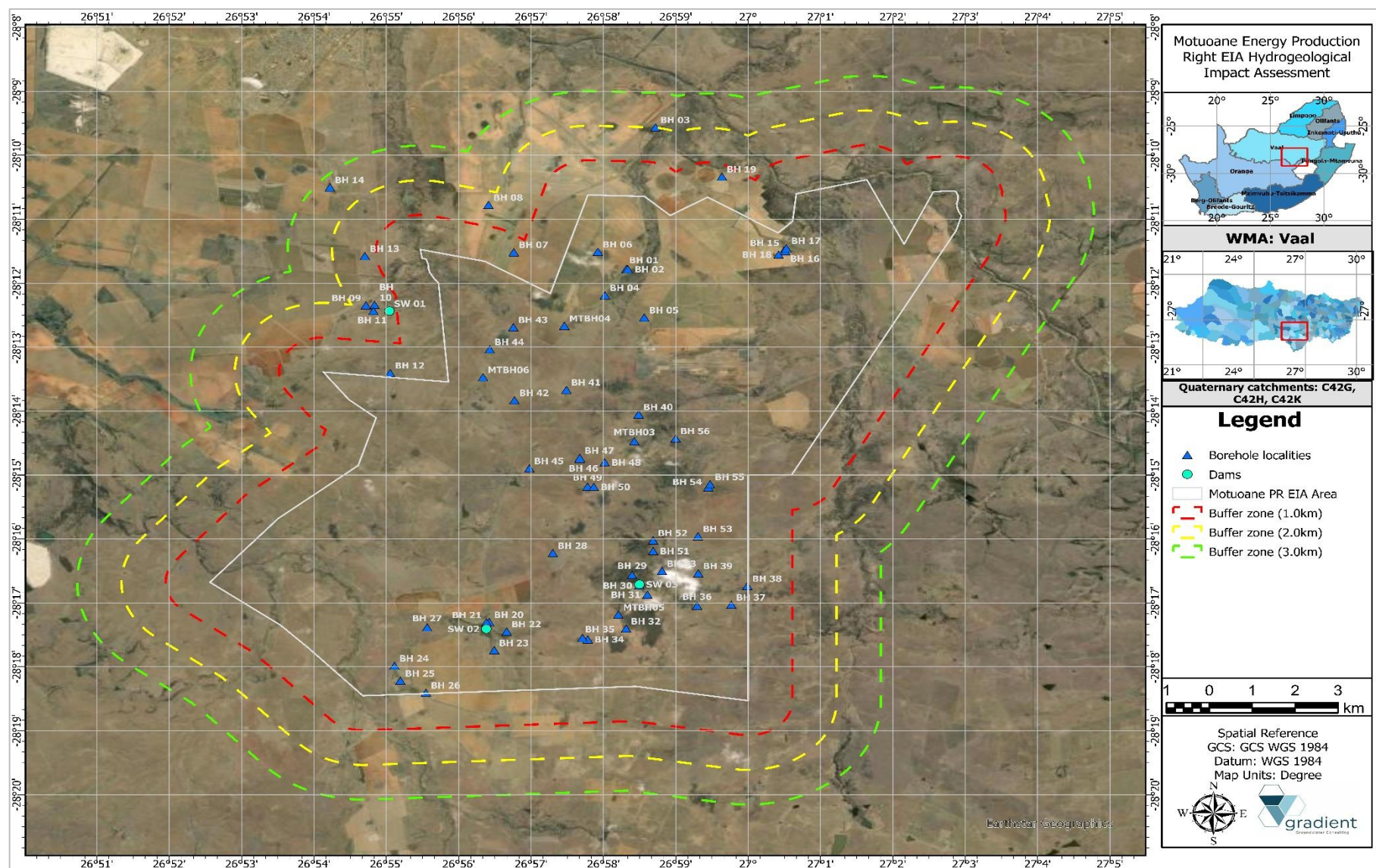


Figure 7-5 Spatial distribution map of the hydrogeological impact assessment area.

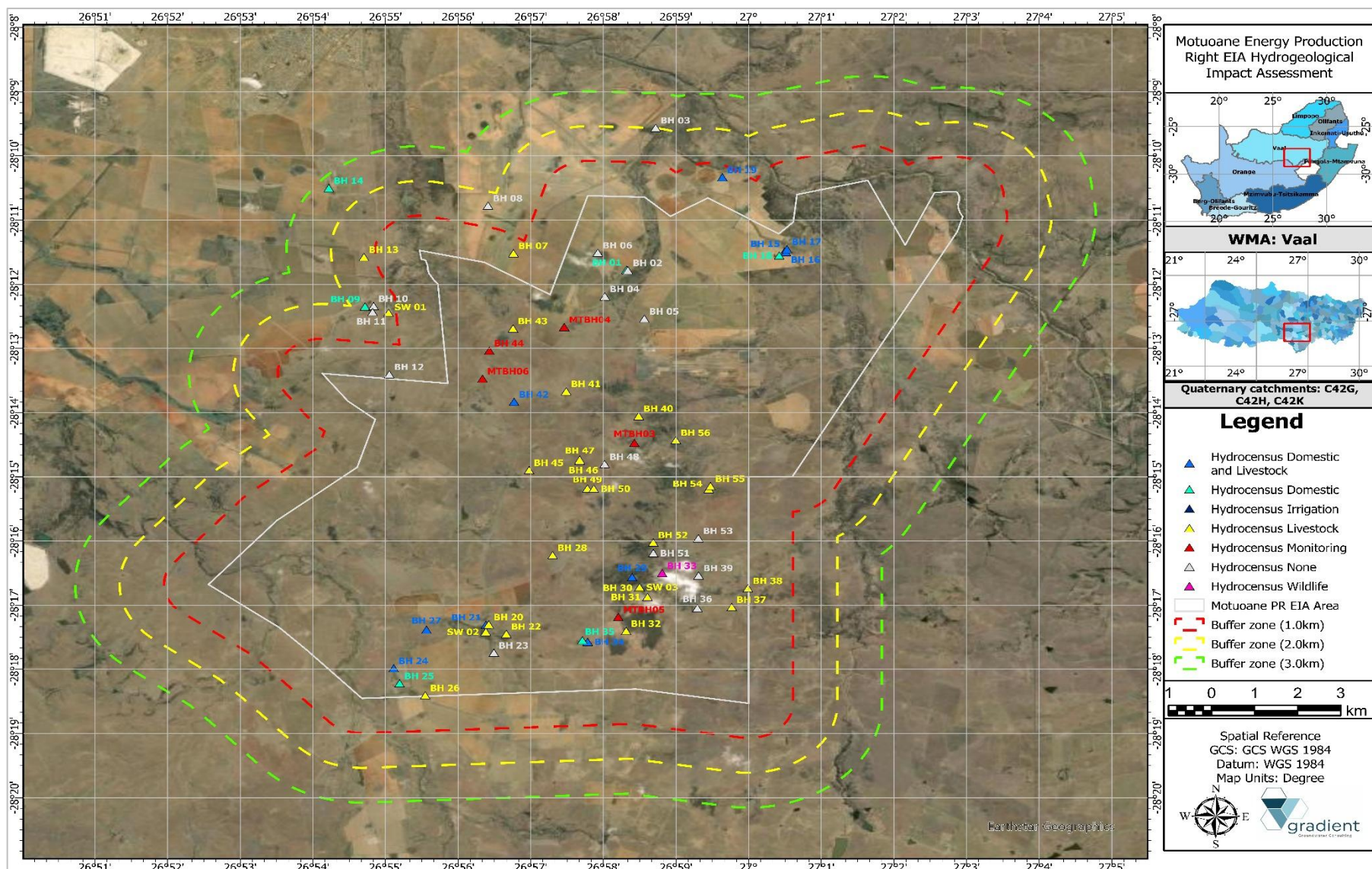


Figure 7-6 Spatial distribution map indicating groundwater status and application.

8. AQUIFER CHARACTERISATION

In order to gather representative on-site aquifer data and relevant information a site characterisation phase was conducted where new monitoring boreholes i.e., site characterisation boreholes were established and subjected to aquifer tests to obtain site representative aquifer parameters and hydraulic properties. The latter was incorporated into the numerical groundwater flow model development and calibration process. The aim of the site characterization was to target various on-site lithologies and hydrostratigraphical units in order to estimate representative hydraulic parameters. All site characterisation work was performed in accordance with SANS 10299-4:2003 standards: Development, maintenance and management of groundwater resources. The following sub-sections summarises the site characterisation and fieldwork conducted.

8.1. Geophysical survey

A geophysical survey was conducted during September 2025 wherein the sub-strata in the direct vicinity of the study area were investigated by applying the magnetic and electro-magnetic (EM) geophysical exploration techniques which were applied according to traverse array design for delineation of sub-surface lineaments and identification of potential preferential groundwater flow pathways to be targeted for site characterisation and monitoring boreholes. **Figure 8-1** shows a structural map of the greater study area with geological lineaments transecting the project site inferred. The latter was used in combination with structural geological interpretation to plan the geophysical survey and traverse layout. Refer to **Table 8-1** for a summary of geophysical traverse coordinates, traverse lengths, station spacings as well as approximate orientations and potential targets. **Figure 8-2** indicates the geophysical traverse array in relation to earmarked site characterisation gaps identified as well as existing geosites recorded as well as project boundary. To follow a brief description and interpretation of geophysical traverses at which drilling targets were executed. All geophysical survey graphs and interpretation including raw data and field-notes are summarised in Appendix B.

Table 8-1 Geophysical traverse summary (Datum: WGS84).

Traverse ID	Start Latitude	Start Longitude	Approximate Length (m)	Potential target	Station spacing (m)	Drilling target	Approximate orientation
Traverse 6	-28.236595	26.981723	400.00	NE-SW as well as NW-SE striking lineaments	10.00	n/a	E-W
Traverse 7	-28.235741	26.981927	600.00	NW-SE striking lineament	10.00	n/a	SE-NW
Traverse 8	-28.244154	26.977983	750.00	Various SW-NE striking lineaments	10.00	MTBH03	SE-NW
Traverse 9	-28.252679	26.993750	1450.00	NW-SE striking lineament	10.00	n/a	SW-NE
Traverse 10	-28.207427	26.952012	800.00	NE-SW striking lineament	10.00	MTBH04	NW-SE
Traverse 11	-28.200461	26.941426	800.00	NE-SW striking lineament	10.00	n/a	NW-SE
Traverse 12	-28.200461	26.941426	800.00	NE-SW striking lineament	10.00	n/a	NW-SE
Traverse 13	-28.280721	26.939537	650.00	NE-SW striking lineament	10.00	n/a	S-N
Traverse 14	-28.293376	26.974412	700.00	Various NW-SE striking lineaments	10.00	n/a	SW-NE
Traverse 15	-28.287420	26.968337	750.00	NW-SE striking lineament	10.00	MTBH05	SW-NE
Traverse 16	-28.229213	26.940949	1050.00	NE-SW striking lineament	10.00	n/a	NW-SE
Traverse 17	-28.246230	26.945356	480.00	NE-SW striking lineament	10.00	n/a	NW-SE
Traverse 18	-28.220336	26.936836	1000.00	NE-SW striking lineament	10.00	MTBH06	NW-SE



Figure 8-1 Map indicating potential regional geological lineaments in relation to proposed infrastructure and activities.



Figure 8-2 Geophysical traverse array in relation to regional geology as well as potential geological lineaments.

8.1.1. Traverse 08

Traverse 08 was surveyed over a lateral distance of 750.0m (10 m-station spacing) and was conducted in an approximate southeast-northwest orientation targeting various southwest-northeast striking lineaments. A prominent magnetic low zone can be observed between stations 100.0-120.0m which can be attributed to interference caused by a high voltage power line and, as such, was not considered. The electro-magnetic profiles indicate a decrease in the vertical dipole reading with an increase in the horizontal dipole reading at station 250.0m as well as 580.0 which may suggest conductance at these segments. Accordingly, the second anomaly was identified as drilling position MTBH03, targeting a potential structure and preferred groundwater flow pathway which may act as contaminant transport mechanism. Refer to **Figure 8-3** for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.2. Traverse 10

Traverse 10 was surveyed over a lateral distance of 800.0m (10 m- station spacing) and was conducted in an approximate northwest-southeast orientation targeting a northeast-southwest striking geological lineament. A magnetic low is observed just before station 200.0m, however this is caused by interference of a nearby windmill. Another magnetic anomaly can be observed between station 610.0-640.0m which is also associated with an increase in the electro-magnetic vertical dipole reading and a decrease in the vertical dipole reading. The latter can be inferred as a potential dyke structure and preferred groundwater flow pathway which may act as contaminant transport mechanism. Accordingly, station 630.0m was identified as drilling position MTBH04. Refer to **Figure 8-4** for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.3. Traverse 15

Traverse 15 was surveyed over a lateral distance of 750.0m (10 m- station spacing) and was conducted in an approximate southwest-northeast orientation targeting a northwest-southeast striking geological lineament. A slight magnetic anomaly is observed just before station 200.0m with a magnetic low observed at station 550.0m. The first magnetic anomaly is associated with a sharp decrease in the vertical dipole reading while an increase in the horizontal dipole reading is noted. Accordingly, this anomaly was identified as drilling position MTBH05, targeting a potential structure and preferred groundwater flow pathway which may act as contaminant transport mechanism. Refer to **Figure 8-5** for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.4. Traverse 18

Traverse 18 was surveyed over a lateral distance of 1.0km (10 m- station spacing) and was conducted in an approximate northwest-southeast orientation targeting a northeast-southwest striking geological lineament. The traverse is characterised by two prominent magnetic highs and anomalies i.e., 380.0m and 510.0m. The electro-magnetic profiles associated with this section indicate a decrease in the vertical dipole reading with an increase in the horizontal dipole reading which may suggest conductance on the edges. Accordingly, station 500.0m was identified as drilling position MTBH06, targeting the weathered perimeter of a potential dyke structure which may act as a preferred groundwater flow pathway and mechanism for contaminant transport.

Refer to **Figure 8-6** for the magnetic curve and electro-magnetic profile summarising relevant information.

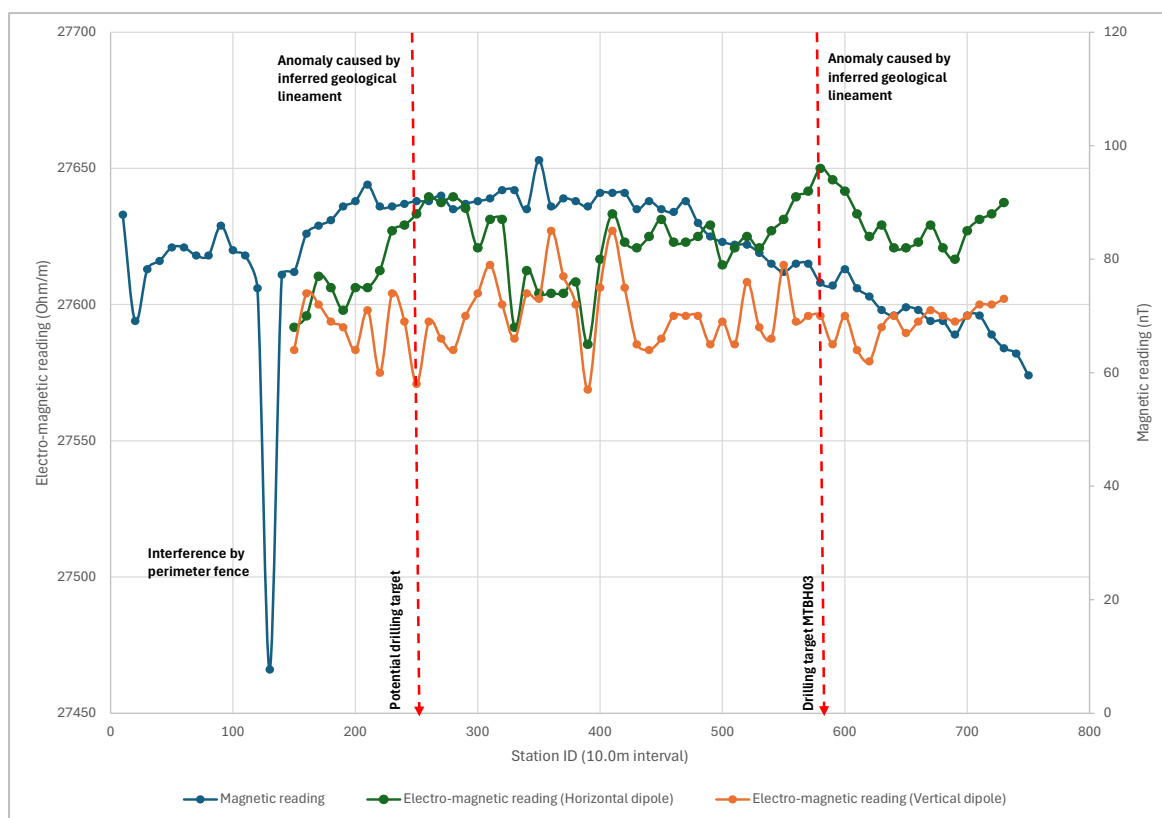


Figure 8-3 Geophysical traverse 08: Magnetic curve as well as electro-magnetic profile with relevant information.

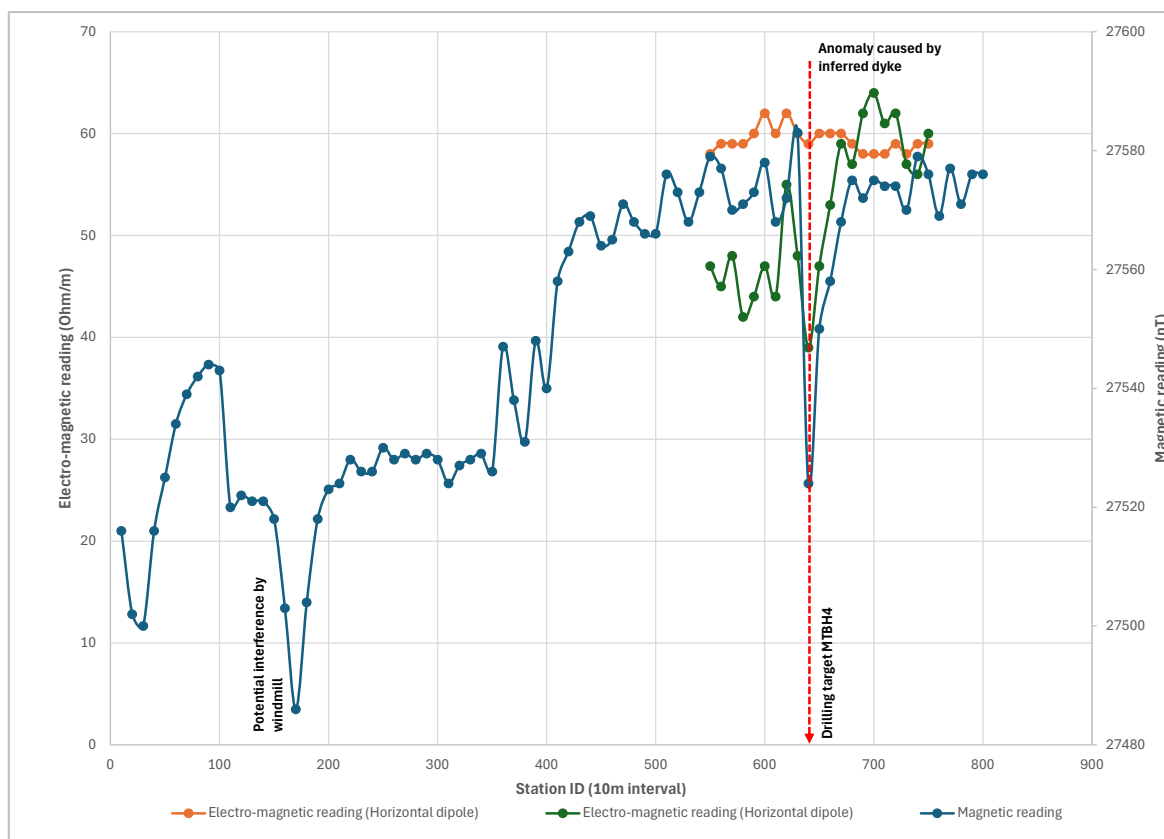


Figure 8-4 Geophysical traverse 10: Magnetic curve as well as electro-magnetic profile with relevant information.

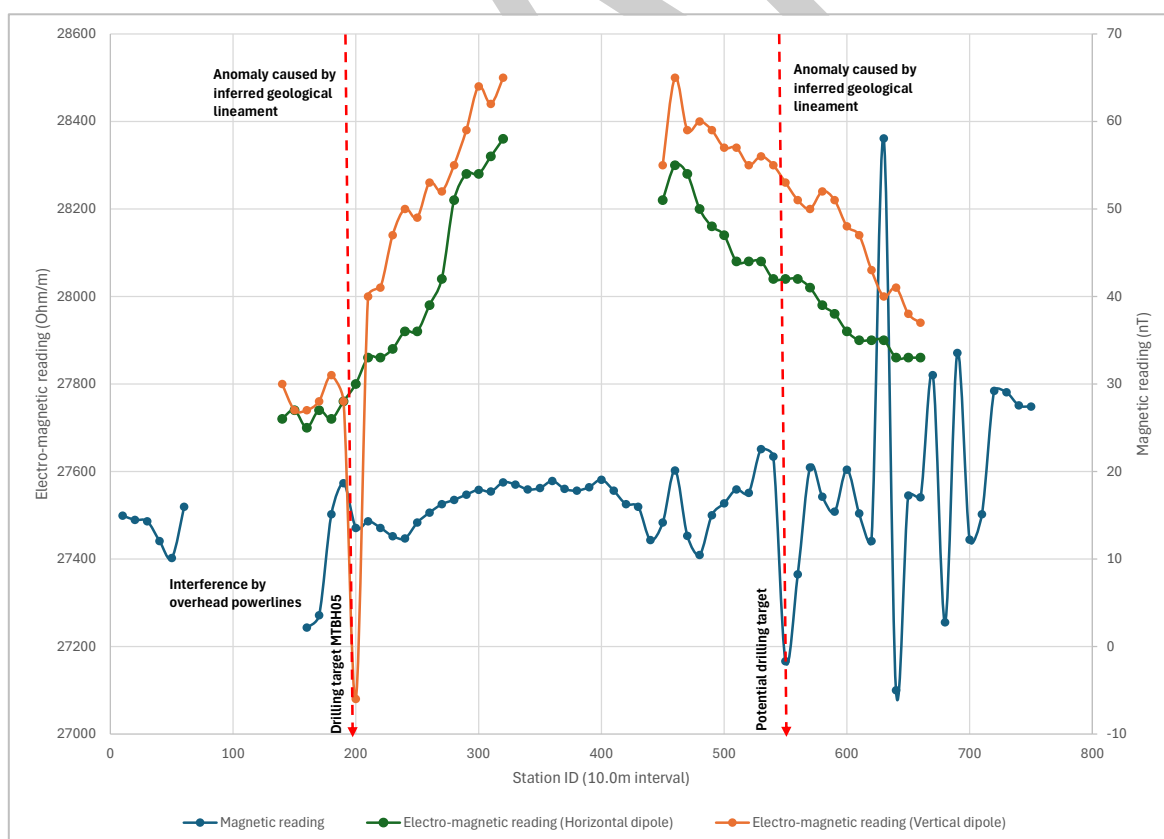


Figure 8-5 Geophysical traverse 15: Magnetic curve as well as electro-magnetic profile with relevant information.

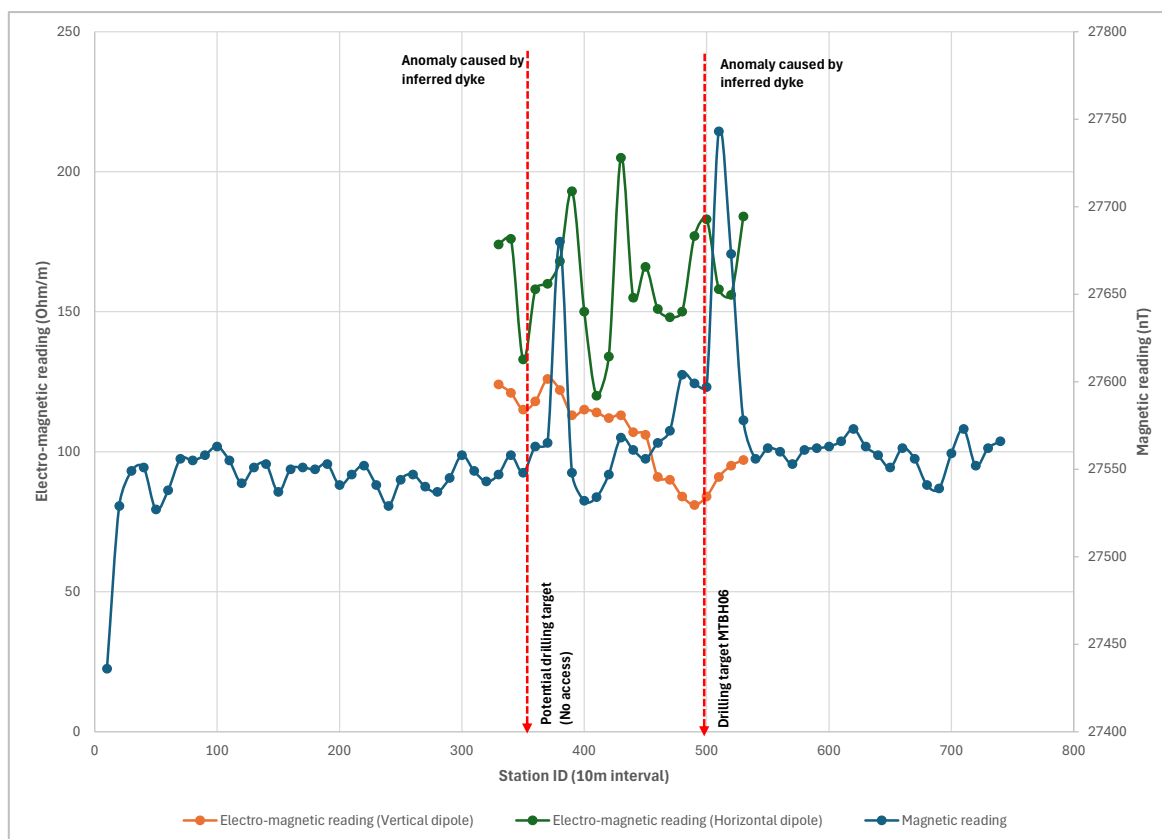


Figure 8-6 Geophysical traverse 18: Magnetic curve as well as electro-magnetic profile with relevant information.

8.2. Drilling

Following the geophysical survey, four drilling targets were identified and incorporated as part of the drilling program which was initiated during December 2025. The drilling technique applied is percussion drilling and the rationale for the placement and drilling of the new boreholes was based on the objectives of the study which include geological and hydrogeological site characterisation. Results from the geophysical survey and site accessibility for the drill rig were considered in the placement of the boreholes. Drilling objectives and placement is summarised in **Table 8-2** whereas borehole technical information is tabulated in **Table 8-3**. **Figure 8-7** shows the newly drilled borehole positions in relation to potential geological lineaments identified. Geological logs of the newly drilled boreholes as well as drilling field-notes are included in Appendix C.

Table 8-2 Drilling targets and objectives.

BH ID	Latitude	Longitude	Aquifer target	Borehole purpose
MTBH03	-28.241076	26.973778	Intergranular and fractured aquifers	Site characterisation and monitoring
MTBH04	-28.211000	26.957670	Intergranular and fractured aquifers	Site characterisation and monitoring
MTBH05	-28.286273	26.970084	Intergranular and fractured aquifers	Site characterisation and monitoring
MTBH06	-28.224400	26.938920	Intergranular and fractured aquifers	Site characterisation and monitoring

Table 8-3 Relevant borehole information summary.

BH ID	BH depth (mbgl)	Static Water level (mbgl)	Borehole diameter (OD Ø)	Casing type	Casing diameter (OD Ø)	Collar height (mm)	Water strike (mbgl)	Blow yield (l/s)
MTBH03	120	1.05	219.0mm(0-6m); 165.0mm (6m-EOH)	Steel (starter = 6m) uPVC (EOH)	165.0mm (0-EOH)	200	58	0.06
MTBH04	120	12.88	219.0mm(0-6m); 165.0mm (6m-EOH)	Steel (starter = 6m) uPVC (EOH)	165.0mm (0-EOH)	200	Seepage (60)	0.33
MTBH05	120	7.94	219.0mm(0-12m); 165.0mm (6m-EOH)	Steel (starter = 12m) uPVC (EOH)	165.0mm (0-EOH)	200	Seepage (30, 60)	None
MTBH06	120	13.09	219.0mm(0-6m); 165.0mm (6m-EOH)	Steel (starter = 6m) uPVC (EOH)	165.0mm (0-EOH)	200	16/30/60/ 102	0.33

Notes: EOH = End of Hole.

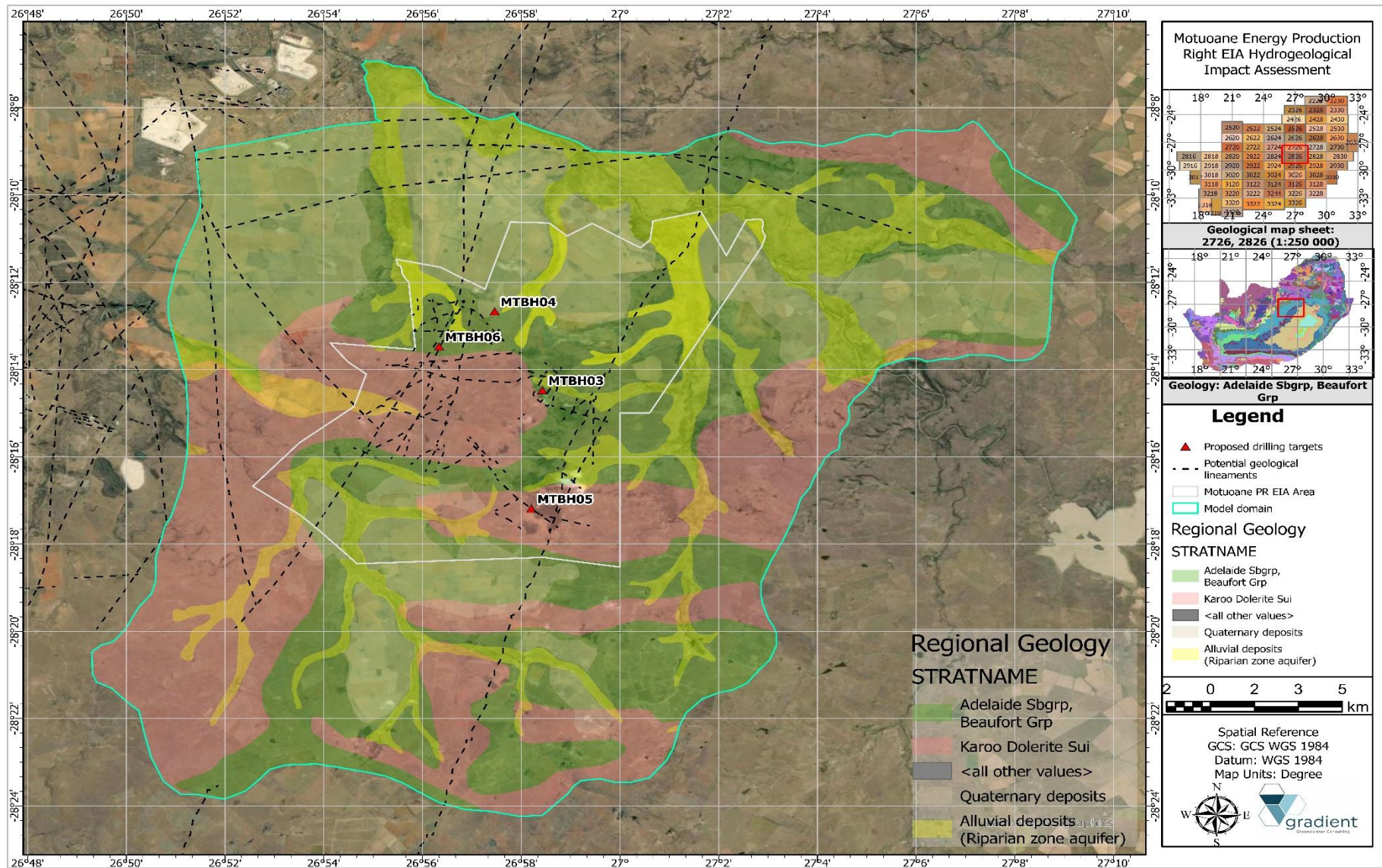


Figure 8-7 Map depicting new drilled site characterisation borehole positions in relation to regional geology and inferred geological lineaments.

To follow is a brief description of each site characterisation borehole drilled.

8.2.1. Drilling locality MTBH03

Borehole locality MTBH03 was drilled at a 165.0mm (6.50") diameter to a depth of 120.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 219.0mm (8.50") and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 6.0mbgl followed by uPVC for the entire length of the hole. A 3.0mm silica gravel-pack was used to fill the borehole annulus surrounding the saturated sediments. Drilling chips collected confirmed the presence of a clay layers followed by highly weathered to moderately weathered sandstone to a depth of approximately 96.0mbgl followed by black shale of the Beaufort Group formations to the end of hole (EOH). Only one major water strike was encountered at depths of 58.0m with a final blow yield of 0.06l/s measured. After borehole development, the static water level was recorded at 1.05mbgl.

8.2.2. Drilling locality MTBH04

Borehole locality MTBH04 was drilled at a 165.0mm (6.50") diameter to a depth of 120.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 219.0mm (8.50") and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 6.0mbgl followed by uPVC for the entire length of the hole. A 3.0mm silica gravel-pack was used to fill the borehole annulus surrounding the saturated sediments. Drilling chips collected confirmed the presence of a sand layer followed by highly weathered, yellowish shale of the Beaufort Group formations up to a depth of 36.0mbgl followed by sandstone to a depth of 114mbgl. Dolerite was encountered at a depth of 114-120mbgl. A seepage zone was encountered within the weathered shale at a depth of approximately 60.0mbgl (final blow yield = 0.33l/s) After borehole development, the static water level was recorded at 12.88mbgl.

8.2.3. Drilling locality MTBH05

Borehole locality MTBH05 was drilled at a 165.0mm (6.50") diameter to a depth of 120.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 219.0mm (8.50") and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 6.0mbgl followed by uPVC for the entire length of the hole. A 3.0mm silica gravel-pack was used to fill the borehole annulus surrounding the saturated sediments. Drilling chips collected confirmed the presence of shallow, highly weathered dolerite, followed by weathered, blue to greenish shale of the Beaufort Group formations up to a depth of 66.0mbgl followed by sandstone to a depth of 120.0mbgl. Dolerite was encountered at a depth of 66.0-90.0mbgl. A seepage zone was encountered within the weathered shale at a depth of approximately 30.0mbgl as well as 60.0mbgl, however seepage rates were not adequate to perform blow yields on. The static water level was recorded at 7.94mbgl.

8.2.4. Drilling locality MTBH06

Borehole locality MTBH06 was drilled at a 165.0mm (6.50") diameter to a depth of 120.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 219.0mm (8.50") and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 6.0mbgl followed by uPVC for the entire length of the hole. A 3.0mm silica gravel-pack was used to fill the borehole annulus surrounding the saturated sediments. Drilling chips collected confirmed the presence of a relatively thin clay layer followed by yellow and blueish shale of the Beaufort Group formations to the end of the hole (EOH). Major water strikes were encountered at depths of 30.0m and 60.0m with seepage zone at 16.0m and 102.0m (final blow yield = 0.33l/s) After borehole development, the static water level was recorded at 13.09mbgl.

8.3. Aquifer testing

Following the drilling phase, the newly established site characterisation boreholes were subjected to hydraulic testing i.e., Constant Rate (CR) pump during January 2026 in order to supplement published aquifer parameter data that was available for the site conditions and setting. Important parameters that can be obtained from borehole test pumping include Hydraulic Conductivity (K), Transmissivity (T) and Storativity (S). These parameters are defined as follows (Krusemann and De Ridder, 1991):

- i. Hydraulic Conductivity (K): This is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. It is normally expressed in metres per day (m/d).
- ii. Transmissivity (T): This is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the full, saturated thickness of the aquifer. Transmissivity is the product of the average hydraulic conductivity and the saturated thickness of the aquifer. Transmissivity is expressed in metres squared per day (m²/d).
- iii. Storativity (S): The storativity of a saturated confined aquifer is the volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface. Storativity is a dimensionless quantity.

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

Equation 8-1 Transmissivity (Cooper-Jacob).

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

where:

T = Transmissivity (m²/d).

Q = Flow of water per unit of time (m³/d).

Δs = Drawdown difference of one log cycle.

Refer to **Table 8-4** for a technical summary of hydraulic testing conducted while **Table 8-5** provides the aquifer hydraulic parameter estimations. Borehole specific drawdown and recovery data are included in Appendix D.

Table 8-4 Constant discharge aquifer tests summary.

BH ID	Blow yield (ℓ/s)	Aquifer test type	Tested yield (ℓ/s)	CR duration (min.)	Water level (mbgl)	Pump depth inlet	Available Drawdown (m)	Drawdown reached (m)	% Drawdown used	Step1 yield (ℓ/s)	Step2 yield (ℓ/s)	Step3 yield (ℓ/s)	Step4 yield (ℓ/s)
MTBH03	0.06	CR	0.15	180.00	1.05	95.00	93.95	93.95	100.00	0.15	-	-	-
MTBH04	0.33	CR	0.20	480.00	12.88	95.00	82.12	47.77	58.17	0.15	-	-	-
MTBH05	None	CR	0.15	300.00	7.94	95.00	87.06	87.06	100.00	0.15	-	-	-
MTBH06	0.33	CR	0.15	120.00	13.09	95.00	81.91	81.91	100.00	0.15	0.30	0.75	PI

Notes: CR = Constant Recharge Test.

PI = Pump Inlet reached.

Table 8-5 Aquifer tests: Hydraulic parameter estimation.

BH ID	Potential hydrostratigraphical unit targeted	HYDROSOLV analysis		FC analysis		Average Values	
		Constant Rate Transmissivity (m ² /d)	Recovery Transmissivity (m ² /d)	Early Transmissivity (m ² /d)	Late Transmissivity (m ² /d)	Transmissivity (m ² /d)	Hydraulic conductivity (m/d)
MTBH03	Beaufort Group formation	0.03	0.02	0.09	0.03	0.05	0.00
MTBH04	Quaternary deposits	0.12	0.11	0.58	0.08	0.27	0.03
MTBH05	Karoo Dolerite Suite	0.05	0.04	0.18	0.07	0.09	0.01
MTBH06	Geological lineament	0.04	0.03	0.05	0.04	0.04	0.004

To follow is a brief description of the constant rate tests performed on newly established site characterisation boreholes along with analysis and interpretation of the water level drawdown and recovery curves.

8.3.1. Constant Rate Test borehole MTBH03

Only one calibration step tests of 0.15l/s was conducted on borehole MTBH03 followed by a constant rate test at a yield of 0.15l/s for a duration of three hours. A maximum drawdown depth of 93.59 mbgl was reached during the pump test duration, representing all the available drawdown utilised. Borehole recovery observed was not good with the borehole not reaching pre-testing water levels within the recovering time. An average transmissivity of 0.05m²/d was calculated for this site characterisation borehole. **Figure 8-8** depicts a scattered plot of the drawdown and recovery data while **Figure 8-9** indicates the Cooper-Jacob method displacement time curve fitment.

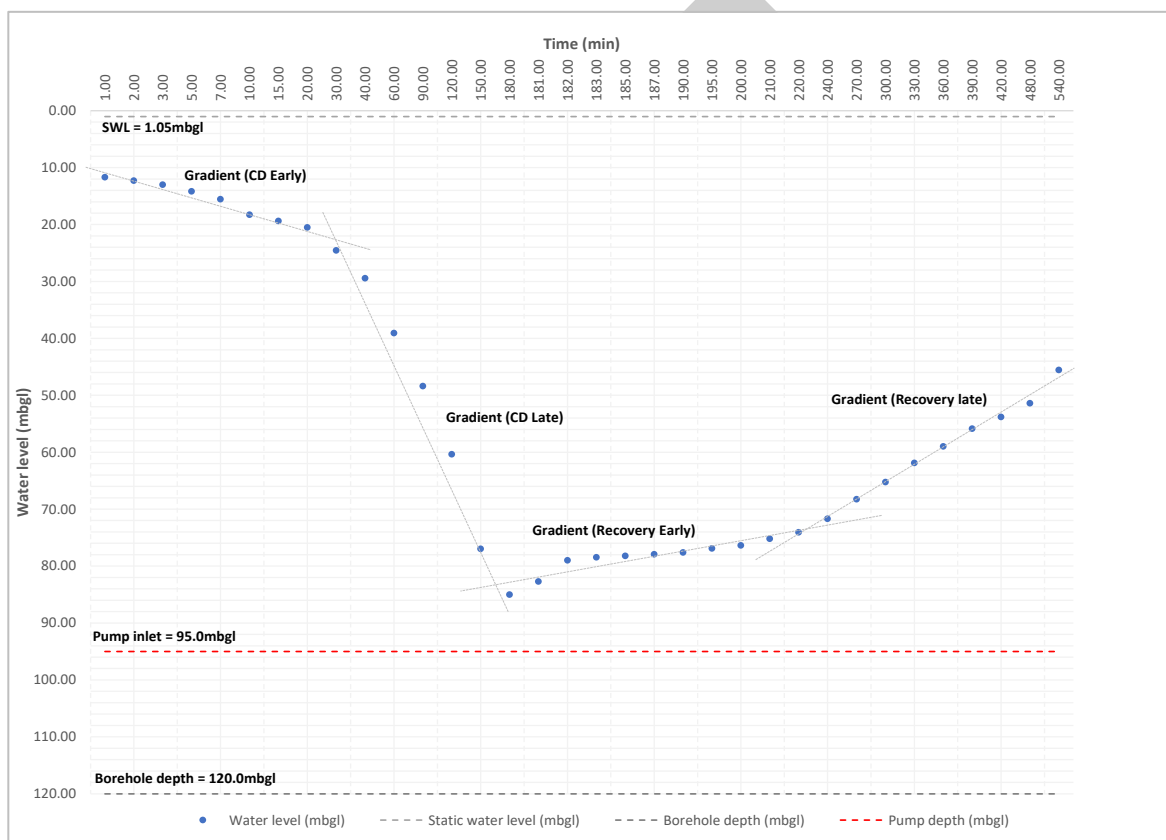


Figure 8-8 Aquifer tests: MTBH03 water level drawdown and recovery scattered plot.

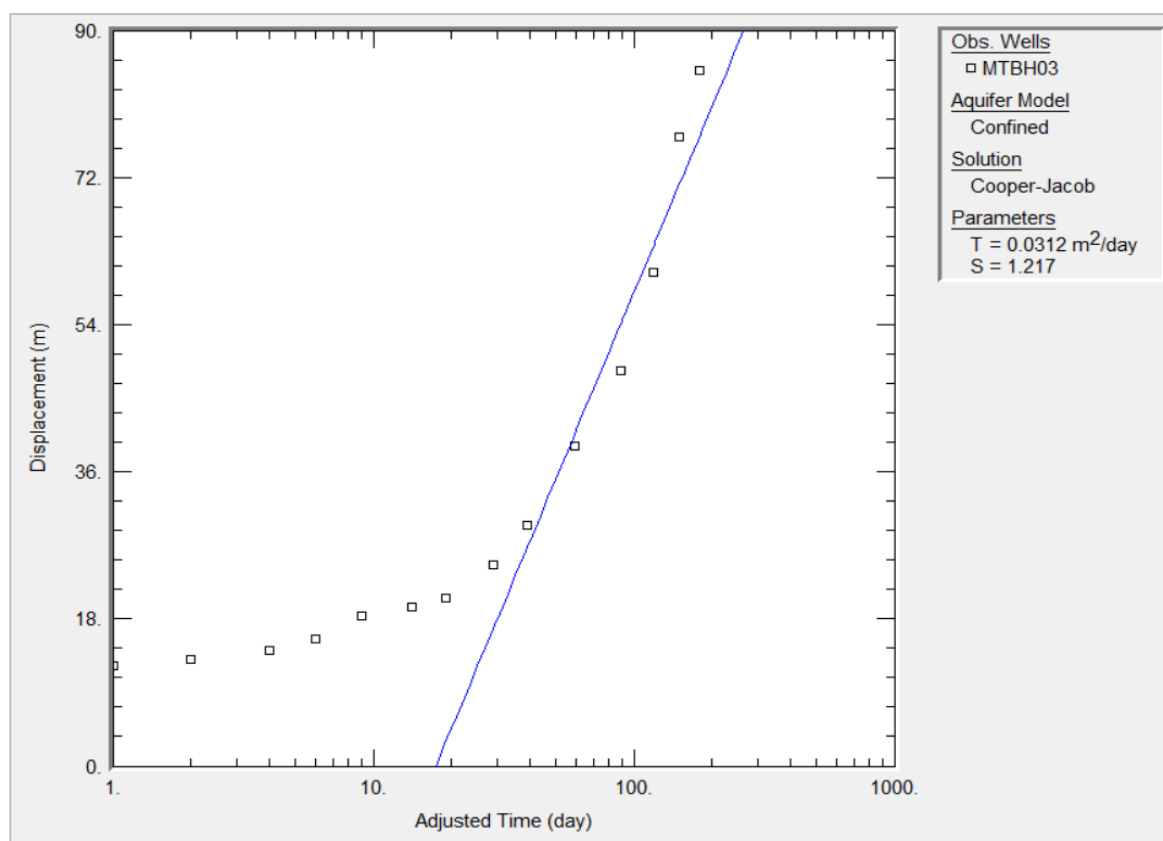


Figure 8-9 Aquifer tests: Cooper-Jacob method displacement time curve for MTBH03.

8.3.2. Constant Rate Test borehole MTBH04

One calibration step test of 0.15l/s was conducted on borehole MTBH04 followed by a constant rate test at a yield of 0.20l/s for a duration of eight hours. A maximum drawdown depth of 47.77 mbgl was reached during the pump test duration, representing >58.0% of available drawdown utilised. Borehole recovery observed was not good with the borehole not reaching pre-testing water levels within the recovering time. An average transmissivity of 0.26m²/d was calculated for this site characterisation borehole. **Figure 8-10** depicts a scattered plot of the drawdown and recovery data while **Figure 8-11** indicates the Theiss method displacement time curve fitment.

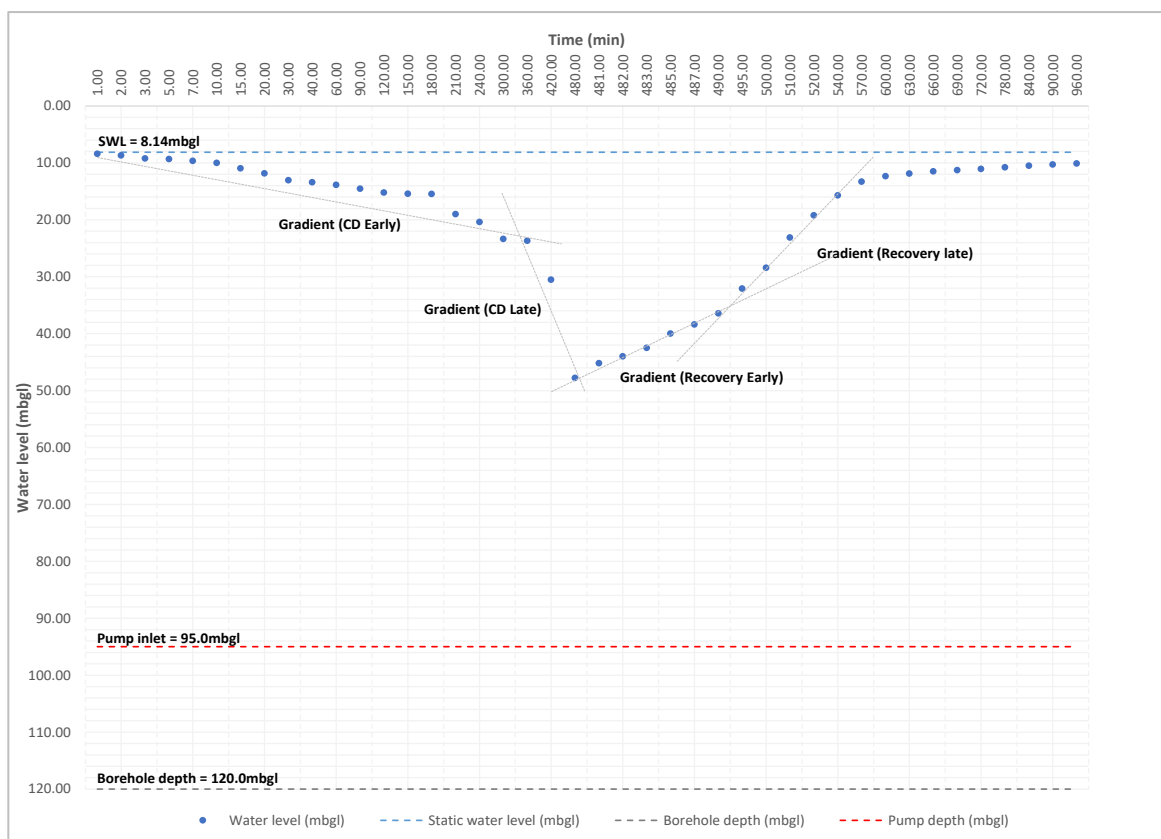


Figure 8-10 Aquifer tests: MTBH04 water level drawdown and recovery scattered plot.

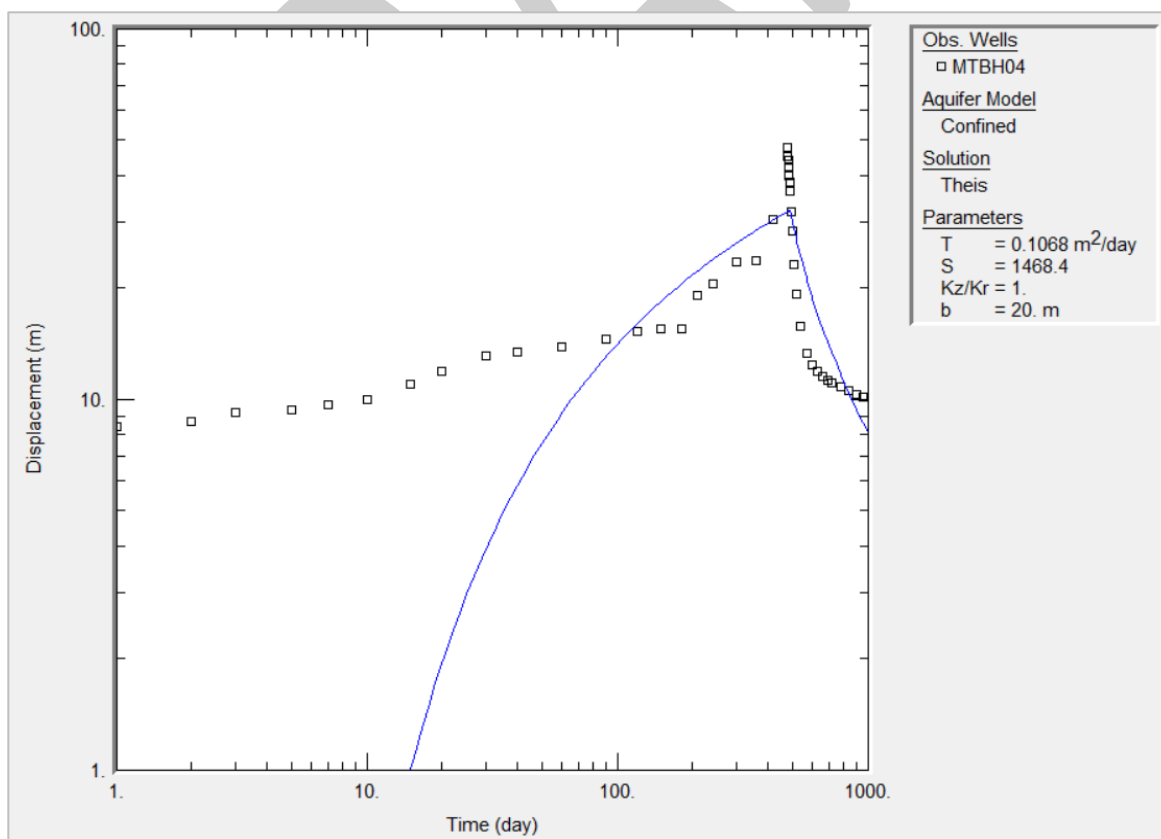


Figure 8-11 Aquifer tests: Theis method displacement time curve for MTBH04.

8.3.3. Constant Rate Test borehole MTBH05

One calibration step test of 0.15l/s was conducted on borehole MTBH05 followed by a constant rate test at a yield of 0.15l/s for a duration of five hours. A maximum drawdown depth of 87.06 mbgl was reached during the pump test duration, representing all the available drawdown utilised. Borehole recovery observed was not good with the borehole not reaching pre-testing water levels within the recovering time. An average transmissivity of 0.09m²/d was calculated for this site characterisation borehole. **Figure 8-12** depicts a scattered plot of the drawdown and recovery data while **Figure 8-13** indicates the Theiss method displacement time curve fitment.

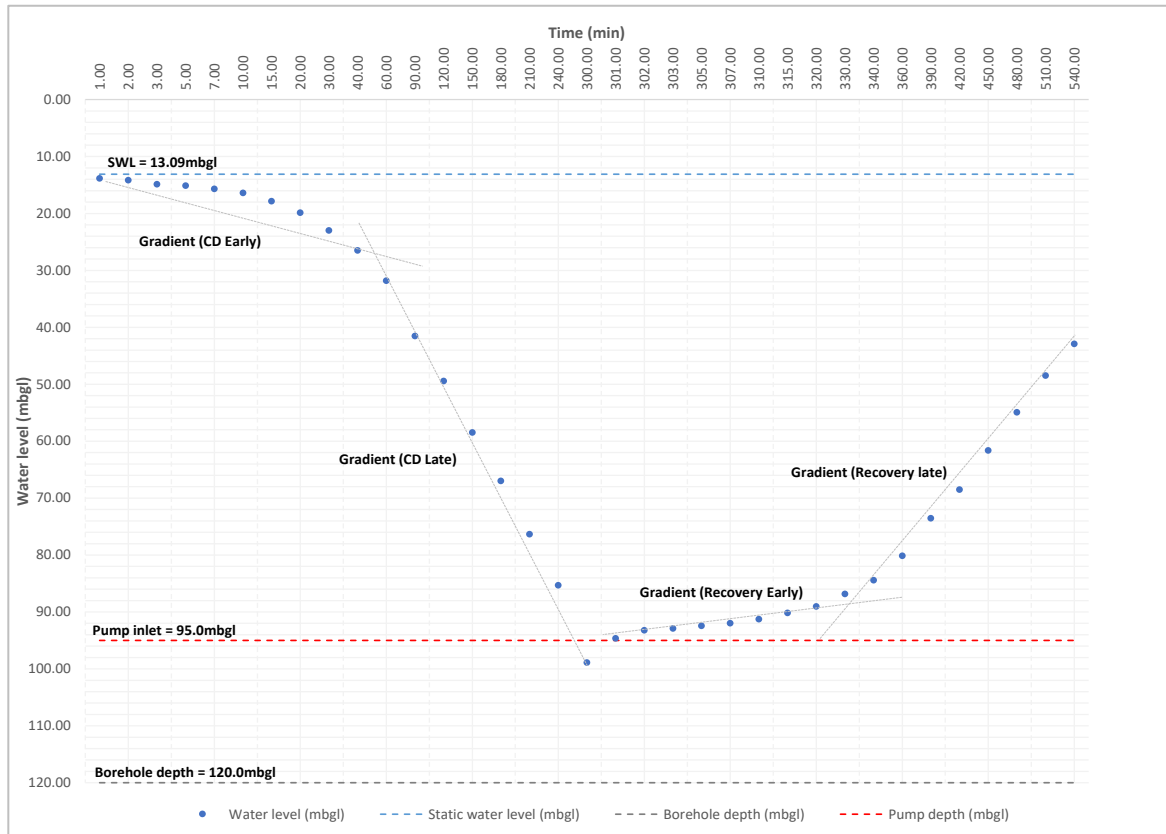


Figure 8-12 Aquifer tests: MTBH05 water level drawdown and recovery scattered plot.

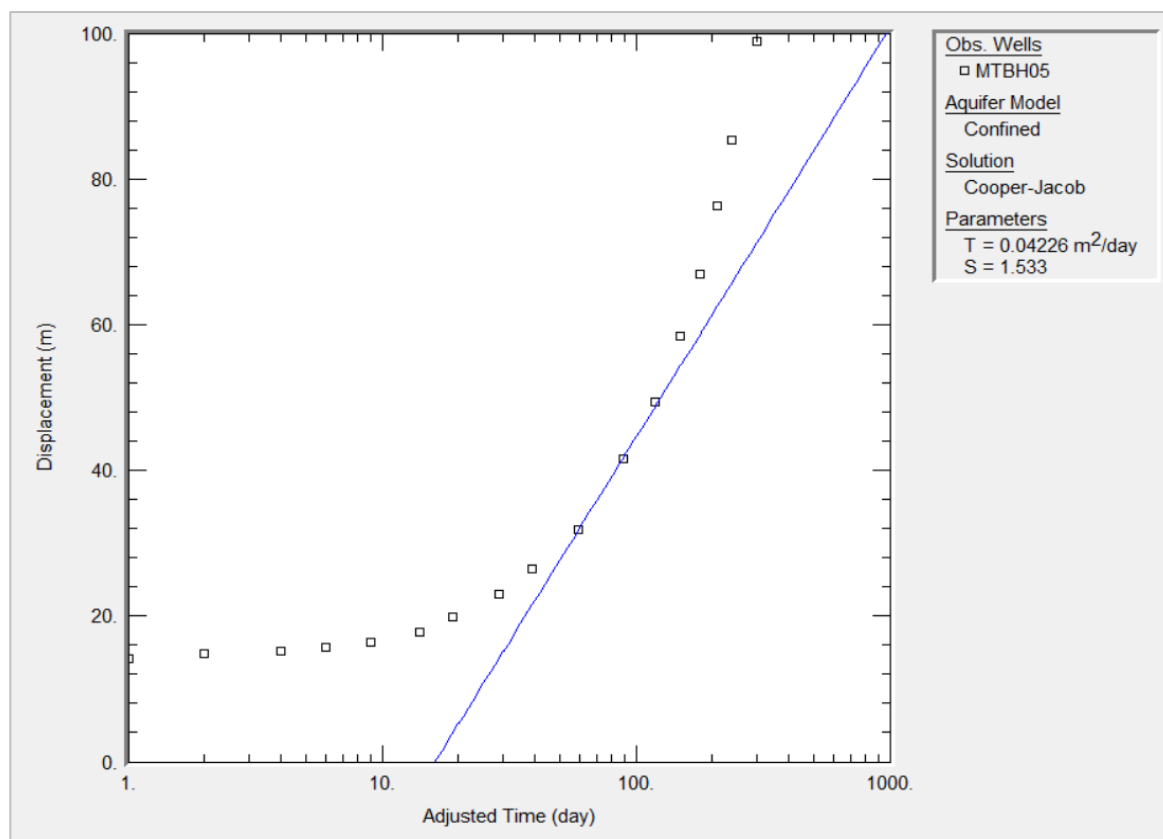


Figure 8-13 Aquifer tests: Theis method displacement time curve for MTBH05.

8.3.4. Constant Rate Test borehole MTBH06

Borehole MTBH06 was subjected to three calibration step tests of 0.15l/s, 0.30l/s and 0.75l/s followed by a constant rate test at a yield of 0.15l/s for a duration of 2 hours after which the pump inlet (PI) was reached. The recovery following the step tests was very poor and the borehole did not return to the pre-testing water level. Consequently, a new water level had to be applied as the revised datum water level. After the constant rate tests, the borehole recovery was very poor again. An average transmissivity of 0.04m²/d was calculated for this site characterisation borehole. **Figure 8-14** depicts a scattered plot of the drawdown and recovery data while **Figure 8-15** indicates the Cooper-Jacob method displacement time curve fitment.

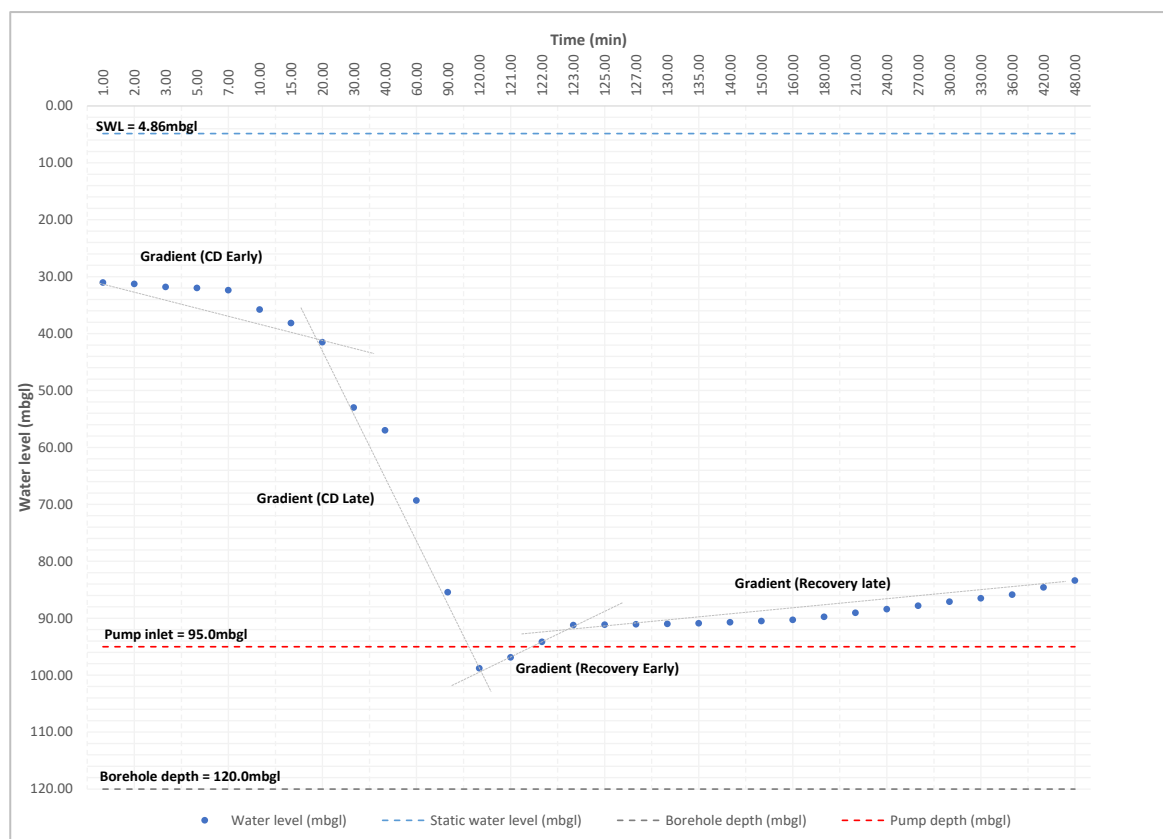


Figure 8-14 Aquifer tests: MTBH06 water level drawdown and recovery scattered plot.

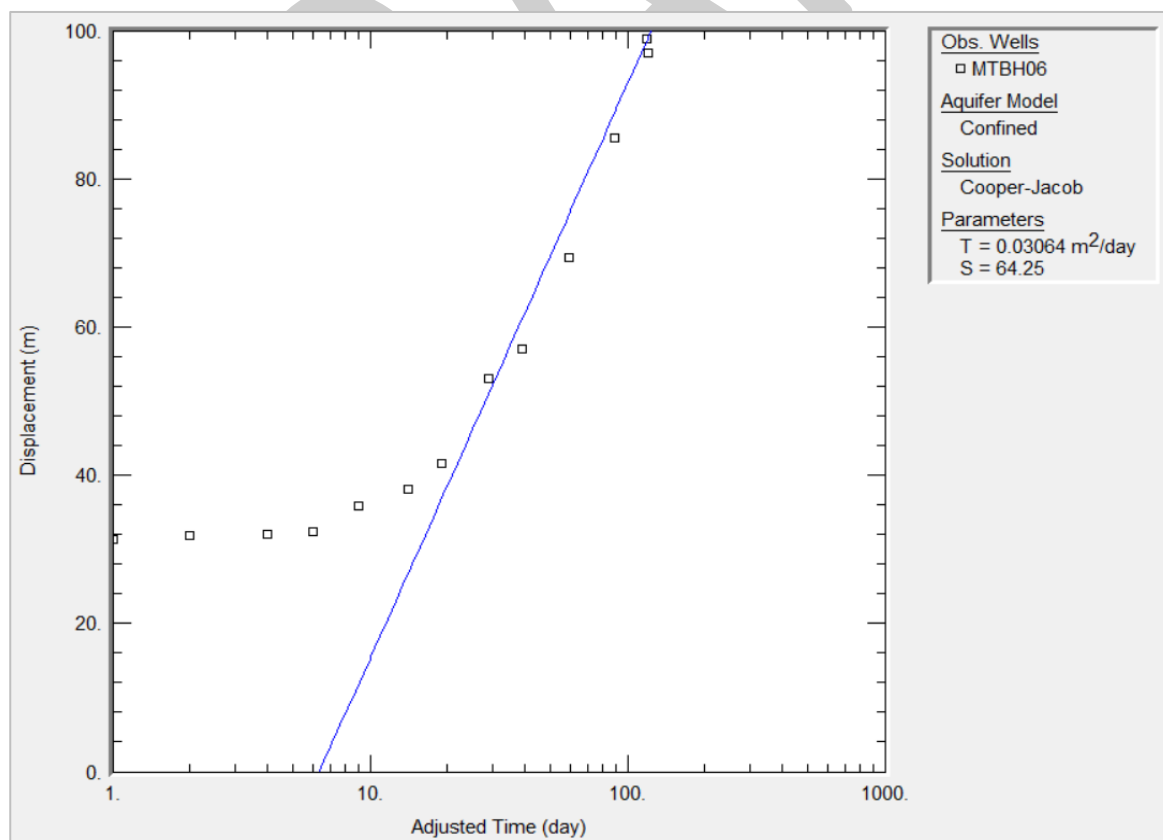


Figure 8-15 Aquifer tests: Theiss method displacement time curve for MTBH06.

9. GROUNDWATER FLOW EVALUATION

The following sub-sections outline the groundwater flow dynamics of the study area.

9.1. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water level elevation from corresponding surface topography. The latter will govern the infiltration rate, as well as effective recharge of rainfall to the aquifer. Furthermore, the nature of the formation(s) forming the unsaturated zone will significantly influence the mass transport of surface contamination to the underlying aquifer(s).

From evaluation of the hydrocensus and site characterisation data it can be concluded that the unsaturated zone within the study area is in the order of <1.0m to >25.0m with a mean thickness of approximately ~8.0m. The variation in the vadose zone thickness and extent observed, can potentially be attributed to the variations in topographical elevation as well as sub-surface lithology. It should be noted that due to the argillaceous nature of the host aquifer(s) the shallow water levels observed at some of the borehole localities can be attributed to clay/silt lenses and be indicative of perched aquifer conditions and not necessarily represent the vadose zone.

9.2. Depth to groundwater

A distribution of borehole water levels recorded as part of the hydrocensus user survey conducted were considered and used to interpolate local groundwater elevation and hydraulic head contours as summarised in **Table 9-1** and **Figure 9-1**. The minimum water level was recorded at 0.16mbgl (BH03), while the deepest water level was measured at borehole locality BH55 (52.44mbgl)⁹. The average water level is calculated at 10.67 mbgl which is much shallower than the regional average water level of between 28.10mbgl (Aquiworx, 2014). From statistical evaluation the 95th percentile of this data set is calculated at 26.17mbgl with the standard deviation of 9.39m. It is noted that various dynamic water levels were recorded, potentially suggesting a pumped aquifer system. The coefficient of variation (CV) calculated is 87.97%, indicating either a dynamic groundwater system or higher variability in topography.

⁹ It should be noted that due to this borehole currently being applied for supply purposes, it can be assumed that this water level represents a dynamic water level.

Table 9-1 Regional water level summary.

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
BH 01	1369.14	3.48	1365.66
BH 02	1368.48	2.58	1365.90
BH 03	1324.88	0.16	1324.72
BH 04	1380.02	3.13	1376.89
BH 06	1375.70	1.52	1374.18
BH 07	1380.00	4.70	1375.30
BH 09	1397.29	4.71	1392.58
BH 13	1386.17	12.25	1373.92
BH 14	1377.40	10.77	1366.63
BH 15	1340.45	10.39	1330.06
BH 16	1340.51	5.04	1335.47
BH 18	1342.31	11.01	1331.30
BH 19	1328.34	2.70	1325.64
BH 22	1414.22	9.43	1404.79
BH 23	1416.85	4.78	1412.07
BH 24	1399.28	9.37	1389.91
BH 27	1399.46	9.19	1390.27
BH 28	1436.30	15.67	1420.63
BH 29	1416.37	27.59	1388.78
BH 32	1441.42	13.69	1427.73
BH 34	1436.60	9.59	1427.01
BH 35	1434.28	25.70	1408.58
BH 40	1414.58	8.92	1405.66
BH 41	1433.80	19.71	1414.09
BH 42	1425.17	12.86	1412.31
BH 44	1389.94	9.53	1380.41
BH 46	1443.22	14.20	1429.02
BH 49	1440.00	1.36	1438.64
BH 52	1400.43	10.63	1389.80
BH 53	1386.25	11.68	1374.57
BH 55	1394.66	52.44	1342.22
BH 56	1388.97	10.36	1378.61
MTBH03	1408.33	1.05	1407.28
MTBH04	1395.00	12.88	1382.12
MTBH05	1433.43	7.94	1425.49
MTBH06	1399.86	13.09	1386.77
Average	1396.09	10.67	1385.42
Minimum	1324.88	0.16	1324.72
Maximum	1443.22	52.44	1438.64
5th Percentile	1337.42	1.28	1328.95
95th Percentile	1440.35	26.17	1428.05
Standard deviation	32.53	9.39	31.02
Coefficient of Variation	2.33	87.97	2.24
Correlation		0.96	

****Cells highlighted in red suggest potential dynamic water levels.**

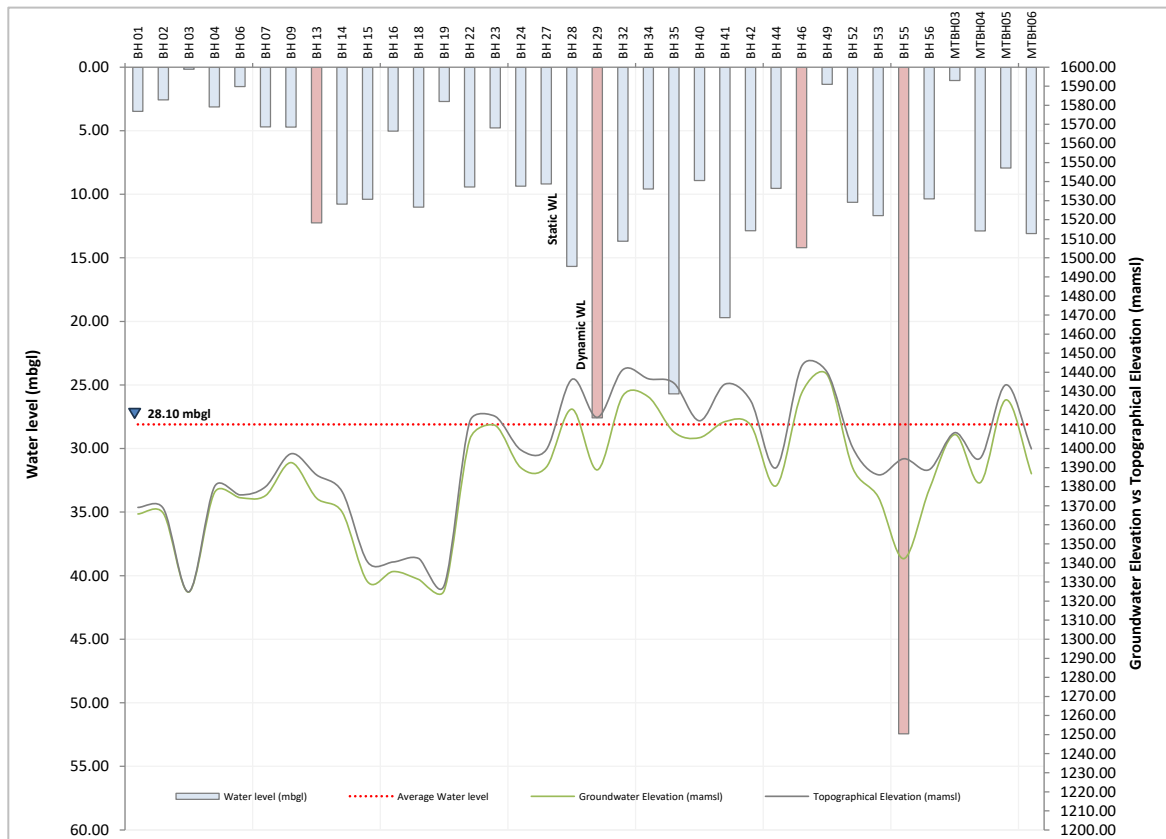


Figure 9-1 Bar chart indicating regional water level summary.

9.3. Groundwater flow direction and hydraulic gradients

Analysed data indicates that the surveyed water levels correlate very well to the topographical elevation with the square of correlation (R^2) indicating a linear association of >0.96 as depicted in **Figure 9-2**. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by surface water divides and will mimic the topography. It should be noted that groundwater abstraction and dynamic water levels observed, can alter local hydraulic gradients and groundwater flow directions. Bayesian interpolation was used to interpolate the hydraulic head distribution throughout the greater study area. Due to various meso-catchments within the study area the regional groundwater flow direction differs. The inferred groundwater flow direction within the northern catchment of the project area will be in a general northern direction towards the lower laying drainage system(s) traversing the project area from where groundwater will discharge as baseflow. The groundwater flow direction within the southern catchment of the project area will be in a general west to southwestern direction as depicted in **Figure 9-3**.

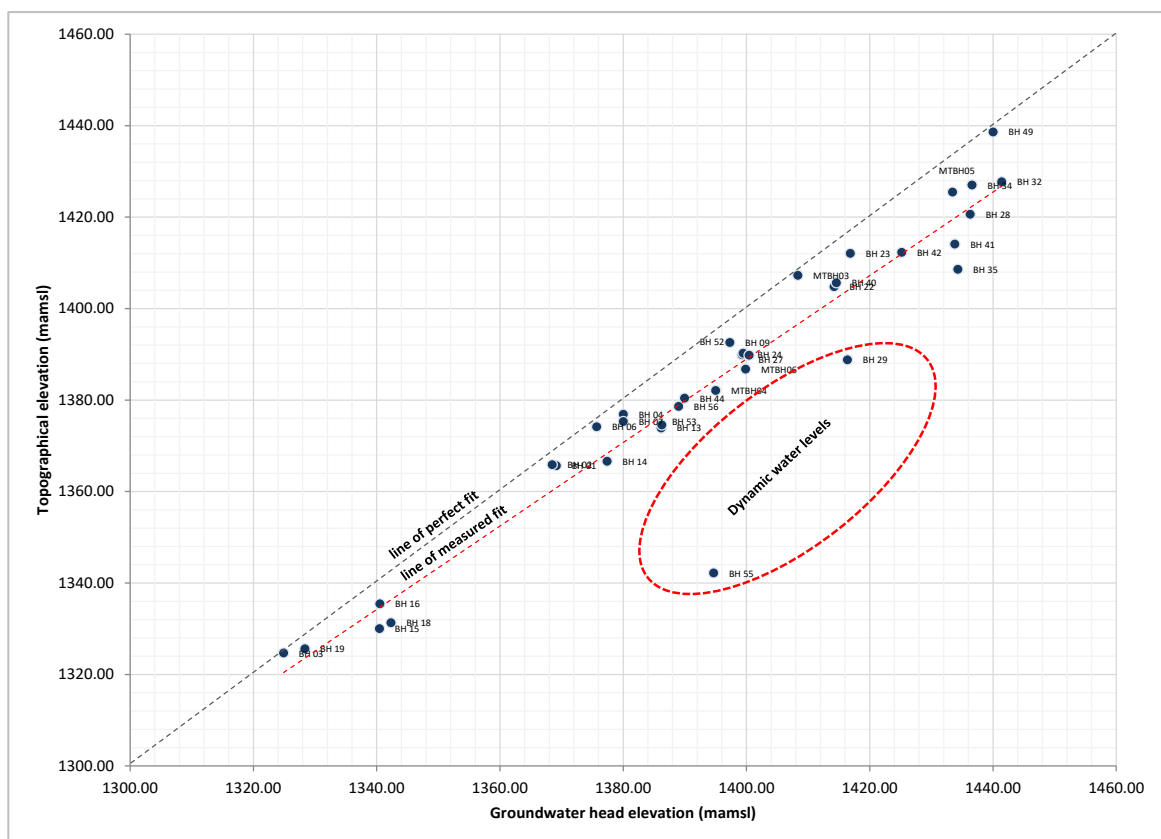


Figure 9-2 Topographical elevation vs. groundwater elevation correlation graph.

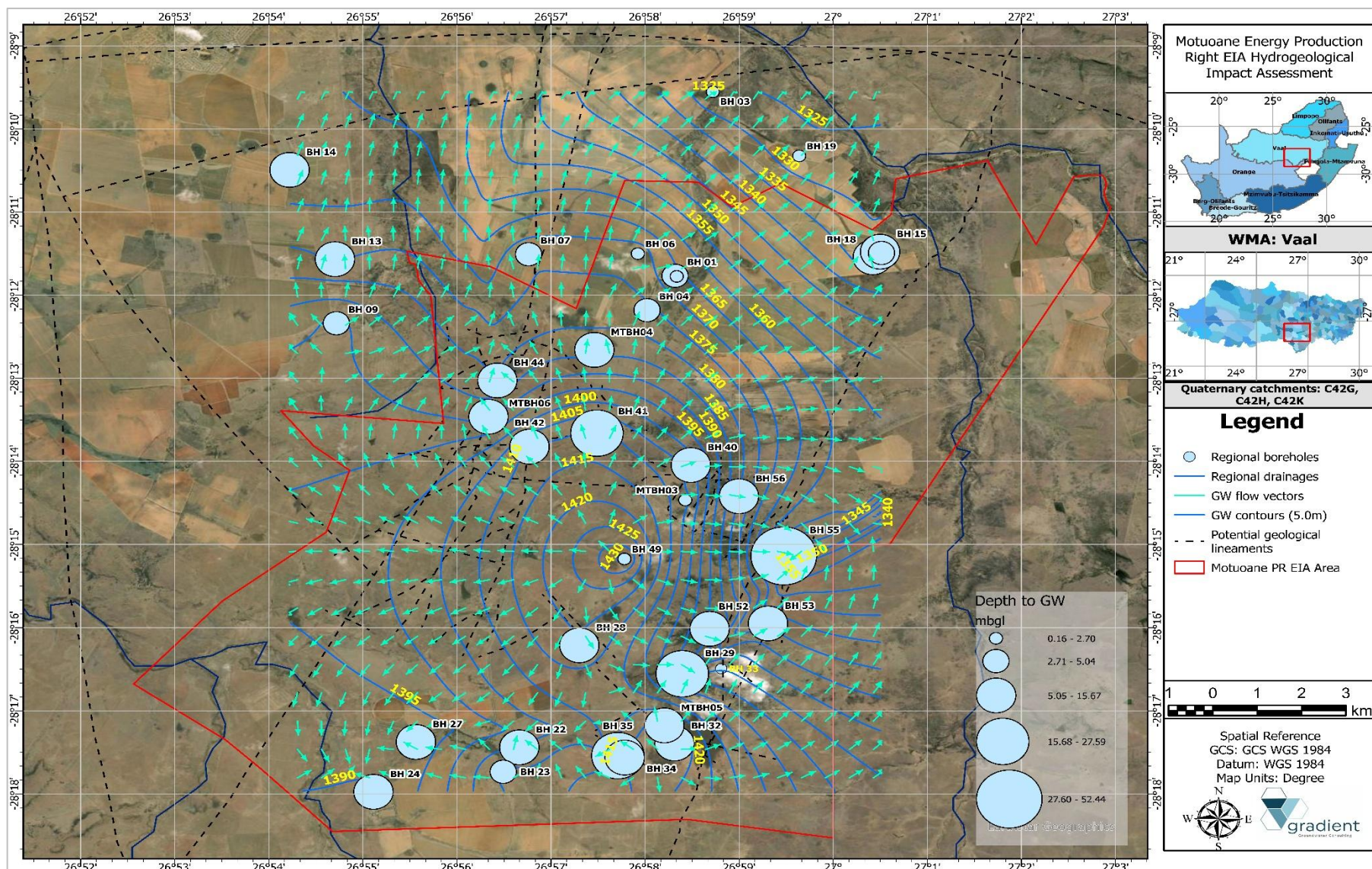


Figure 9-3 Regional groundwater flow direction and depth to groundwater.

Groundwater flow path lines are lines perpendicular to groundwater contours, flow generally occurs faster where contours are closer together and gradients are thus steeper. The groundwater or hydraulic gradient is the change in the hydraulic head over a certain distance, mathematically it is the difference in hydraulic head over a distance along the flow path between two points. The latter provides an indication of the direction of groundwater flow. The following equation can be applied:

Equation 9-1 Hydraulic gradient.

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

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dl = Horizontal distance between two observation points...

The average groundwater gradient (*i*) of the shallow, intergranular aquifer in the vicinity of proposed gas production footprints is relatively flat and calculated at a mean 0.003, with a maximum of 0.005 in a north to south orientation and a minimum of 0.001 in a general southeast to northwest orientation as summarised in **Table 9-2** below.

Table 9-2 Inferred groundwater gradient and seepage direction.

Inferred seepage direction	Hydraulic gradient (<i>i</i>)
N to S	0.005
E to W	0.004
SW to NE	0.001
SE to NW	0.0036
Minimum	0.001
Maximum	0.005
Standard deviation	0.001
Geometric Mean	0.003

9.4. Darcy flux and groundwater flow velocity

The Darcy flux (or velocity) is a function of the hydraulic conductivity (K) and the hydraulic gradient as suggested by Equation 9-2 whereas the seepage velocity can be defined as the Darcy flux divided by the effective porosity¹⁰ (Equation 9-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

Equation 9-2 Darcy flux.

$$v = Ki$$

Equation 9-3 Seepage velocity.

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

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ϕ = effective porosity.

The expected seepage rate from potential contamination originating at the proposed gas production activities as well as associated infrastructure is estimated at an average of approximately 4.0m/a, with a maximum distance of ~5.93m/a in a general southern direction as summarised in **Table 9-3** below¹¹.

Table 9-3 Darcy flux and seepage rates.

Shallow, intergranular aquifer	Hydraulic gradient (i)	Hydraulic conductivity (K)	Darcy flux (m/d)	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
N to S	0.0045	0.1800	0.0008	0.0500	0.016	5.93
E to W	0.0038	0.1800	0.0007	0.0500	0.014	5.01
SW to NE	0.0014	0.1800	0.0003	0.0500	0.005	1.83
SE to NW	0.0036	0.1800	0.0007	0.0500	0.013	4.75
Minimum	0.0014	0.1800	0.0003	0.0500	0.005	1.83
Maximum	0.0045	0.1800	0.0008	0.0500	0.016	5.93
Standard deviation	0.0012	0.0000	0.0002	0.0000	0.004	1.54
Geometric Mean	0.0030	0.1800	0.0005	0.0500	0.011	4.00

¹⁰ It should be noted that effective porosity percentages have been assumed and in situ tests have not been conducted to confirm these ratios.

¹¹ This estimate does however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by faults and fracture zones or igneous contact zones like the intrusive dykes that have higher transmissivities than the general aquifer matrix. Such structures may cause flow velocities to increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

10. HYDROCHEMISTRY

To assess future impacts of the proposed gas production activities on the groundwater regime, it is necessary to develop a baseline/background to be applied as benchmark prior to onset. The following section serves to characterise ambient groundwater quality and develop a relevant baseline for future reference.

10.1. Water quality analysis

The South African National Standards (SANS 241: 2015) have been applied to assess the water quality within the project area. The standards specify a maximum limit based on associated risks for constituents (Refer to Table 10-1). Water samples were submitted for analysis at a SANAS accredited laboratory for inorganic and organic analysis. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health) and elemental concentrations above this range are classed as unsuitable for domestic consumption without treatment. These standards were selected for use as the current and future water uses in the area are primarily domestic application and/or livestock watering.

Table 10-1 SANS 241:2015 risks associated with constituents occurring in water.

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

Table 10-2 SANS 241:2015 physical aesthetic, operational and chemical parameters.

Parameter	Risk	Unit	Standard limits ^a
Physical and aesthetic determinants			
Electrical conductivity (EC)	Aesthetic	mS/m	≤170
Total Dissolved Solids (TDS)	Aesthetic	mg/l	≤1200
Turbidity ^b	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH ^c	Operational	pH units	≥5 to ≤9,7
Chemical determinants – macro			
Nitrate as N ^d	Acute health	mg/l	≤11
Sulphate as SO ₄ ²⁻	Acute health	mg/l	≤500
	Aesthetic	mg/l	≤250
Fluoride as F	Chronic health	mg/l	≤1.5
Ammonia as N	Aesthetic	mg/l	≤1.5
Chloride as Cl ⁻	Aesthetic	mg/l	≤300
Sodium as Na	Aesthetic	mg/l	≤200
Zinc as Zn	Aesthetic	mg/l	≤5
Chemical determinants – micro			
Antimony as Sb	Chronic health	mg/l	≤0.02
Arsenic as As	Chronic health	mg/l	≤0.010
Cadmium as Cd	Chronic health	mg/l	≤0.003
Total chromium as Cr	Chronic health	mg/l	≤0.050
Copper as Cu	Chronic health	mg/l	≤2.0
Iron as Fe	Chronic health	mg/l	≤2.0
	Aesthetic	mg/l	≤0.30
Lead as Pb	Chronic health	mg/l	≤0.010
Manganese as Mn	Chronic health	mg/l	≤0.50
	Aesthetic	mg/l	≤0.10
Mercury as Hg	Chronic health	mg/l	≤0.006
Nickel as Ni	Chronic health	mg/l	≤0.07
Selenium as Se	Chronic health	mg/l	≤0.010
Uranium as U	Chronic health	mg/l	≤0.015
Vanadium as V	Chronic health	mg/l	≤0.2
Aluminium as Al	Operational	mg/l	≤0.3

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

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

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

d This is equivalent to nitrate at 50 mg/l NO₃⁻.

10.2. Data validation

The laboratory precision was validated by employing the plausibility of the chemical analysis, electro neutrality (E.N.) which is determined according to Equation 10-1, below. An error of less than 5.0% is an indication that the analysis results are of suitable precision for further evaluation. All water samples analysed indicate good plausibility (<5.0%) and data can be considered as accurate and correct (Table 10-3).

Equation 10-1 Electro-neutrality.

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

Table 10-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
SW 01	1.016	1.016	2.01%
SW 02	4.290	4.290	2.96%
SW 04	9.277	9.277	0.35%
SW 05	7.184	7.184	2.90%
BH 01	7.967	7.967	1.65%
BH 03	4.149	4.149	-0.02%
BH 04	4.757	4.757	2.58%
BH 06	8.919	8.919	2.79%
BH 07	11.125	11.125	2.82%
BH 09	9.727	9.727	1.55%
BH 13	7.481	7.481	2.31%
BH 14	9.110	9.110	1.78%
BH 15	4.239	4.239	2.17%
BH 19	4.835	4.835	2.55%
BH 1	9.330	9.330	2.53%
BH 2	13.340	13.340	1.26%
BH 3	9.544	9.544	2.69%
BH 4	10.436	10.436	2.39%
BH 5	8.409	8.409	0.11%
BH 6	8.252	8.252	2.78%
BH 20	6.384	6.384	1.48%
BH 22	6.328	6.328	0.41%
BH 25	9.456	9.456	0.51%
BH 26	9.363	9.363	1.02%
BH 27	9.100	9.100	2.74%
BH 28	8.363	8.363	-0.46%
BH 29	8.365	8.365	1.23%
BH 32	6.606	6.606	2.14%
BH 34	7.417	7.417	2.87%
BH 35	5.277	5.277	0.81%
BH 38	7.572	7.572	1.22%
BH 40	6.587	6.587	-0.66%
BH 41	7.171	7.171	1.96%
BH 42	5.512	5.512	2.15%
BH 43	8.628	8.628	2.76%
BH 44	8.482	8.482	2.88%
BH 45	7.463	7.463	1.33%
BH 47	7.538	7.538	2.66%
BH 49	8.908	8.908	2.45%
BH 52	6.060	6.060	0.45%
BH 53	5.914	5.914	2.23%
BH 55	10.788	10.788	2.82%
BH56	8.854	8.854	2.70%

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

Table 10-4, Table 10-5 as well as Table 10-6 below classify water quality according to pH, salinity as well as hardness.

Table 10-4 Hydrochemical classification according to pH-values.

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

Table 10-5 Hydrochemical classification according to salinity.

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

Table 10-6 Hydrochemical classification according to hardness.

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

10.3. Water quality

The hydrochemical results of the hydrocensus boreholes water samples analysed suggest the overall ambient groundwater quality is good with most macro and micro determinants falling within or below the SANS 241:2015 limits. Groundwater can be described as neutral, saline to very saline and hard to very hard. The groundwater quality is impacted by the geological formations, which were deposited in shallow marine environments and are therefore naturally saline.

It is observed that borehole localities BH01, BH07, BH09, BH14 as well as BH19 indicate elevated Nitrate (NO_3) concentrations. The latter may be attributed to the agricultural land-use activities dominating the greater study area with elevated NO_3 concentrations potentially derived from leachate of fertilizer to the local aquifer. Refer to **Figure 10-3** for a spatial distribution map of nitrate concentrations per borehole locality.

Newly drilled site characterisation boreholes, including borehole BH35, suggest elevated Fluoride (F) concentrations while borehole MTBH06 also indicates increased Aluminum (Al) concentrations. The latter may be ascribed to natural geochemical processes as Aluminium is abundant in feldspars and clay minerals observed on site.

Surface water can be described as neutral, saline and moderately soft to slightly hard. Surface water collected from local earth dams and analysed can be classified as good with all macro and micro determinants falling within or below the SANS 241:2015 limits while river samples analysed (SW4 and SW5) suggest slightly elevated Aluminum (Al) and Iron (Fe) concentration. Aluminum is usually kept in solution in wetlands or peat-rich catchments while weathering input from high runoff events can also transport aluminum-rich sediments into

surface water.

Table 10-7 to **Table 10-10** summarises groundwater quality analysis for the hydrocensus samples analysed whereas **Table 10-11** tabulates water quality analysis for the surface water samples analysed. **Figure 10-1** depicts a bar-chart of the major anion and cation composition for all samples analysed while **Figure 10-2** shows spatial distribution of the total inorganic hydrochemical content. Refer to Appendix E for water quality analysis laboratory certificates.

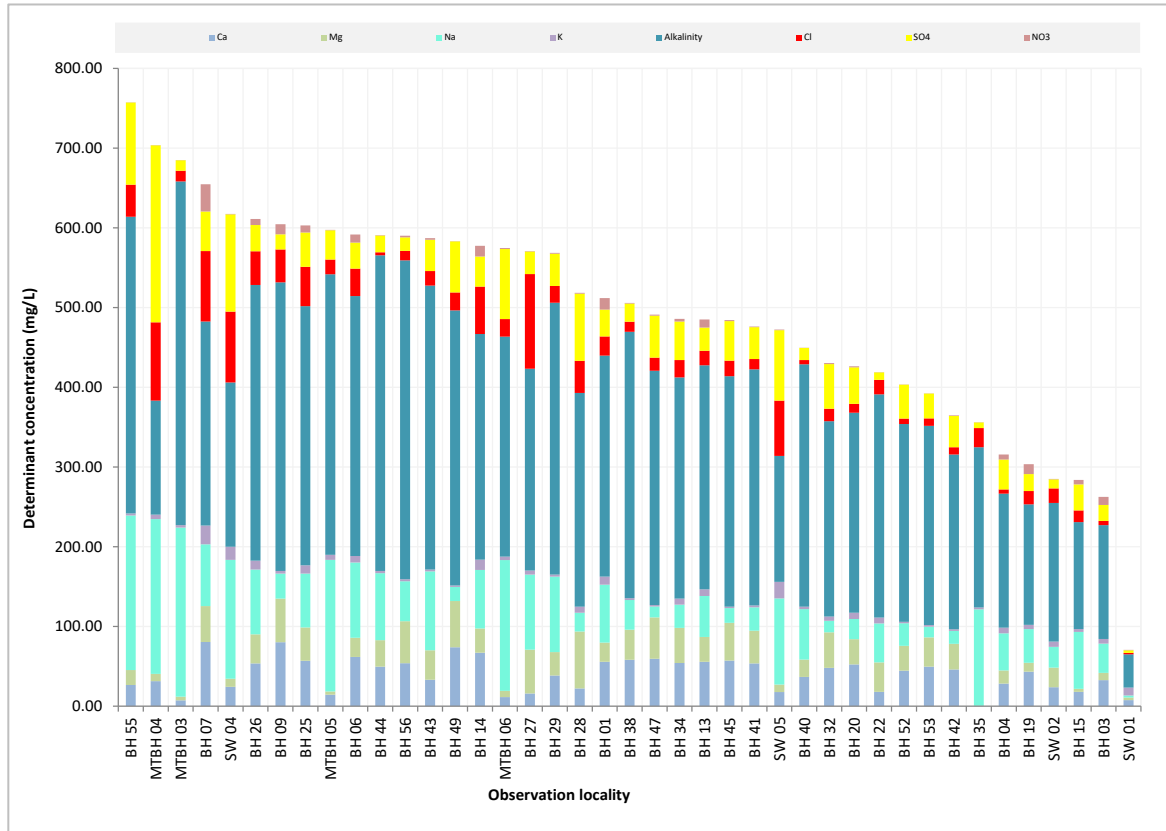


Figure 10-1 Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of hydrocensus samples analysed.

Table 10-7 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	BH 01	BH 03	BH 04	BH 06	BH 07	BH 09	BH 13	BH 14	BH 15	BH 19
Physical determinants													
Colour	-	-	-	Clear	Clear	Rusty	Clear	Clear	Yellowish	Clear	Clear	Clear	Clear
Temperature	°C	-	-	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
General parameters													
pH	-	Operational	≥5.0 ≤ 9.5	8.13	8.08	8.00	8.01	7.92	7.97	8.12	7.94	8.29	8.12
EC	mS/m	Aesthetic	≤170.0	72.20	40.60	46.20	82.10	113.00	88.10	66.40	90.40	42.50	49.10
TDS		Aesthetic	≤ 1 200.0	450.74	240.15	270.51	496.03	669.91	503.60	407.94	510.64	250.85	285.98
Total Alkalinity	CaCO ₃ /l	-	-	277.00	143.00	168.00	326.00	256.00	362.00	281.00	283.00	134.00	150.94
Total Hardness	mg/l	-	-	238.58	119.46	139.11	253.15	386.98	426.18	266.83	292.99	60.97	154.24
Anions													
Cl	mg/l	Aesthetic	≤300.0	24.10	5.13	5.31	34.50	88.40	41.40	18.20	59.30	14.80	16.80
SO ₄	mg/l	Acute health	≤500.0	33.70	20.20	37.50	32.70	49.43	18.90	29.00	37.80	32.70	21.40
F	mg/l	Acute health	≤1.50	0.09	<0.09	0.19	0.14	<0.09	<0.09	0.10	0.10	0.78	0.09
NO ₃ < N	mg/l	Acute health	≤12.0	14.40	10.10	6.34	9.97	34.28	12.74	10.20	13.40	5.48	12.40
PO ₄	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	0.09	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NH ₃	mg/l	Acute health	≤1.5	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals													
Na	mg/l	Aesthetic	≤200.0	72.70	36.70	46.50	94.50	77.30	31.20	51.40	73.30	71.40	42.40
K	mg/l	Aesthetic	≤50.0	10.10	5.65	7.06	8.12	23.60	3.34	8.52	13.10	3.59	5.29
Ca	mg/l	Aesthetic	≤150.0	55.80	32.80	28.50	61.80	80.60	80.30	55.90	67.20	18.10	43.30
Mg	mg/l	Operational	70.0	24.10	9.12	16.50	24.00	45.10	54.80	30.90	30.40	3.83	11.20
Ba	mg/l	Operational	0.7	0.05	0.01	0.02	0.05	0.27	<0.01	<0.01	0.04	<0.01	0.06
B	mg/l	Operational	2.4	0.03	<0.01	0.01	0.04	<0.01	<0.01	0.03	0.06	0.24	<0.01
Cd	mg/l	Operational	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	mg/l	Operational	2.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	mg/l	Operational	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Al	mg/l	Operational	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	mg/l	Acute health	2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	mg/l	Acute health	0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-8 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 20	BH 22	BH 25	BH 26	BH 27	BH 28	BH 29	BH 32	BH 34	BH 35
Physical determinants													
Colour	-	-	-	Clear	Clear	Clear	Clear	Yellowish	Yellowish	Clear	Yellowish	Clear	Clear
Temperature	°C	-	-	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
General parameters													
pH	-	Operational	≥5.0 ≤ 9.5	8.06	7.81	7.81	8.28	8.52	7.95	8.06	8.10	8.00	9.25
EC	mS/m	Aesthetic	≤170.0	58.00	56.50	89.40	86.40	87.80	71.40	76.40	60.50	67.70	49.80
TDS		Aesthetic	≤ 1 200.0	330.44	308.51	503.95	498.81	472.10	415.64	436.74	336.90	386.27	285.00
Total Alkalinity	CaCO3/l	-	-	251.00	280.00	325.00	346.00	253.24	268.00	341.00	245.00	277.47	201.00
Total Hardness	mg/l	-	-	261.80	197.72	314.46	284.40	266.85	349.55	217.20	303.77	316.94	1.77
Anions													
Cl	mg/l	Aesthetic	≤300.0	11.00	18.20	49.50	42.30	118.56	40.30	21.00	15.60	21.90	24.20
SO ₄	mg/l	Acute health	≤500.0	45.80	9.50	43.10	32.90	28.40	84.30	40.50	55.90	48.30	6.98
F	mg/l	Acute health	≤1.50	0.10	0.14	0.10	0.20	0.20	0.10	0.16	<0.09	<0.09	6.88
NO ₃ < N	mg/l	Acute health	≤12.0	1.27	<0.35	8.89	7.48	0.59	1.10	1.07	1.28	3.30	<0.35
PO ₄	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	0.12	0.05	0.04	<0.03	0.03
NH ₃	mg/l	Acute health	≤1.5	<0.45	1.10	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals													
Na	mg/l	Aesthetic	≤200.0	25.20	48.70	67.70	81.20	94.00	23.70	94.80	14.40	29.20	121.00
K	mg/l	Aesthetic	≤50.0	7.89	7.32	10.20	11.10	5.10	7.48	2.38	5.50	7.43	2.19
Ca	mg/l	Aesthetic	≤150.0	52.40	18.00	57.00	53.70	16.00	22.40	38.50	48.10	54.20	0.51
Mg	mg/l	Operational	70.0	31.80	37.10	41.80	36.50	55.10	71.30	29.40	44.60	44.10	0.12
Ba	mg/l	Operational	0.7	0.02	<0.01	0.01	0.04	<0.01	0.01	0.04	<0.01	<0.01	<0.01
B	mg/l	Operational	2.4	<0.01	0.03	0.04	0.04	0.04	<0.01	0.12	<0.01	<0.01	0.59
Cd	mg/l	Operational	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	mg/l	Operational	2.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	mg/l	Operational	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Al	mg/l	Operational	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	mg/l	Acute health	2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	mg/l	Acute health	0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-9 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 38	BH 40	BH 41	BH 42	BH 43	BH 44	BH 45	BH 47	BH 49	BH 52
Physical determinants													
Colour	-	-	-	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Temperature	°C	-	-	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
General parameters													
pH	-	Operational	≥5.0 ≤ 9.5	7.85	7.08	7.51	7.73	7.94	7.81	7.98	8.00	7.88	8.00
EC	mS/m	Aesthetic	≤170.0	67.10	59.70	65.70	51.70	75.60	71.60	66.00	68.30	75.60	53.60
TDS		Aesthetic	≤ 1 200.0	374.64	328.93	360.00	279.69	452.48	432.50	373.32	378.01	446.92	304.68
Total Alkalinity	CaCO ₃ /l	-	-	334.00	304.00	296.00	219.00	356.00	396.00	289.00	293.89	345.00	248.00
Total Hardness	mg/l	-	-	300.99	181.41	302.76	247.71	234.85	260.98	337.70	362.80	423.87	240.10
Anions													
Cl	mg/l	Aesthetic	≤300.0	12.80	5.45	12.90	9.30	18.30	3.63	19.50	16.60	22.50	6.90
SO ₄	mg/l	Acute health	≤500.0	22.80	15.10	40.20	39.10	39.20	21.20	49.50	52.50	64.10	42.50
F	mg/l	Acute health	≤1.50	<0.09	0.34	<0.09	<0.09	0.26	0.27	<0.09	<0.09	<0.09	0.19
NO ₃ < N	mg/l	Acute health	≤12.0	0.65	<0.35	0.63	0.73	2.10	<0.35	1.33	1.29	0.42	<0.35
PO ₄	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NH ₃	mg/l	Acute health	≤1.5	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals													
Na	mg/l	Aesthetic	≤200.0	37.20	63.40	29.50	16.10	99.00	83.90	18.50	13.60	17.70	28.20
K	mg/l	Aesthetic	≤50.0	2.35	2.93	2.30	2.26	2.49	2.87	1.90	1.64	1.63	1.87
Ca	mg/l	Aesthetic	≤150.0	58.20	36.70	53.80	46.10	33.20	49.60	57.40	59.70	74.10	44.70
Mg	mg/l	Operational	70.0	37.80	21.80	40.90	32.20	36.90	33.30	47.20	51.90	58.00	31.20
Ba	mg/l	Operational	0.7	0.13	0.09	0.17	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
B	mg/l	Operational	2.4	0.05	0.20	<0.01	<0.01	0.05	0.03	<0.01	<0.01	<0.01	0.08
Cd	mg/l	Operational	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	mg/l	Operational	2.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	mg/l	Operational	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Al	mg/l	Operational	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	mg/l	Acute health	2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	mg/l	Acute health	0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-10 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 52	BH 53	BH 55	BH 56	MTBH 03	MTBH 04	MTBH 05	MTBH 06
Physical determinants											
Colour	-	-	-	Clear	Rusty	Greyish	Clear	Clear	Clear	Clear	Clear
Temperature	°C	-	-	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
General parameters											
pH	-	Operational	≥5.0 ≤ 9.5	8.00	7.94	7.93	7.78	7.93	7.80	7.71	8.06
EC	mS/m	Aesthetic	≤170.0	53.60	54.50	98.90	77.00	88.80	107.00	75.70	75.40
TDS		Aesthetic	≤ 1 200.0	304.68	292.28	609.89	437.77	518.80	649.97	458.45	476.67
Total Alkalinity	CaCO3/l	-	-	248.00	250.00	372.00	400.00	431.00	143.00	352.00	276.00
Total Hardness	mg/l	-	-	240.10	274.66	143.84	351.86	37.57	116.38	53.34	60.84
Anions											
Cl	mg/l	Aesthetic	≤300.0	6.90	9.30	40.30	12.00	13.50	98.20	18.40	21.90
SO ₄	mg/l	Acute health	≤500.0	42.50	31.10	103.00	16.80	13.10	222.00	36.80	87.80
F	mg/l	Acute health	≤1.50	0.19	<0.09	0.58	0.11	4.13	2.14	1.04	2.20
NO ₃ < N	mg/l	Acute health	≤12.0	<0.35	<0.35	<0.35	2.16	<0.35	<0.35	<0.35	1.37
PO ₄	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NH ₃	mg/l	Acute health	≤1.5	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals											
Na	mg/l	Aesthetic	≤200.0	28.20	13.60	194.00	50.20	212.00	194.00	165.00	164.00
K	mg/l	Aesthetic	≤50.0	1.87	1.89	2.54	2.34	3.16	5.61	6.22	4.40
Ca	mg/l	Aesthetic	≤150.0	44.70	49.80	26.60	54.00	7.46	31.60	14.50	11.50
Mg	mg/l	Operational	70.0	31.20	36.50	18.80	52.70	4.60	9.10	4.16	7.80
Ba	mg/l	Operational	0.7	<0.01	<0.01	0.01	<0.01	0.09	0.02	0.03	0.02
B	mg/l	Operational	2.4	0.08	<0.01	0.22	0.01	0.52	0.35	0.24	0.69
Cd	mg/l	Operational	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	mg/l	Operational	2.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	mg/l	Operational	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003	<0.003	<0.003	<0.01	<0.003	<0.003	<0.003	<0.003
Al	mg/l	Operational	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	1.85
Fe	mg/l	Acute health	2.0	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	0.77
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.06	<0.01
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	mg/l	Acute health	0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-11 Hydrochemistry: Surface water quality evaluation of hydrocensus samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	SW 01	SW 02	SW 04	SW 05
Physical determinants							
Colour	-	-	-	Brownish	Yellowish	Rusty	Rusty
Temperature	°C	-	-	21.00	21.00	21.00	21.00
General parameters							
pH	-	Operational	≥5.0 ≤ 9.5	7.99	8.30	7.95	7.74
EC	mS/m	Aesthetic	≤170.0	10.30	41.10	90.90	71.60
TDS		Aesthetic	≤ 1 200.0	57.46	218.03	541.98	424.34
Total Alkalinity	CaCO ₃ /l	-	-	41.70	174.00	206.00	158.00
Total Hardness	mg/l	-	-	32.24	160.41	102.93	83.03
Anions							
Cl	mg/l	Aesthetic	≤300.0	1.88	18.02	88.90	69.40
SO ₄	mg/l	Acute health	≤500.0	3.21	11.45	122.00	88.30
F	mg/l	Acute health	≤1.50	0.11	0.11	0.17	0.22
NO ₃ < N	mg/l	Acute health	≤12.0	0.71	0.54	0.50	0.89
PO ₄	mg/l	Acute health	≤5.0	<0.03	0.13	0.28	1.27
NH ₃	mg/l	Acute health	≤1.5	<0.45	<0.45	<0.45	<0.45
Cations and metals							
Na	mg/l	Aesthetic	≤200.0	2.75	26.10	149.00	108.00
K	mg/l	Aesthetic	≤50.0	9.72	6.63	16.50	20.80
Ca	mg/l	Aesthetic	≤150.0	7.70	24.00	24.40	17.80
Mg	mg/l	Operational	70.0	3.16	24.40	10.20	9.37
Ba	mg/l	Operational	0.7	0.21	<0.01	0.03	<0.01
B	mg/l	Operational	2.4	0.02	<0.01	0.04	0.03
Cd	mg/l	Operational	0.003	<0.002	<0.002	<0.002	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02	<0.02	<0.02	<0.02
Cu	mg/l	Operational	2.00	<0.01	<0.01	<0.01	<0.01
Pb	mg/l	Operational	0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003	<0.003	<0.003	<0.003
Al	mg/l	Operational	0.3	0.17	0.06	2.63	5.12
Fe	mg/l	Acute health	2.0	0.10	0.05	1.28	2.51
Mn	mg/l	Operational	0.4	0.08	<0.01	<0.01	<0.01
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01
U	mg/l	Acute health	0.015	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	0.02	<0.01	<0.01	<0.01

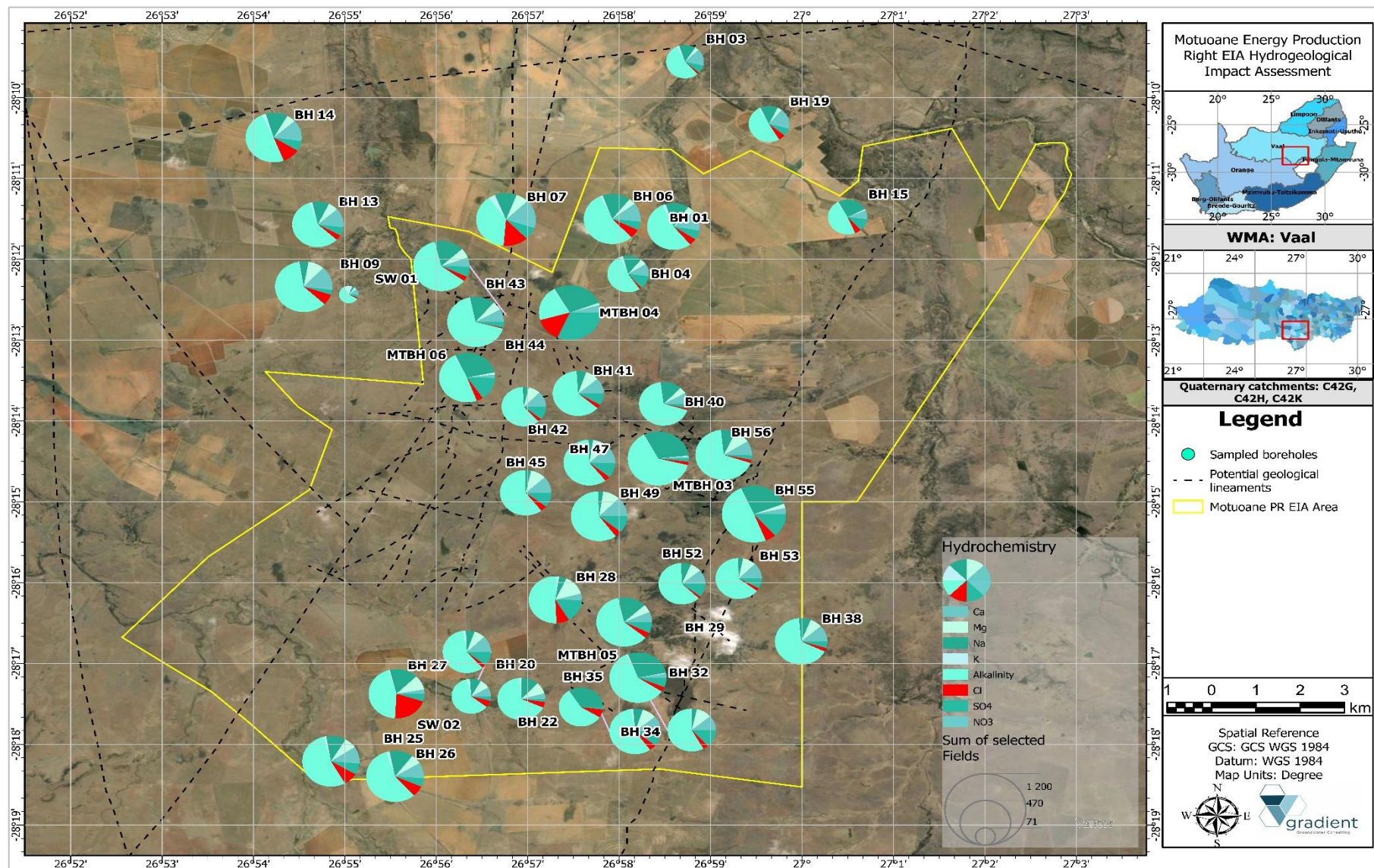


Figure 10-2 Total hydrochemical analysis spatial distribution map.

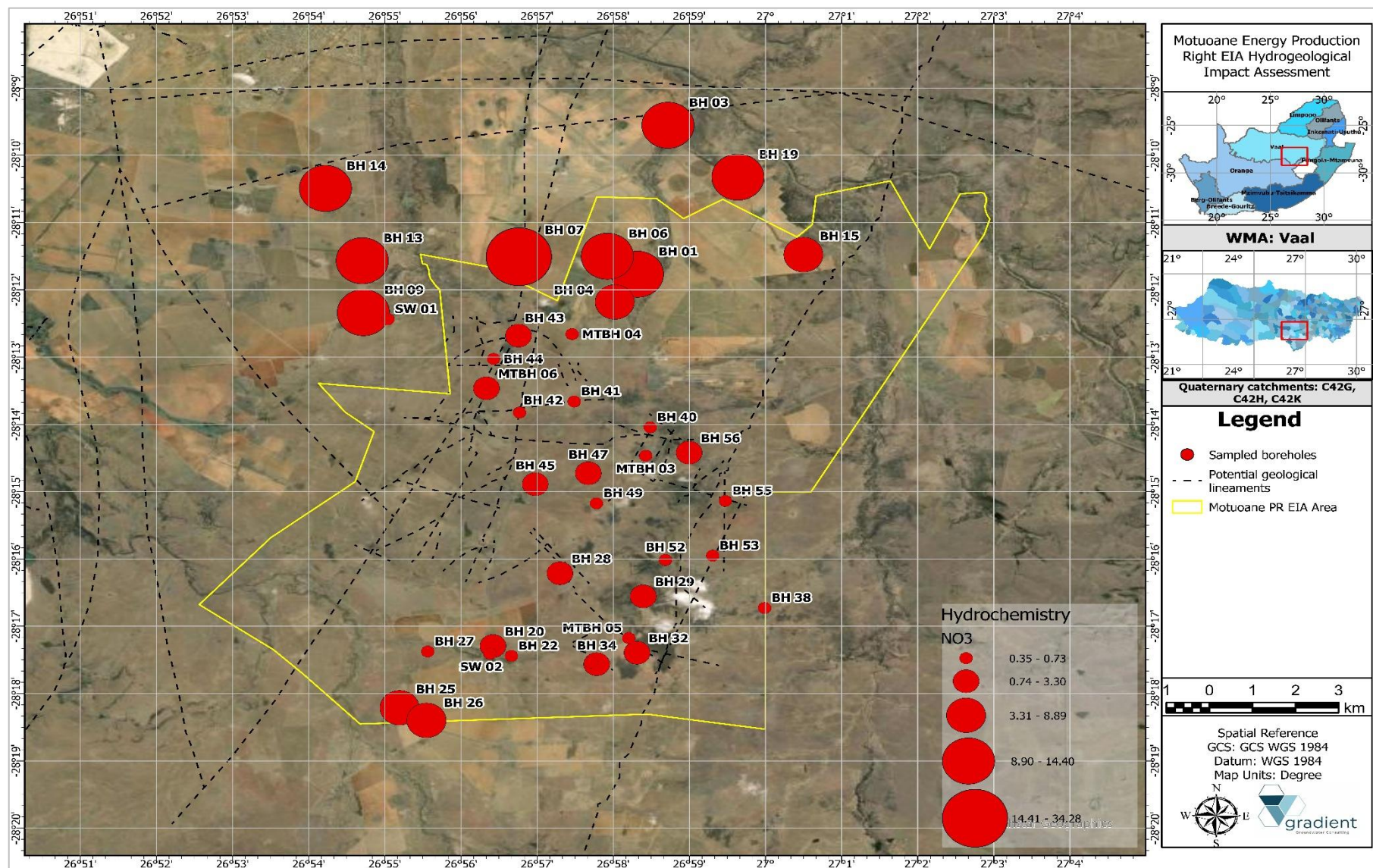


Figure 10-3 Spatial distribution map for the Nitrate (NO₃) concentrations.

10.4. Dissolved methane and ethane analysis

In order to formulate a groundwater baseline in terms of dissolved methane and ethane, newly drilled boreholes were subjected to testing and evaluation. Refer to **Table 10-12** for a summary of the analysis results with **Figure 10-4** depicting a weighted average spatial distribution map for dissolved methane analysis. It is noted that the overall ambient groundwater quality with reference to dissolved methane and ethane is good with the no boreholes exceeding the U.S. Department of the Interior guidelines. Refer to Appendix E for the laboratory certificates.

Table 10-12 Hydrochemistry: Site characterisation borehole dissolved methane and ethane compared to U.S. Department of the Interior guidelines.

Determinant	Unit	Risk	U.S. Department of the Interior	MTBH03	MTBH04	MTBH05	MTBH06
Methane	mg/l	Acute health	≤ 10.0 mg/l	9.500	0.039	0.490	0.022
Ethane	mg/l	Acute health	-	0.032	<0.0130	<0.0130	<0.0130

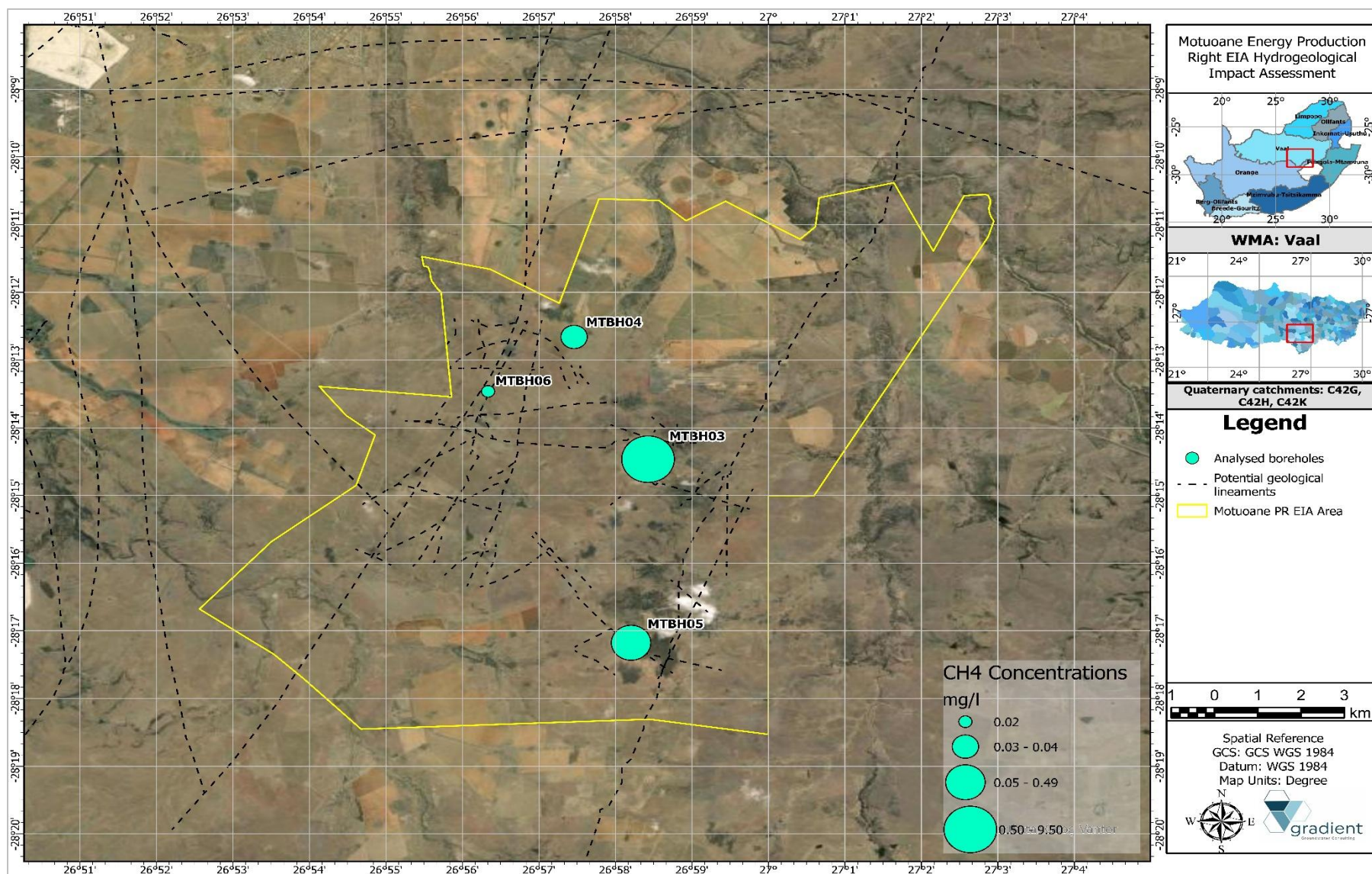


Figure 10-4 Spatial distribution map of boreholes analysed for dissolved methane.

10.5. Hydrochemical signature

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

10.5.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots as summarised in **Figure 10-5**. Different water types derived from different environments plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area generally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and coordinated regimes. **Figure 10-6** and Figure 10-7 depict piper diagrams developed from the groundwater quality analysis results while **Figure 10-8** indicates a piper diagram from the surface water samples analysed.

The majority of groundwater samples analysed in general suggest no cation dominance while the dominant anion is carbonate/bicarbonate (characteristically a recently recharged and unimpacted groundwater environment). Borehole locality BH04 shows Sodium-Chloride dominance usually associated with old stagnant water while borehole localities BH01, BH03, BH05, BH06, BH15, BH35 as well as BH55 are characteristically an area of dynamic and coordinated environment (Sodium/ Potassium-Carbonate dominance).

The surface water samples analysed can be categorized as either having a Calcium-Bi-carbonate signature from an unpolluted surface water source (earth dams) whereas the river samples analysed suggest a Sodium-Chloride dominance.

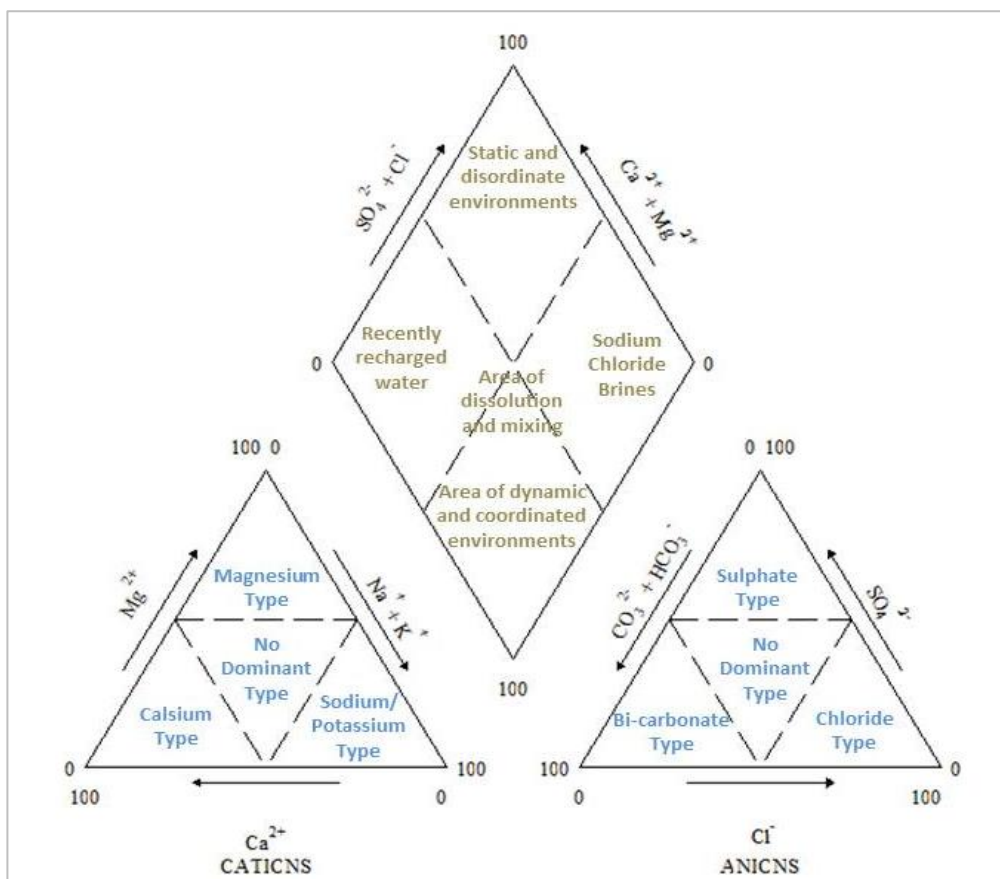


Figure 10-5 Piper diagram indicating classification for anion and cation facies in terms of ion percentages

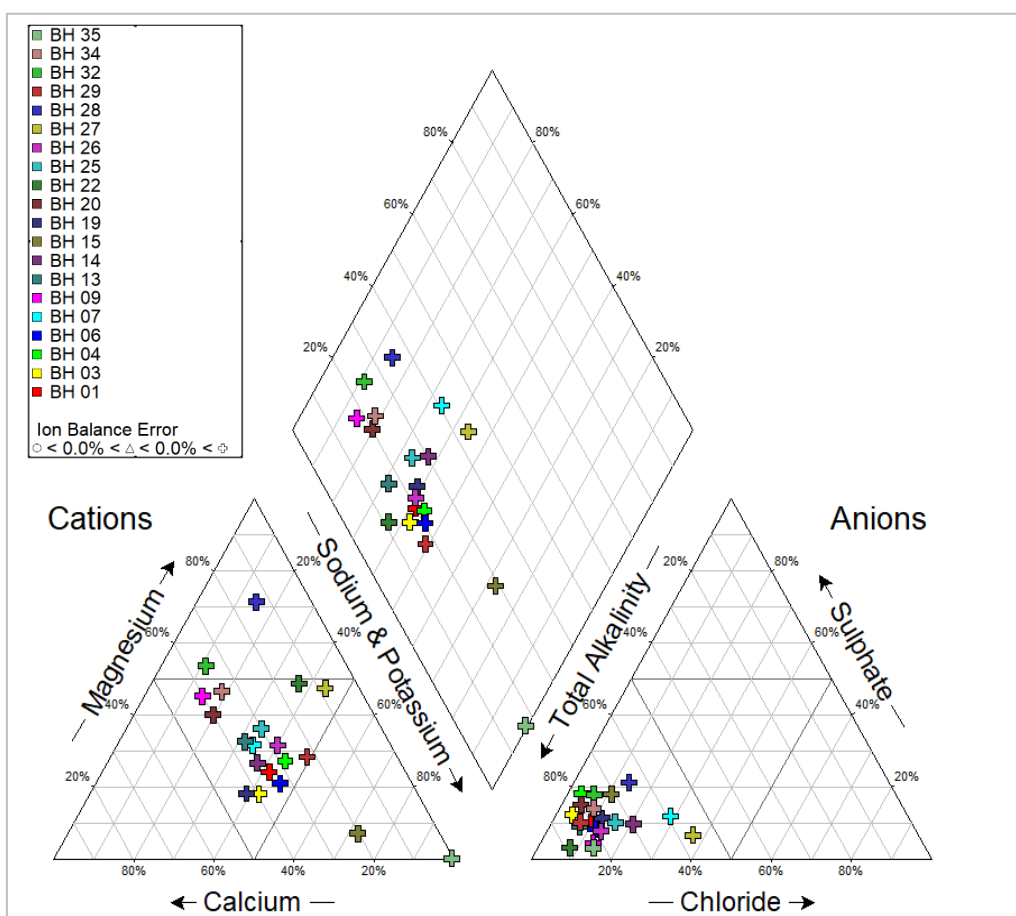


Figure 10-6 Piper diagram indicating major anions and cations of groundwater samples analysed.

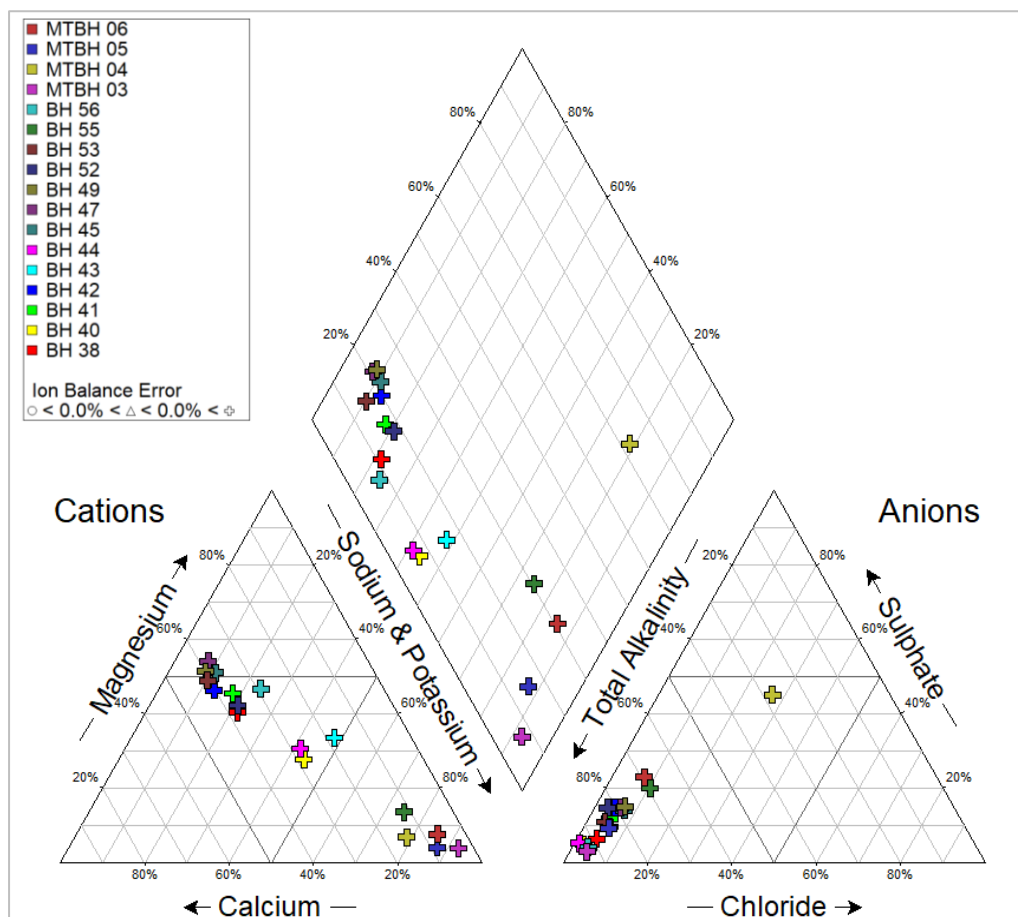


Figure 10-7 Piper diagram indicating major anions and cations of groundwater samples analysed.

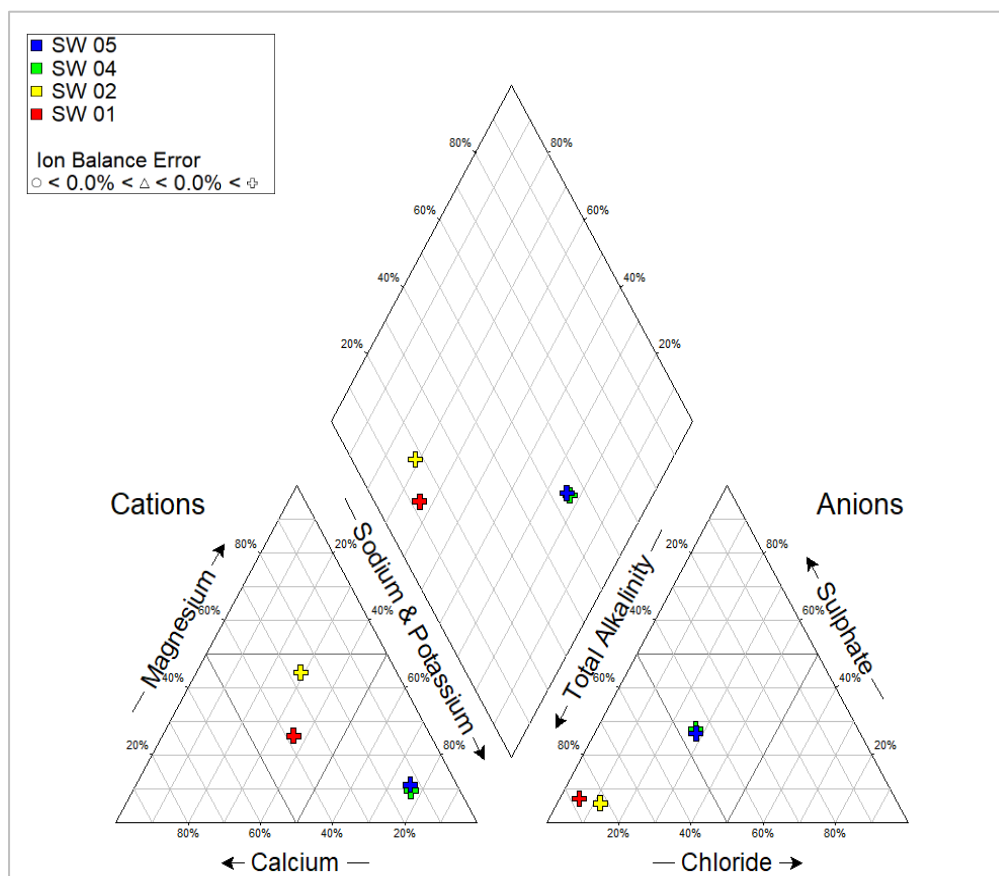


Figure 10-8 Piper diagram indicating major anions and cations of surface water samples analysed.

10.5.2. Stiff diagrams

A Stiff diagram, or Stiff pattern, is a graphical representation of chemical analyses and major anions and cations, first developed by H.A. Stiff in 1951. STIFF diagrams plot the equivalent concentrations of major anions and cations on a horizontal scale on opposite sides of a vertical axis. The plot point of each parameter is linked to the adjacent point creating a polygon around the vertical axis. Water with similar major ion ratios will show similar geometries. **Figure 10-9** and **Figure 10-10** depict Stiff diagrams compiled from the hydrocensus groundwater sampling analysis.

It is evident that the following borehole localities BH27, BH28, BH35 and BH55 indicate a different ion composition and geometry compared to the other groundwater sampling localities and suggest a potentially different aquifer or hydrostratigraphical units being targeted, possibly a more stagnant water source. Newly established site characterisation boreholes also suggest a more dominant Sodium/Potassium dominance which also and may also represent a deeper aquifer unit being.

Figure 10-11 indicates a Stiff diagram compiled from the surface water samples analysed. The local earth dams sampled, which are fed by rainfall runoff and indicative of recently recharged and unimpacted water, differ from the Rietspruit and other river sample analysed. The latter have a higher salt load and suggest a shift towards Sodium/Potassium dominance which can potentially be attributed to more saline baseflow discharge to the local drainage system being a gaining stream.

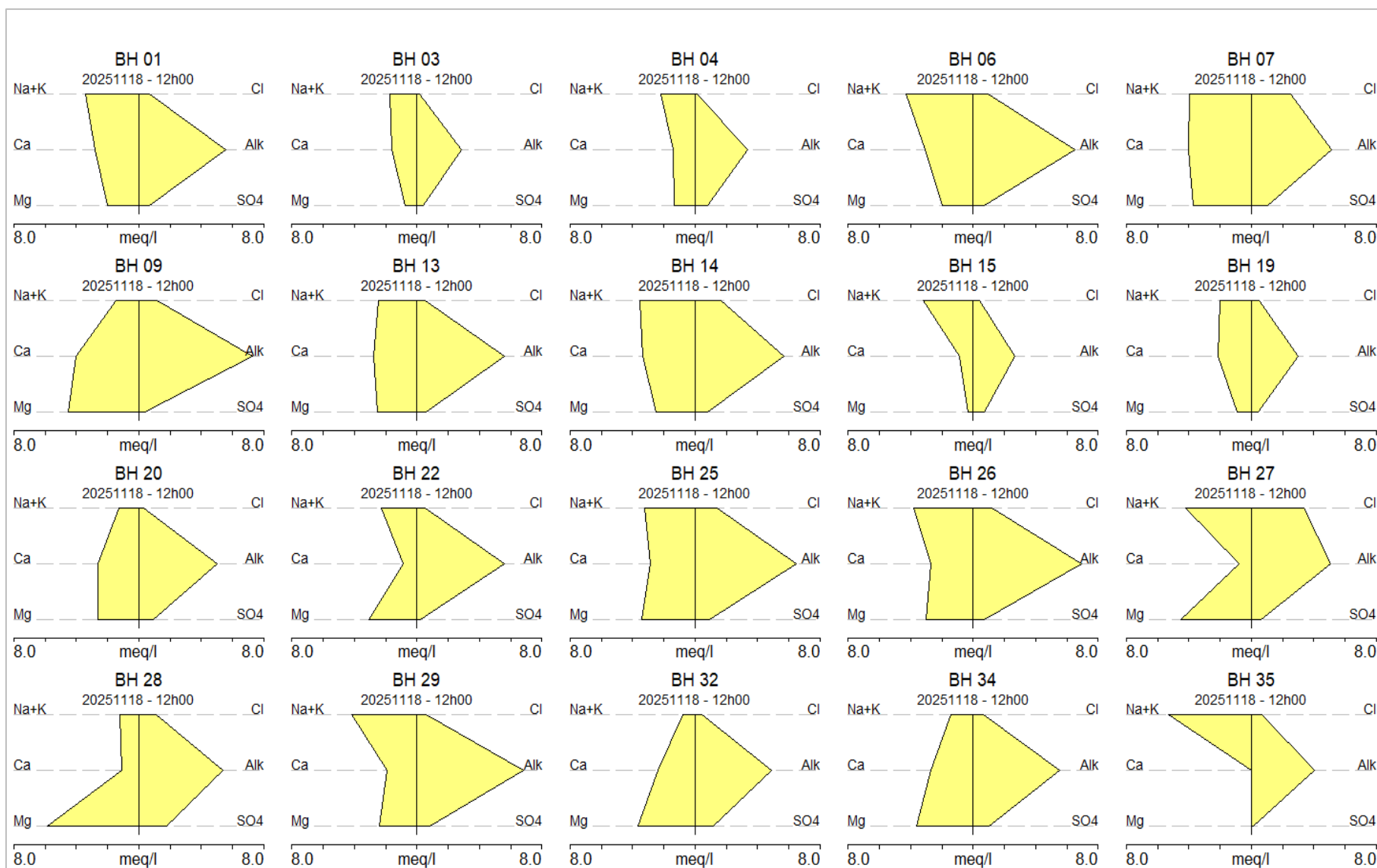


Figure 10-9 Stiff diagrams representing the groundwater samples analysed.

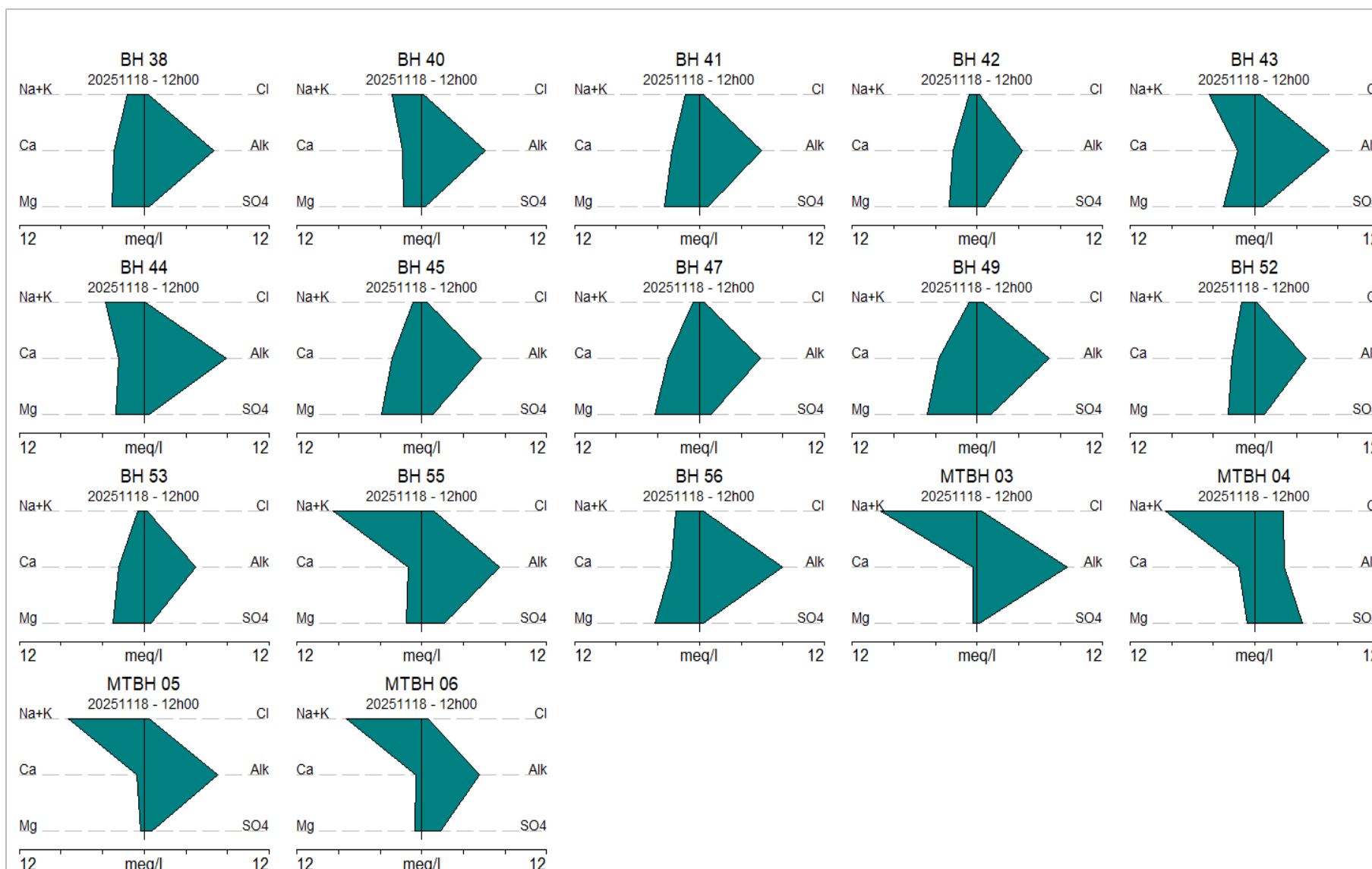


Figure 10-10 Stiff diagrams representing the groundwater samples analysed (cont.).

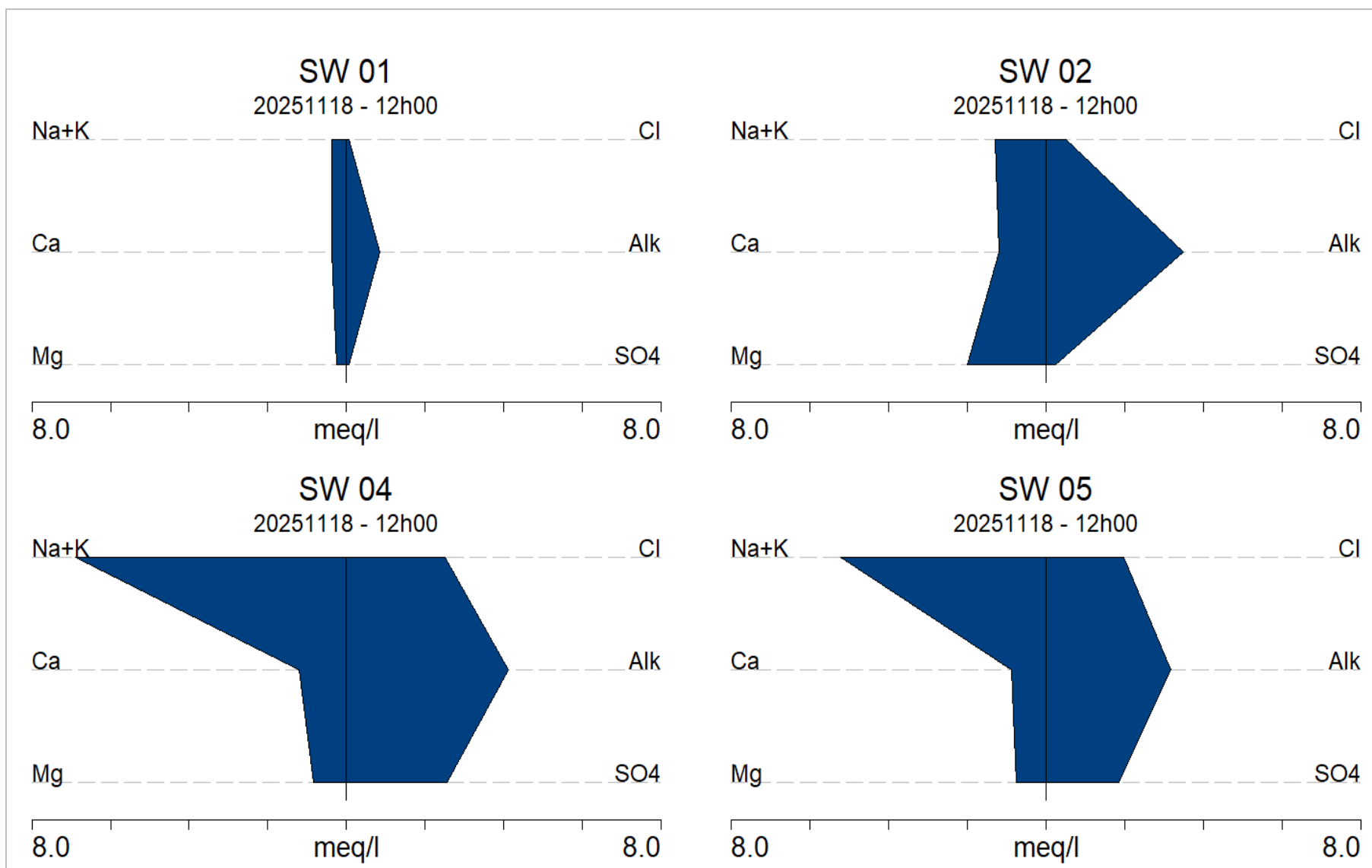


Figure 10-11 Stiff diagrams representing the surface water samples analysed.

10.5.3. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems as depicted in **Figure 10-12**. Different fields of the diagram could be summarised as follows:

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

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

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

Field 04: Often associated with mining related SO_4 contamination.

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

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

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

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

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

Most groundwater samples analysed can be classified as either Field01/ Field 02 i.e., mostly fresh, clean and relatively young with HCO_3^- and CO_3 dominance evident indicative of an unimpacted groundwater environment or Field 03 (often associated with Na ion exchange between groundwater and aquifer material). Borehole localities BH06 can be classified as Field06, suggesting old stagnant NaCl dominated water that has mixed with clean water (refer to **Figure 10-14**). **Figure 10-15** indicates an expanded Durov diagram compiled from the surface water samples analysed. The local earth dams sampled, SW01 and SW02, can be classified as Field 02 i.e., clean and relatively young with HCO_3^- and CO_3 dominance evident indicative of an unimpacted surface water environment, while the river samples analysed (SW04 and SW05) can be classified as Field06, suggesting old stagnant NaCl dominated water that has mixed with clean water. The latter have a higher salt load and suggest a shift towards Sodium/Potassium dominance which can potentially be attributed to more saline baseflow discharge to the local drainage system being a gaining stream or influence from more saline runoff entering the water bodies.

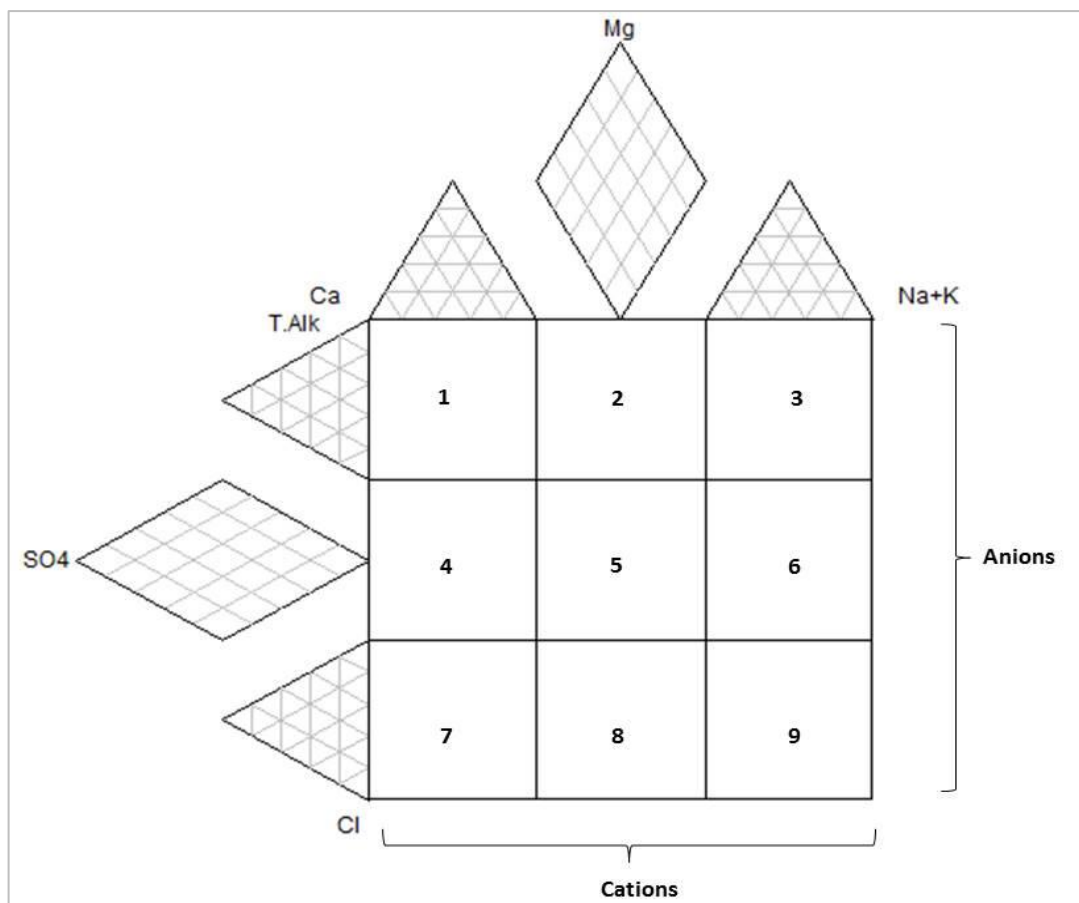


Figure 10-12 Extended Durov diagram indicating major anions and cations.

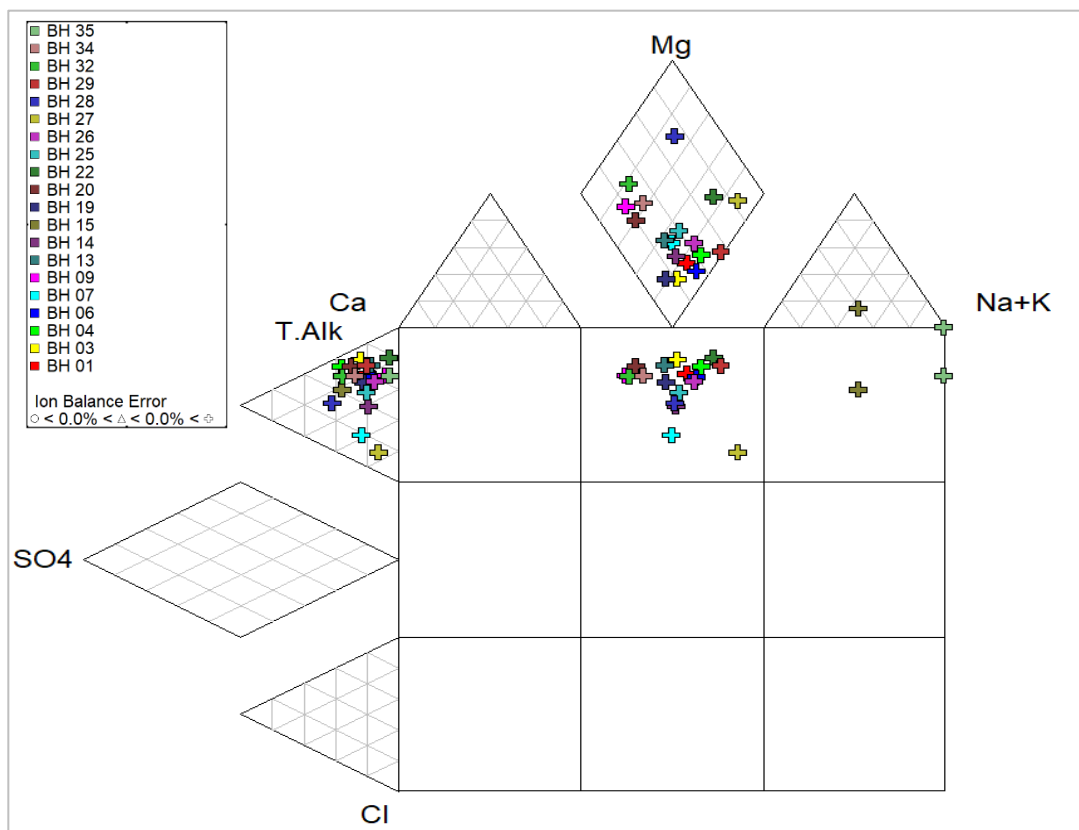


Figure 10-13 Extended Durov diagram of groundwater samples analysed.

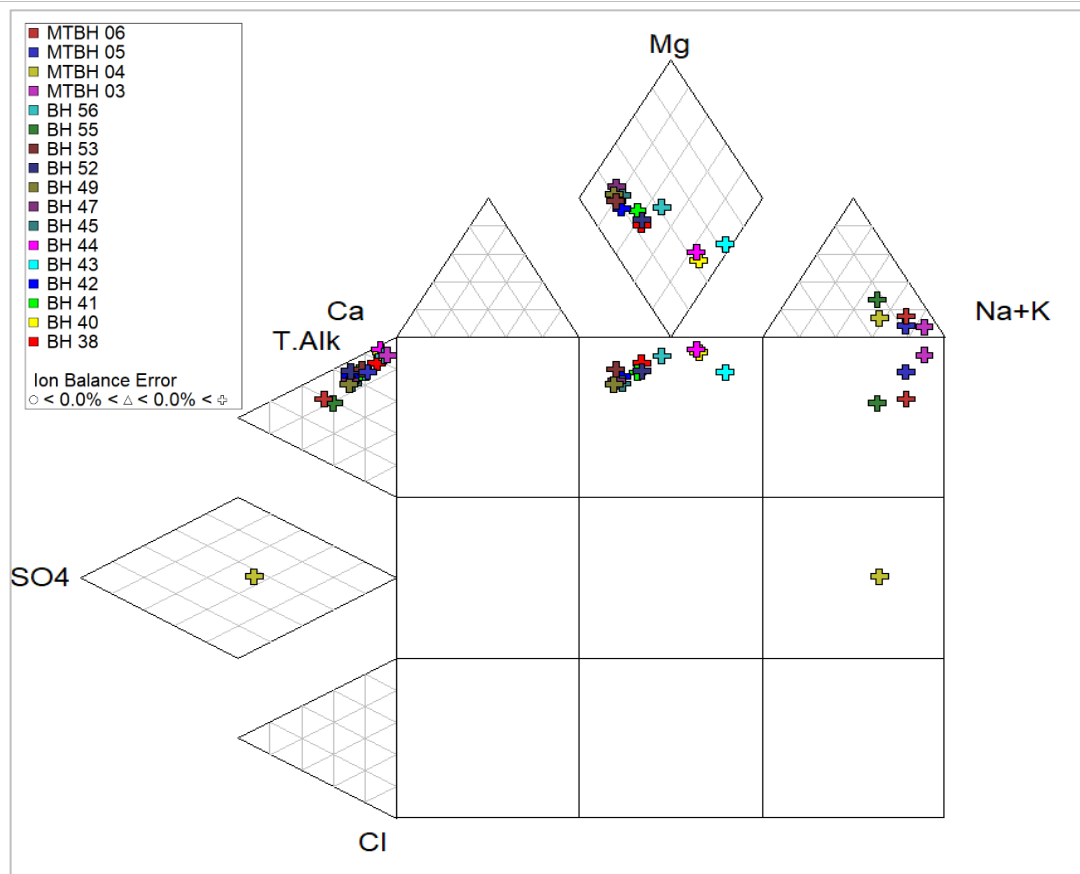


Figure 10-14 Extended Durov diagram of groundwater samples analysed (cont.).

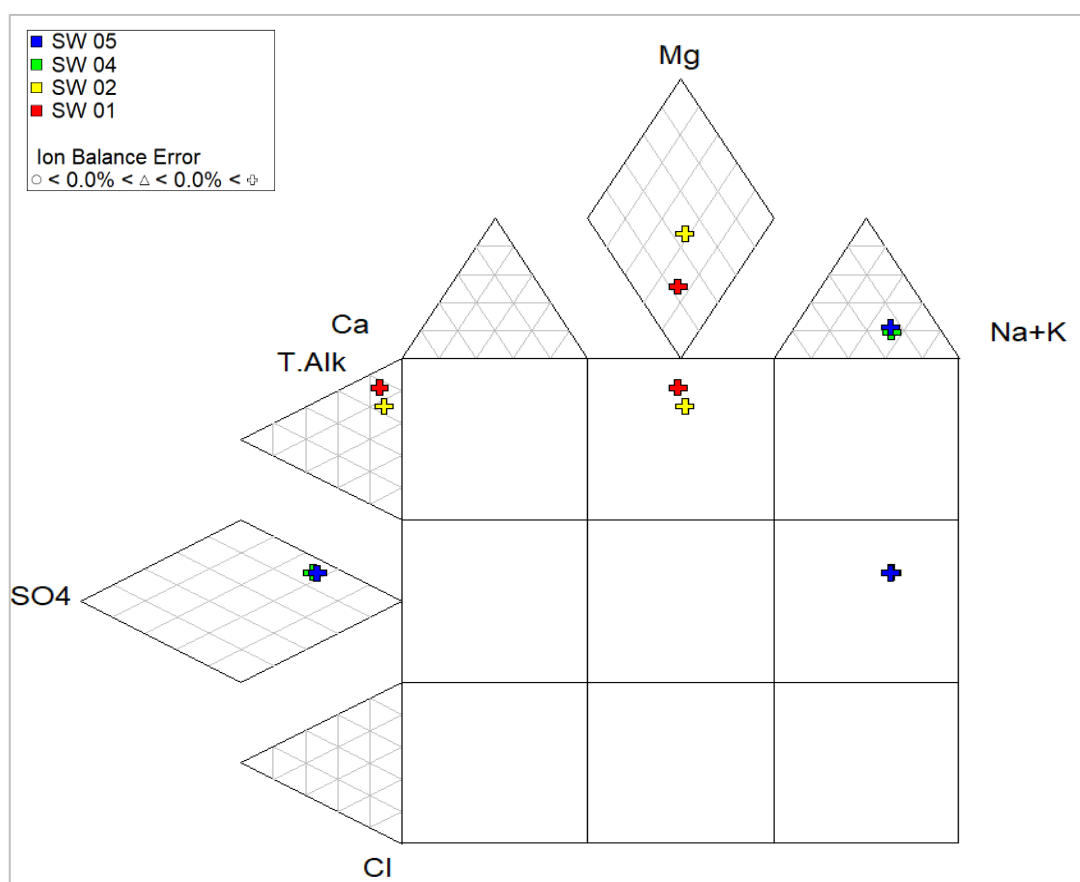


Figure 10-15 Extended Durov diagram of surface water samples analysed. .

11. AQUIFER CLASSIFICATION AND GROUNDWATER MANAGEMENT INDEX

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

Equation 11-1 GQM Index.

$$\text{GQM Index} = \text{Aquifer system management} \times \text{Aquifer vulnerability}$$

11.1. Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). Aquifer classification forms a very useful planning tool which can be applied to guide the management of groundwater systems. According to the aquifer classification map of South Africa the project area is underlain by a “**Minor aquifer**”. It should however be noted that due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon or depleted, the targeted aquifer in some instances can be classified as a sole source aquifer. Refer to **Figure 11-1** (DWS, 2013). The classifications and definitions for each aquifer system are summarised in **Table 11-1**.

Table 11-1 Aquifer System Management Classes (After Parsons , 1995).

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

11.2. Aquifer vulnerability

Aquifer vulnerability can be defined as the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a “**Moderate**” vulnerability rating. Refer to **Figure 11-2** (DWS, 2013).

11.3. Aquifer susceptibility

Aquifer susceptibility is a qualitative measure of relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities. According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a “**Medium**” susceptibility rating. Refer to **Figure 11-3** (DWS, 2013).

Table 11-2 Groundwater Quality Management Index.

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

11.4. Groundwater contamination risk assessment

The concept of groundwater vulnerability to contamination by applying the DRASTIC methodology was introduced by Aller et al. (1987) and refined by the US EPA (United States Environmental Protection Agency). DRASTIC is an acronym for a set of parameters that characterise the hydrogeological setting and combined evaluated vulnerability: Depth to water level, Net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and Hydraulic Conductivity. This method provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeological parameters. Lynch et al (1994) suggests a considerable variation in terms of hydraulic conductivity in hard rock aquifers and revised this methodology to accommodate local aquifer conditions accordingly. Parameters used as part of the index are summarised in **Table 11-3**. The DRASTIC index (DI) can be computed by applying **Equation 11-2**. According to the DRASTIC index methodology applied, the activities and associated infrastructure’s risk to groundwater pollution of the shallow, intergranular aquifer system, is rated as “**Moderate**”, $Di = 105$, while the risk to groundwater pollution of the alluvial, riparian zone (primary aquifer) system(s), is rated as “**High**”, $Di = 154$ (refer to **Table 11-5**).

Equation 11-2 DRASTIC Index (Di).

$$D_i = DrD\lambda + RrR\lambda + ArA\lambda + SrS\lambda + TrT\lambda + IrI\lambda$$

where:

D = Depth to Water Table

R = Recharge

A = Aquifer media.

S = Soil media.

T = Topographic aspect.

I = Impact of vadose zone media.

C = Conductivity.

Table 11-3 DRASTIC Index.

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

Where **D**, **R**, **A**, **S**, **T**, **I**, and **C** are the parameters, *r* is the rating value, and λ the constant weight assigned to each parameter as summarised in **Table 11-4** below (Lynch et al, 1994).

Table 11-4 Ratings assigned to groundwater vulnerability parameters (Lynch et al, 1994).

Depth to groundwater (D_R)		Net Recharge (R_R)	
Range (m)	Rating	Range (mm)	Rating
0 – 5	10	0 – 5	1
5 – 15	7	5 – 10	3
15 – 30	3	10 – 50	6
> 30	1	50 – 100	8
		> 100	9
Aquifer Media (A_R)		Soil Media (S_R)	
Range	Rating	Range	Rating
Dolomite	10	Sand	8 – 10
Intergranular	8	Shrinking and/or aggregated clay	7 - 8
Fractured	6	Loamy sand	6 - 7
Fractured and weathered	3	Sandy loam	5 - 6
Topography (T_R)		Sandy clay loam and loam	4 - 5
Range (% slope)	Rating	Silty clay loam, sandy clay and silty loam	3 - 4
0 – 2	10	Clay loam and silty clay	2 – 3
2 – 6	9		
6 – 12	5		
12 – 18	3		
> 18	1		
Impact of the vadose zone (I_R)			
Range			Rating
Gneiss, Namaqua metamorphic rocks			3
Ventersdorp, Pretoria, Griqualand West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt,			
Waterberg, Soutspansberg, Karoo (northern), Bushveld, Olifantshoek			4
Karoo (southern)			5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini			6
Dolomite			9
Beach sands and Kalahari			10

Table 11-5 DRASTIC weighting factors: Shallow, intergranular aquifer.

Parameter	Range	Rating	Description	Relative weighting	
Depth to water (D) (mbgl)	0 - 5	10	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5	
	5 -15	7			
	15 - 30	3			
	> 30	1			
Net recharge (R) (mm/a)	0-5	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer.	3	
	5-10	3			
	10-50	6			
	50-100	8			
	> 100	9			
Aquifer media (A)	Dolomite	10	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings within an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential.	4	
	Intergranular	8			
	Fractured	6			
	Fractured and weathered	3			
Soil media (S)	Sand	10	Refers to the uppermost weathered portion of the vadose zone characterised by significant biological activity. Soil has a significant impact on the amount of recharge.	2	
	Shrinking and/or aggregated clay	8			
	Loamy sand	6			
	Sandy loam	5			
	Sandy clay	4			
	Silty loam	3			
	Silty clay and clay loam	2			
Topography (T) (Slope %)	0 - 2	10	Refers to the slope of the land surface. It helps a pollutant to runoff or remain on the surface in an area long enough to infiltrate it.	1	
	2 - 6	9			
	6 - 12	5			
	12 - 18	3			
	> 18	1			
Impact of vadose zone (I)	Gneiss, Namaqua metamorphic rocks	3	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5	
	Ventersdorp, Pretoria, Griekwaland West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (Northern), Bushveld, Olifantshoek	4			
	Karoo (Southern)	5			
	Table Mountain, Witteberg Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6			
	Dolomite	9			
	Beach sands and Kalahari	10			
DRASTIC Index (Di) = 105					

Table 11-6 DRASTIC weighting factors: Alluvial, riparian zone aquifer.

Parameter	Range	Rating	Description	Relative weighting			
Depth to water (D) (mbgl)	0 - 5	10	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5			
	5 -15	7					
	15 - 30	3					
	> 30	1					
Net recharge (R) (mm/a)	0-5	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer.	3			
	5-10	3					
	10-50	6					
	50-100	8					
Aquifer media (A)	> 100	9	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings within an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential.	4			
	Dolomite	10					
	Intergranular	8					
	Fractured	6					
Soil media (S)	Fractured and weathered	3	Refers to the uppermost weathered portion of the vadose zone characterised by significant biological activity. Soil has a significant impact on the amount of recharge.	2			
	Sand	10					
	Shrinking and/or aggregated clay	8					
	Loamy sand	6					
	Sandy loam	5					
	Sandy clay	4					
	Silty loam	3					
Silty clay and clay loam	2						
Topography (T) (Slope %)	0 - 2	10	Refers to the slope of the land surface. It helps a pollutant to runoff or remain on the surface in an area long enough to infiltrate it.	1			
	2 - 6	9					
	6 - 12	5					
	12 - 18	3					
	> 18	1					
Impact of vadose zone (I)	Gneiss, Namaqua metamorphic rocks	3	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5			
	Ventersdorp, Pretoria, Griekwaland West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (Northern), Bushveld, Olifantshoek	4					
	Karoo (Southern)	5					
	Table Mountain, Witteberg Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6					
	Dolomite	9					
	Beach sands and Kalahari	10					
	DRASTIC Index (Di) = 154						

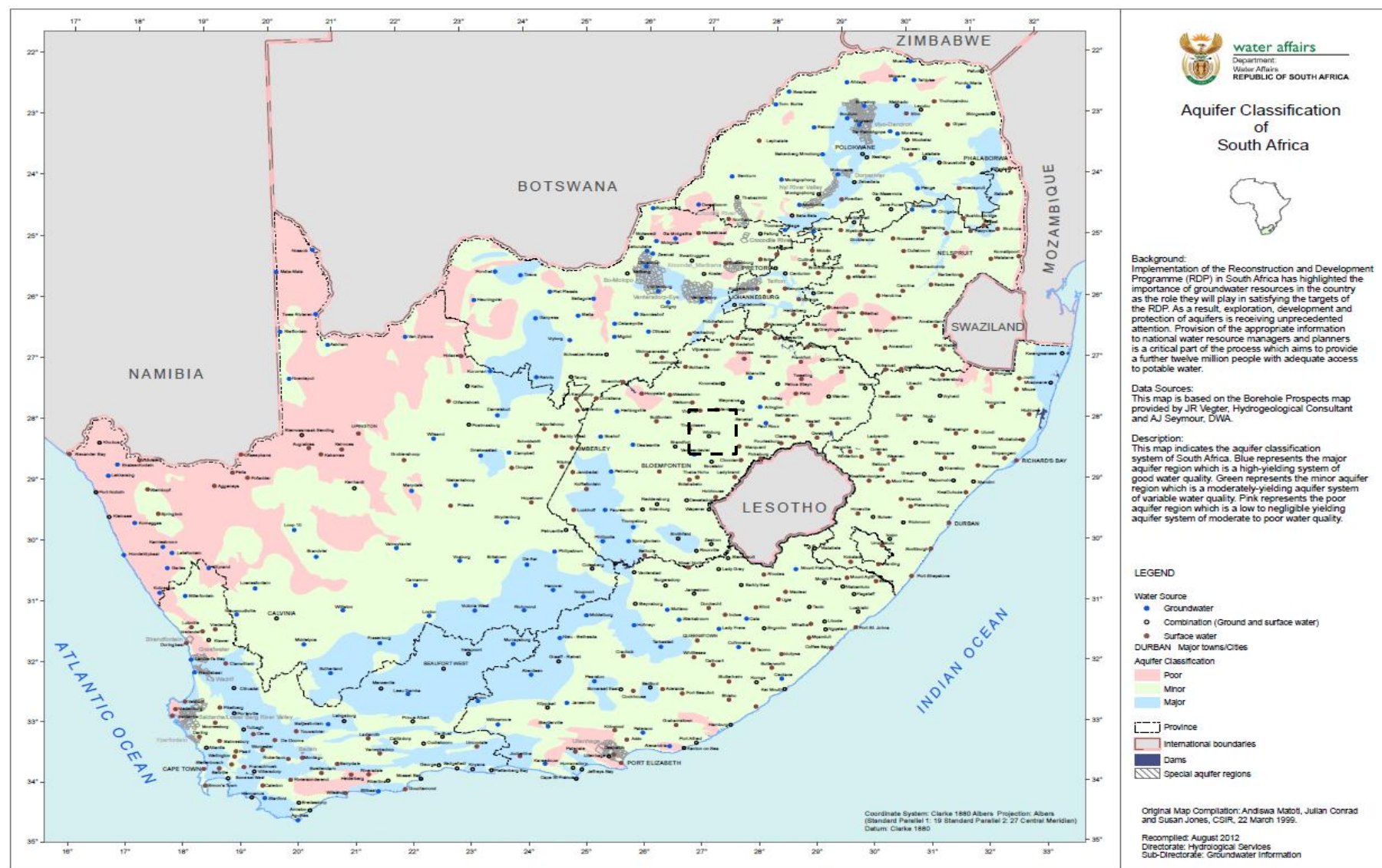


Figure 11-1 Aquifer classification of South Africa (DWS, 2013).

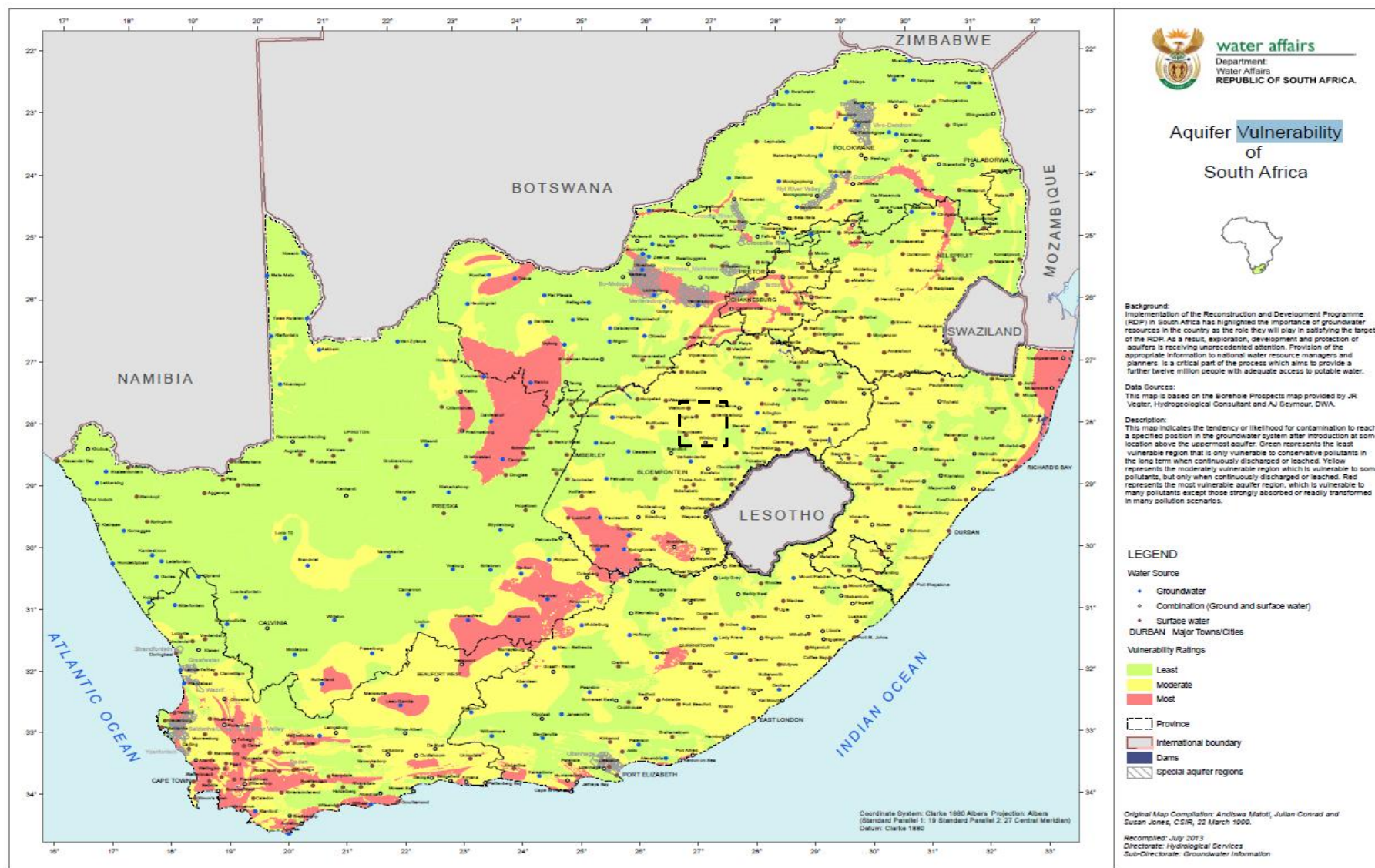


Figure 11-2 Aquifer vulnerability of South Africa (DWS, 2013).

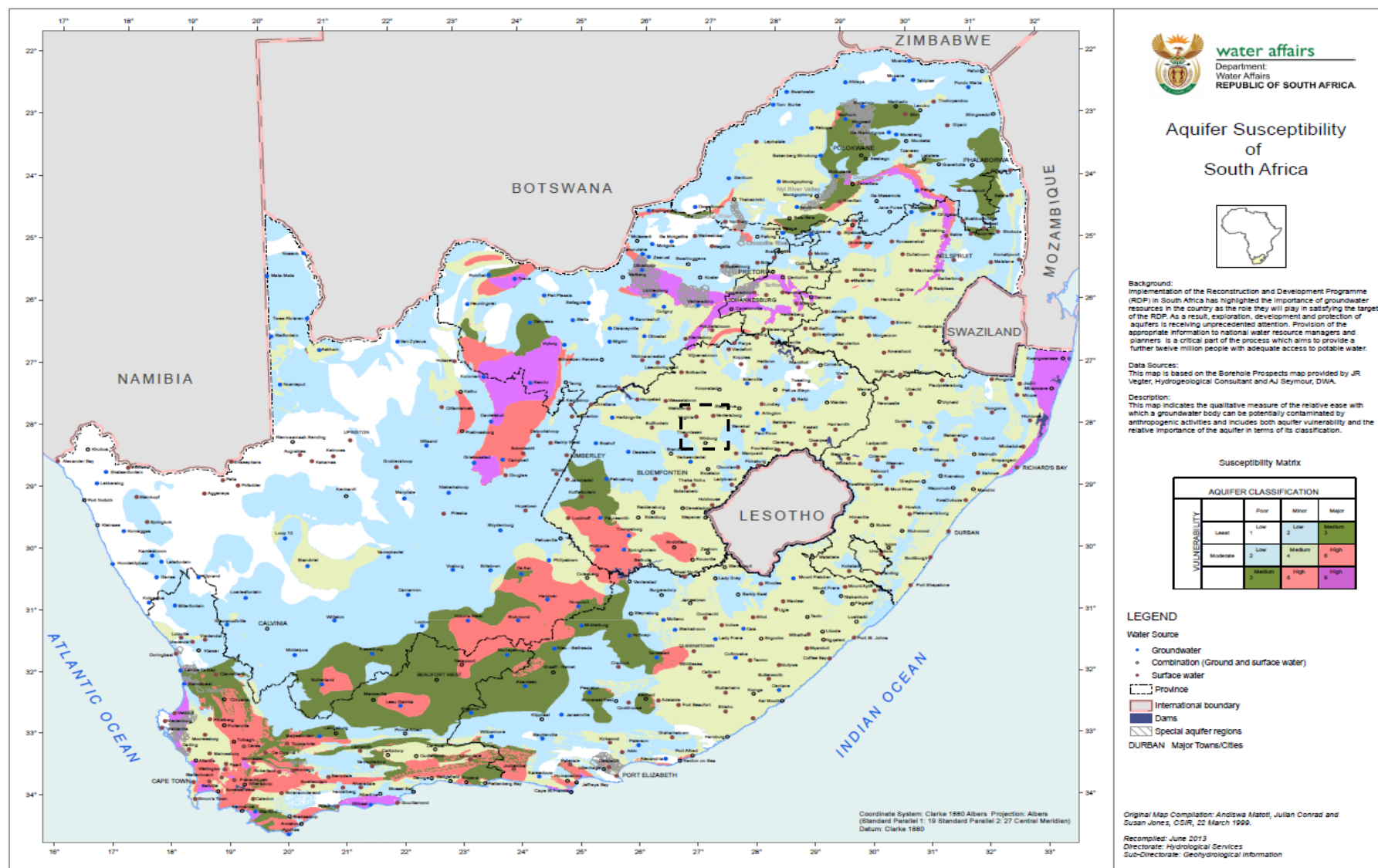


Figure 11-3 Aquifer Susceptibility of South Africa (DWS, 2013).

11.5. Source-pathway-receptor evaluation

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors. The pollution linkage concept relies on the identification of a potential pollutant (i.e. source) on-site which is likely to have the potential to cause harm to a receptor by means of a pathway by which the receptor may be exposed to the contaminant (Figure 11-4).

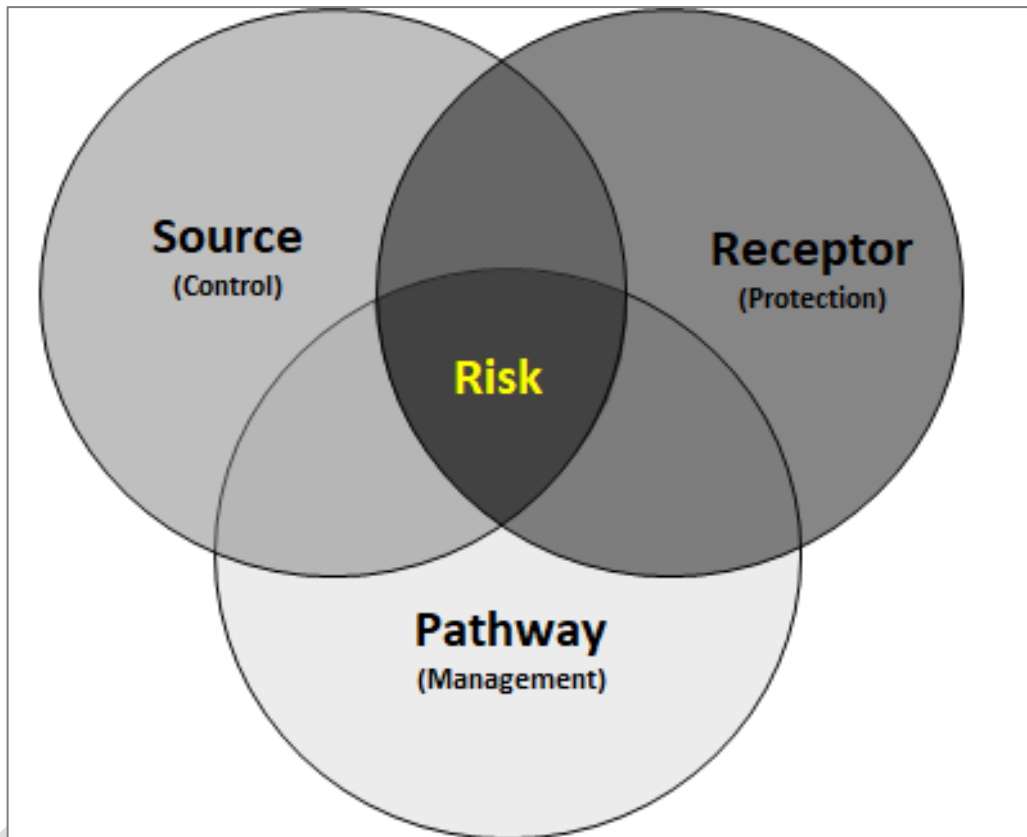


Figure 11-4 Source pathway receptor principle.

11.5.1. Potential sources

The following potential sources have been identified:

- i. Seepage of poor-quality water and leachate of waste products including drilling mud sump(s).
- ii. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- iii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- iv. Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.
- v. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.

11.5.2. Potential pathways

The following aquifer pathways have been identified:

- i. Vertical flow through the unsaturated/vadose zone as well as saturated zone to the underlying intergranular and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.
- ii. Preferential flow-paths include the contact between the depth of weathering and fresh un-weathered rock, fractures, faults, joints and bedding planes. Secondary fractures may also potentially act as transport mechanisms.
- iii. If not adequately sealed and suitably mitigated, gas production wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

11.5.3. Potential receptors

The following receptors were identified:

- i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.
- ii. Down-gradient drainages and streams including associated riparian zone aquifer system(s) and baseflow contribution.
- iii. Private or neighbouring boreholes associated with relevant fracture zones and/or structures(s) if intercepted by the pollution plume migration footprint.

12. HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. Data gathered during the desk study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system. **Figure 12-1** depicts a generalised hydrogeological conceptual model for similar environments and illustrates 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. **Figure 12-2** depicts a west- east cross section of the study area for the pre-operational scenario while **Figure 12-3** indicates the same cross section for the post-operational scenario with relevant groundwater information included (Refer to **Figure 13-2** for spatial reference).

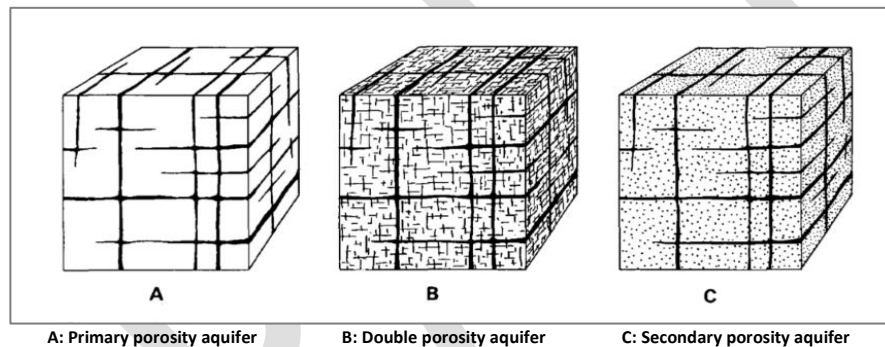


Figure 12-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

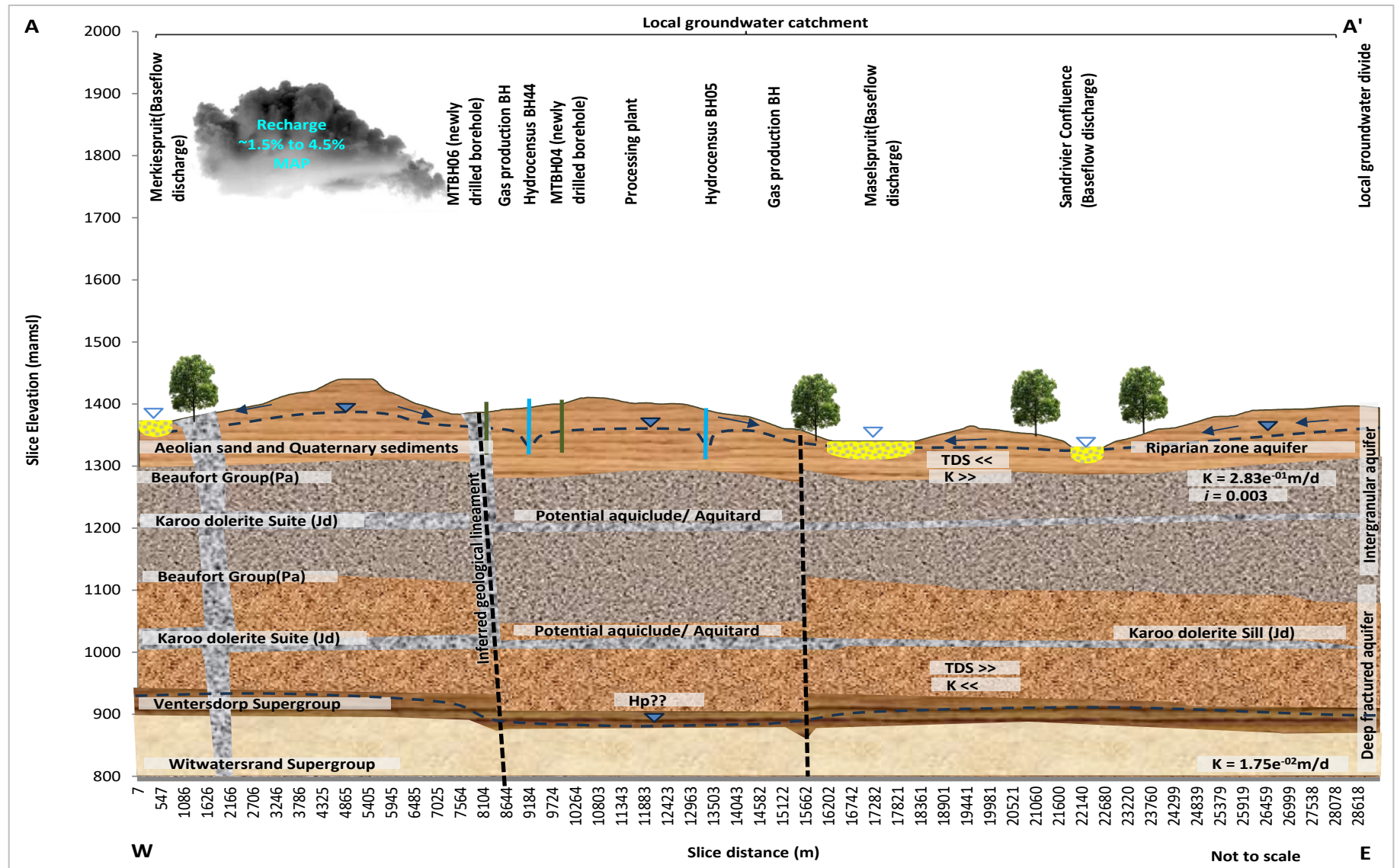


Figure 12-2 Hydrogeological conceptual model: West- East cross section (A-A') (Pre-operational) (Refer to Figure 13-2).

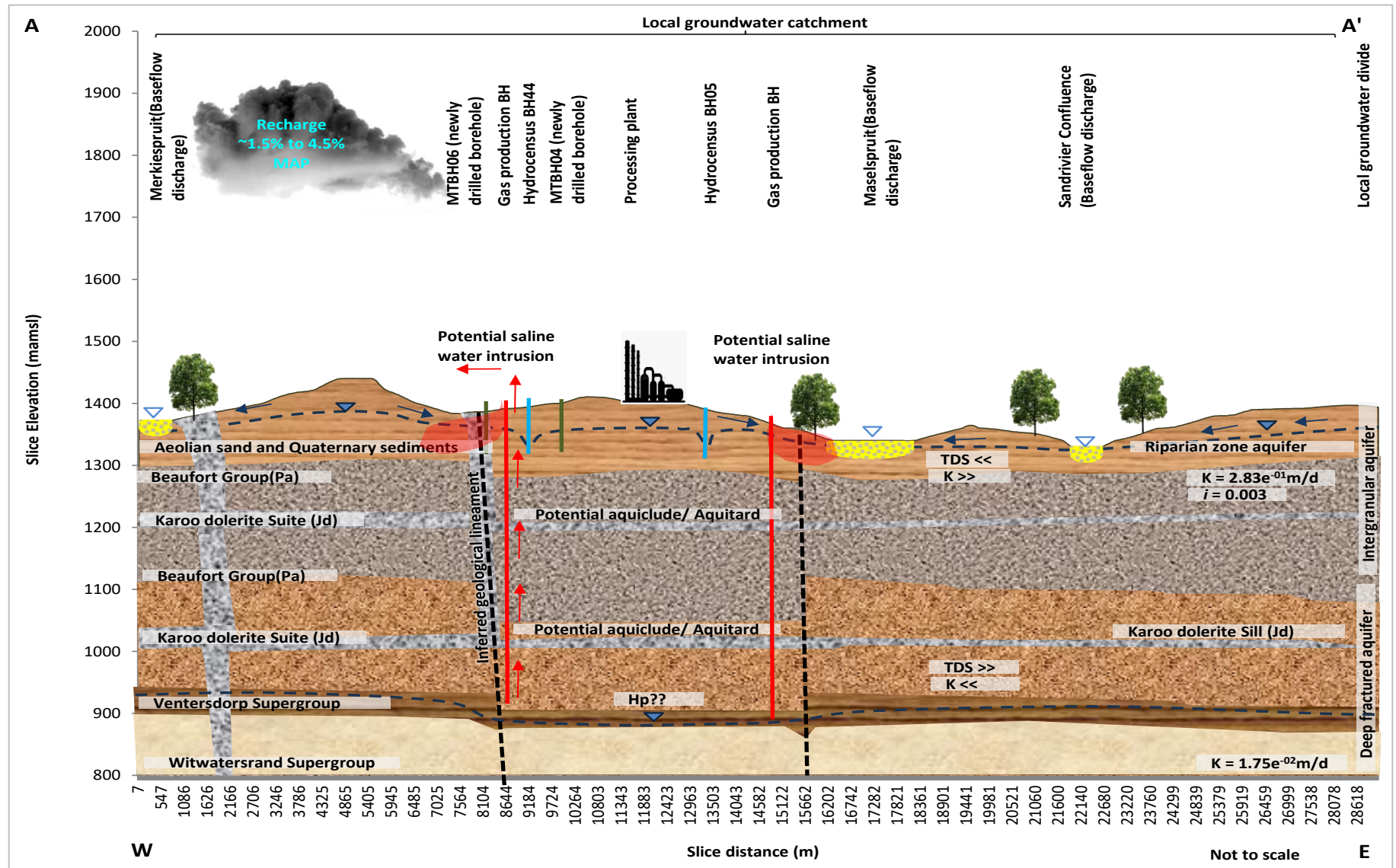


Figure 12-3 Hydrogeological conceptual model: South- North cross section (A'-A') (Post-operational) (Refer to Figure 13-2).

13. NUMERICAL GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

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

13.1. Approach to modelling

The typical workflow and modelling approach employed is summarised in **Figure 13-1** below and encompass a conceptualisation phase, calibration phase as well as a prediction phase.

It should be noted that modelling scenarios will be based on the worst-case approach to identify the most severe potential outcomes, ensuring preparedness for low-likelihood but high-impact events. A worst-case scenario is a concept in risk management wherein the modeller, considers the most severe possible outcome that can reasonably be projected to occur in a given situation and is a common form of strategic planning. The “worst case” scenario approach is applied to determine the maximum potential and in particular useful when the modelling is associated with high uncertainties (Matthias, K (2011); Haimes, Y (2008)).

Thus, although there is some evidence that the deeper, saline-water bearing aquifer, is depressurised, with gradient-driven solute transport unlikely, migration of saline groundwater, along with a poorly constructed and jeopardised well have been simulated to serve as a worst-case scenario in order to formulate adequate mitigation and management measures.

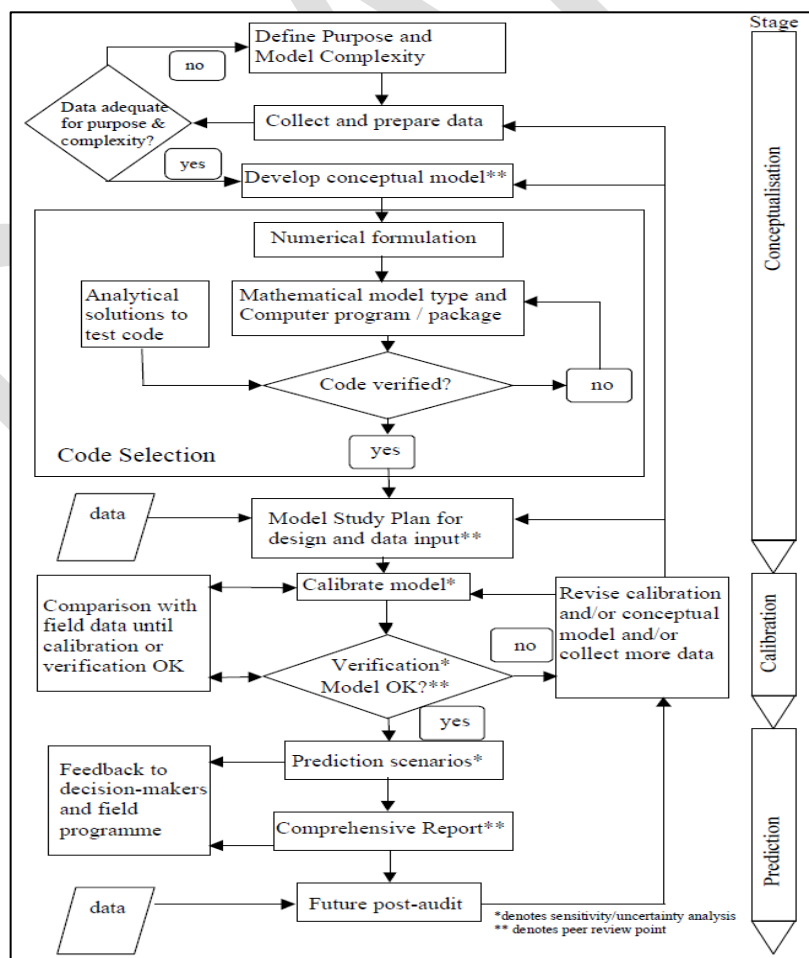


Figure 13-1 Workflow numerical groundwater flow model development.

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

Equation 13-1 Simplified groundwater balance.

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

where:

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

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

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

The piezometric gradient, which can be measured from site characterisation 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 $\text{m}^3/\text{m}^2/\text{d}$) 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).

13.2. 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.

13.3. Model development

13.3.1. Model domain

A model grid was created with global origin X: -2624.58[m] and Y: -3126301.40[m] using triangular prism type of elements. The model has a width of 32630.4[m], height of 31998.1[m], depth of 769.61[m] and spans an area of $6.48 \times 10^8 \text{m}^2$ with a volume of $\sim 4.18 \times 10^{11} \text{m}^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e., discharge zones and no-flow zones (**Figure 13-2**). **Figure 13-3** indicates the model super mesh view from which the finite element mesh was generated. The Supermesh in FEFLOW forms the framework for the generation of a finite-element mesh. It contains all the basic geometrical information the mesh generation algorithm needs. While in the very simplest case the Supermesh only defines the outline of the model area, i.e., consists of one single polygon, the concept offers many more possibilities: Supermeshes can be composed of an arbitrary number of polygons, lines and points in 2D and for 3D layer-based meshing, or solids, lines and points when working with unstructured mesh geometry in 3D. Their respective features and purposes are described in the following sections. **Figure 13-4** and **Figure 13-5** shows the model finite element mesh (FEM) construction. **Figure 13-6** and **Figure 13-7** depicts a respective cross section on which the hydrogeological conceptual model is based on.

13.3.2. Model construction

The model was constructed from FEM and consist of eight layers i.e., nine slices, 496 559 triangular prism elements per layer, a total of 3 972 472 elements for the model domain, with 248 583 nodes per slice a total of 2 237 247 nodes for the model domain. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 1.0%.
- Interior holes: 0.
- Obtuse angled triangles: 0.30% > 120°, 4.60% > 90°.

13.3.3. Model layers

The groundwater model consists of eight layers (nine slices), 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 (**Table 13-1**):

- i. **Layer 01:** A shallow quaternary and recent types of sediments (unconfined) are characteristically a primary porosity aquifer associated with alluvium material deposited in flood plains of the main rivers traversing the study area (Average thickness = ~5.0m).
- ii. **Layer 02:** A shallow, intergranular aquifer (unconfined to semi-confined) occurring in the transitional soil and weathered bedrock formations of the Karoo Supergroup (Mudstone of the Adelaide Sbgrp, Beaufort Grp) underlain by more consolidated bedrock (Average thickness = ~50.0m).
- iii. **Layer 03:** A deeper fractured aquifer (semi-confined to confined) where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock of the Karoo Supergroup (Siltstone of the Adelaide Sbgrp, Beaufort Grp) (Average thickness = ~105.0m).
- iv. **Layer 04:** Karoo Dolerite Suite (Sill) which may potentially act as an aquitard (Average thickness = 25.0m).
- v. **Layer 05:** A deep fractured aquifer (confined) where groundwater flow will be dictated by transmissive fracture zones that occur in the competent host rock of the Karoo Supergroup (Shale of the Adelaide Sbgrp, Beaufort Grp)(Average thickness = ~200.0m).
- vi. **Layer 06:** Karoo Dolerite Suite (Sill) which may potentially act as an aquitard (Average thickness = 25.0m).
- vii. **Layer 07:** A deep fractured aquifer (confined) where groundwater flow will be dictated by transmissive fracture zones that occur in the competent host rock of the Ventersdorp Supergroup lavas (Average thickness = ~50.0m).
- viii. **Layer 08:** A deep fractured aquifer (confined) where groundwater flow will be dictated by transmissive fracture zones that occur in the competent host rock of the Witwatersrand Supergroup quartzites (Average thickness = ~120.0m).

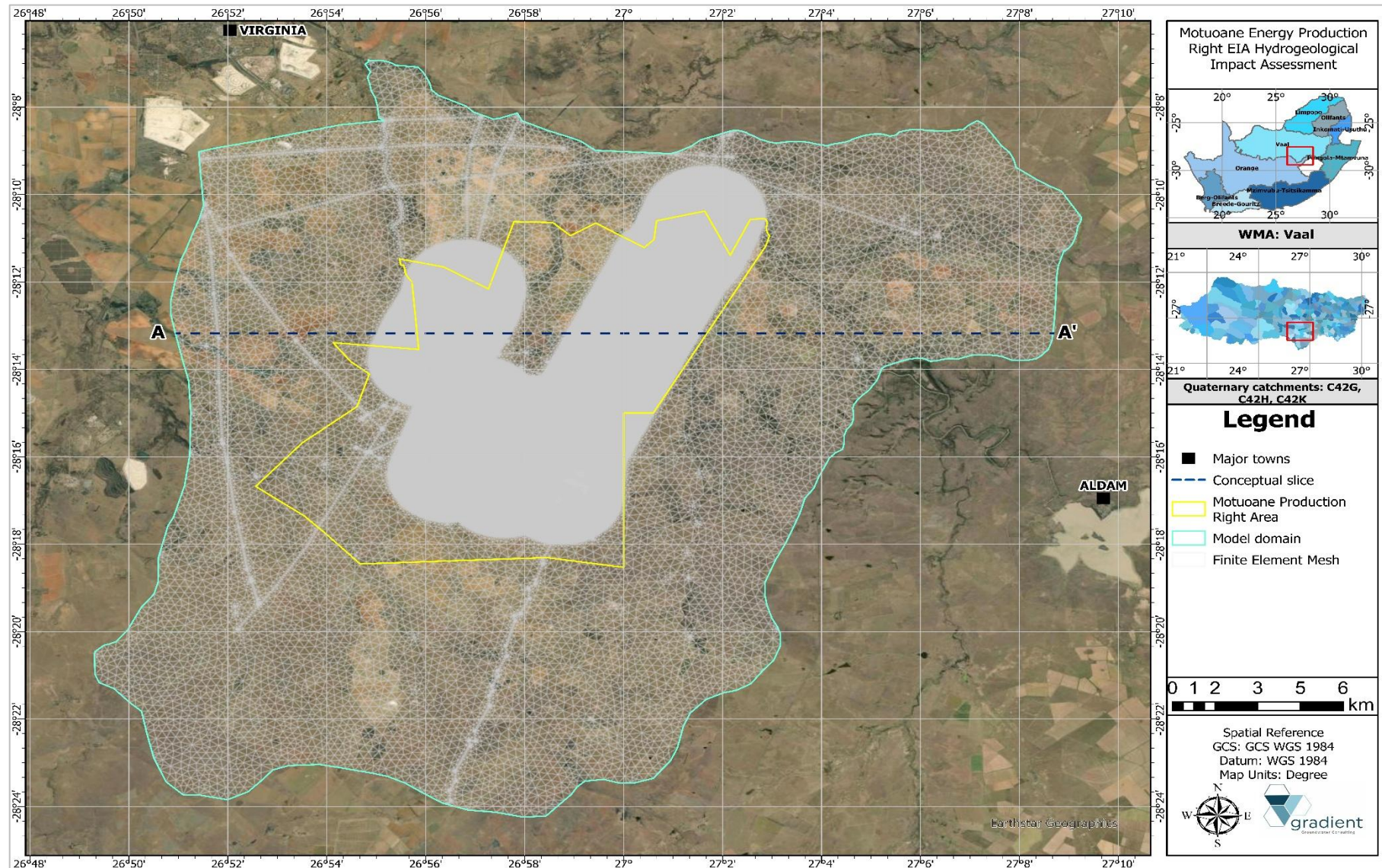


Figure 13-2 Model domain: Aerial extent.

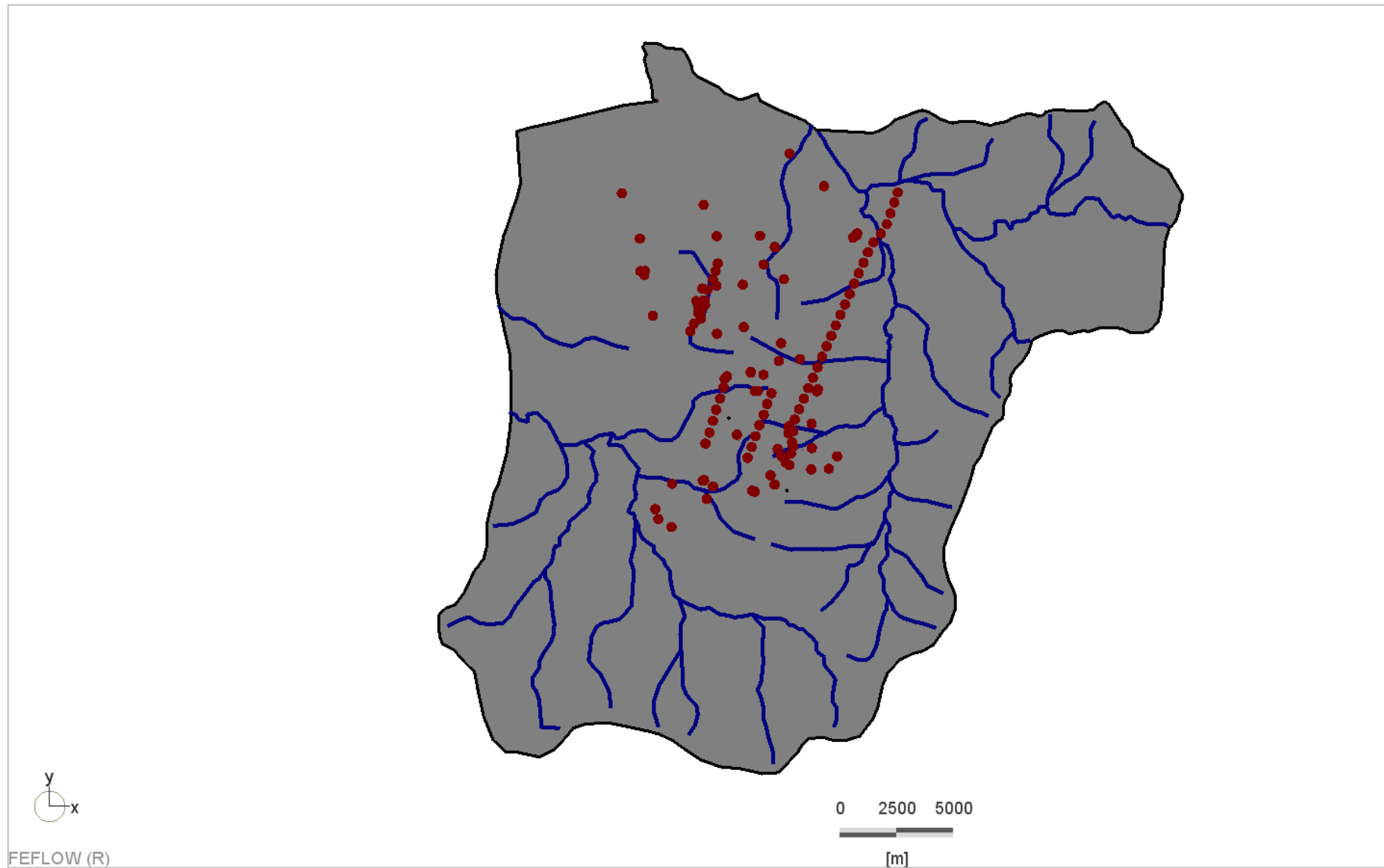


Figure 13-3 Model domain: Supermesh view.

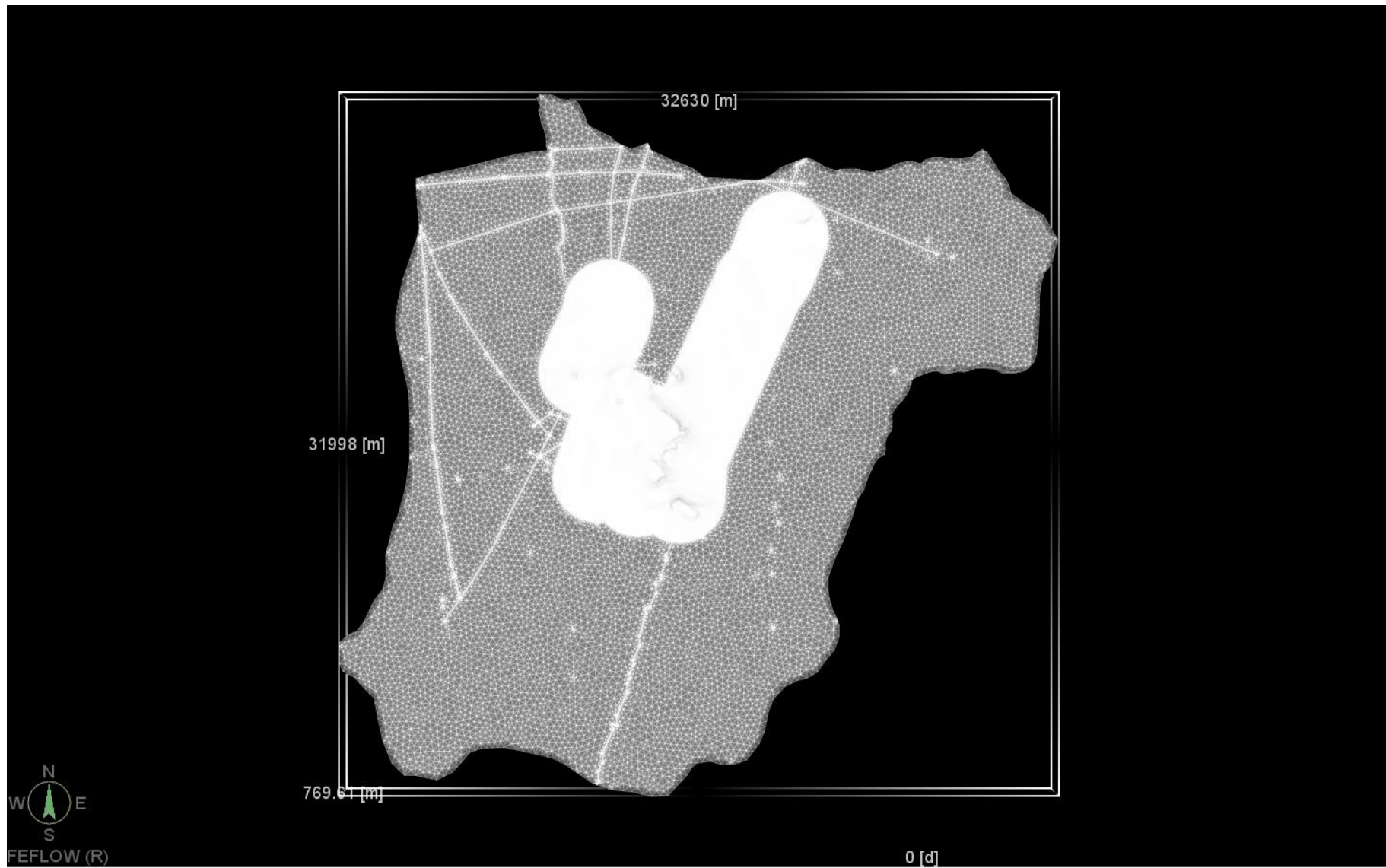


Figure 13-4 Model domain 3-D FEM mesh in a plan view depicting a plan-view orientation .

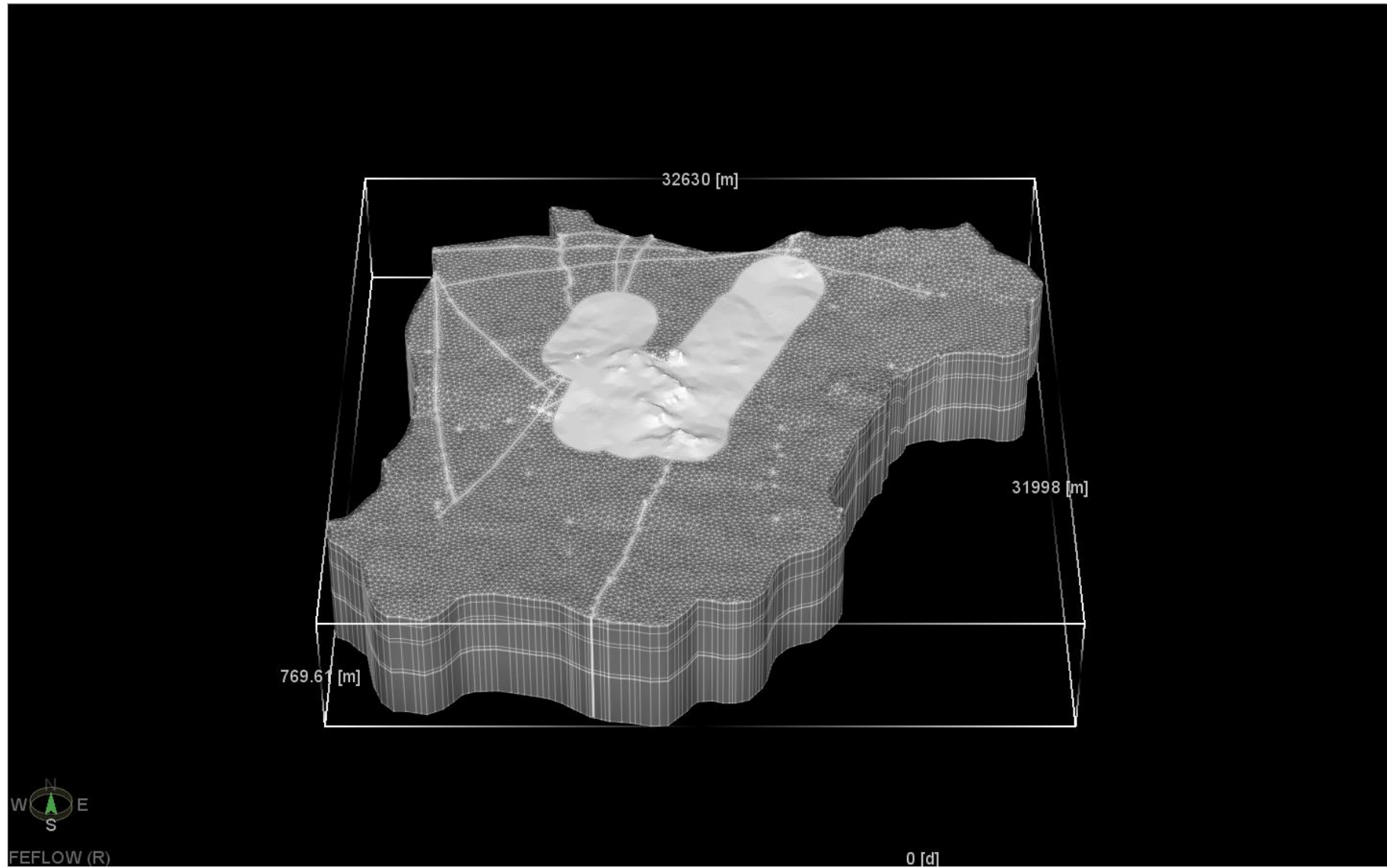


Figure 13-5 Model domain 3-D FEM mesh depicting a plan view and cross sectional view in a west-east orientation.

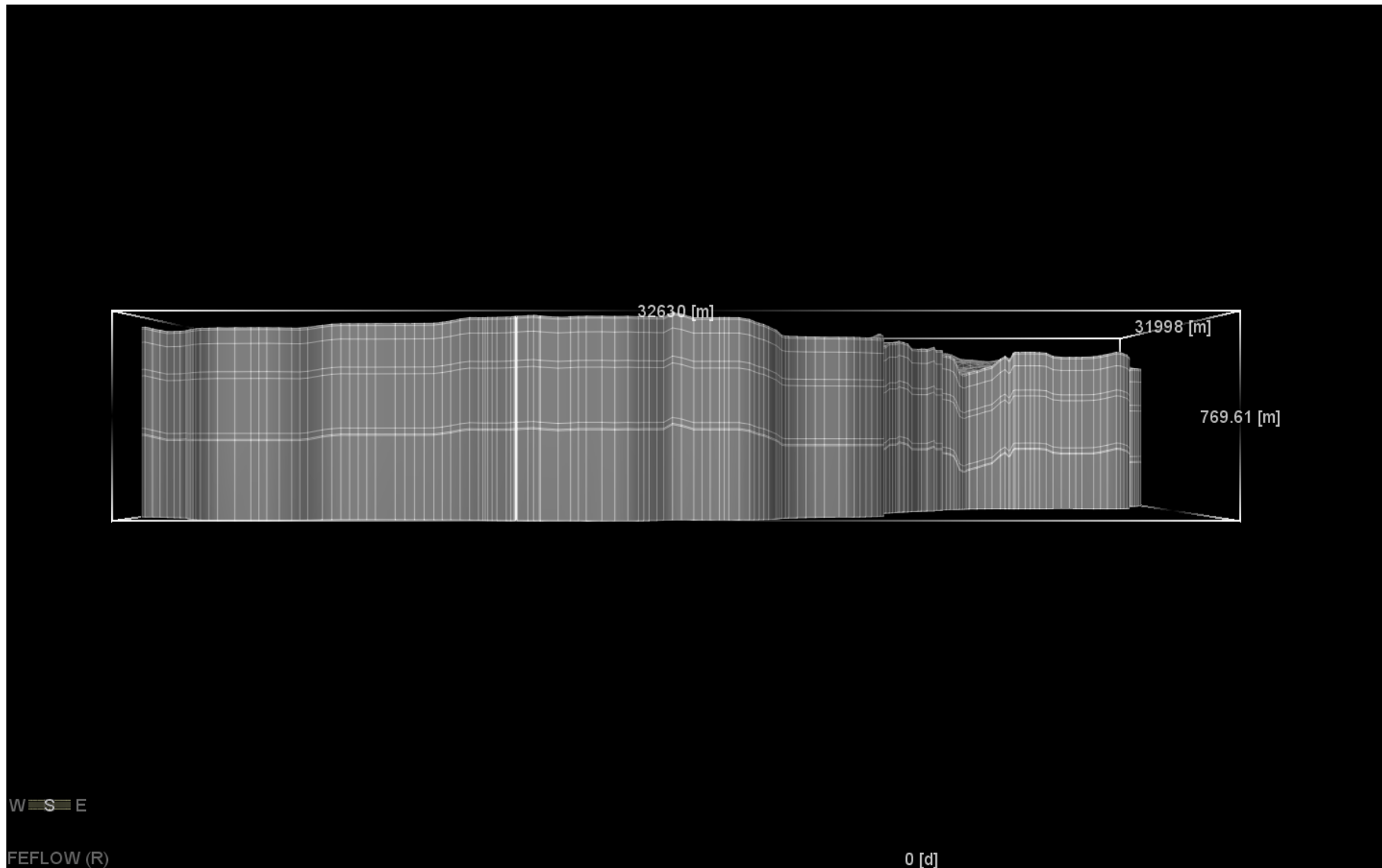


Figure 13-6 Model domain 3-D FEM mesh view depicting a cross sectional view in a south-north orientation.

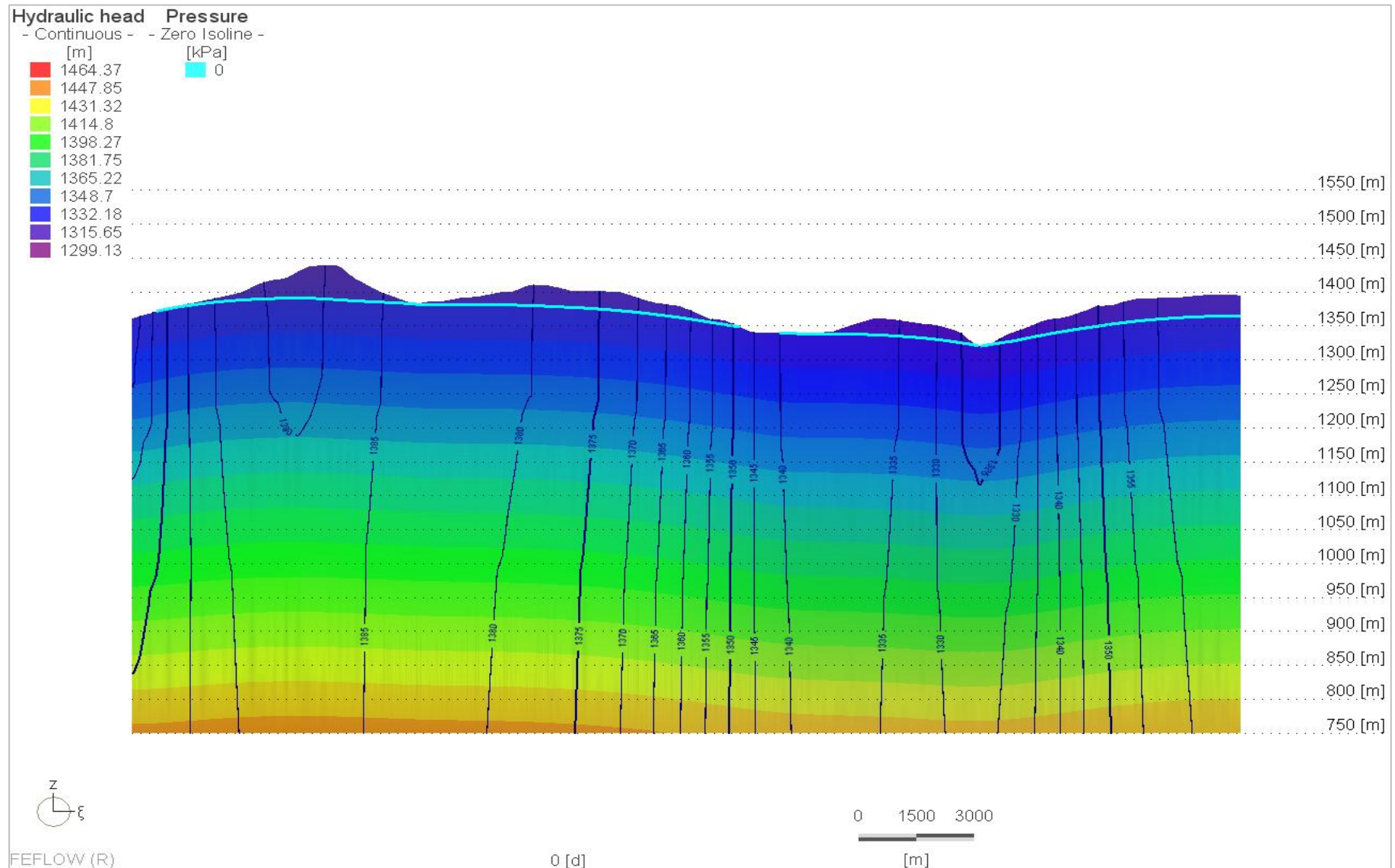


Figure 13-7 Model domain 3-D FEM mesh view (cross sectional view west-east orientation of conceptual slice A-A').

13.3.4. Boundary conditions

For the purposes of this model, it is assumed that the lower perimeter of the model domain i.e., competent Witwatersrand Supergroup quartzite formations are assumed to generally be impermeable and serves to isolate the weathered and fractured aquifer systems from potentially deeper aquifer units. Accordingly, this boundary is represented numerically as a “no-flow” boundary condition and was assigned as such. Topographical high perimeters (groundwater divides) were assigned as no-flow boundaries while major rivers i.e., Sandrivier, Maselspruit, Schoemanspruit and Doringrivier were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain¹². **Figure 13-12** indicates different boundary conditions assigned within the model domain.

13.4. Model hydraulic properties

The following sections provide a brief overview of the model hydraulic parameters assigned as part of the model development and calibration. It should be noted that the hydraulic parameter values assigned were directed by the site characterisation and aquifer tests phase performed (Refer to Section 8.3) as well as literature values published for similar hydrogeological environments. The model calibration was also used to guide refinement of aquifer parameter values¹³ as depicted in **Figure 13-13**. **Table 13-1** provides a summary of aquifer hydraulic parameter values per layer.

13.4.1. Hydraulic Conductivity

The average hydraulic conductivity (K) value assigned for the shallow, intergranular aquifer is calculated at $2.83\text{E}^{-01}\text{m/d}$ ranging from $5.00\text{E}^{-01}\text{m/d}$ for Quaternary deposits, $2.50\text{E}^{-01}\text{m/d}$ for weathered Beaufort Group, Adelaide Subgroup formations to $1.00\text{E}^{-01}\text{m/d}$ for the more competent Karoo dolerite formations. Loose alluvial deposit sediments of the riparian zone aquifer associated with local drainages has been assigned a hydraulic conductivity value of $2.00\text{E}^{00}\text{m/d}$ for while a value of $1.00\text{E}^{00}\text{m/d}$ has been applied for the more permeable geological lineaments¹⁴ traversing the study area. The average hydraulic conductivity for the deeper, fractured aquifer is calculated at $1.75\text{E}^{-02}\text{m/d}$. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in **Figure 13-8**. 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.

¹² Refer to “gaining stream” assumption.

¹³ 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.

¹⁴ Due to the risk involved of local and regional geological lineaments acting as preferred pathways for groundwater flow and contaminant transport mechanisms, the model explicitly simulated geological structures (fault zones and dyke contacts) as “permeable linear zones”. These zones were assigned higher hydraulic conductivity values compared to the matrix rock to simulate preferential flow.

13.4.2. Sources and sinks

The primary source to groundwater is through recharge. An approximation of recharge for the model domain is estimated at between ~8.0mm/a assigned for denser Karoo dolerite formations, ~12.0mm/a assigned for Beaufort Group, Adelaide Subgroup formations, ~18.0mm/a assigned for permeable geological lineaments traversing the study area, 20.0mm/a assigned for Quaternary deposits and 25.0mm/a assigned for loose alluvial deposit sediments associated with local drainages as indicated in **Figure 13-9** below. Major sinks from the model domain include groundwater abstraction from privately owned and community boreholes as well as groundwater discharge to baseflow.

13.4.3. Storativity and specific storage

Specific storage values were assigned per hydrostratigraphical units and ranges between 1.00E^{-05} for denser Karoo dolerite formations to 3.00E^{-02} for loose alluvial deposit sediments associated with local drainages as indicated in **Figure 13-10** below.

13.4.4. Porosity

A porosity value ranging from 10.0% (loose alluvial deposits), 7.50% (permeable geological lineaments), 5.0% (Quaternary deposits), 3.0% (Weathered Beaufort Group, Adelaide Subgroup formations) to 0.50% (denser Karoo matrix of the deeper aquifer) was assigned per model layer as shown in **Figure 13-11** below.

13.4.5. Longitudinal and Transversal Dispersivities

A longitudinal dispersivity value of 5.0m 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 0.5m was selected for this parameter during the simulations.

13.4.6. Longitudinal and Transversal Dispersivities

A longitudinal dispersivity value of 5.0m 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 0.5m was selected for this parameter during the simulations.

13.4.7. Molecular Diffusion

Under normal groundwater flow conditions, dispersion usually overwhelms diffusion. However, diffusion start playing a role in solute migration when the groundwater velocity is very low. FEFLOW uses an effective diffusion coefficient (Default value: $10^{-9} \text{ m}^2/\text{s}$), which accounts for the porous medium by applying the following formula:

Equation 13-2 Diffusion coefficient.

where:

θ = porosity

τ = tortuosity (≤ 1)

D_{free} = free-water diffusion coefficient

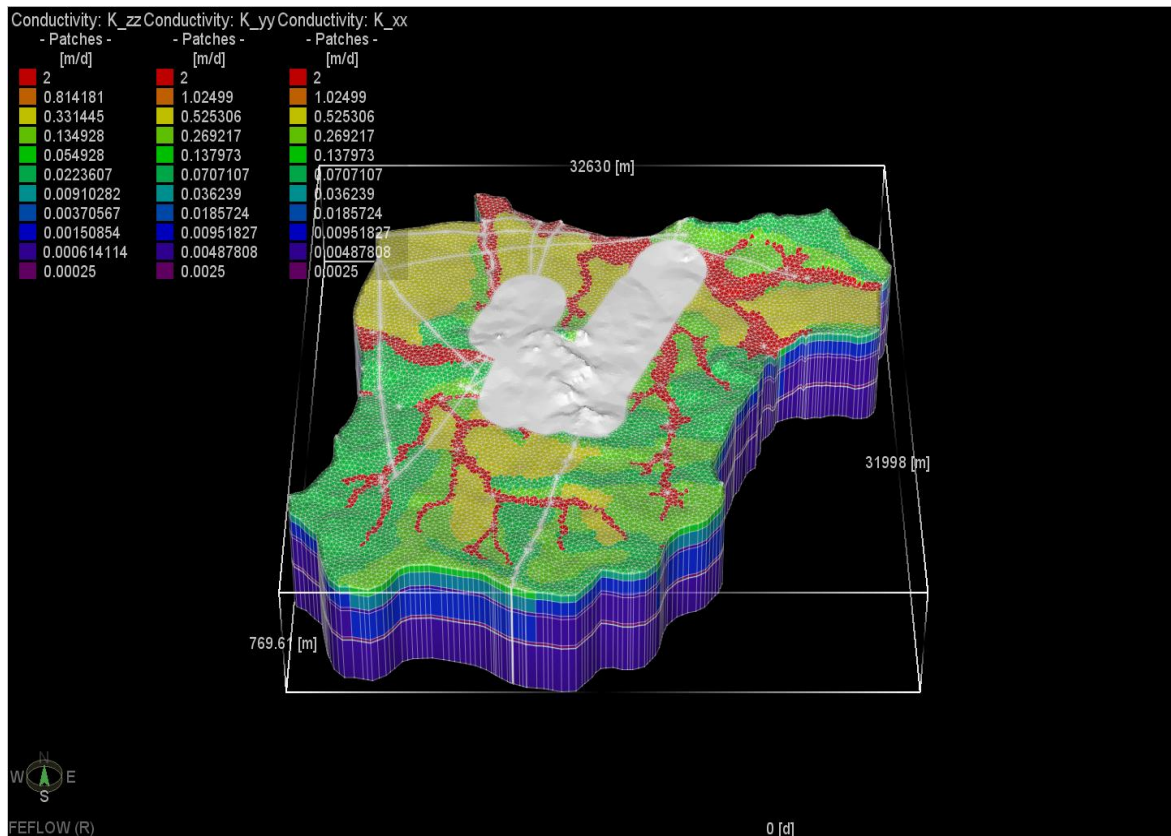


Figure 13-8 Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.

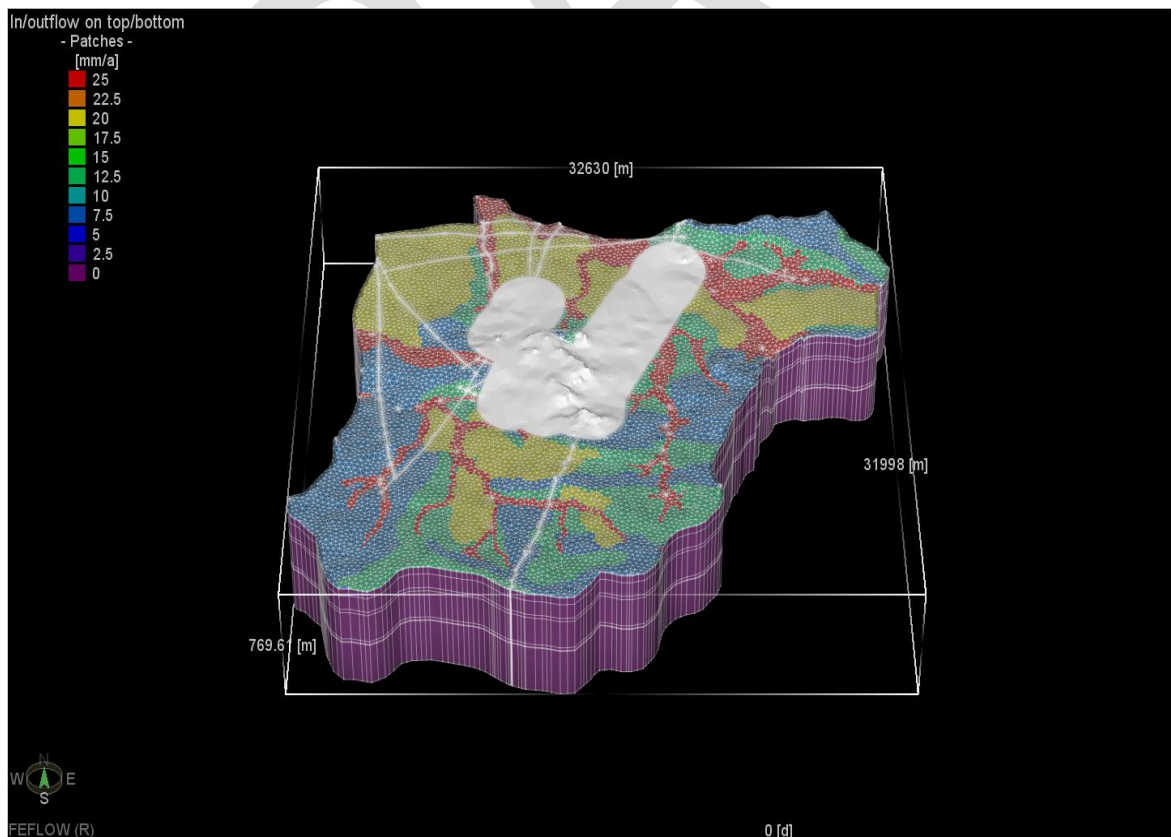


Figure 13-9 Model development: Numerical groundwater flow model: Recharge distribution.

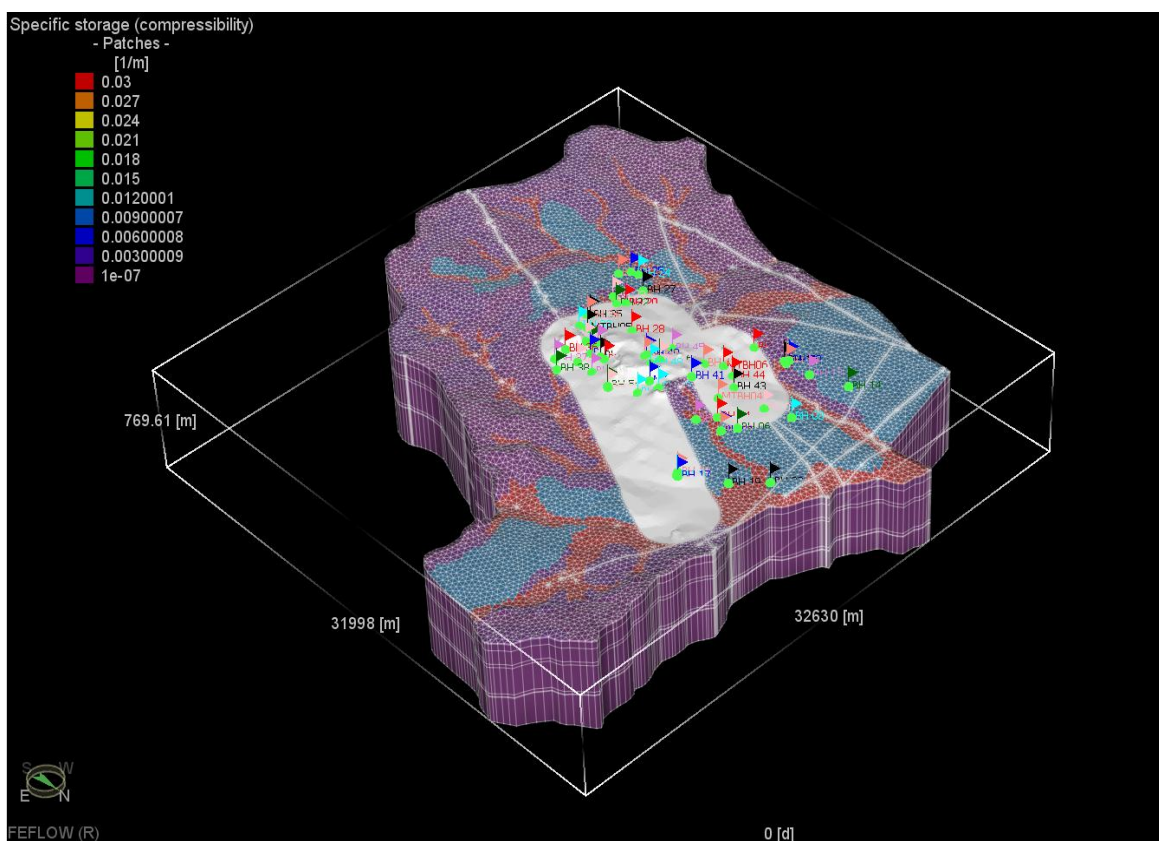


Figure 13-10 Model development: Numerical groundwater flow model: Specific storage distribution.

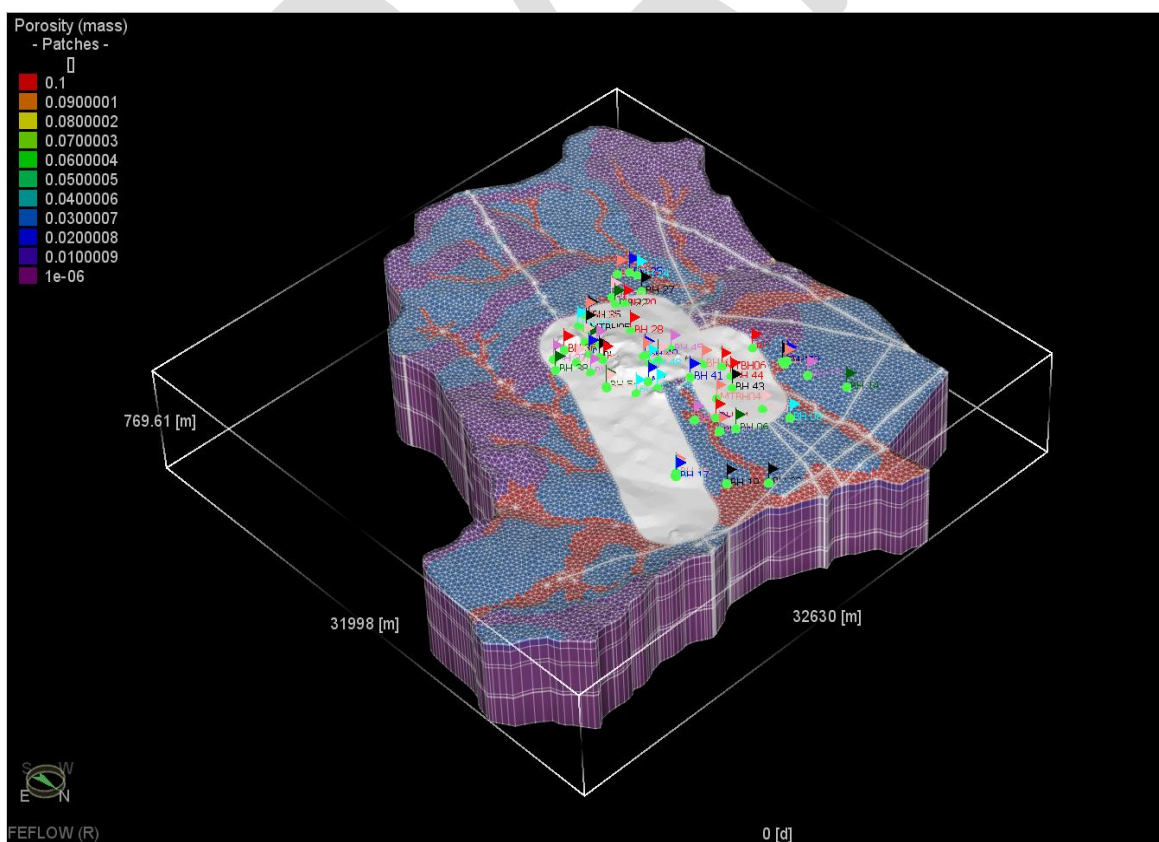


Figure 13-11 Model development: Numerical groundwater flow model: Porosity distribution.

Table 13-1 Model set-up: Hydraulic Parameters.

Model Layer	Hydrostratigraphic unit	Approximate layer thickness (m)	Hydraulic Conductivity (K)		Recharge (Re) In/Outflow on top/bottom (mm/a)	Specific storage (Sc) Sc (1/m)	Porosity (n)
			K _{x,y} 1:1 (m/d)	K _z 1:10 (m/d)			
Layer 01	Alluvial deposits	5.00	2.00E+00	2.00E+00	25.0	3.00E-02	1.00E-01
	Quaternary deposits (Qs)		5.00E-01	5.00E-01	20.0	1.00E-02	5.00E-02
	Adelaide Sbgrp, Beaufort Grp (Pa)		2.50E-01	2.50E-02	12.0	1.00E-03	3.00E-02
	Karoo Dolerite Suite (Jd)		1.00E-01	1.00E-02	8.0	1.00E-05	5.00E-03
	Geological lineaments		1.00E+00	1.00E-01	18.0	5.00E-03	7.50E-02
Layer 02	Mudstone of the Adelaide Sbgrp, Beaufort Grp (Pa)	50.00	1.25E-01	1.25E-02	0.0	2.50E-04	7.50E-03
	Karoo Dolerite Suite (Jd)		5.00E-02	5.00E-03		2.50E-06	1.25E-03
	Geological lineaments		5.00E-01	5.00E-02		1.25E-03	1.88E-02
Layer 03	Siltstone of the Adelaide Sbgrp, Beaufort Grp (Pa)	105.00	2.50E-02	2.50E-03	0.0	5.00E-05	1.50E-03
	Karoo Dolerite Suite (Jd)		1.00E-02	1.00E-03		5.00E-07	2.50E-04
	Geological lineaments		1.00E-01	1.00E-02		2.50E-04	3.75E-03
Layer 04	Karoo Dolerite Suite (Sill) (Jd)	25.00	5.00E-03	5.00E-04	0.0	1.00E-05	1.00E-04
Layer 05	Shale of the Adelaide Sbgrp, Beaufort Grp (Pa)	200.00	1.25E-02	1.25E-03	0.0	2.50E-05	7.50E-04
	Karoo Dolerite Suite (Jd)		5.00E-03	5.00E-04		2.50E-07	1.25E-04
	Geological lineaments		5.00E-02	5.00E-03		1.25E-04	1.88E-03
Layer 06	Karoo Dolerite Suite (Sill) (Jd)	25.00	2.50E-03	2.50E-04	0.0	1.00E-05	1.00E-04
Layer 07	Ventersdorp Supergroup Lava	50.00	5.00E-02	5.00E-03	0.0	1.00E-06	1.00E-05
Layer 08	Witwatersrand Supergroup Quartzite	120.00	5.00E-03	5.00E-04	0.0	1.00E-07	1.00E-06

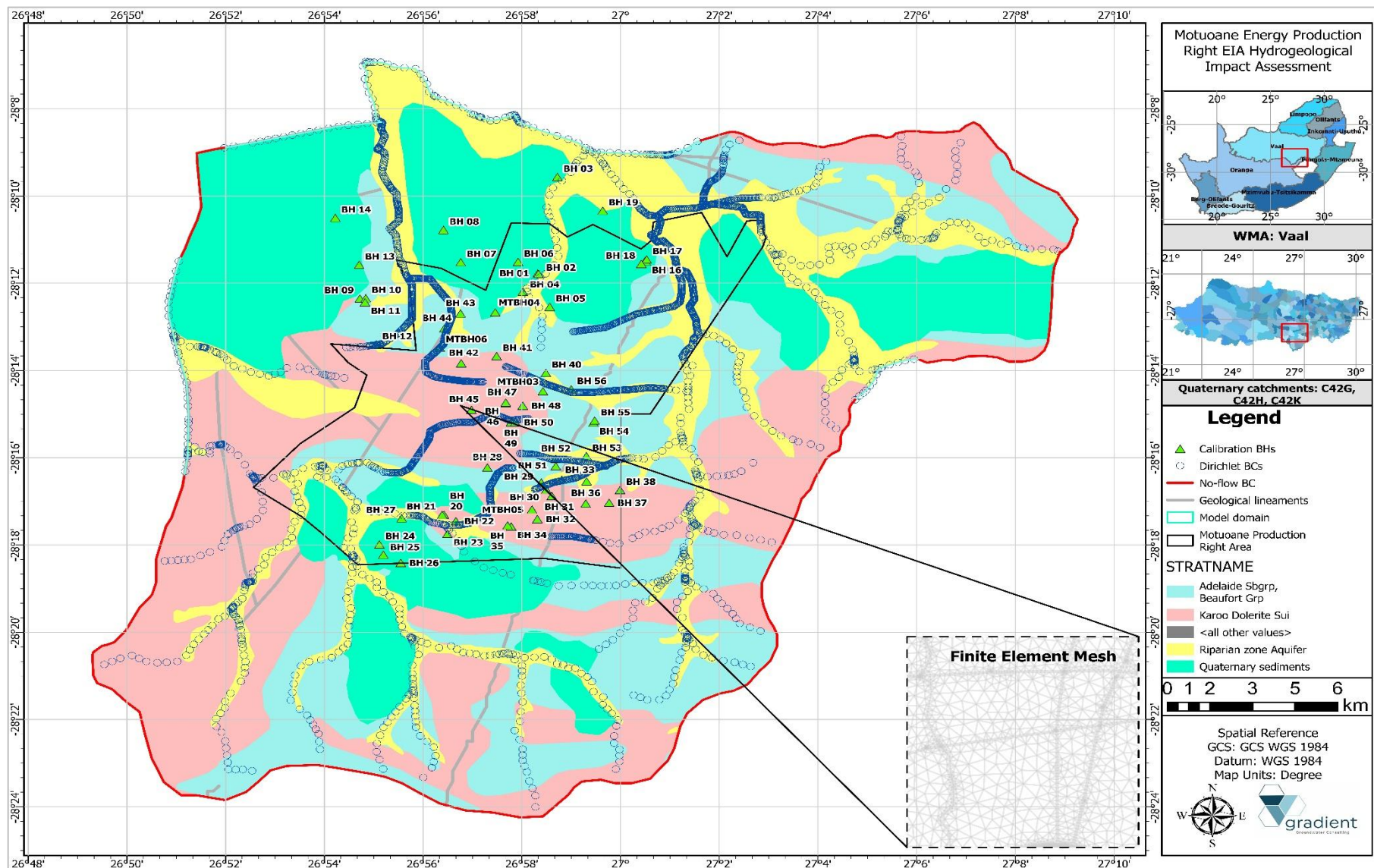


Figure 13-12 Hydrostratigraphic units and model boundary conditions.

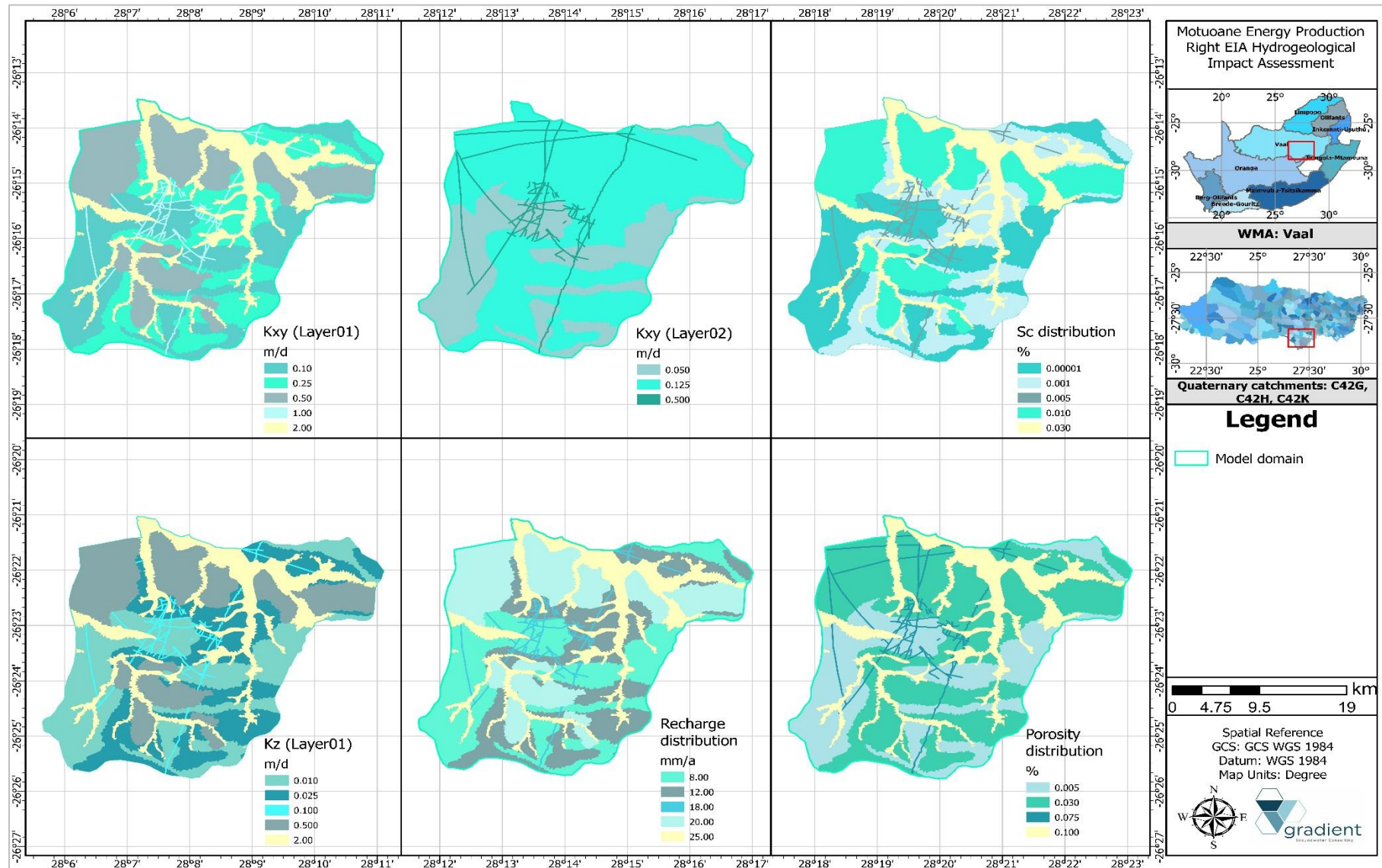


Figure 13-13 Numerical groundwater flow model: Hydraulic properties.

13.5. Model calibration

13.5.1. Steady state calibration (∞)

A steady state groundwater flow model was developed to simulate equilibrium conditions, i.e., pre-development 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 storage coefficient. 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 13-2**. Observed groundwater levels were plotted against measured water levels and a correlation of ~ 0.98 was obtained (refer to **Figure 13-14**, **Figure 13-15** and **Figure 13-16**) while **Figure 13-17** indicate calibration error margin per borehole observation locality. **Figure 13-18** and **Figure 13-19** 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): -1.16m.
- ii. Mean Absolute Error (MAE): 5.29m.
- iii. Normalised Root Mean Square Deviation (NRMSE): 6.18% i.e., represents the deviation between observed and calibration water levels across the model domain.

Table 13-2 Steady State Model Calibration – Statistical Summary.

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
BH 01	1369.06	3.48	1365.58	1366.54	-0.96	0.96	0.92
BH 02	1368.34	2.58	1365.76	1366.37	-0.61	0.61	0.37
BH 03	1324.83	0.16	1324.67	1322.75	1.92	1.92	3.71
BH 04	1380.02	3.13	1376.89	1374.92	1.97	1.97	3.87
BH 06	1375.53	1.52	1374.01	1366.78	7.23	7.23	52.29
BH 07	1380.00	4.70	1375.30	1369.18	6.13	6.13	37.52
BH 09	1397.08	4.71	1392.37	1384.80	7.57	7.57	57.35
BH 13	1386.12	12.25	1373.87	1378.33	-4.46	4.46	19.93
BH 14	1377.42	10.77	1366.65	1372.29	-5.64	5.64	31.82
BH 15	1340.47	10.39	1330.08	1333.77	-3.69	3.69	13.64
BH 16	1340.46	5.04	1335.42	1333.67	1.75	1.75	3.06
BH 18	1342.23	11.01	1331.22	1336.52	-5.30	5.30	28.07
BH 19	1328.26	2.70	1325.56	1330.01	-4.45	4.45	19.82
BH 22	1414.26	9.43	1404.83	1407.98	-3.14	3.14	9.89
BH 23	1416.83	4.78	1412.05	1413.88	-1.83	1.83	3.36
BH 24	1399.24	9.37	1389.87	1395.43	-5.56	5.56	30.92
BH 27	1399.45	9.19	1390.26	1397.22	-6.95	6.95	48.37
BH 28	1436.33	15.67	1420.66	1408.67	11.99	11.99	143.76
BH 29	1415.41	27.59	1387.82	1400.79	-12.97	12.97	168.12
BH 32	1441.41	13.69	1427.72	1415.25	12.48	12.48	155.63
BH 34	1436.74	9.59	1427.15	1420.29	6.86	6.86	47.03
BH 35	1434.40	25.70	1408.70	1420.13	-11.43	11.43	130.53
BH 44	1389.94	9.53	1380.41	1385.20	-4.79	4.79	22.91
BH 52	1400.14	10.63	1389.51	1392.55	-3.04	3.04	9.27
BH 53	1386.13	11.68	1374.45	1382.73	-8.28	8.28	68.53
BH 56	1388.98	10.36	1378.62	1382.67	-4.05	4.05	16.43
MTBH04	1394.66	12.88	1381.78	1381.90	-0.12	0.12	0.01
MTBH06	1399.78	13.09	1386.69	1389.65	-2.96	2.96	8.76
Average	1387.98	9.49	1378.50	1379.65	-1.16	5.29	40.57
Minimum	1324.83	0.16	1324.67	1322.75	-12.97	0.12	0.01
Maximum	1441.41	27.59	1427.72	1420.29	12.48	12.97	168.12
Correlation	0.98						
Σ					-32.35	148.14	1135.88
1/n					-1.16	5.29	40.57
Root Mean Square Deviation (RMSD)					1.07	2.30	6.37
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)					6.18		

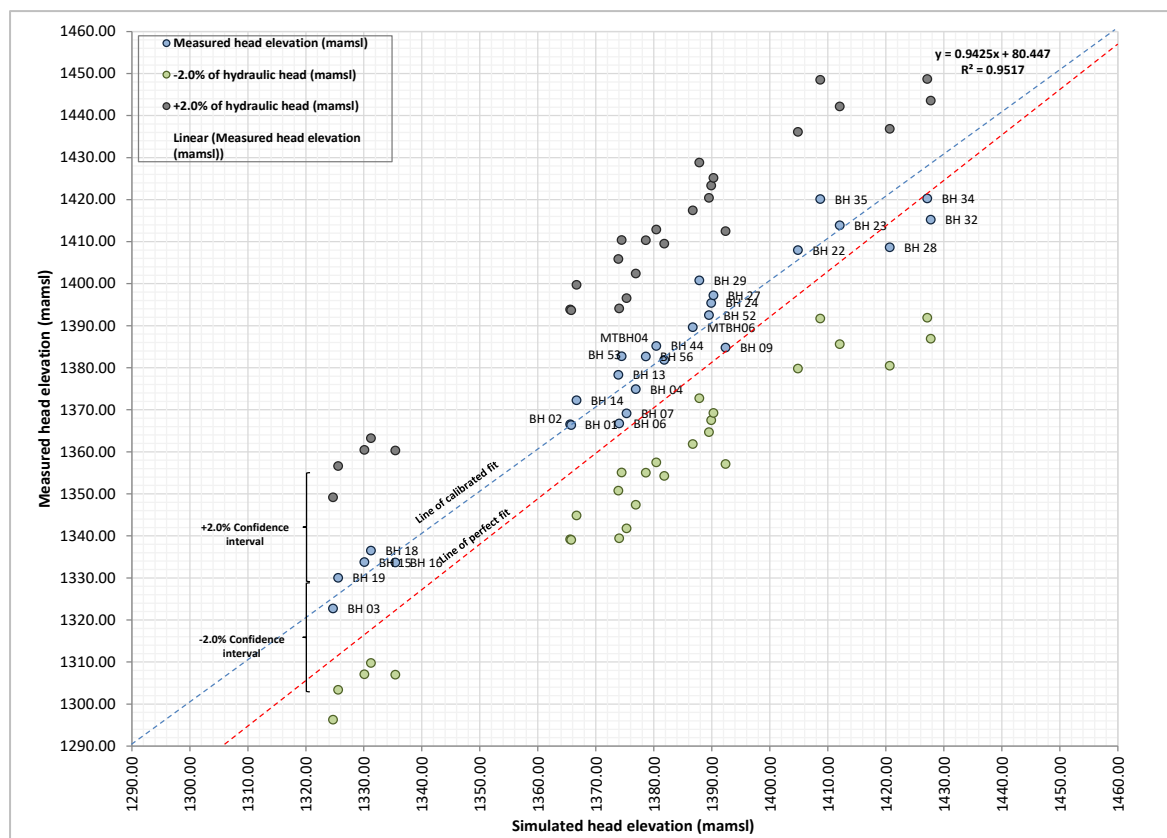


Figure 13-14 Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.

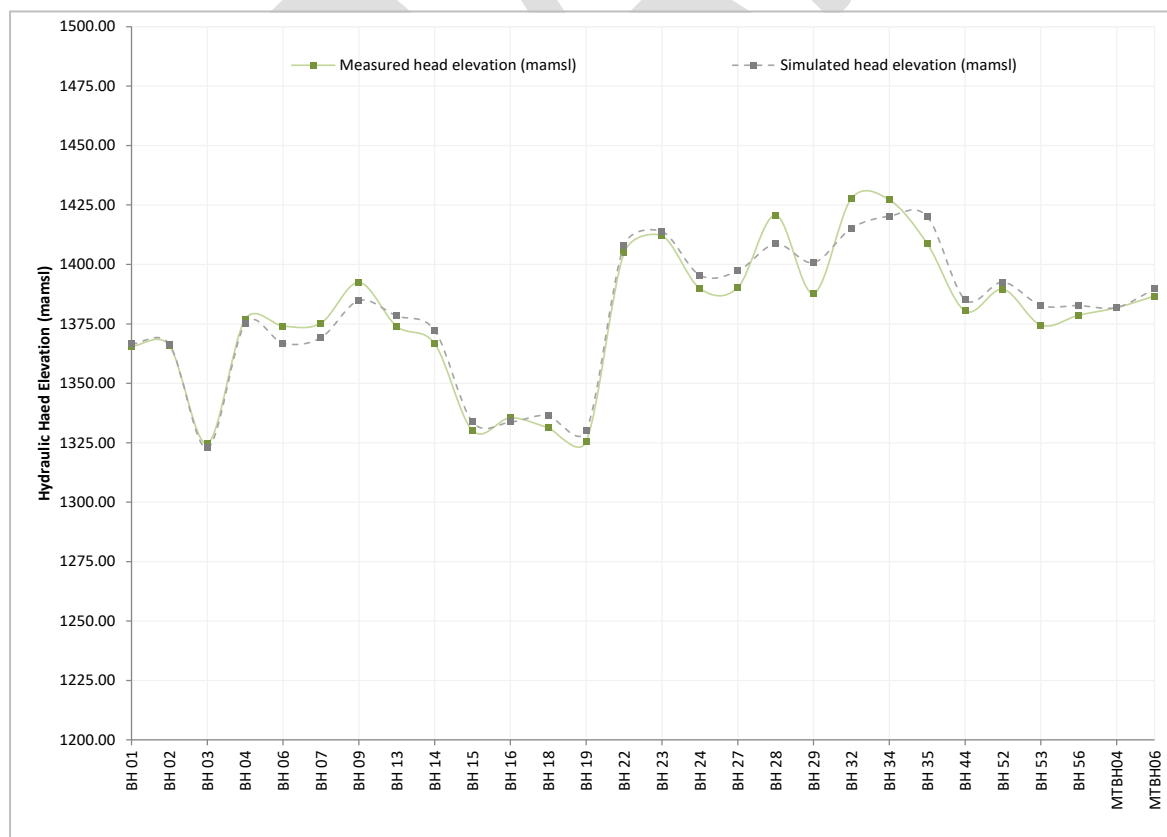


Figure 13-15 Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.

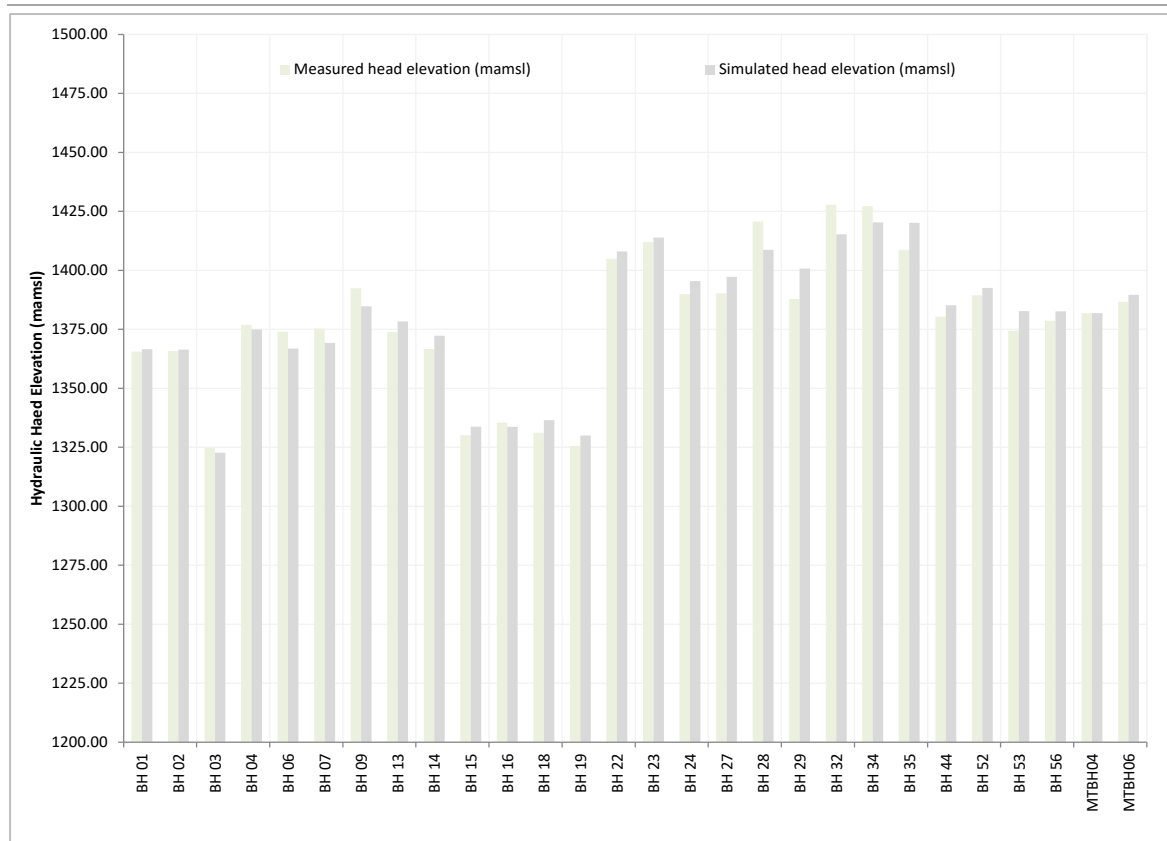


Figure 13-16 Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.

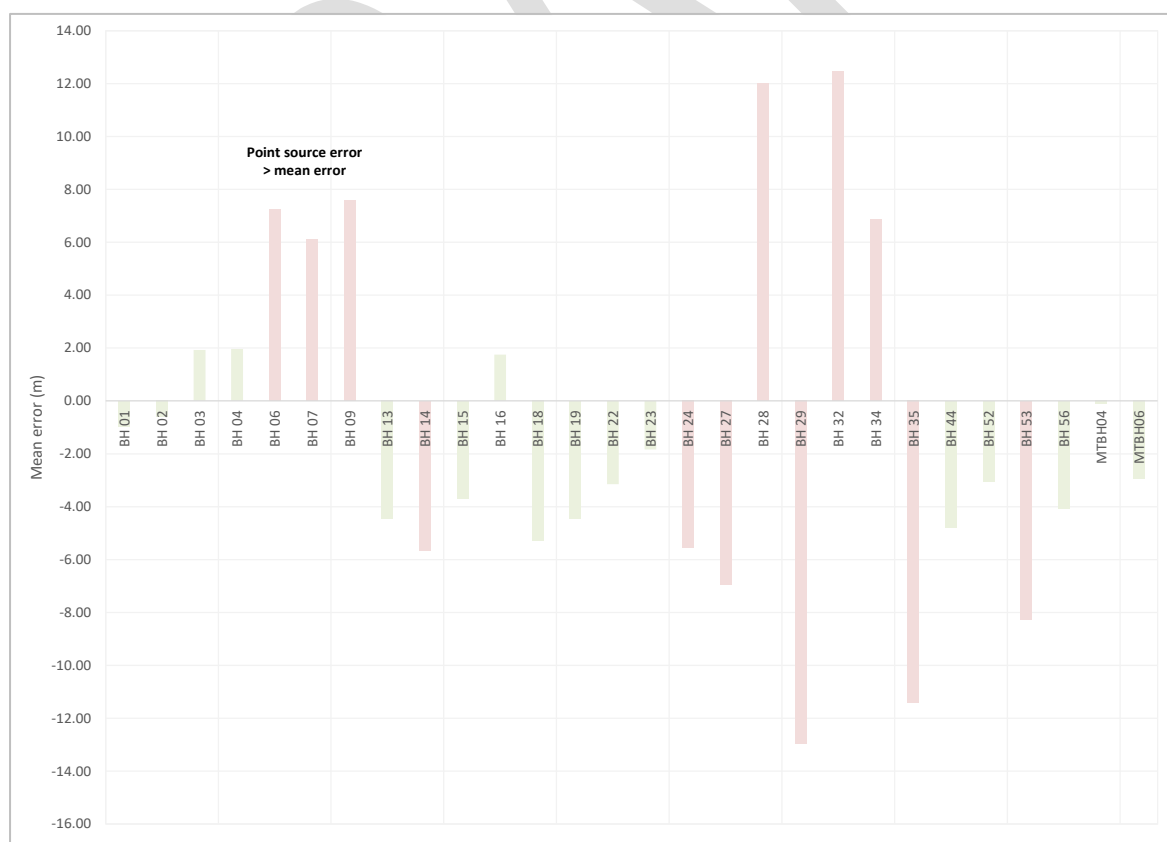


Figure 13-17 Model steady state calibration: Bar-chart of simulated vs. measured hydraulic head elevation.

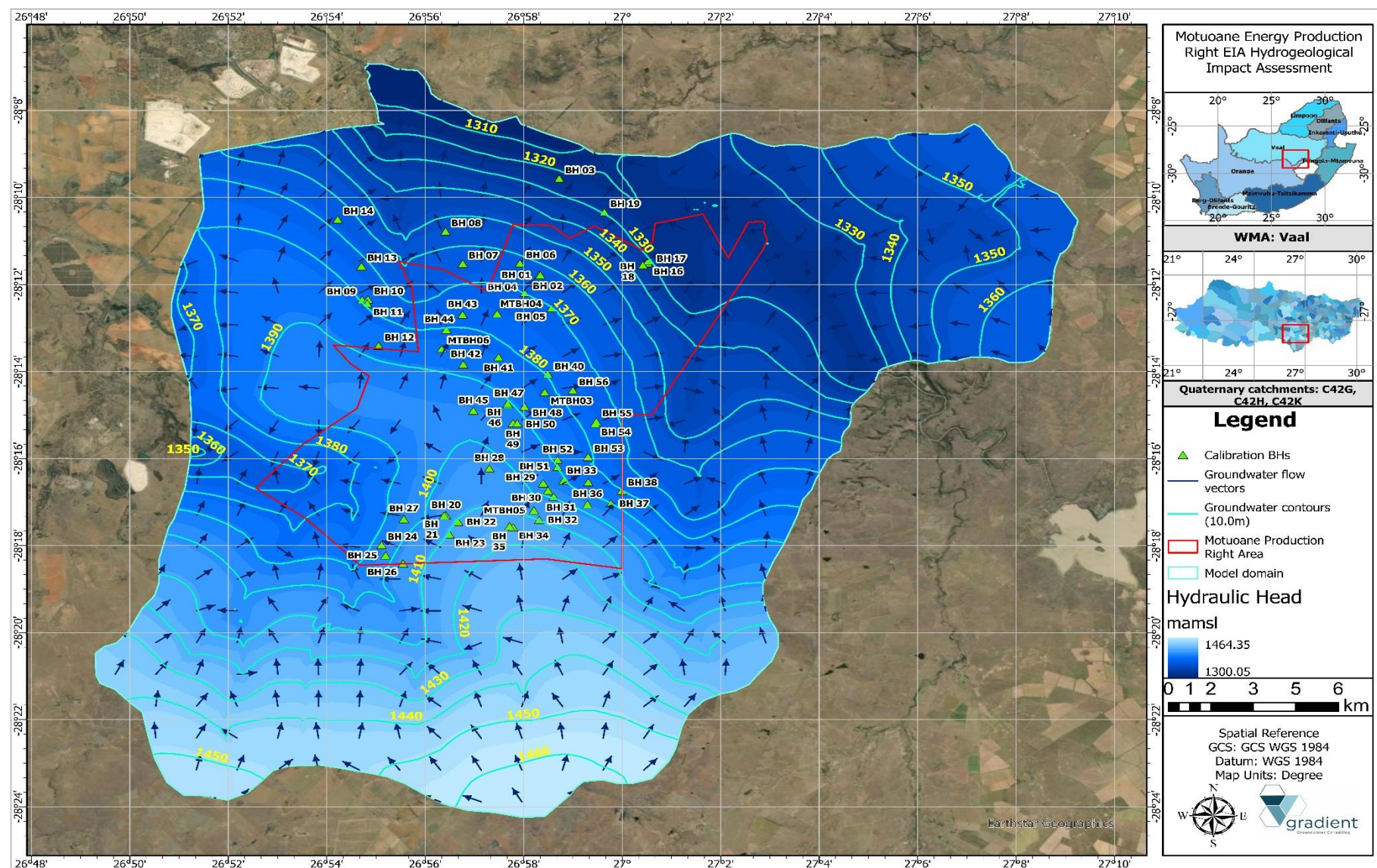


Figure 13-18 Model calibration: steady state hydraulic heads and groundwater flow direction.

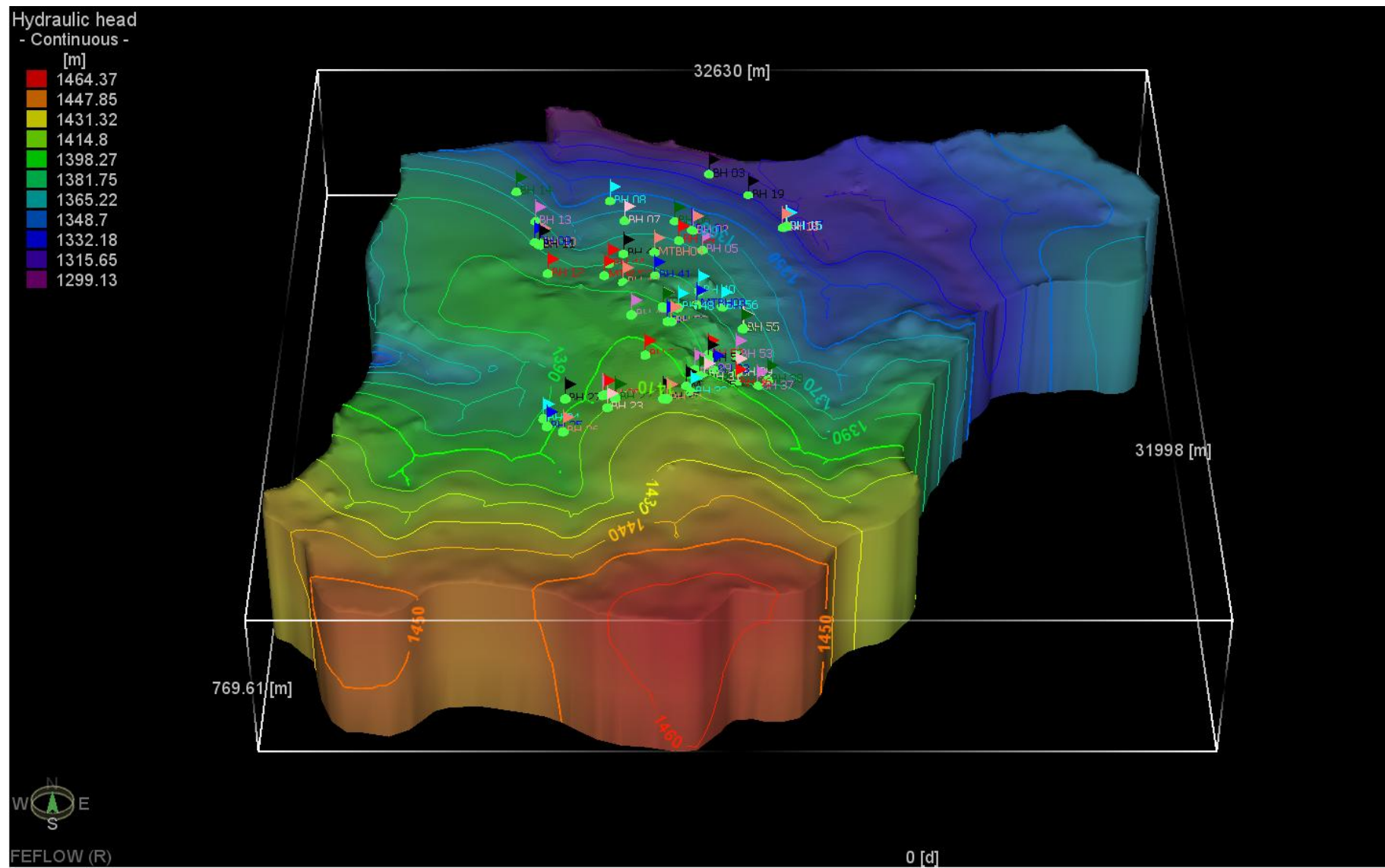


Figure 13-19 Model calibration: steady state hydraulic head distribution.

13.5.2. 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 13-2** it is noted that the model tends to be more sensitive to a downward variation in recharge and an increase in hydraulic conductivity as observed in **Figure 13-20**, **Figure 13-21** and **Figure 13-22**¹⁵.

Table 13-3 Steady State Model Calibration – Sensitivity analysis.

Parameter	Scenario: Base Case	Scenario: -75.0% of calibrated K-value	Scenario: +75.0% of calibrated K-value	Scenario: -75.0% of calibrated recharge	Scenario: +75.0% of calibrated recharge
Correlation	0.98	0.97	0.96	0.96	0.97
Mean Error	-1.16	1.74	5.85	6.84	-0.25
Mean Abs Error	5.29	5.87	7.47	8.12	5.17
RMSD	6.37	7.55	9.74	10.55	6.42
NRMSD	6.18%	7.32%	9.45%	10.24%	6.23%

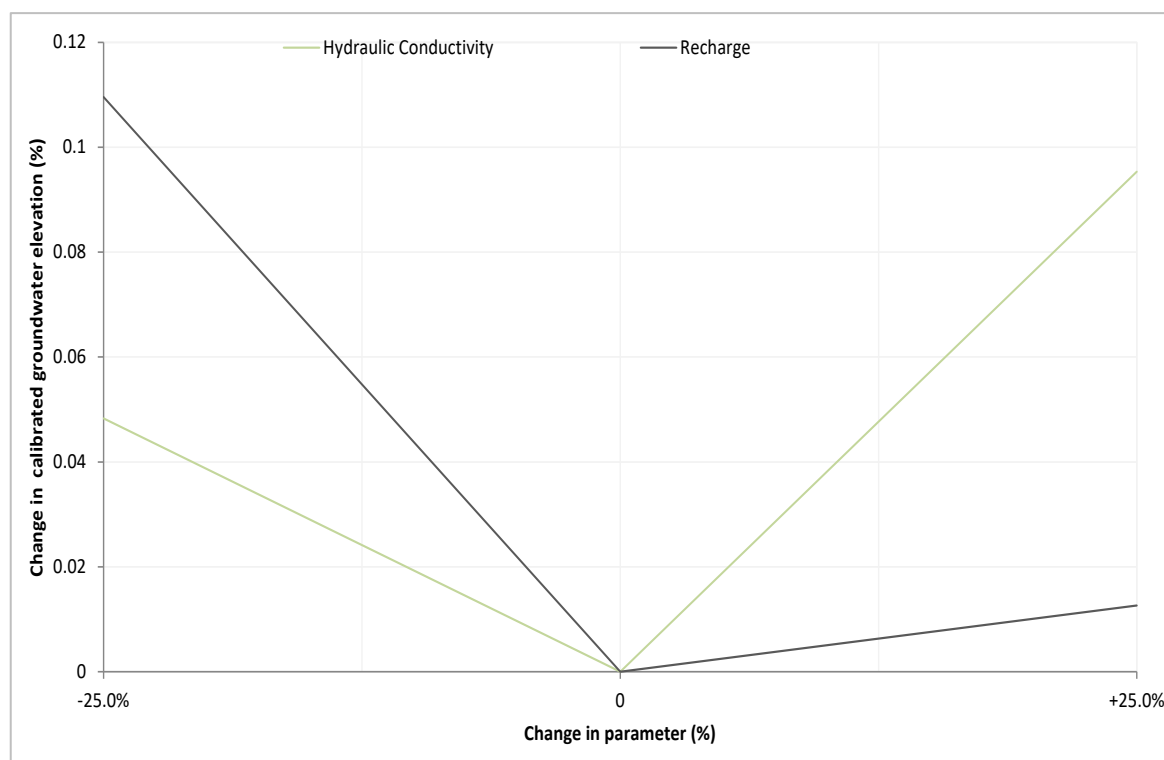


Figure 13-20 Model steady state calibration: sensitivity analysis for monitoring locality BH03.

¹⁵Recharge 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.

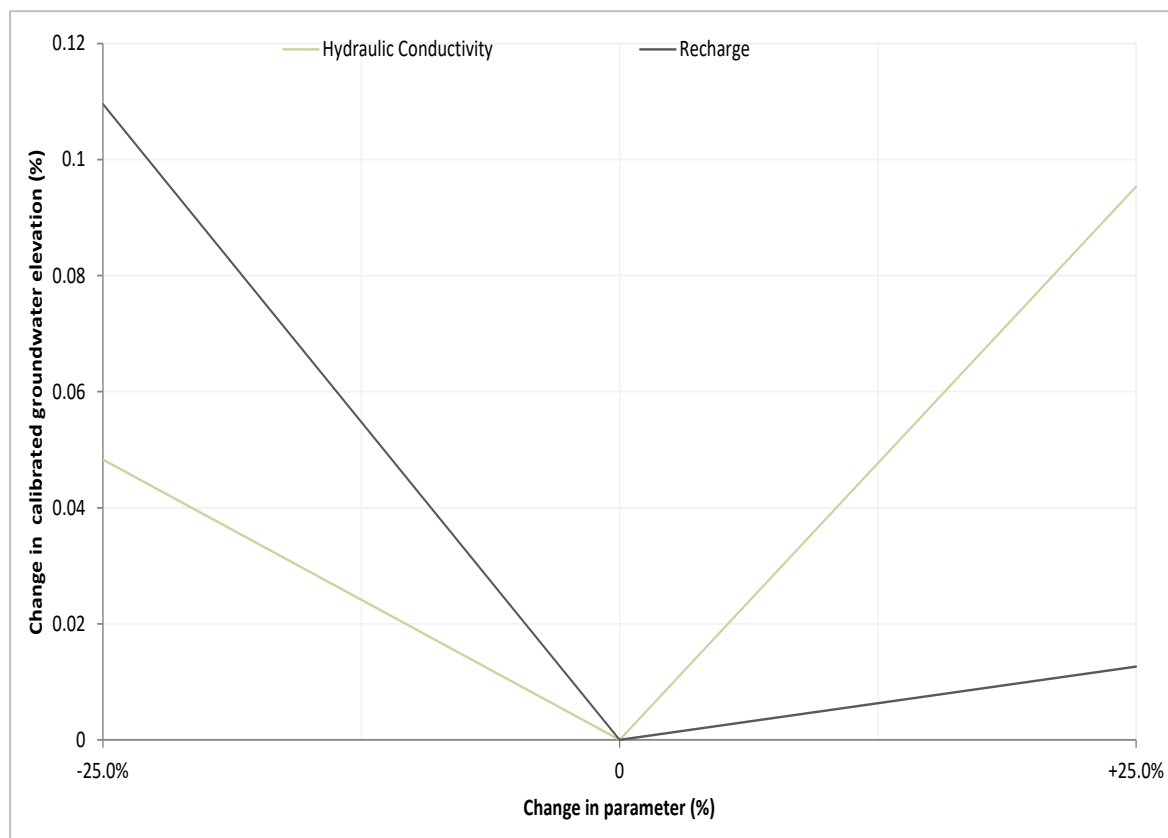


Figure 13-21 Model steady state calibration: sensitivity analysis for monitoring locality BH23.

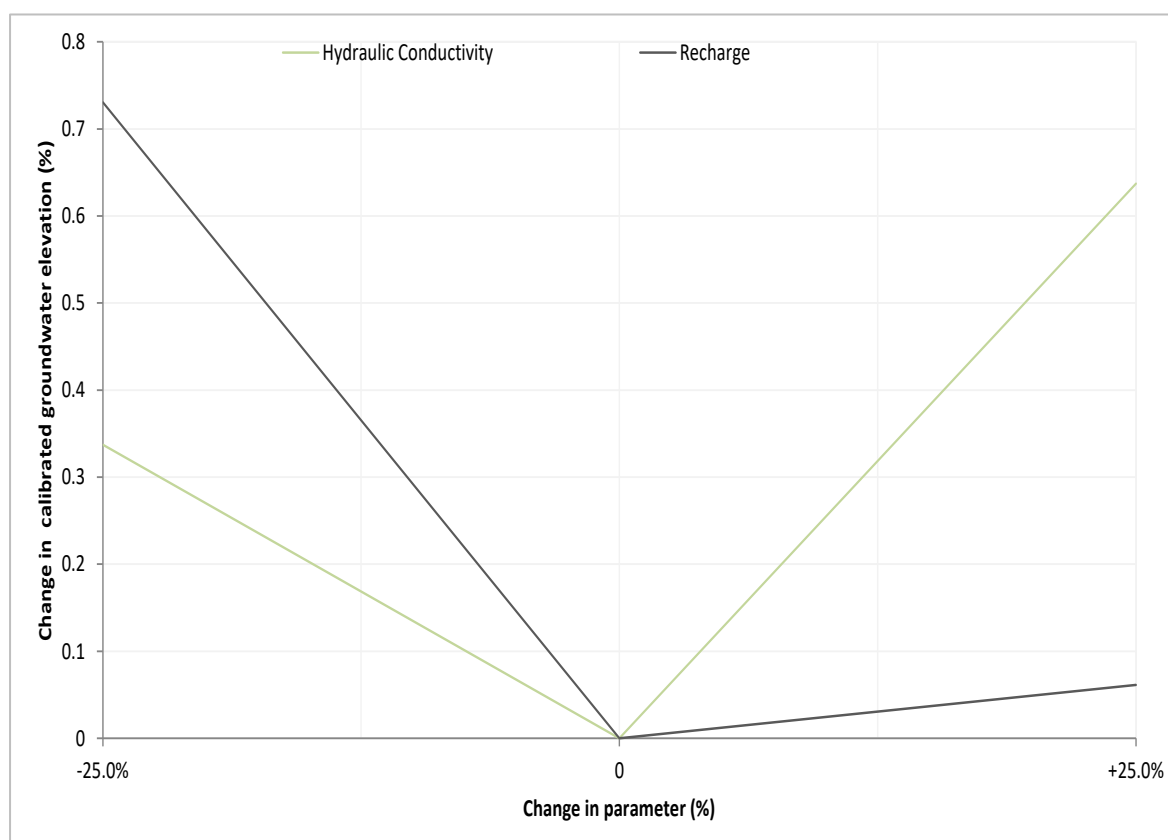


Figure 13-22 Model steady state calibration: sensitivity analysis for monitoring locality BH56.

13.6. 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 13-3 Groundwater flow.

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

where:

h = hydraulic head [L]

K_x, K_y, K_z = 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]

13.7. Numerical mass transport model

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

Equation 13-4 Advection-dispersion.

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

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 phenomena¹⁶;

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

p = density of pollutant;

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

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

¹⁶ 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.

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. Contaminant transport scenarios serve as tool for management purposes and the simulation results indicate the expected plume migration. The latter can be used to establish additional monitoring points to be applied as transient input for model updates and re-calibration.

It should be noted that the contaminant transport scenarios serve as a tool for management purposes with advective transport simulating the potential leachate concentrations from waste facilities, however, does not include biochemical breakdown and cation/anion exchange reactions which will further retard plume migration.

Various source terms and contaminant proxies were applied as part of the mass transport migration simulations and include saline groundwater emanating from the deep, fractured aquifer from leaking gas production boreholes (TDS = 7 832.0 mg/l - based on hydrochemical analysis of water samples representing this aquifer unit). Pulles et al (2005) indicates that groundwater associated with the deeper hydrostratigraphical units has TDS concentrations of around 4000.0mg/l, the major salt being sodium chloride.

A contaminant transport scenario was conducted simulating stray methane gas (CH_4) from leaking gas proposed production boreholes. The drilling of gas production wells could result in the migration of stray gas from the deep-seated fracture zones to formations higher up in the geological sequence. This impact has been recorded in the US where hydraulic fracturing, dewatering or a combination of these has occurred (Jackson et al, 2013). It should be stated that the applicant does not intend to undertake hydraulic fracturing or any well stimulation and, as such, no dewatering will be required. Accordingly, the risk of stray gas migration is therefore expected to be low. It should be noted that this scenario is highly unlikely under natural conditions as the gas production zone(s) is separated from the shallow and potable Karoo aquifer by very low permeability shale formations which will act as an aquitard towards any groundwater and stray gas migration. This is however provided that well construction, including cementation and the installation of steel casing, is sound. As such, the impact assessment evaluated represents a worst-case scenario and simulates the eventual occurrence once stray gas does reach the shallow aquifer.

As methane gas reaches saturation in water at 28 milligrams per litre (mg/L) at atmospheric pressure (Eltschlager et al., 2001), this concentration was applied as source term for this scenario. According to the U.S. Environmental Protection Agency (EPA, 2011) as well as U.S. Department of the Interior, Office of Surface Mining (2011), methane concentrations below 10.0mg/L are generally considered safe.

Various management scenarios were modelled for the purposes of planning and decision making with stress periods listed in **Table 13-4**:

- i. **Scenario 01:** Steady state water balance (∞).
- ii. **Scenario 02:** Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the operational gas production phase.
- iii. **Scenario 03:** Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the operations gas production phase.
- iv. **Scenario 03:** Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the operations gas production phase.
- v. **Scenario 04:** Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios).
- vi. **Scenario 05:** Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios).
- vii. **Scenario 06:** Gas processing plant alternative evaluation and site selection.

Table 13-4 Summary of model stress-periods.

Stress period	Description
Year01 – Year30	Gas production operational phase
Year 30 – Year 80	50-years post closure
Year 80 – Year 130	100-years post closure

13.7.1. Scenario 01: Steady state baseline water balance (∞)

Table 13-5 summarises the groundwater catchment water balance representing baseline steady state conditions. Recharge is assumed the only source of inflow to the system and has been simulated at $2.738\text{E}^{+04}\text{m}^3/\text{d}$, while the largest loss to the groundwater system is via groundwater contribution to baseflow, $2.737\text{E}^{+04}\text{m}^3/\text{d}$. Water captured as storage equates to $1.328\text{E}^{+01}\text{m}^3/\text{d}$ while water released from storage is calculated as $4.400\text{E}^{-01}\text{m}^3/\text{d}$. The imbalance of the delineated aquifer unit, ignoring internal transfer, is calculated at $2.284\text{E}^{+01}\text{m}^3/\text{d}$.

Table 13-5 Catchment water balance: Scenario 01 – Steady state baseline water balance.

Scenario 01 – Steady State Catchment Groundwater Balance			
Parameter	Inflow (m^3/d)	Outflow (m^3/d)	Balance (m^3/d)
Recharge (m^3/d)	2.738E+04	0.000E+00	2.738E+04
Dirichlet/ Drain conductance (m^3/d)	0.000E+00	2.737E+04	-2.737E+04
Storage Capture(-)/Release(+)(m^3/d)	1.328E+01	4.400E-01	1.284E+01
Imbalance ignoring internal transfer (m^3/d)	0.000E+00	2.284E+01	-2.284E+01
Total (m^3/d)	2.739E+04	2.739E+04	0.000E+00

13.7.2. Scenario 02: Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the operational gas production phase

This scenario summarises the simulated point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase (30-year period).

It should be noted that, due care will be taken to ensure that all production boreholes will be properly constructed and adequately sealed, a cautious approach i.e., “worst-case” scenario have been followed during the modelling of leaking boreholes. Accordingly, the unmitigated scenario entails simulation of a potential pollution plume migrating through open production boreholes i.e., uncased with no cement or grouting implemented. If casing and cementing will be performed according to the specifications provided, theoretically the migration of a pollution plume through the preferred groundwater flow pathway created by the borehole will be insignificant.

Due to the linear correlation of the groundwater elevation within the shallow, intergranular aquifer compared to relevant topographical elevation, the simulation indicates that the generated TDS pollution plume will generally mimic topography and will migrate from the gas production borehole(s) towards the lower laying drainage system. It is evident that regional geological lineaments act as preferred pathways for groundwater flow and contaminant transport mechanisms.

It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~180.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~350.0m during the operational phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer.

Figure 13-23 summarises a time-series graph of the TDS mass load contribution to conceptually placed receptors situated in close proximity to simulated gas production boreholes (positioned 50m and 100m from the respective boreholes). It can be observed that the TDS mass load contribution ranges between ~980.0mg/l to approximately 1660.0mg/l, which is slightly above the SANS 241:2015 limits.

Figure 13-24 summarises a time-series graph of the TDS mass load contribution to existing boreholes in the vicinity of the proposed gas production boreholes. It can be observed that the TDS mass load contribution ranges between < as the current background concentration of ~350.0mg/l to a maximum of approximately 800.0mg/l, which is below the SANS 241:2015 limits. It can be observed the mass load contribution is a function of the distance to the source or gas production borehole. It can be noted that conceptual receptors situated within the unconsolidated, riparian zone aquifer, reaches quasi-steady state much quicker than conceptual receptors within the denser Karoo formations. The latter can be attributed to more sluggish groundwater movement associated with the Beaufort group formations.

Figure 13-25 indicates the simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south with **Figure 13-26** showing the simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east.

Figure 13-27 indicates the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south while **Figure 13-28** depicts the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east for the operational phase.

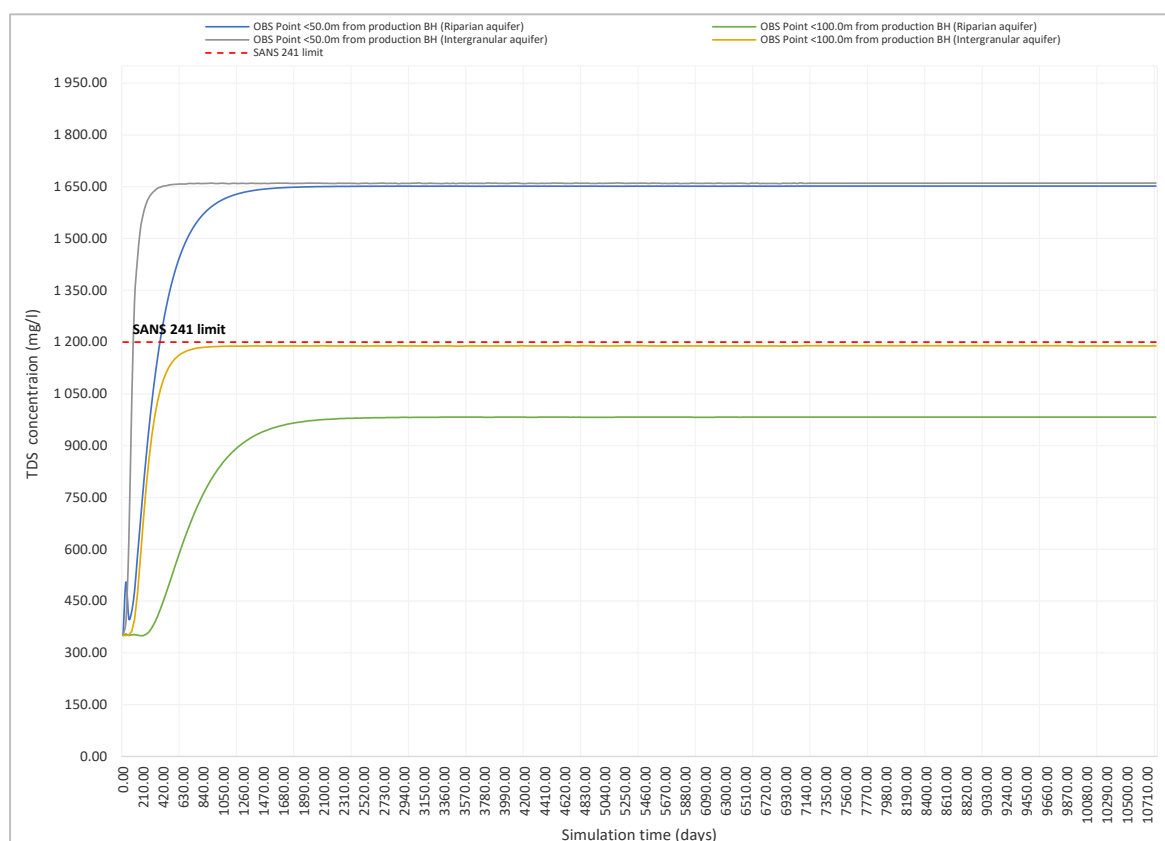


Figure 13-23 Scenario 02: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Operational phase).

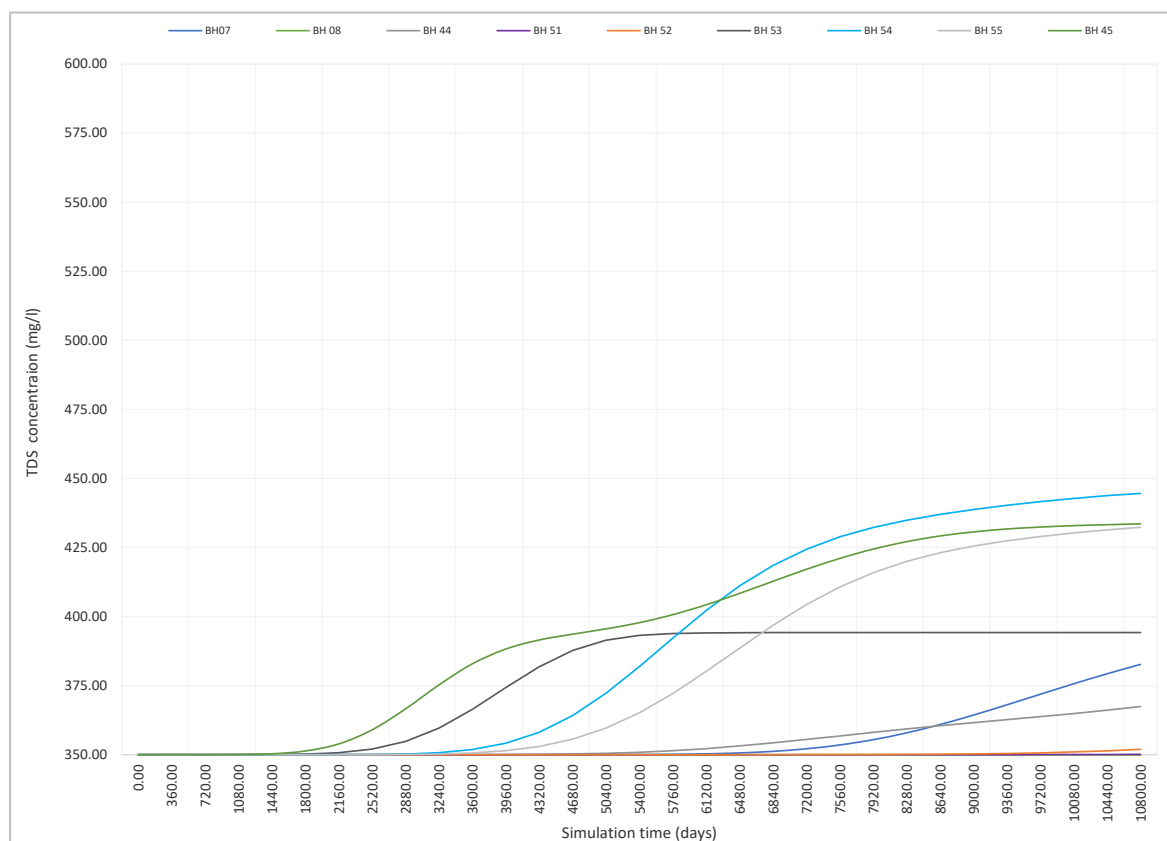


Figure 13-24 Scenario 02: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on existing regional boreholes (Operational phase).

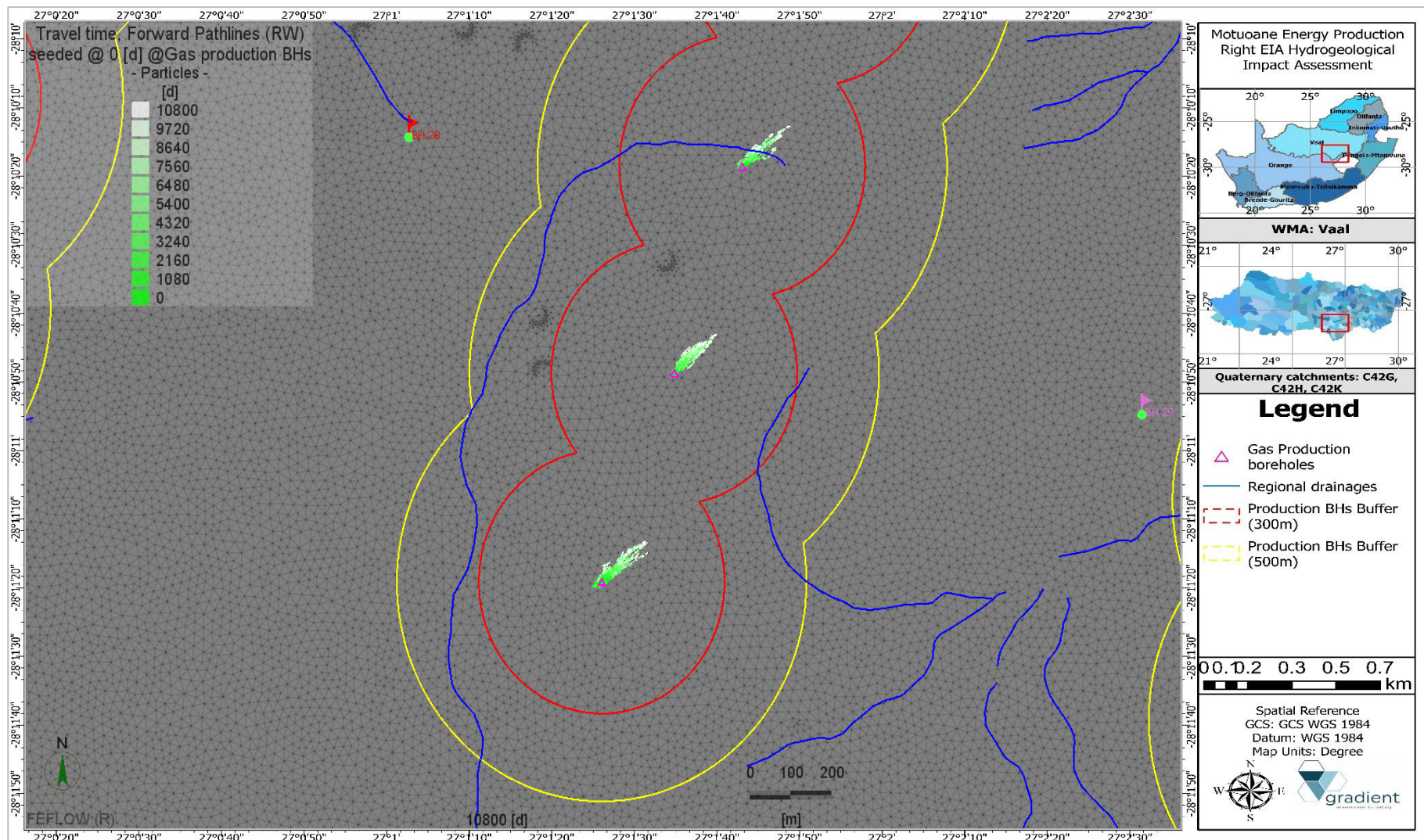


Figure 13-25 Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).

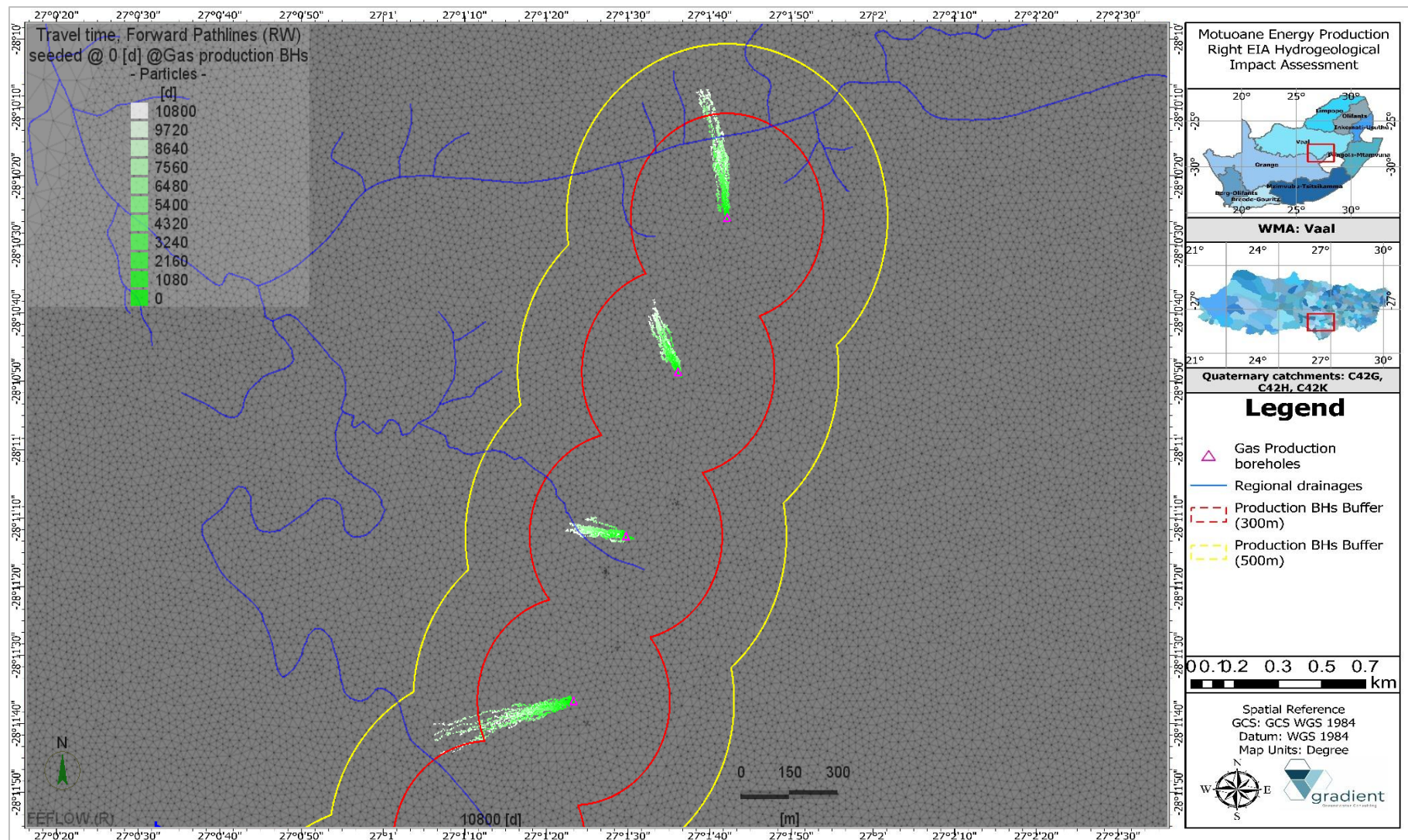


Figure 13-26 Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).

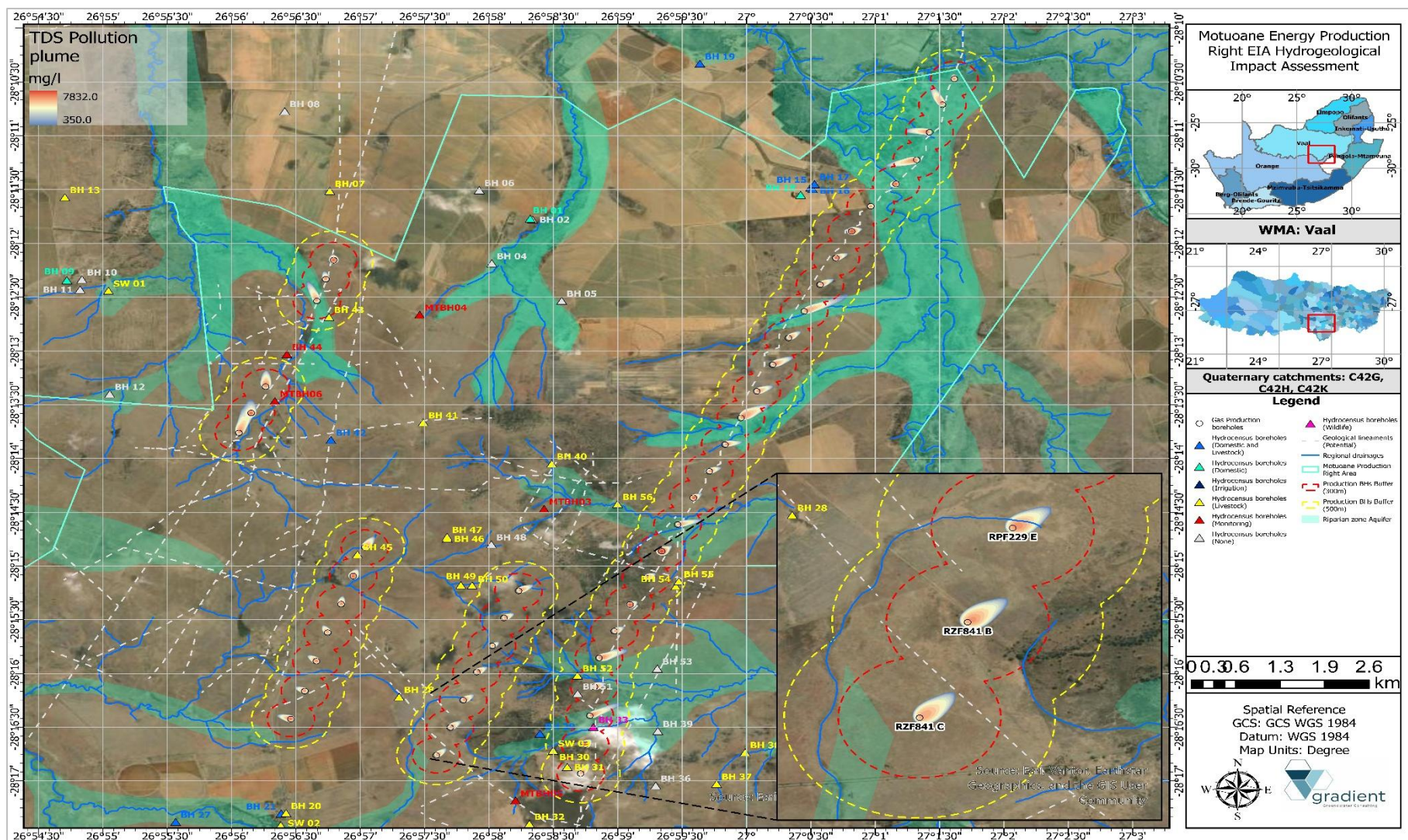


Figure 13-27 Scenario 02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).

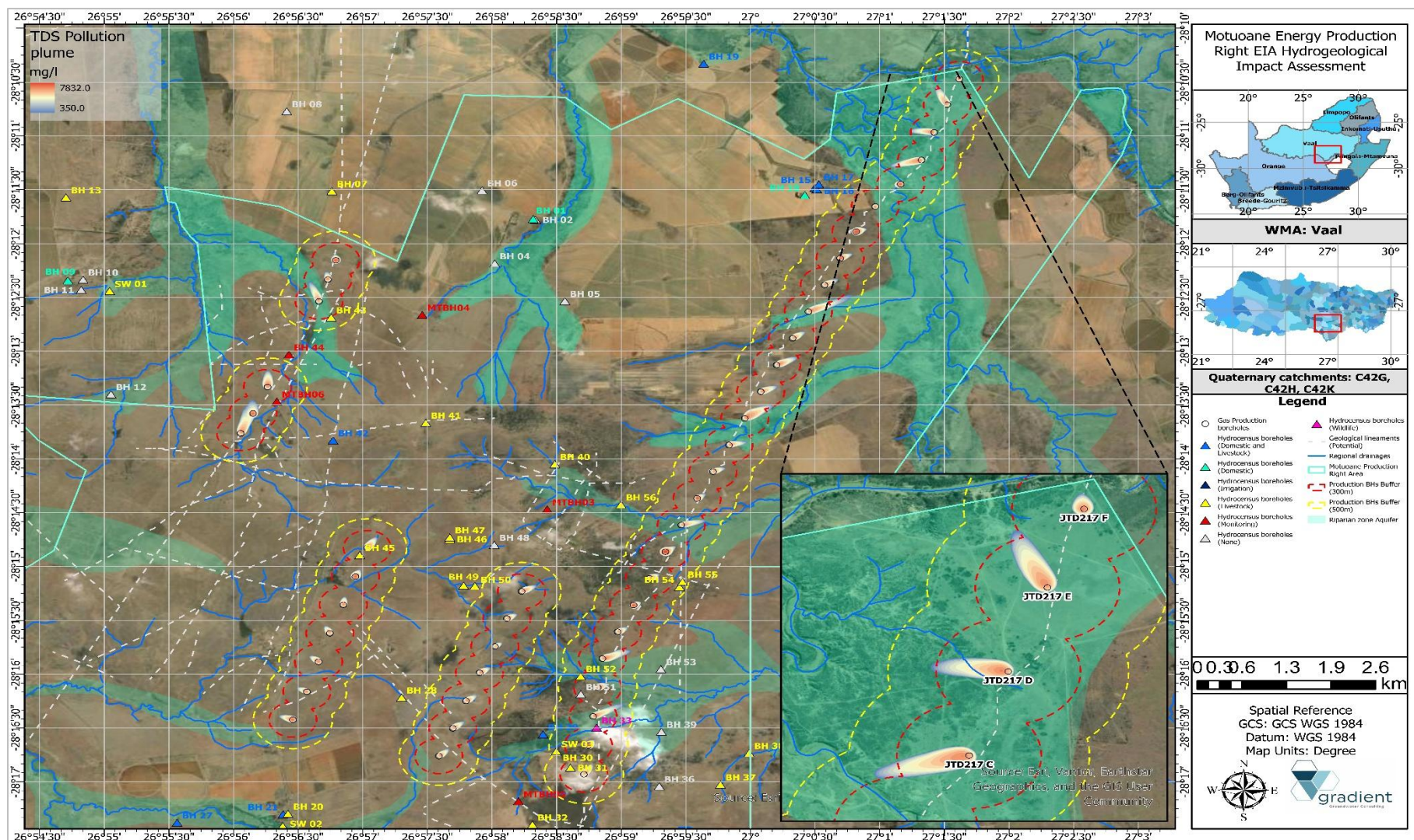


Figure 13-28 Scenario S02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).

13.7.3. Scenario 03: Migration of stray methane (CH₄) gas emanating from the production zone to the overlying, potable aquifer(s) during the operations gas production phase

This scenario summarises the simulated point source pollution plume migration of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase (30-year period).

It should be noted that, due care will be taken to ensure that all production boreholes will be properly constructed and adequately sealed, a cautious approach i.e., “worst-case” scenario have been followed during the modelling of leaking boreholes (unmitigated scenario).

The simulation indicates that the generated CH₄ pollution plume will also generally mimic topography and will migrate from the gas production borehole(s) towards the lower laying drainage system.

It can be observed that the simulated pollution plume migration is also more sluggish within the denser Karoo formations, reaching a maximum distance of ~150.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~300.0m during the operational production phase.

The simulation indicates that the potential pollution plumes will also not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer.

Figure 13-29 summarises a time-series graph of the CH₄ mass load contribution to conceptually placed receptors targeting the shallow, intergranular as well as riparian zone aquifers for the operational phase. It is evident that source term mass load contribution to is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole.

Figure 13-30 summarises a time-series graph of the CH₄ mass load contribution to existing boreholes in the vicinity of the proposed gas production boreholes. It can be observed that the CH₄ mass load contribution ranges between ~0.15mg/l (which is the current background concentration) to a maximum of approximately 0.49mg/l, which is below the EPA safety threshold (2011) of 10.0mg/l.

Figure 13-31 indicates the CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south while **Figure 13-32** depicts the CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east for the operational phase.

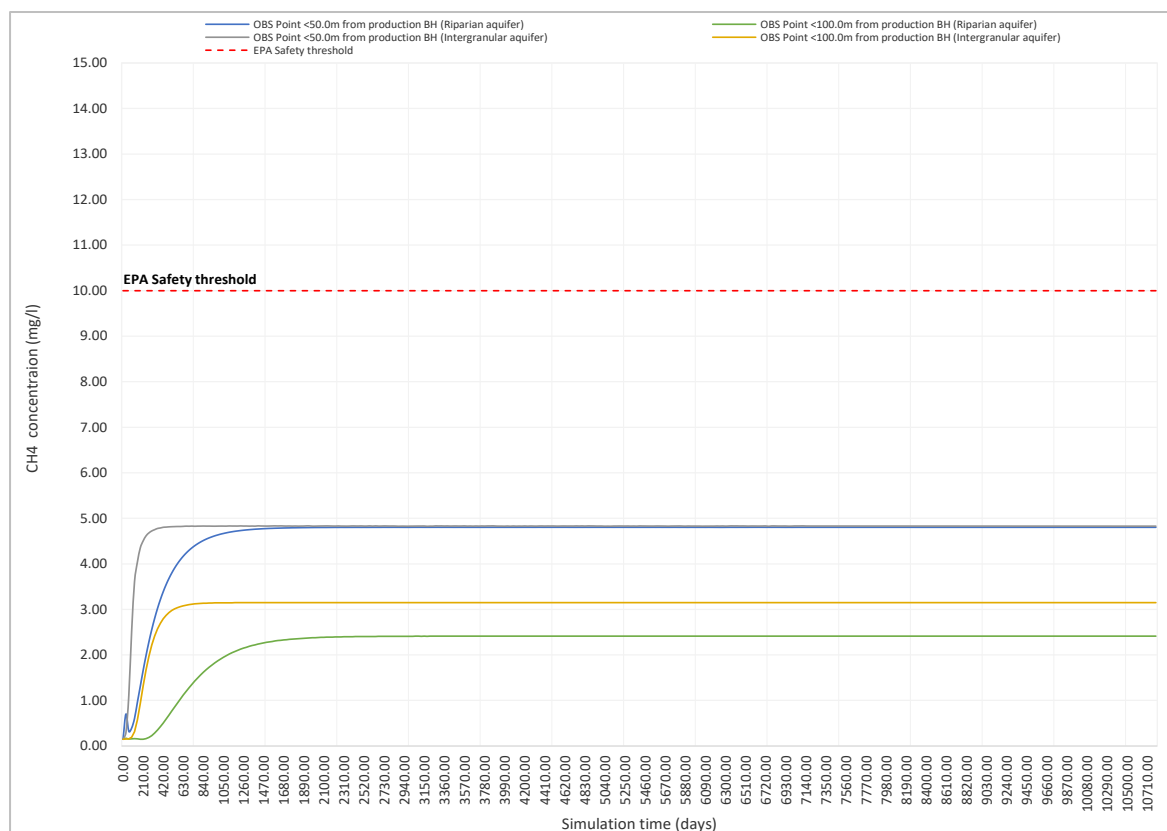


Figure 13-29 Scenario 03: Time-series graph indicating the CH₄ mass load contribution of the production zone on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Operational phase).

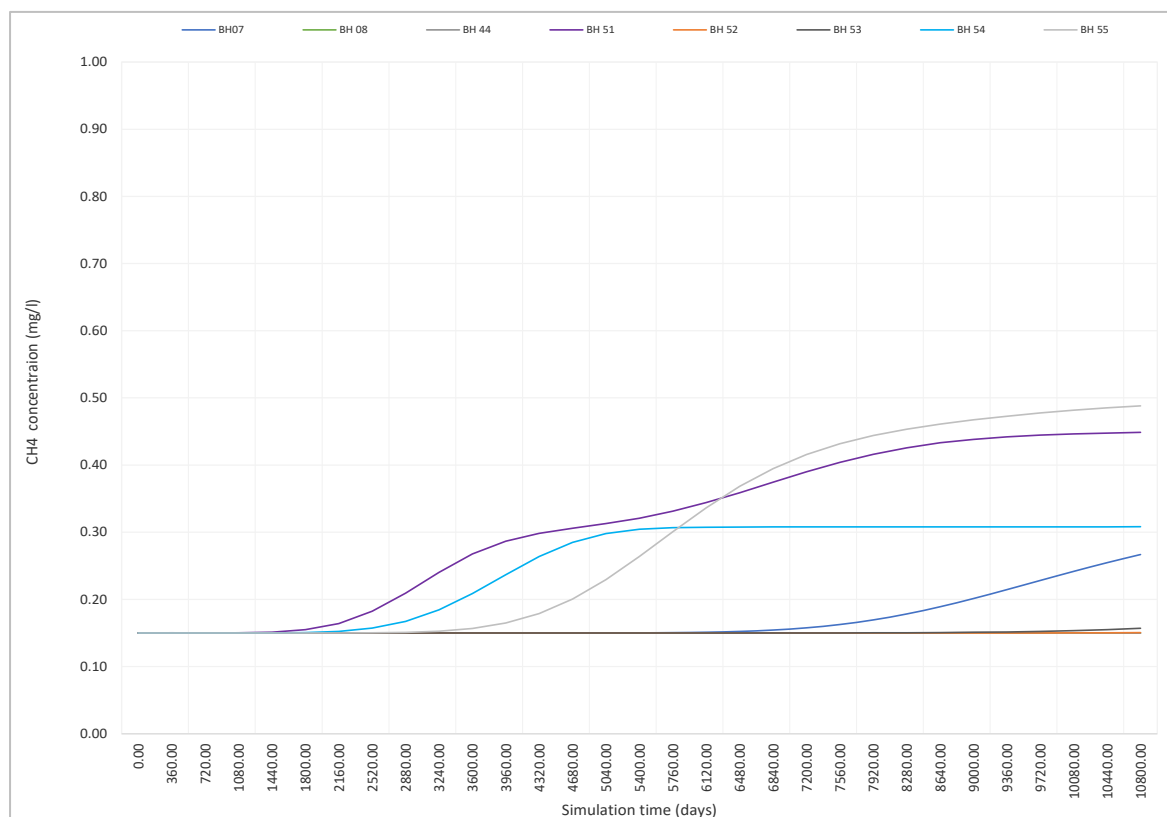


Figure 13-30 Scenario 02: Time-series graph indicating the CH₄ mass load contribution of deeper, fractured (saline) aquifer on existing boreholes (Operational phase).

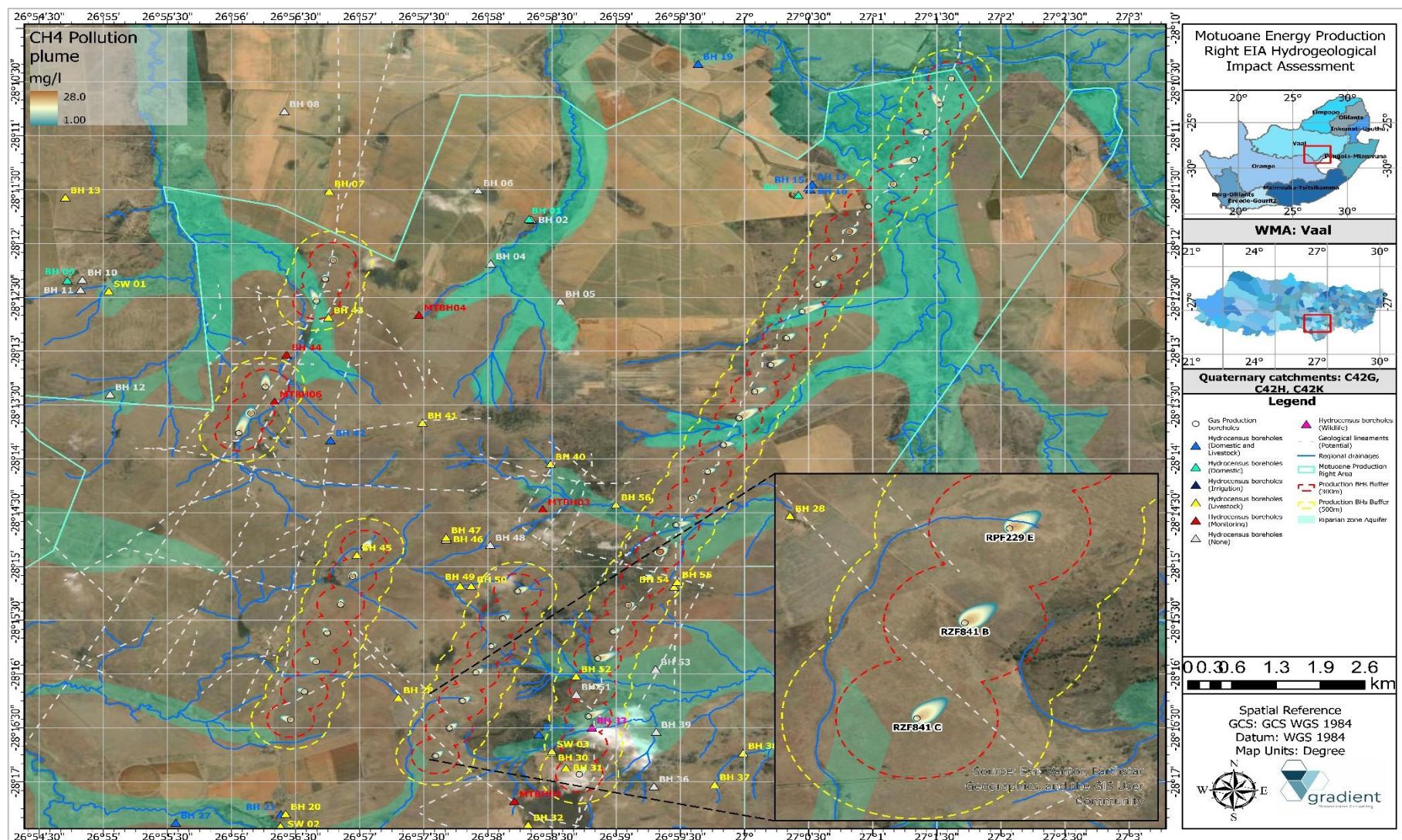


Figure 13-31 Scenario 03: CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Operational phase).

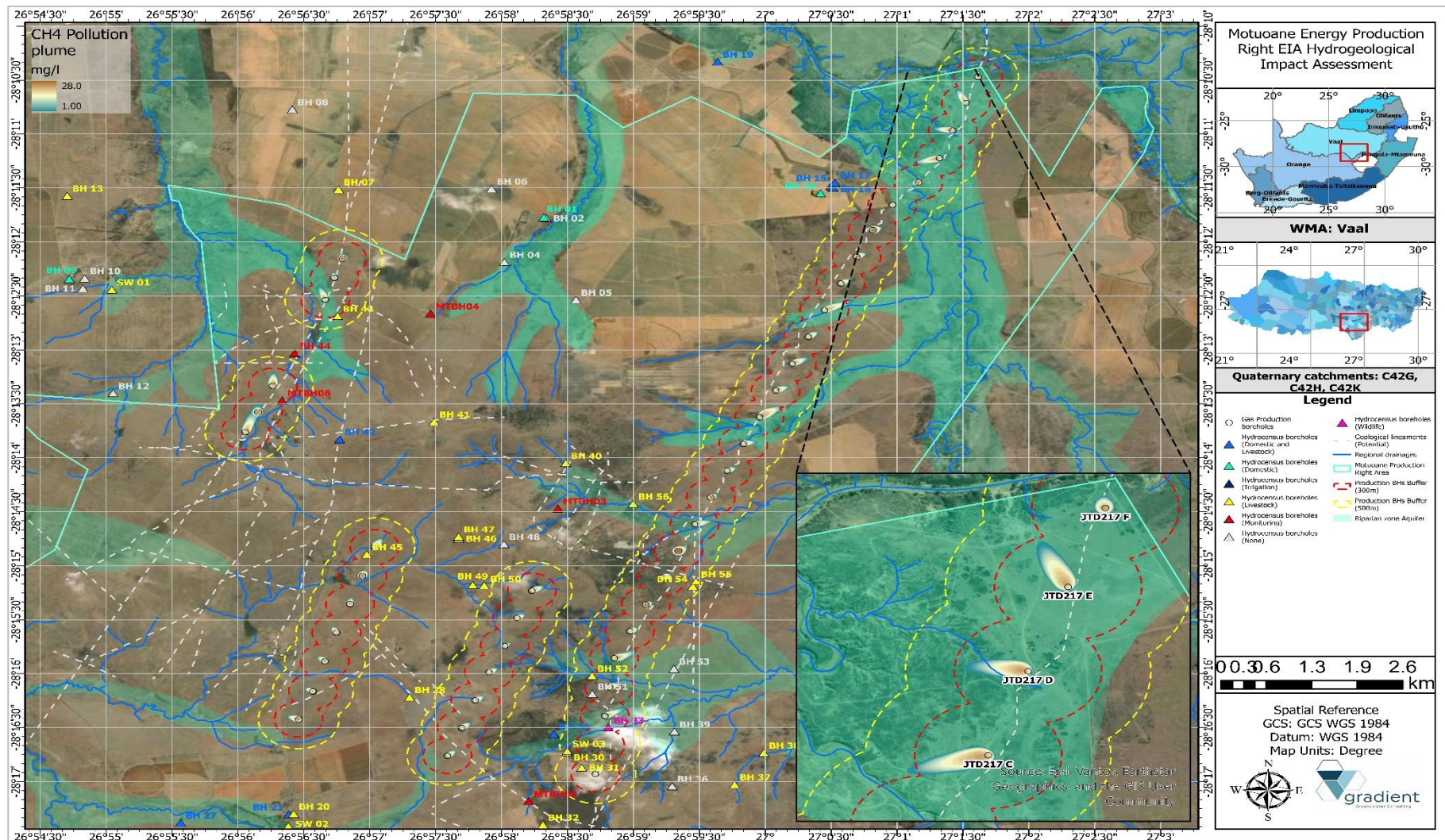


Figure 13-32 Scenario 03: CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Operational phase).

13.7.4. Scenario 04: Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios)

This scenario summarises the simulated point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase.

The simulation indicates that the generated TDS pollution plume will also mimic topography during the post-closure phase and will propagate towards the lower lying drainage system.

After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~250.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial deposits of the riparian zone is ~450.0m.

It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems.

Figure 13-33 summarises a time-series graph of the TDS mass load contribution to conceptually placed receptors situated in close proximity to simulated gas production boreholes (positioned 50m and 100m from the respective boreholes) for the post-closure phase. It can be observed that the TDS mass load contribution has reached an equilibrium above the SANS 241:2015 limits ranging between ~950.0mg/l to approximately > 1 600.0mg/l.

Figure 13-34 depicts a time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on existing boreholes in the vicinity of the proposed gas production boreholes targeting the potable shallow, intergranular aquifer for the post-closure phase. It can be observed that the TDS mass load contribution ranges between ~380.0mg/l to a maximum of approximately 480.0mg/l, however remains below the SANS 241:2015 limits.

Figure 13-35 depicts the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south while **Figure 13-36** depicts the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east for the post-closure phases.

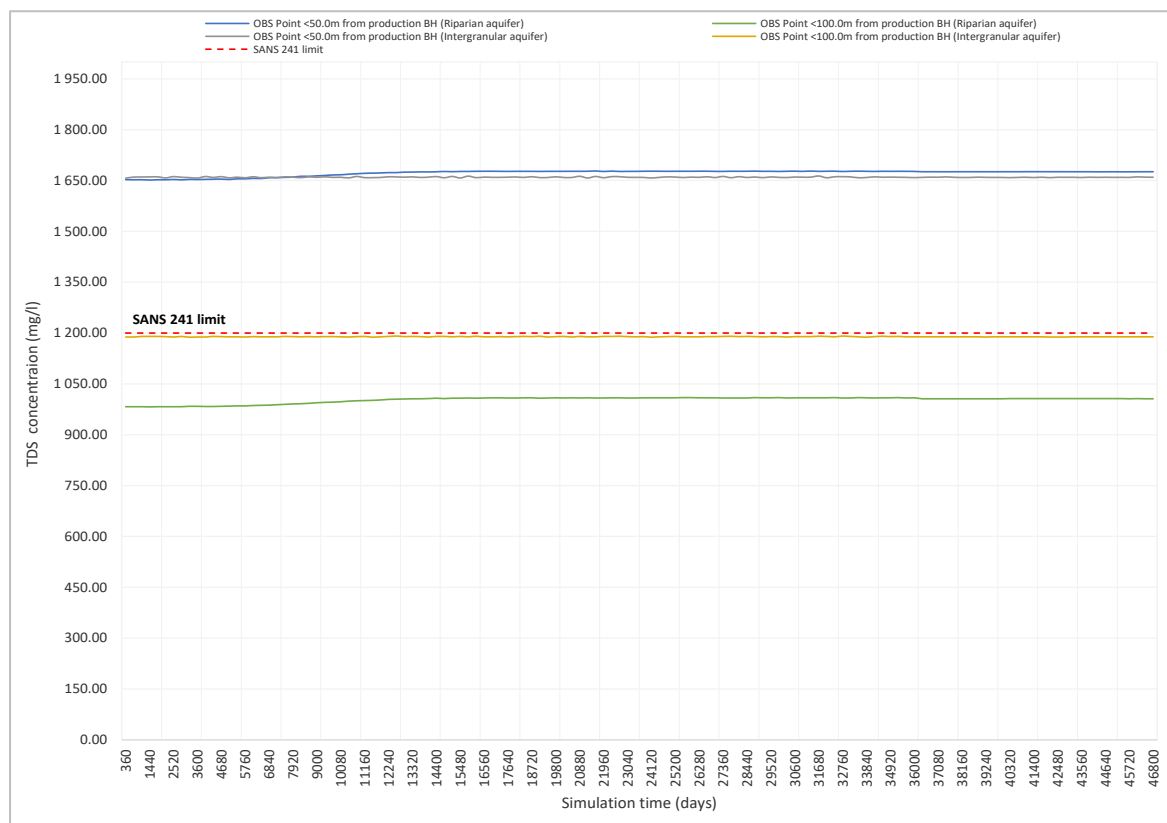


Figure 13-33 Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).

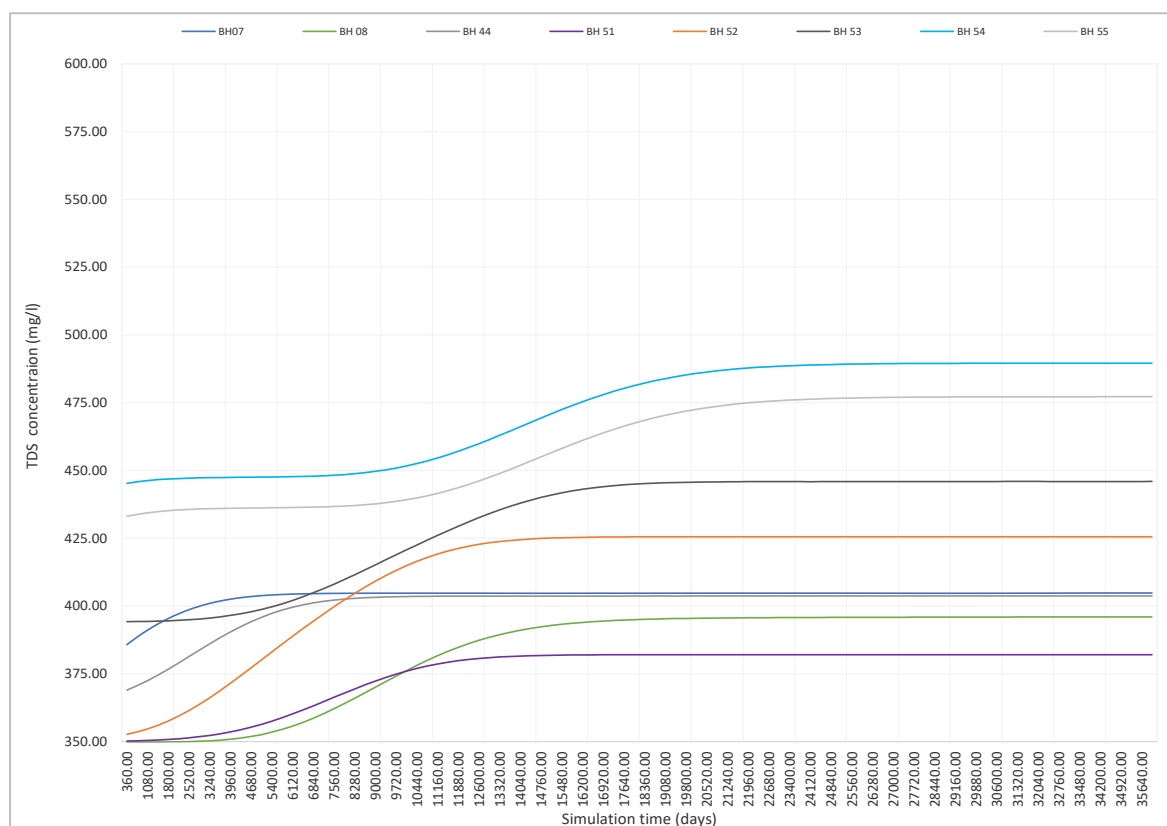


Figure 13-34 Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targeting the potable shallow, intergranular aquifer (Post-closure phase).

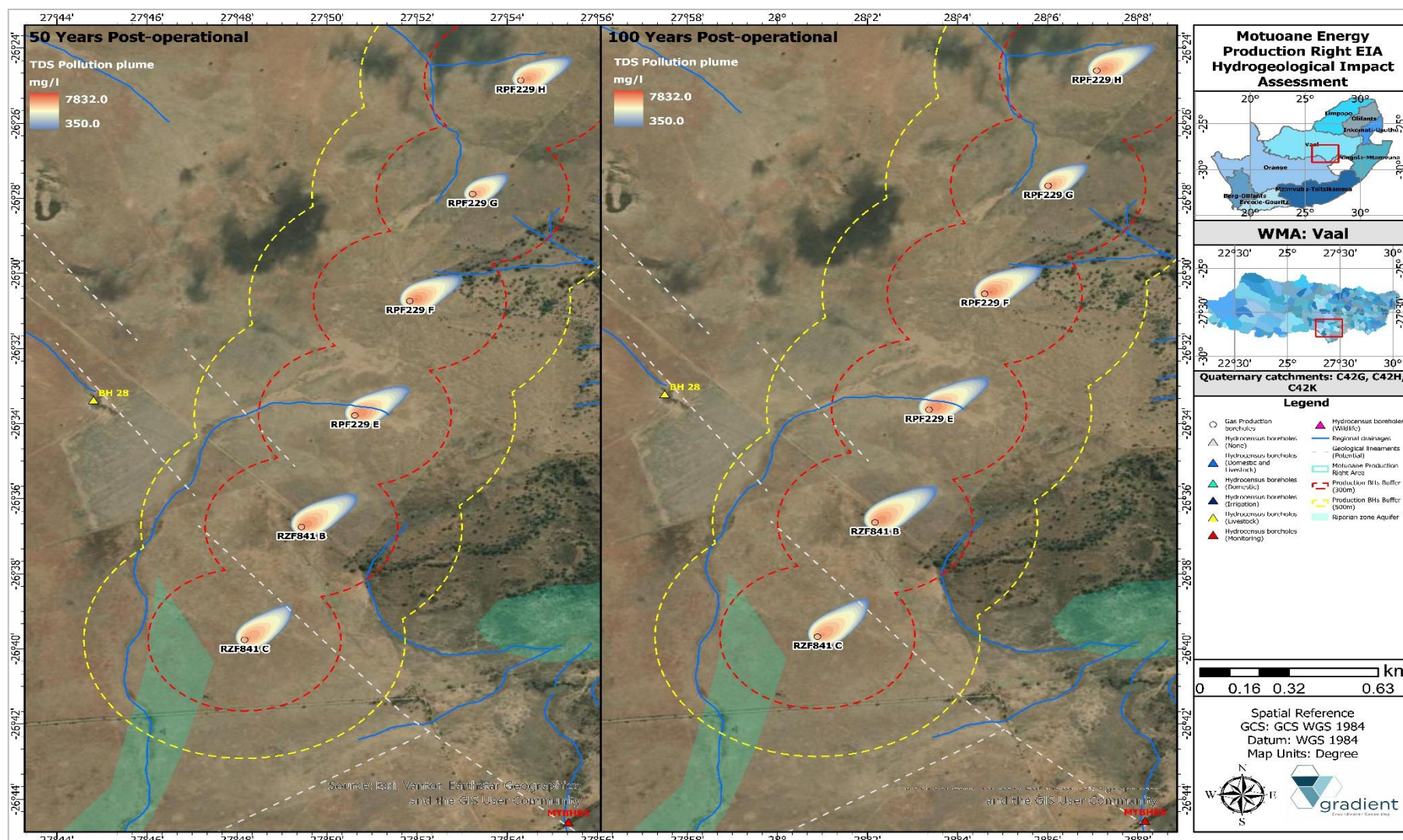


Figure 13-35 Scenario 04: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Post-closure phase).

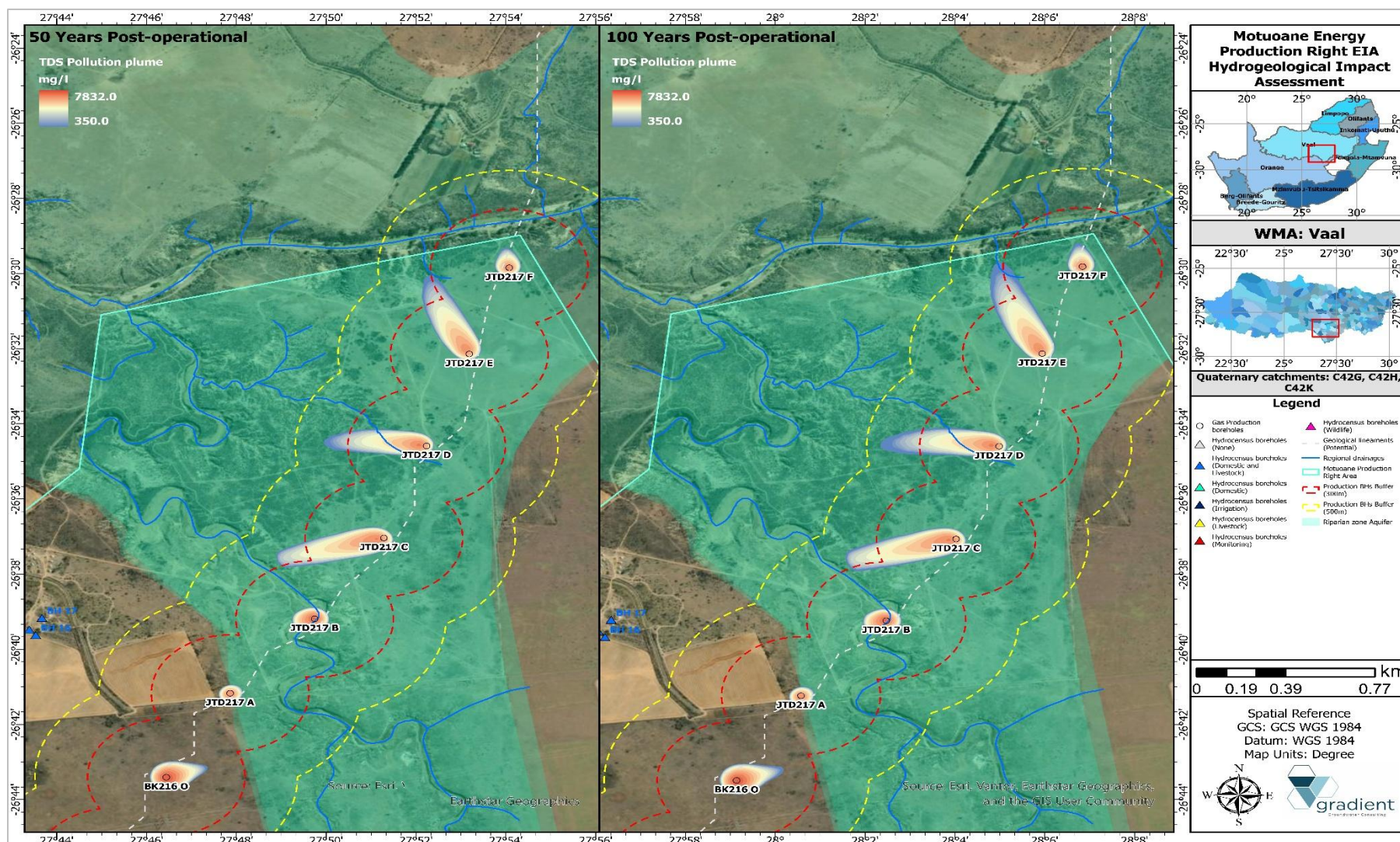


Figure 13-36 Scenario 04: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Post-closure phase).

13.7.5. Scenario 05: Migration of stray methane (CH₄) gas emanating from the production zone to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios)

This scenario summarises the simulated point source pollution plume migration from of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the decommissioned gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated CH₄ pollution plume will also mimic topography during the post-closure phase and will propagate towards the lower laying drainage system.

After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~180.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial deposits of the riparian zone is ~350.0m.

It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems.

Figure 13-37 summarises a time-series graph of the CH₄ mass load contribution to conceptually placed receptors targeting the shallow, intergranular as well as riparian zone aquifers for the post-closure phase. It can be observed that the CH₄ mass load contribution has reached an equilibrium below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole.

Figure 13-38 summarises a time-series graph of the CH₄ mass load contribution to existing boreholes in the vicinity of the proposed gas production boreholes for the post-closure phase. It can be observed that the CH₄ mass load contribution ranges between <0.15mg/l (current background concentration) to a maximum of approximately 0.65mg/l, however remains below the EPA safety threshold (2011) of 10.0mg/l.

Figure 13-39 depicts the CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south while **Figure 13-40** depicts the CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east for the post-closure phases.

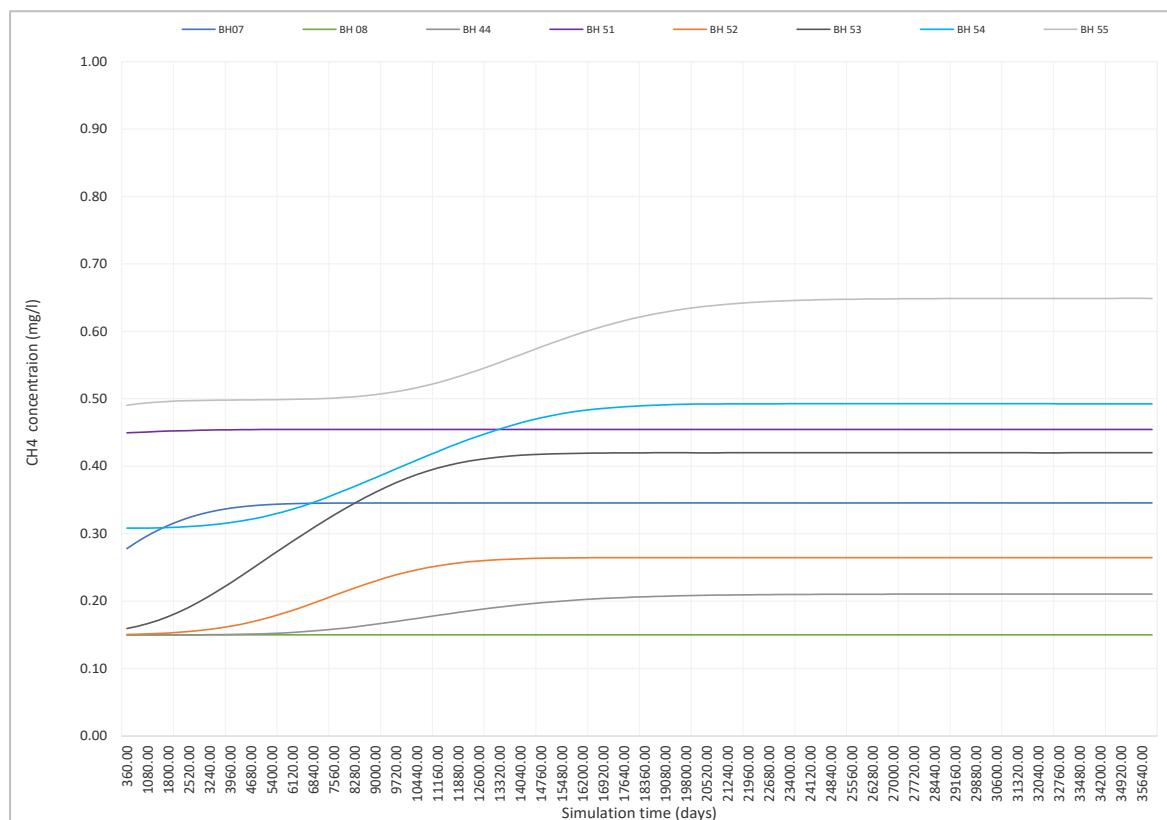


Figure 13-37 Scenario 05: Time-series graph indicating the CH4 mass load contribution of deeper, fractured and saline aquifer on observation boreholes targeting the potable shallow, intergranular aquifer (Post-closure phase).

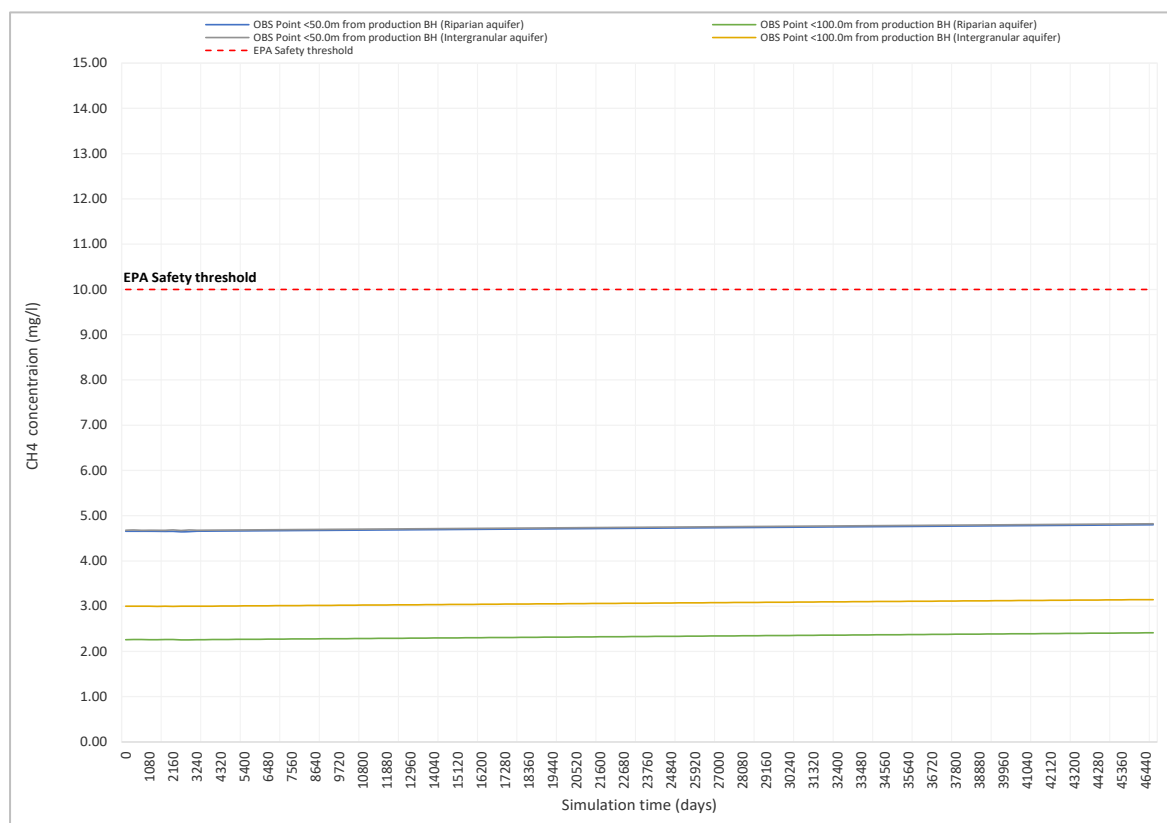


Figure 13-38 Scenario 05: Time-series graph indicating the CH4 mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).

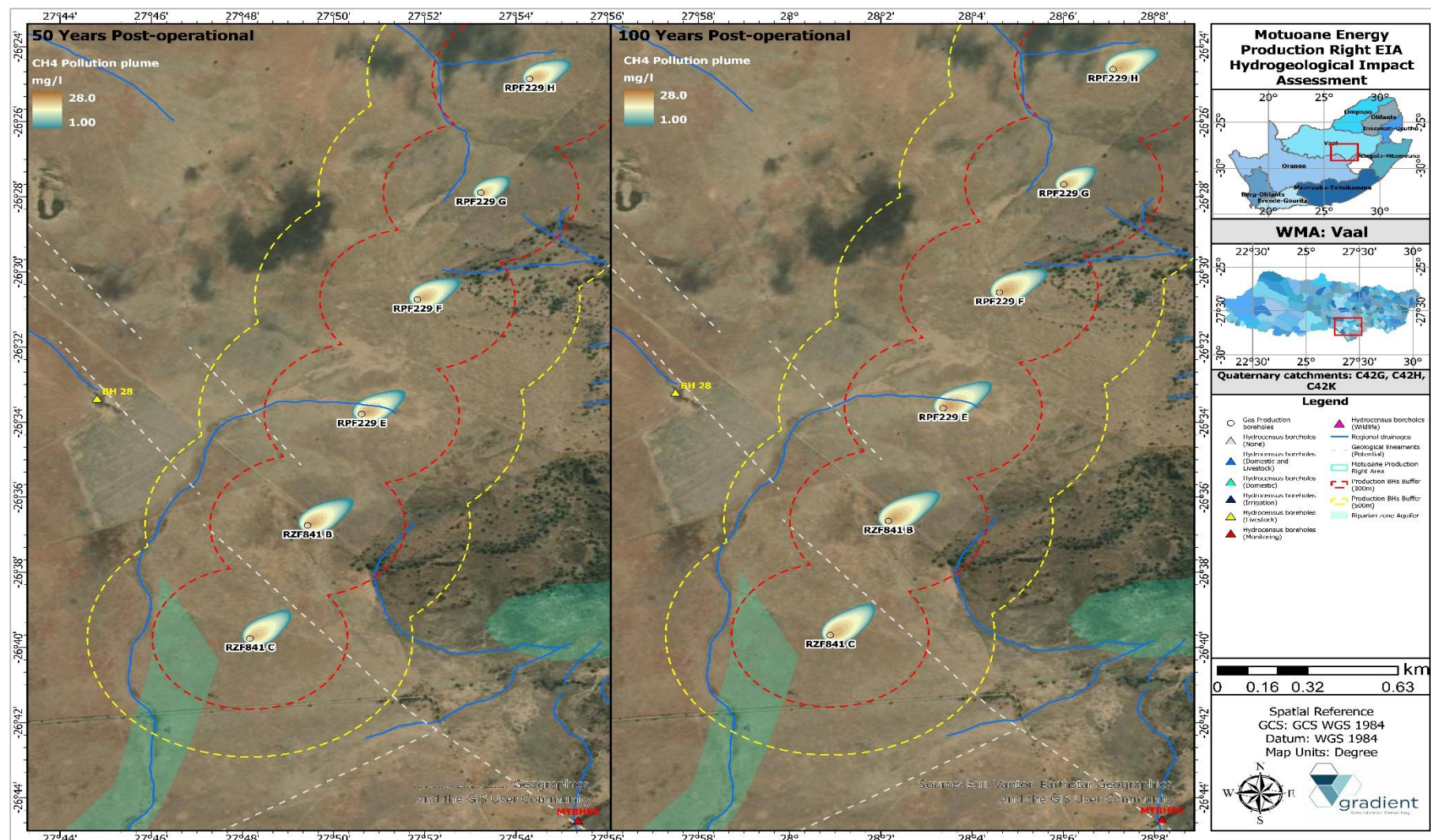


Figure 13-39 Scenario 05: CH₄ pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of production boreholes RZ841 towards the south (Post-closure phase).

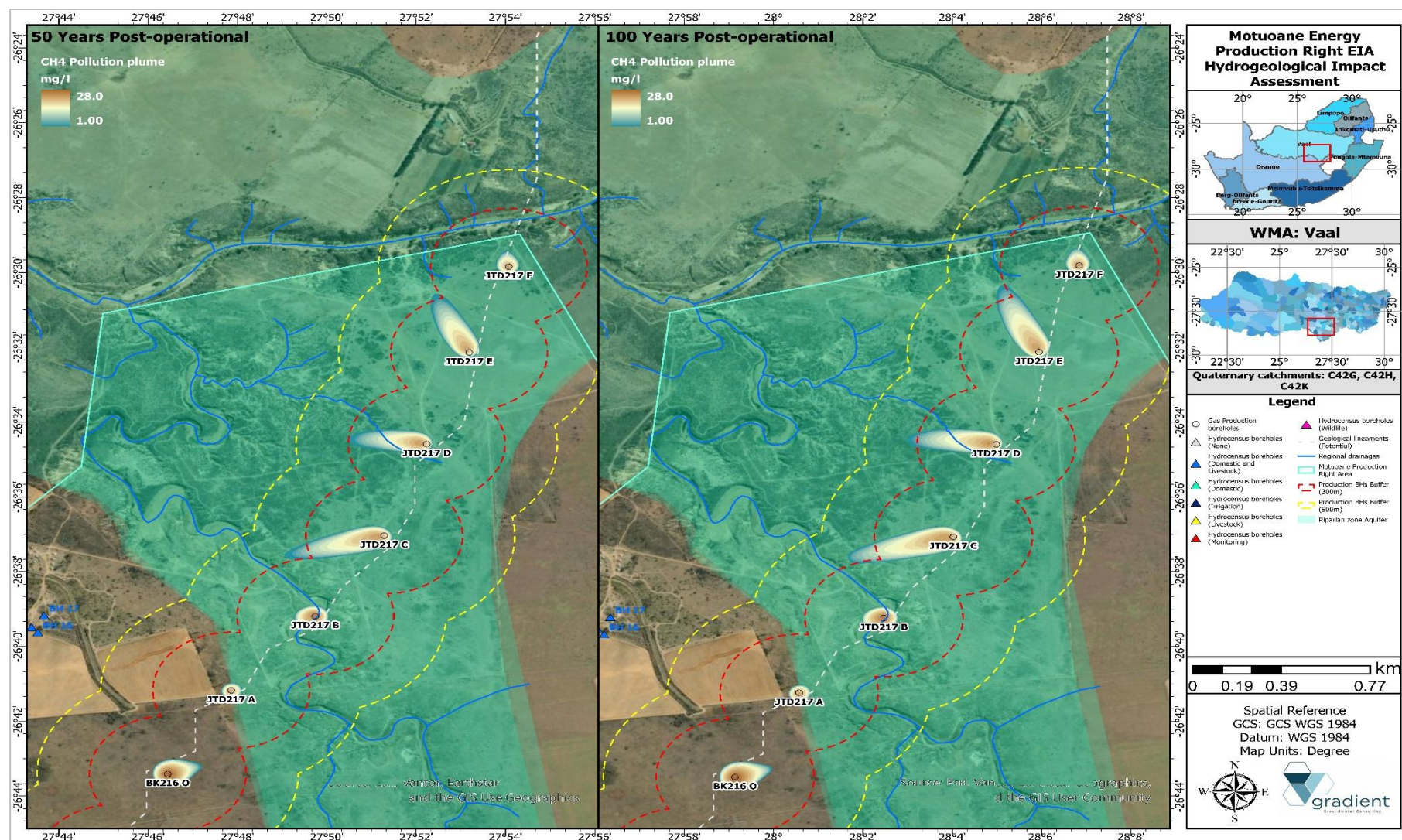


Figure 13-40 Scenario 05: CH4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of production boreholes JTD217 towards the north-east (Post-closure phase).

13.7.6. Scenario 06: Gas processing plant alternative evaluation and site selection

This scenario evaluates the three site alternatives for the proposed processing plant footprint (refer to **Figure 4-3** for reference). **Figure 13-41** depicts a time-series graph indicating the TDS mass load contribution of the potential waste infrastructure to a conceptually positioned receptor within the sensitive riparian zone aquifer for the duration of the operational phase. It can be observed that the TDS mass load contribution ranges between <350.0mg/l (which is the current background value) for Plant locality C, to a maximum of approximately 1700.0mg/l for Plant locality B.

Figure 13-42 indicates the simulated particle tracking of contaminants originating from potential waste infrastructure associated with the proposed gas processing plant for alternative footprints (Operational phase). It can be observed that processing plant locality B suggest the most potential impact on the riparian zone aquifer with processing plant locality C indicating the least potential impact. It should however be noted that processing plant locality C is situated in close proximity to a geological lineament which can serve as a potential mechanism and preferred pathway for groundwater flow and contaminant transport.

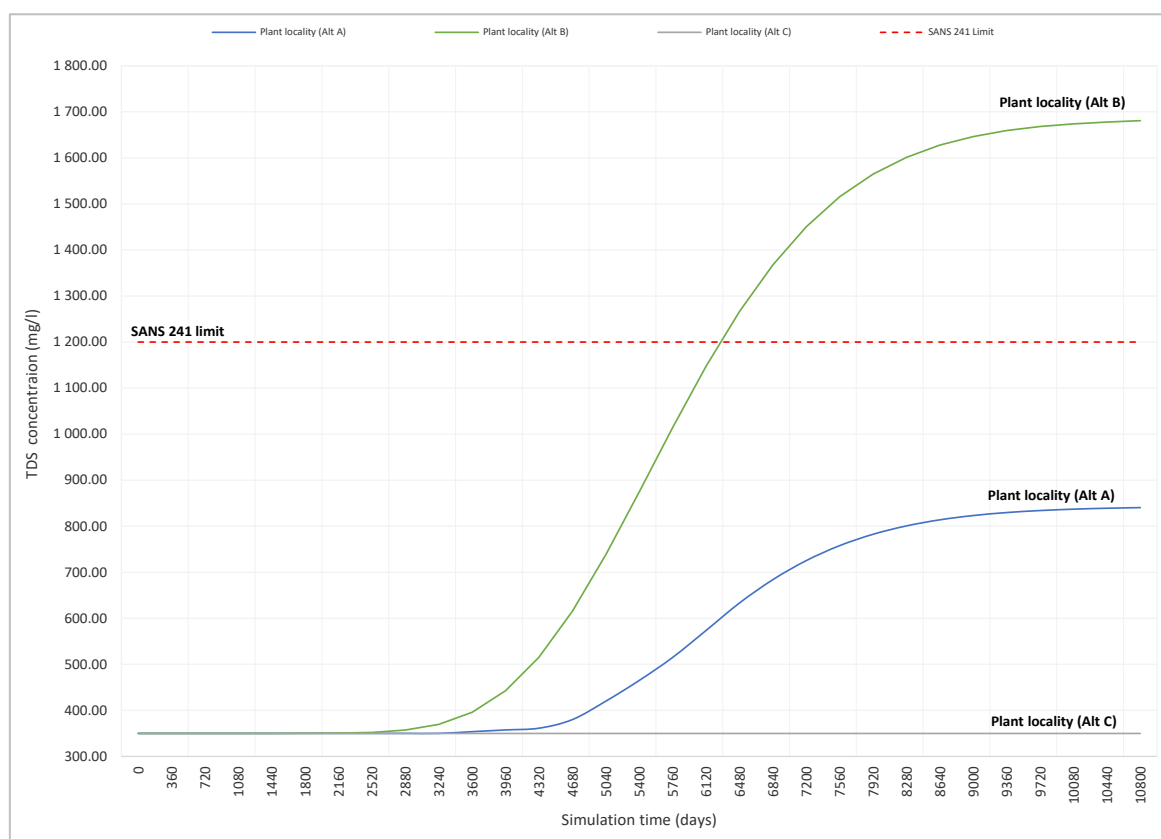


Figure 13-41 Scenario 06: Time-series graph indicating the TDS mass load contribution of the processing plant waste infrastructure to observation boreholes targetting the potable shallow, intergranular aquifer (Operational phase).

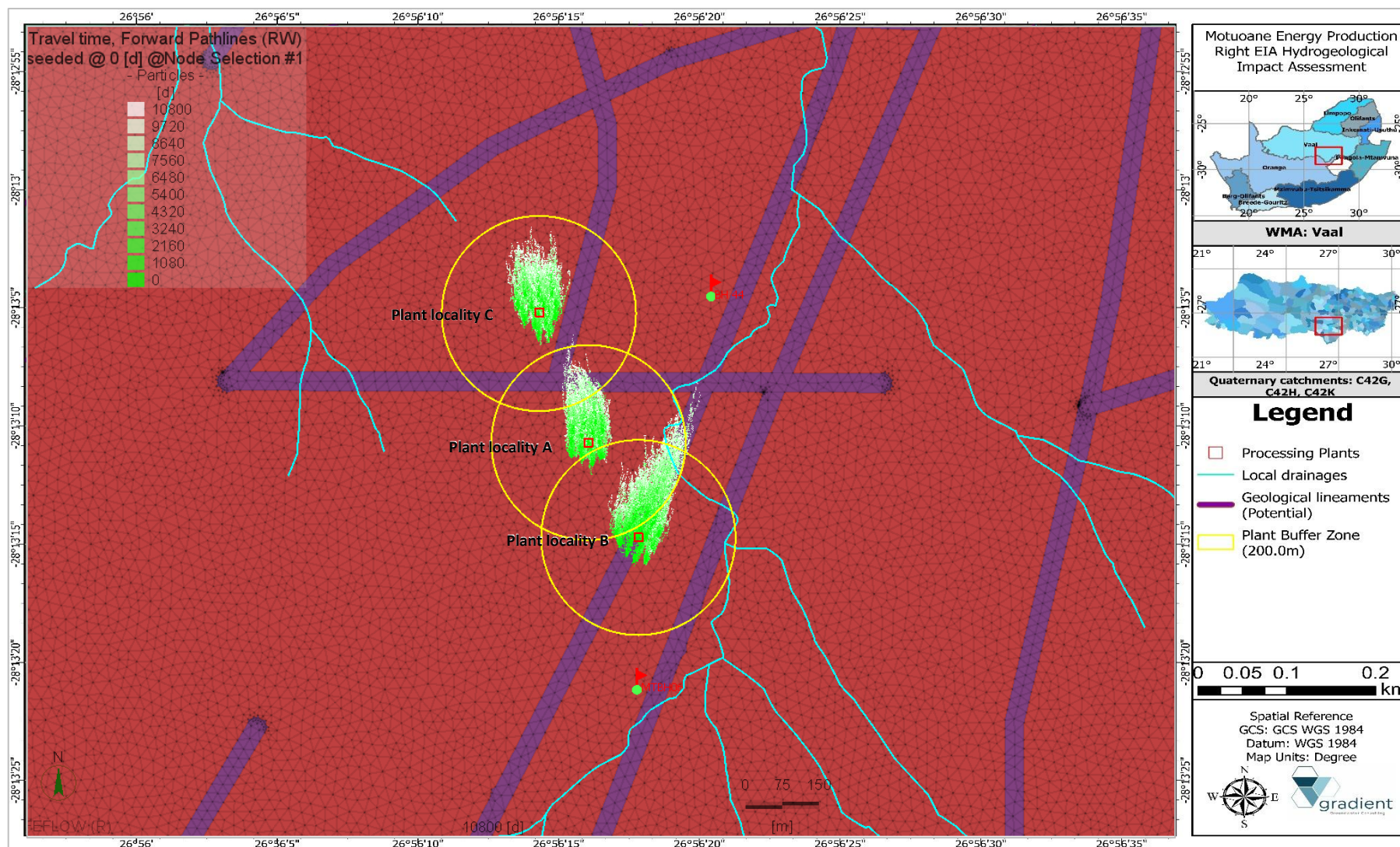


Figure 13-42 Scenario 06: Simulated particle tracking of contaminants originating from potential waste infrastructure associated with the proposed gas processing plant for alternatives footprints (Operational phase).

14. ENVIRONMENTAL IMPACT ASSESSMENT

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

14.1. Methodology

An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human and/or other related activities. The impact significance rating methodology, as presented herein and utilised for all EIMS Impact Assessment Projects, is guided by the requirements of the NEMA EIA Regulations 2014 (as amended). The approach may be altered or substituted on a case-by-case basis if the specific aspect being assessed requires such- such instances require prior EIMS Project Manager approval. The broad approach to the significance rating methodology is to determine the significance (S) of an environmental risk or impact by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relating this to the probability/ likelihood (P) of the impact occurring. The S is determined for the pre- and post-mitigation scenario. In addition, other factors, including cumulative impacts and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the S to determine the overall final significance rating (FS). The impact assessment will be applied to all identified alternatives.

14.2. Determination of Environmental Risk

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

Equation 14-1 Impact Consequence.

$$C = (E + D + M + R)(N4)$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in **Table 14-1** below with **Table 14-2** summarising the probability scorings.

Table 14-1 Criteria for Determining Impact Consequence.

Aspect	Description	Weight
Nature	Likely to result in a negative/ detrimental impact.	-1
	Likely to result in a positive/ beneficial impact.	1
Extend	Activity (i.e. Highly localised, limited to the area applicable to the specific activity).	1
	Site (i.e. within the development property or site boundary, or the area within a few hundred meters of the site).	2
	Local (i.e. beyond the site boundary within the Local administrative boundary (e.g. Local Municipality) or within consistent local geographical features, or the area within 5 km of the site).	3
	Regional (i.e. Far beyond the site boundary, beyond the Local administrative boundaries within the Regional administrative boundaries (e.g. District Municipality), or extends into different distinct geographical features, or extends between 5 and 50 km from the site).	4
	Provincial / National / International (i.e. extends into numerous distinct geographical features, or extends beyond 50 km from the site).	5
Duration	Immediate (<1 year, quickly reversible).	1
	Short term (1-5 years, less than project lifespan).	2
	Medium term (6 – 15 years).	3
	Long term (the impact will cease after the operational life span of the project).	4
	Permanent (>65 years, no mitigation measure of natural process will reduce the impact after construction/ operation/ decommissioning).	5
Magnitude	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected).	1
	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected, or affected environmental components are already degraded).	2
	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way; moderate improvement for positive impacts; or where change affects area of potential conservation or other value, or use of resources).	3
	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease; high improvement for positive impacts; or where change affects high conservation value areas or species of conservation concern), or	4
	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease, substantial improvement for positive impacts; or disturbance to pristine areas of critical conservation value or critically endangered species).	5
Reversibility	Impact is reversible without any time and cost.	1
	Impact is reversible without incurring significant time and cost.	2
	Impact is reversible only by incurring significant time and cost.	3
	Prohibitively high time and cost.	4
	Irreversible impact.	5

Once the C has been determined, the significance is determined in accordance with the standard risk assessment relationship by multiplying the C and the P. Probability is rated/ scored as per **Table 14-2**.

It is noted that both environmental risks as well as environmental impacts should be identified and assessed. Environmental Risk can be regarded as the potential for something harmful to happen to the environment, and in many instances is not regarded as something that is expected to occur during normal operations or events (e.g. unplanned fuel or oil spills at a construction site). Probability and likelihood are key determinants or variables of environmental risk. Environmental Impact can be regarded as the actual effect or change that happens to the environment because of an activity and is typically an effect that is expected from normal operations or events (e.g. vegetation clearance from site development results in loss of species of concern). Typically, the probability of an unmitigated environmental impact is regarded as highly likely or certain (management and mitigation measures would ideally aim to reduce this likelihood where possible). In summary, environmental risk is about what could happen, while environmental impact is about what does happen.

Table 14-2 Probability scoring.

Probability	Improbable (Rare, the event may occur only in exceptional circumstances, the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <5% chance).	1
	Low probability (Unlikely, impact could occur but not realistically expected; >5% and <20% chance).	2
	Medium probability (Possible, the impact may occur; >20% and <50% chance).	3
	High probability (Likely, it is most probable that the impact will occur- > 50 and <90% chance), or	4
	Definite (Almost certain, the impact is expected to, or will, occur, >90% chance).	5

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

Equation 14-2 Significance.

$$S = C \cdot P$$

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25 as summarised in **Table 14-3**. These **ER** scores are then grouped into respective classes as described in **Table 14-4**.

Table 14-3 Determination of Environmental Risk.

Consequence	5 - Very High	5	10	15	20	25
	4 - high	4	8	12	16	20
	3 - Medium	3	6	9	12	15
	2 - Low	2	4	6	8	10
	1 - Very low	1	2	3	4	5

Table 14-4 **Significance classes.**

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

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

14.3. Impact prioritization

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

- i. Cumulative impacts; and
- ii. The degree to which the impact may cause irreplaceable loss of resources.

To ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented. The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in **Table 14-5**.

Table 14-5 Criteria for Determining Prioritisation.

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

The impact priority is therefore determined as follows:

Equation 14-3 Priority.

$$\text{Priority} = CI + LR$$

The result is a priority score which ranges from 3 to 9 and a consequent **PF** ranging from 1 to 2 (Refer to **Table 14-6** below).

Table 14-6 Determination of Prioritisation Factor.

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

In order to determine the final impact significance (**Table 14-7**), the **PF** is multiplied by the **ER** of the post mitigation scoring. The ultimate aim of the **PF** is an attempt to increase the post mitigation environmental risk rating by a full ranking class, if all the priority attributes are high (i.e., if an impact comes out with a medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

Table 14-7 Final Environmental Significance Rating.

Significance Rating	Description
<-25	Very High (Impacts in this class are extremely significant and pose a very high environmental risk. In certain instances, these may represent a fatal flaw. They are likely to have a major influence on the decision and may be difficult or impossible to mitigate. Offset's may be necessary).
<-13.75 to -25	High negative (These impacts are significant and must be carefully considered in the decision-making process. They have a high environmental risk or impact and require extensive mitigation measures).
-8.5 to -13.75	Medium-High negative (i.e. Impacts in this class are more substantial and could have a significant environmental risk. They may influence the decision to develop in the area and require more robust mitigation measures).
<-4.25 to <-8.5	Medium- Low negative (i.e. These impacts are slightly more significant than low impacts but still do not pose a major environmental risk. They might require some mitigation measures but are generally manageable).
-1 to -4.25	Low negative (i.e. Impacts in this class are minor and unlikely to have a significant environmental risk. They do not influence the decision to develop in the area and are typically easily mitigated).
0	No impact
1 to 4.25	Low positive
>4.25 to <8.5	Medium-Low positive
8.5 to 13.75	Medium-High positive
>13.75	High positive

The significance ratings and additional considerations applied to each impact will be used to provide a quantitative comparative assessment of the alternatives being considered. In addition, professional expertise and opinion of the specialists and the environmental consultants will be applied to provide a qualitative comparison of the alternatives under consideration. This process will identify the best alternative for the proposed project. **Figure 14-1** depicts the hydrogeological sensitive areas identified.

14.4. Impact Identification and significance ratings

Potential impacts associated with different project phases are briefly discussed below.

14.4.1. Construction phase: Associated activities and impacts

Refer to **Table 14-8** for a summary of the impact risk matrix and significance ratings for the construction phase. During the construction phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures. The main impacts associated with the construction phase activities include the following:

- i. Site clearing and vegetation removal may cause increased turbidity and sediment loads in groundwater.
- ii. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads into recharge areas.
- iii. Poor quality leachate including sewage and domestic wastewater emanating from the construction camp may have a negative impact on groundwater quality.
- iv. Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.

- v. Borehole drilling can introduce various potential contaminants including drilling muds/additives and hydrocarbons into host-aquifers which may have a detrimental effect on the water quality.
- vi. Drilling activities can disturb sediments and may result in silt formation in groundwater and can cause siltation within the potable water aquifer.
- vii. Encountering of major water strikes and blow-out during the drilling process may reduce local groundwater levels.
- viii. Groundwater pollution as a result of produced formation water or wastewater spills and seepage from drilling sumps.
- ix. Handling of borehole drilling chips may pose a risk to groundwater contamination.
- x. Borehole construction in terms of casing installation and concrete works might have a negative impact on groundwater quality.
- xi. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
- xii. Anthropogenic activities and movement related to the construction phase can cause potential groundwater pollution.
- xiii. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.
- xiv. Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.
- xv. Unplanned releases of formation water.
- xvi. Unplanned event such as well explosion can release saline formation water and gasses.

Table 14-8 Impact assessment and significance rating: Construction phase summary.

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
1	Site clearing and vegetation removal may cause increased turbidity and sediment loads in groundwater. Sediment loads may potentially be transported by drainages systems regionally, however will only last for the construction phase of the project. This impact will potentially be reversible only by incurring significant time and costs and has a low probability (pre-mitigation) and improbable probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-5.5	Medium to low -	-2	Low -	2	3	1.38	-2.75	Low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
2	Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads into recharge areas. Contaminated stormwater may potentially be transported by drainages systems regionally, however will only last for the construction phase of the project. This impact will potentially be reversible only by incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-8.25	Medium to low -	-4	Low -	2	3	1.38	-5.50	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
3	Poor quality leachate including sewage and domestic wastewater emanating from the construction camp may have a negative impact on groundwater quality. Contaminants originating from domestic wastewater and sewage may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-6.75	Medium to low -	-3	Low -	2	3	1.38	-4.13	Low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
4	Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources. Hydrocarbon pollutants originating from heavy vehicles and drilling rigs may potentially reach the regional, potable water aquifer, however will only last for the construction phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-9.75	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
5	Borehole drilling can introduce various potential contaminants including drilling muds/additives and hydrocarbons into host-aquifers which may have a detrimental effect on the water quality. These contaminants may reach the local potable water aquifer however will only last for the construction phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-12	Medium to high -	-6	Medium to low -	2	3	1.38	-8.25	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
6	Drilling activities can disturb sediments and may result in silt formation in groundwater and can cause siltation within the potable water aquifer. These sediments may reach the local potable water aquifer however will only last for the construction phase of the project. This impact will potentially be reversible only by incurring significant time and costs and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-10	Medium to high -	-6	Medium to low -	2	3	1.38	-8.25	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
7	Encountering of major water strikes and blow-out during the drilling process may reduce local groundwater levels. Removal of water from storage may negatively impact on the local potable water aquifer however will only last for the construction phase of the project. This impact will potentially be reversible only by incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated low as there is a low probability that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-6.75	Medium to low -	-3.5	Low -	2	3	1.38	-4.81	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
8	Groundwater pollution as a result of produced formation water or wastewater spills and seepage from drilling sumps. Contaminants originating from wastewater spills and drilling sumps may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-12	Medium to high -	-6	Medium to low -	2	3	1.38	-8.25	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
9	Handling of borehole drilling chips may pose a risk to groundwater contamination. Contaminants originating from the drilling chips may potentially reach the site, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-6.75	Medium to low -	-2.5	Low -	2	3	1.38	-3.44	Low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
10	Borehole construction in terms of casing installation and concrete works might have a negative impact on groundwater quality. Contaminants originating from the concrete works may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-11	Medium to high -	-5.25	Medium to low -	2	3	1.38	-7.22	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
11	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution. Contaminants originating from hazardous chemical substances may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-8.25	Medium to low -	-3.5	Low -	2	3	1.38	-4.81	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
12	Anthropogenic activities and movement related to the construction phase can cause potential groundwater pollution. Contaminants originating from anthropogenic activities may potentially reach the regional, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-12	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
13	Groundwater pollution as a result of contact with drilling fluids, additives and lubricants. Contaminants originating from drilling fluids and additives may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-12	Medium to high -	-7.5	Medium to low -	2	3	1.38	-10.31	Medium to high -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
14	Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out. Contaminants originating from saline water may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a high probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-11	Medium to high -	-6	Medium to low -	1	3	1.25	-7.50	Medium to low -
15	Unplanned releases of formation water. Contaminants originating from deeper, formation water may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a low probability (pre-and post-mitigation) of occurring. The cumulative impact is rated low as it is improbable that formation water will be encountered simultaneously. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-5	Medium to low -	-3	Low -	1	3	1.25	-3.75	Low -

Identifier	Impact	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
16	Unplanned event such as well explosion can release saline formation water and gasses. Contaminants originating from deeper, formation water may potentially reach the local, potable water aquifer, however will only last for the construction phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a low probability (pre-and post-mitigation) of occurring. The cumulative impact is rated low as it is improbable that formation water will be encountered simultaneously. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-5	Medium to low -	-3	Low -	1	3	1.25	-3.75	Low -

14.4.2. Operational phase: Associated activities and impacts

Refer to **Table 14-9** for a summary of the impact risk matrix and significance ratings for the operational phase. During the operational phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. The main impacts associated with the operational phase activities include the following:

- i. Inadequate casing or cementing can create a vertical flow pathway between different aquifers/ hydrostratigraphical units or between the production zone and potable aquifer.
- ii. Migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- iii. Upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- iv. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
- v. Gas production can alter pressure differences and alter hydraulic gradients between different hydrostratigraphical units resulting in modification of local groundwater flow pathways.
- vi. Poor quality leachate may emanate from the gas production zone which may have a negative impact on groundwater quality.
- vii. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
- viii. Operation and maintenance of heavy vehicles as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
- ix. Leaking pipelines may cause contamination of groundwater resources.

Table 14-9 Impact assessment and significance rating: Operational phase summary.

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
1	Inadequate casing or cementing can create a vertical flow pathway between different aquifers/ hydrostratigraphical units or between the production zone and potable aquifer. Contaminants originating from the deeper, saline aquifer may potentially reach the local, potable water aquifer which can last for the duration of the operational phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
2	Migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers. Contaminants originating from wastewater spills and drilling sumps may potentially reach the local, potable water aquifer, which can last for the duration of the operational phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-4.5	Medium to low -	3	3	1.50	-6.75	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
3	Upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers. Stray gas originating from the deep aquifer may potentially reach the local, potable water aquifer which can last for the duration of the operational phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
4	Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area. This impact can last for the duration of the operational phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
5	Gas production can alter pressure differences and alter hydraulic gradients between different hydrostratigraphical units resulting in modification of local groundwater flow pathways. This impact can last for the duration of the operational phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
6	Poor quality leachate may emanate from the gas production zone which may have a negative impact on groundwater quality. Contaminants originating from the gas production zone may potentially reach the local, potable water aquifer which can last for the duration of the operational phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-9.75	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
7	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution. Contaminants originating from hazardous chemical substances may potentially reach the local, potable water aquifer which can last for the duration of the operational phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-9.75	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
8	Operation and maintenance of heavy vehicles as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources. Hydrocarbon pollutants originating from heavy vehicles and drilling rigs may potentially reach the regional, potable water aquifer which can last for the duration of the operational phase of the project. This impact will potentially be reversible without incurring significant time and costs and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-10.5	Medium to high -	-5	Medium to low -	2	3	1.38	-6.88	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
9	Leaking pipelines may cause contamination of groundwater resources. Pollutants originating from the pipeline infrastructure may potentially reach the regional, potable water aquifer however which will last for the duration of the operational phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-10.5	Medium to high -	-5	Medium to low -	2	3	1.38	-6.88	Medium to low -

14.4.3. Post-operational and decommissioning phase: Associated activities and impacts

Refer to **Table 14-10** for a summary of the impact risk matrix and significance ratings for the post-operational and decommissioning phase. During the decommissioning phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. The main impacts associated with the operational phase activities include the following:

- i. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
- ii. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing an upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
- iii. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
- iv. Poor quality leachate may emanate from production zone footprint areas which may have a negative impact on groundwater quality.
- v. De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
- vi. Site de-establishment and removal of infrastructure can potentially cause increased turbidity and sediment loads in groundwater.
- vii. Legacy groundwater contamination i.e., historical spills and leakages can contribute to continued groundwater-quality deterioration during the post-closure phase.

Table 14-10 Impact assessment and significance rating: Decommissioning phase summary.

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
1	Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers. Saline water may potentially reach the regional, potable water aquifer which may have a long-term impact and will continue through the decommissioning phase. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
2	Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing an upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers. Formation gas may potentially reach the regional, potable water aquifer which may have a long-term impact and will continue through the decommissioning phase. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
3	Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area. This impact may potentially have a negative effect on the regional, potable water aquifer which may have a long-term impact and will continue through the decommissioning phase. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated high as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-14	High -	-7.5	Medium to low -	3	3	1.50	-11.25	Medium to high -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
4	Poor quality leachate may emanate from production zone footprint areas which may have a negative impact on groundwater quality. Poor quality leachate may potentially reach the regional, potable water aquifer which may have a long-term impact and will continue through the decommissioning phase. The reversibility of this impact may potentially be prohibitively high time and cost and has a medium probability (pre-mitigation) and a low probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-9.75	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
5	De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources. Hydrocarbon pollutants originating from heavy vehicles and drilling rigs may potentially reach the regional, potable water aquifer however will only last for the de-mobilisation period of the decommissioning phase of the project. The reversibility of this impact may potentially be prohibitively high time and cost and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-13	Medium to high -	-4.5	Medium to low -	2	3	1.38	-6.19	Medium to low -

Identifier	Impact	Pre-Mitigation Significance	Pre-Mitigation Significance	Post-mitigation Significance Score	Post-Mitigation Significance	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
6	Site de-establishment and removal of infrastructure can potentially cause increased turbidity and sediment loads in groundwater. Sediment loads may potentially be transported by drainages systems regionally, however will only last for the de-establishment period of the decommissioning phase of the project. This impact will potentially be reversible only by incurring significant time and costs and has a high probability (pre-mitigation) and a medium probability (post-mitigation) of occurring. The cumulative impact is rated medium as it is probable that this impact may result in a spatial and temporal cumulative change. The value of the resource being impacted on is rated as high due to the shallow aquifer being used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon.	-9	Medium to high -	-3.75	Low -	2	3	1.38	-5.16	Medium to low -

14.4.4. Associated activities and cumulative impacts

A cumulative impact can be defined as a historical impact, current impact as well as reasonably foreseeable future activities and impacts which may become significant when combined with impacts from similar or different activities. The greater study area is characterised by existing agricultural activities, mining developments including associated infrastructure, existing gas exploration and production activities as well as renewable energy developments. As the gas production activities do not require significant groundwater abstraction, the main cumulative impact(s) will focus on groundwater quality. Agricultural activities can introduce several contaminant sources such as nitrate, phosphates, pesticides as well as hydrocarbons whereas mining activities can also introduce contaminants such as sulphates, metals, acidity, salinity as well as hydrocarbons. Hydrocarbons and sediments originating from renewable energy developments is also potential water quality risks while gas exploration and production operations may introduce contaminants such as drilling fluids, hydrocarbons, produced formation water as well as potential formation gasses. If the latter occur within the same aquifer unit, the cumulative effect can be substantial with progressive degradation of groundwater quality a major risk. It should be noted that the deep, saline aquifer is separated from the potable water aquifer by competent confining formations, and if gas wells are properly constructed and sealed, the incremental groundwater contribution of the gas development will be relatively low, even though the broader area has substantial cumulative development pressure taking into account all other sectors currently active.



Figure 14-1 Hydrogeological sensitivity map.

15. GROUNDWATER MANAGEMENT PLAN

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

15.1. Potential impacts and associated risks

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

- i. Inadequate casing or cementing can create a vertical flow pathway between different aquifers/ hydrostratigraphical units or between the production zone and potable aquifer.
- ii. Gas production can alter pressure differences and alter hydraulic gradients between different hydrostratigraphical units resulting in modification of local groundwater flow pathways.
- iii. Upward migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- iv. Upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
- v. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
- vi. Hydrocarbon contamination of groundwater resources caused by heavy vehicles, drilling rigs as well as associated machinery on-site may cause hydrocarbon contamination or other petroleum products of groundwater resources.
- vii. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants used in the drilling mud sump(s) to the intergranular, potable aquifer(s) during the construction as well as operational phases.

15.2. Key responsibilities

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

- i. The Licensee shall appoint a suitably qualified and responsible person to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.
- ii. An ECO must be appointed to oversee the rehabilitation phase and ensure least possible harm to biodiversity and ensure compliance to the rehabilitation plan.
- iii. Compile annual reports that will be submitted to the applicable regulatory authorities.
- iv. Annual external audits should be conducted to ensure that waste facilities are maintained and functioning effectively and according to licence conditions.
- v. Any water use activity exercised in terms of Section 21 of the National Water Act (Act 36 of 1998) should be authorised.
- vi. Listed environmental activities should be authorised in terms of the National Environmental Management Act (Act 107 of 1998).

15.3. Mitigation and management

It should be noted that area ER315, which overlapped (now is adjacent to this proposed production right area), operates under an approved EMPr with associated mitigation and management measures included. Accordingly, any mitigation and management measures listed below which is already in the approved EMPr, should be taken note of, however should not be included in the new EMPr (refer to Appendix F). To follow is a brief description of mitigation and management measures to be implemented per phase.

15.3.1. Construction phase: Management and mitigation measures

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

- i. Pre-development monitoring can be considered in order to formulate a baseline to serve as benchmark going forward. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.
- ii. Areas where vegetation have been cleared such as drilling pads shall be rehabilitated as soon as possible to minimise erosion. Erosion control measures should be put in place where it is deemed necessary **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- iii. Clean surface water runoff to be diverted around disturbed areas and discharged to the downstream catchment zones.

- iv. Develop and implement a stormwater management plan in accordance with GN704 to separate dirty/contact water from clean water circuits.
- v. Location of construction camps must be carefully considered and within the approved area to ensure that the site does not impact on sensitive areas identified during the Environmental Assessment phase or field work **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- vi. Sites must be located, where possible, on previously disturbed areas and every effort must be made to keep the footprint as small as possible.
- vii. Should drilling within the riparian zone and primary porosity aquifer be necessary, pitless drilling must be undertaken in order to minimise potential contamination of this sensitive groundwater receptor.
- viii. All construction should take place during the sunny days, as far as possible. Should activities be undertaken during rainy days, additional measures should be implemented in consultation with the ECO **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- ix. Any excess sand, stone and cement must be removed or reused from site on completion of the construction period and disposed at a registered disposal facility. Certificates of safe disposal for general and recycled waste must be maintained and retained on file **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- x. Hazardous substance containment facilities to be used during construction phase should comply with the relevant hazardous substance storage legislation to ensure spillages are contained **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xi. All hazardous substances used on-site should have an applicable Safety Data Sheet (SDS) to provide information regarding the hazards, emergency response, protective measures and correct storage methodology.
- xii. All hazardous substances and material used on-site should be stored in a dedicated, closed-off facility with an impervious floor and bunded area to prevent seepage and/or run-off in case of accidental spills **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xiii. The use of all materials, fuels and chemicals which could potentially leach into groundwater must be controlled.
- xiv. Construction vehicles and machines must be serviced and maintained regularly to ensure that oil spillages are limited **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xv. Workshop areas must be monitored for oil and fuel spills **(This mitigation measure is included in the approved EMPr for exploration area ER315).**

- xvi. Drip trays must be provided if refuelling of construction vehicles is done on site. Further to this, spill kits must be readily available in case of accidental spillages **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xvii. Employees must be trained in terms of emergency response towards bulk chemical and hydrocarbon spillages.
- xviii. An appropriate number of spill kits must be available and must be in all areas where activities are being undertaken.
- xix. Leaking equipment must be repaired immediately or be removed from site to facilitate repair.
- xx. An integrated groundwater monitoring program should be developed and implemented to ensure that groundwater monitoring is conducted and to formulate groundwater baseline conditions to be used as benchmark for future comparison.

15.4. Operational phase: Management and mitigation measures

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

- i. It is recommended that the monitoring program and network as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated on a bi-annual basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.
- ii. Prior to drilling of the proposed production borehole targets, an updated hydrocensus user survey should be conducted within a 500.0m buffer zone at target areas where limited boreholes were surveyed to identify any potential groundwater receptors or privately owned boreholes being utilised. It should be noted that a hydrocensus surveys was conducted as part of this investigation to cover the majority of buffer zone areas, however an updated survey is recommended in order to verify any newly established borehole positions and will be used to substitute the existing database.
- iii. Additional monitoring boreholes in close proximity to drilling targets should be established in order to formulate a groundwater baseline to be applied as benchmark for potential groundwater impacts.
- iv. If significant gas is encountered during drilling, respective boreholes should be sealed-off with a combination of casing and grouting to ensure isolation of the gas from the host-aquifer(s). Well design will be undertaken according to designs developed by a qualified well engineer.
- v. Any open boreholes may continue acting as preferential flow conduits between the deeper, saline and shallow, potable water aquifer. Accordingly, abandoned boreholes should be sealed off with a combination of casing and grouting **(This mitigation measure is included in the approved EMPr for exploration area ER315).**

- vi. Daily inspections of drilling pads must be implemented and operated according to best practise guidelines.
- vii. All geological core samples should be removed and borehole drilling pads should be cleaned and mud sumps rehabilitated **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- viii. Cut of trench and berm must be constructed around the drill pad to prevent contaminated surface runoff from entering shallow aquifers and surrounding water resources **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- ix. Heavy vehicles and machinery must be serviced and maintained regularly to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- x. Hazardous substance containment facilities to be used during operational phase should comply with the relevant hazardous substance storage legislation to ensure spillages are contained **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xi. Develop and implement a stormwater management plan in accordance with GN704 to separate dirty/contact water from clean water circuits. All water retention structures, stormwater dams and drilling sumps etc. should be constructed to have adequate freeboard (0.8m below overflow level) to be able to contain water from 1:50 year rain events.
- xii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair.
- xiii. A rehabilitation plan must be developed based on site-specific issues and requirements including soft and hard engineering interventions and revegetation. A rehabilitation plan must be developed based on site-specific issues and performed in accordance to best practise guidelines and guided by the closure and rehabilitation plans **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xiv. All actively used drill mud sumps should be adequately liner with an appropriate barrier system to isolate and prevent seepage of contaminants to the host aquifer. Furthermore, a biodegradable polymer should be used as drilling lubricant **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- xv. All drilling fluids/polymers should be removed from the borehole as far as possible to prohibit possible bacterial contamination of the borehole and aquifer **(This mitigation measure is included in the approved EMPr for exploration area ER315).**

- xvi. Geological logs and data recording should include major water strikes and depths, water loss or water make volumes and depths as well as blow yields if applicable. Should water from the deeper, fractured aquifer be encountered, a sample should be collected to be subjected for inorganic testing as well as isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.
- xvii. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed gas production drilling be recorded along with associated water levels and hydrochemistry and incorporated into an updated groundwater database for future reference.
- xviii. The existing conceptual model should be refined with newly gathered geological data and the groundwater flow model recalibrated with updated time-series monitoring data on a biennial basis to be applied as water management tool. Scenario predictions and model simulations should be conducted and interpreted by an external and independent specialist.

15.5. Post-operational and decommissioning phase: Management and mitigation measures

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

- i. In the event that the casing and/or cementation in a well failure, the well can become a high-permeability conduit for saline water and stray gas from deep-seated formations to the overlying shallow Karoo aquifers. All production wells should be sealed-off with a combination of casing and grouting to ensure isolation of the gas from the host-aquifer(s).
- ii. Sealed off boreholes should also be equipped with gas-detection equipment and monitored throughout the decommissioning phase in order to serve as an early warning for potential stray gas migration into the shallow, potable aquifer.
- iii. The contractor should prepare a consolidated site-specific closure/sealing plan to be submitted to relevant authorities as part of the post-closure plan and certificate for approval. The plan should include a detailed description of the following aspects:
 - Calliper Logging should be conducted to identify and investigate potential blockages/cavities within well.
 - Cement Bond Logging should be performed to investigate the current integrity of the casing and cementation.
 - Contractor to determine the most suitable and appropriate closure, sealing and rehabilitation strategy with specific focus on the plugging method to ensure no vertical gas and/or fluid movements within the well.
 - Contractor to prepare a consolidated site-specific closure/sealing plan to be submitted for approval.

- Develop cement formulation for cementing the entire well annulus.
- Develop cement formulation to top-up “no bond” or “poor bond” cemented sections between casing and formation walls – ensure cement seals and does not disperse into porous formations.
- Cement formulations and volumetric calculations to be approved by well engineer/cement specialist.
- Contractor must ensure cement mixture seals the entire well length along the well annulus. Cement plugs must be stacked along the full length and diameter of the well to surface (open hole section above the packer as well as the upper casing) to ensure efficient redundancy.
- All plugs must be tagged to ensure successful placement.
- Cementation extent: Should be from end of hole (bottom of well) to surface.
- Cementation technique: Squeeze technique - this displacement method minimizes the contamination of the cement by being able to displace fluid within the well, thus allowing for a more stable well plug. Contractor must also make use of wiper plugs for cement displacement.
- Contractor to conduct cement top-ups along the annulus and existing cemented sections showing “no bond” or “poor bond” from logging results.
- A surface / shallow cement plug (+/- 50m below ground Level) must be set, and the well casing must be cut and capped 1 m below ground level to remove the wellhead and all casing above this point.
- Integrity of the plugs must be confirmed by setting weight down on the upper most plug (using the drill string) as well as a differential pressure test for 4 hours at determined pressure with less than 10% bleed over the period. Pressure test data to be captured in 15-minute intervals for the entire 4-hour testing period.
- Contractor to prepare a comprehensive project report containing the following:
 - o Calliper and CBL logging results;
 - o Cement formulations and Material Safety Datasheets of all additives;
 - o Cementation methodology and photographs;
 - o Recorded pressure test data;
 - o Well tagging photographs and coordinates;
 - o Surface rehabilitation photographs.

- iv. Well-specific plugging requirements should be implemented to protect the shallow potable Karoo aquifers at closure. The integrity of the seals will be pressure tested before the well decommissioning can be signed off.
- xix. Mixing and pouring of cement and grouting should take place on a temporary impermeable layer or in a container to avoid spillage **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- v. A surface casing vent flow test should be conducted to determine whether gas or liquid or a combination thereof is escaping from the casing. If gas is detected during this test, additional seals should be designed and implemented.
- vi. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures.
- vii. A rehabilitation plan must be developed based on site-specific issues and performed in accordance to best practise guidelines and guided by the closure and rehabilitation plans **(This mitigation measure is included in the approved EMPr for exploration area ER315).**
- viii. All preferred groundwater flow pathways which are in direct connection with surface topography i.e., unrehabilitated boreholes should be sealed off and rehabilitated according to best practise guideline.
- ix. It is expected that post-closure the generated pollution plume and local groundwater contamination footprint will decay and be diluted by rainfall recharge, however the lasting effect and subsequent impact on neighbouring borehole qualities should be monitored with alternative water supply sources or compensation measures available for nearby users if impacted on.

16. MONITORING

A monitoring program consists of taking regular measurements of the quantity and/or quality of a water resource at specified intervals and at specific locations to determine the chemical, physical and biological nature of the water resource and forms the foundation on which water management is based. Monitoring programmes are site-specific and need to be tailored to meet a specific set of needs or expectations. DWA's Best Practice Guideline – G3: Water Monitoring Systems (DWA, 2006), as illustrated in **Figure 16-1** used as guideline for the development of this water monitoring program.

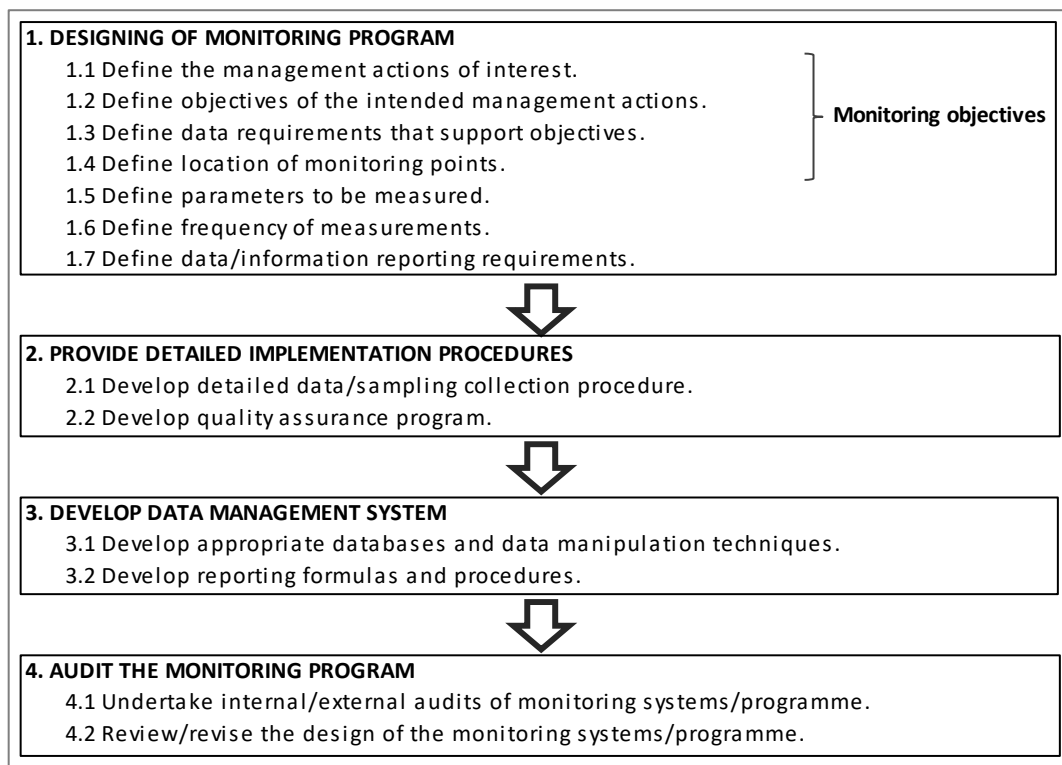


Figure 16-1 Monitoring programme (DWA, 2006).

16.1. Monitoring Objectives

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

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

16.2. Monitoring network

Table 16-2 summarises the proposed monitoring network with relevant information while **Figure 16-2** indicating a spatial distribution map of the monitoring localities in relation associated activities. It is recommended that additional monitoring boreholes be strategically placed in close proximity to proposed production zones in order to serve as early warning system for potential water level and water quality impacts which may arise. The monitoring network includes privately owned boreholes situated in close proximity to proposed production borehole drilling targets, newly drilled site characterisation boreholes as well as newly proposed monitoring localities to be incorporated into the monitoring network. It should be noted that newly proposed monitoring borehole positions proposed are conceptual only should be refined in consultation with a suitably qualified hydrogeologist by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms. Depending on the outcome of the geophysical survey, proposed boreholes can be established as a pair in order to target the shallow, intergranular or primary porosity as well as fractured aquifer units should it be applicable.

16.3. Determinants for analysis

Baseline and background water quality results should be evaluated to set a site-specific limit per parameter and applied as benchmark for monitoring purposes. The latter should also include a dissolved gas analyses in order to formulate a pre-development baseline for future reference. Refer to Table 16-1 to be used as early-warning thresholds. 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 forward¹⁷. Chemical variables to form part of the sampling run are listed below. Groundwater monitoring boreholes should be analysed for the following chemical constituents:

- i. **Physical and aesthetic determinants:** pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Hardness.
- ii. **Macro determinants:** Total Alkalinity (Malk + PAlk), Sulphate (SO₄), Nitrate (NO₃), Chloride (Cl), Fluoride (F), Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na).
- iii. **Micro determinants:** Aluminium (Al), Iron (Fe), Manganese (Mn), Cadmium (Cd), Total Chromium (Cr), Chromium (6⁺), Cyanide (CN), Arsenic (As), Copper (Cu), Uranium (U), Radon, Nickel (Ni), Lead (Pb), Cobalt (Co) and Zinc (Zn), dissolved Methane (CH₄), dissolved Ethane (C₂H₆).
- iv. **Organic determinants:** Total Oil and Grease, Dissolved Organic Carbon (DOC), Total Organic Carbon (TOC), Total Petroleum Hydrocarbons (TPH), GRO C6-C10, TPH C28-C40.

¹⁷ 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.

Table 16-1 Current background water quality.

Determinant	Unit	Risk	SANS 241:2015 limits	Regional background value
General parameters				
pH	-	Operational	$\geq 5.0 \leq 9.5$	7.94
EC	mS/m	Aesthetic	≤ 170.0	67.46
TDS		Aesthetic	$\leq 1\ 200.0$	387.73
Total Alkalinity	CaCO ₃ /l	-	-	289.84
Total Hardness	mg/l	-	-	248.87
Anions				
Cl	mg/l	Aesthetic	≤ 300.0	21.63
SO ₄	mg/l	Acute health	≤ 500.0	38.16
F	mg/l	Acute health	≤ 1.50	0.29
NO ₃ < N	mg/l	Acute health	≤ 12.0	3.76
PO ₄	mg/l	Acute health	≤ 5.0	0.06
NH ₃	mg/l	Acute health	≤ 1.5	1.10
Cations and metals				
Na	mg/l	Aesthetic	≤ 200.0	58.73
K	mg/l	Aesthetic	≤ 50.0	4.63
Ca	mg/l	Aesthetic	≤ 150.0	44.20
Mg	mg/l	Operational	70.0	33.63
Ba	mg/l	Operational	0.7	0.05
B	mg/l	Operational	2.4	0.09
Cd	mg/l	Operational	0.003	<0.002
Cr ⁶⁺	mg/l	Operational	0.05	<0.02
Cu	mg/l	Operational	2.00	<0.01
Pb	mg/l	Operational	0.01	<0.01
Hg	mg/l	Operational	0.006	<0.003
Al	mg/l	Operational	0.3	<0.01
Fe	mg/l	Acute health	2.0	0.08
Mn	mg/l	Operational	0.4	0.06
As	mg/l	Acute health	0.01	<0.009
CN	mg/l	Acute health	0.2	<0.01
U	mg/l	Acute health	0.015	<0.01
Zn	mg/l	Acute health	5.0	0.01

16.4. Water levels

Water levels should be monitored to evaluate the potential impact of production borehole drilling on aquifer storage and replenishment including privately owned, neighbouring boreholes.

16.5. Monitoring frequency

Groundwater monitoring, i.e., water level measurements and water quality analysis should be conducted on a monthly basis at dedicated monitoring boreholes. Water quality monitoring can be decreased to quarterly intervals once the drilling phase is concluded and the production phase is initiated, however this should be implemented only if the water quality results do not suggest an increasing trend in determinants analysed. Water level and water quality monitoring at privately owned boreholes situated within the target areas buffer zone should be conducted on a biannual basis (after the wet and dry rainy seasons). Water quality reports summarising monitoring results should be submitted to the Regional Head of the Department within timeframes as stipulated in the WUL conditions.

16.6. Sampling procedure

The sampling procedure for groundwater should be done according to the protocol by Weaver, 1992. It should be noted that the sampling procedure refers to basic inorganic groundwater quality analysis, and more specific sampling protocols may be required for dissolved gasses and/or hydrocarbon sampling. The actions can be summarised as follows:

- i. Calibrate the field instruments before every sampling run. Read the manufacturers manual and instructions carefully before calibrating and using the instrument.
- ii. Bail the borehole.
- iii. Sample for chemical constituents – remove the cap of the plastic 1 litre sample bottle, but do not contaminate inner surface of cap and neck of sample bottle with hands. Fill the sample bottle without rising.
- iv. Leave sample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
- v. Replace the cap immediately.
- vi. Complete the sample label with a water-resistant marker and tie the label to the neck of the sample bottle with a string or rubber band. The following information should be written on the label.
 - A unique sample number and description
 - The date and time of sampling
 - The name of the sampler
- vii. Place sample in a cooled container (e.g., cool box) directly after collection. Try and keep the container dust-free and out of any direct sunlight. Do not freeze samples.
- viii. Complete the data sheet for the borehole.
- ix. See to it that the sample gets to the appropriate laboratory as soon as possible, samples for chemical analysis should reach the laboratory preferably within seven days.

Table 16-2 Integrated monitoring network and programme.

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality *	Water level	
Newly drilled monitoring boreholes						
MTBH03	-28.241076	26.973778	Newly established monitoring borehole targeting the fractured aquifer.	Quarterly	Monthly	As in Section 16.3
MTBH04	-28.211000	26.957670	Newly established monitoring borehole targeting the fractured aquifer.	Quarterly	Monthly	
MTBH05	-28.286273	26.970084	Newly established monitoring borehole targeting the fractured aquifer.	Quarterly	Monthly	
MTBH06	-28.224400	26.938920	Newly established monitoring borehole targeting the fractured aquifer.	Quarterly	Monthly	
Privately owned monitoring boreholes						
BH7	-28.191800	26.946020	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	As in Section 16.3
BH16	-28.191540	27.008550	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH18	-28.192410	27.007000	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH30	-28.278690	26.974910	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH31	-28.281070	26.976780	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH33	-28.274890	26.980150	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH39	-28.275510	26.988510	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH43	-28.211350	26.945930	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH44	-28.217110	26.940480	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH45	-28.248140	26.949610	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH50	-28.252940	26.964460	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH51	-28.269690	26.978120	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH52	-28.266910	26.978100	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH53	-28.265830	26.988440	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH54	-28.253070	26.990840	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
BH55	-28.252290	26.991230	Privately owned borehole situated in close proximity to proposed gas production borehole.	Bi-annual	Bi-annual	
Newly proposed monitoring boreholes**						
MTBH07	-28.207664	26.943958	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	As in Section 16.3
MTBH08	-28.227951	26.934893	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH09	-28.275280	26.938445	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH10	-28.263949	26.942999	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH11	-28.251696	26.949592	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH12	-28.278265	26.961347	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH13	-28.265875	26.966074	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH14	-28.253549	26.971019	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	
MTBH15	-28.276652	26.980435	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly	

MTBH16	-28.268338	26.981381	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH17	-28.263796	26.982178	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH18	-28.243371	26.991904	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH19	-28.230849	26.997846	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH20	-28.226360	27.000569	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH21	-28.209985	27.008820	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH22	-28.194086	27.016713	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH23	-28.190759	27.019429	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH24	-28.182748	27.023170	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH25	-28.174130	27.026810	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH26	-28.272824	26.980524	Down-gradient conceptual borehole situated within the production zone buffer area.	Quarterly	Monthly
MTBH27	-28.218615	26.939636	Down-gradient conceptual borehole situated in close proximity to the processing plant.	Quarterly	Monthly

Notes: *Water quality monitoring frequency can be determined based on the relevant project phase and water quality trends.

Notes: **Monitoring to commence in conjunction with gas production borehole drilling schedule.

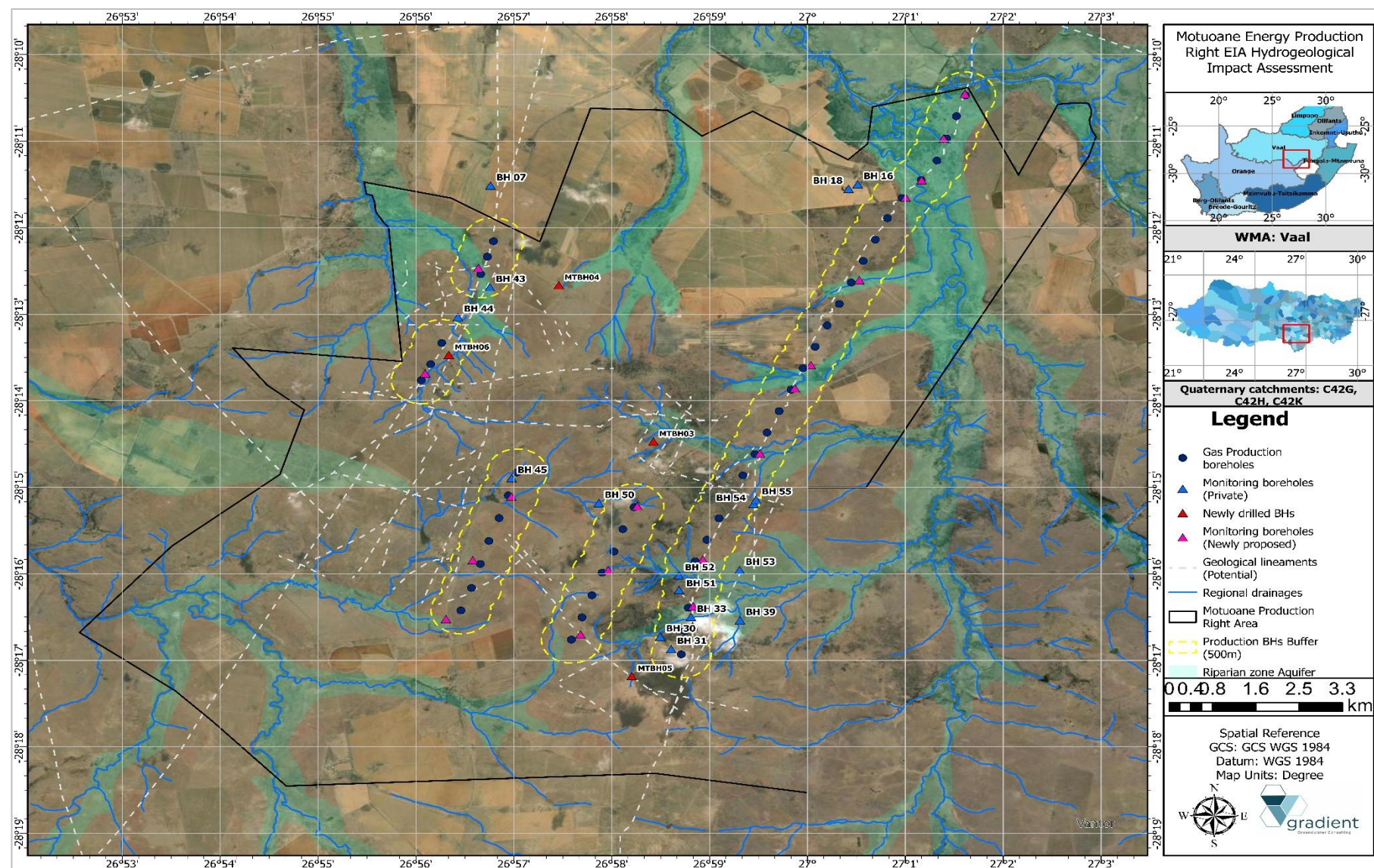


Figure 16-2 Integrated groundwater monitoring network.

17. CONCLUSIONS

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

- i. The objective of this investigation is to determine the status quo of the regional groundwater system and quantify and qualify potential impacts from the proposed gas production and extraction on sensitive environmental receptors.
- ii. The topography of the greater study area has a generally flat to gently undulating topography becoming more undulating and hillier towards the east and can be classified as a lowland with hills. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features. The latter may play a potential role in the dynamics of local groundwater flow and pollution plume migration.
- iii. The hydrology of the region is characterised by predominately perennial watercourses with primary rivers in and around the study area the Merriespruit, Steenbokspruit and Maselspruit, draining the northern section of the production right area in a general northwestern direction, forming a confluence with the Sand River flowing on the northern perimeter in a general southwestern direction. The southern section of the production rig area is drained by the Doringspruit as well as Schoemanspruit flowing in a general western direction. It can be assumed that there will be groundwater contribution to baseflow.
- iv. Due to the perennial nature of the local drainage system, it is expected that the inferred groundwater flow direction will mimic the topography and surface water hydrology.
- v. The regional geology consists of various lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort Group within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. Accordingly, hydraulic conductivity of the host aquifer formations is expected to be sluggish, with the exception of saturated quaternary deposits and potential lineaments where the permeability can be an order of magnitude higher.
- vi. Structural analysis also suggests a potential east-west striking fault zone towards the central zone of the production right area. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.
- vii. The study area is predominantly underlain by a Class d2 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.1 and 0.5 L/s) with host aquifers consisting primarily of arenaceous and argillaceous strata. It should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however will not only be multi-layered, but also multi-porous with variable

thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer.

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

- **A shallow Quaternary (perched and unconfined) aquifer:** These aquifers consist of recent types of sediments and are characteristically primary porosity aquifers, such that groundwater flow occurs in the pore spaces between soil and sediment particles. These aquifers are formed by alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth. Clay lenses in the soil and unsaturated zones may cause local, perched water tables which occur above the regional water table.
- **A shallow, intergranular aquifer within the Beaufort Group and Karoo Dolerite Suite:** These aquifers occur in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually, these aquifers can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. In secondary porosity aquifers, groundwater flow occurs along fractures, while water is stored within the rock matrix. Due to higher effective porosity (n) this aquifer is more susceptible to impacts from contaminant sources compared to confined aquifers.
- **A deeper, fractured aquifer within Beaufort Group and Karoo Dolerite Suite formations:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured mudstone and siltstone sequences as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

ix. Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater.

x. The average water level is calculated at 10.67 mbgl which is much shallower than the regional average water level of between 28.10mbgl. The coefficient of variation calculated is 87.97%, indicating either a dynamic groundwater system or higher variability in topography.

xi. Analysed data indicates that the surveyed water levels correlate very well to the topographical elevation with the square of correlation (R^2) indicating a linear association of >0.96 . Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by surface water divides and will mimic the topography. The inferred groundwater flow direction within

the northern catchment of the project area will be in a general northern direction towards the lower laying drainage system(s) traversing the project area from where groundwater will discharge as baseflow. The groundwater flow direction within the southern catchment of the project area will be in a general west to southwestern direction.

- xii. According to the aquifer classification map of South Africa the project area is underlain by a “**Minor aquifer**” with a “**Moderate**” vulnerability rating and a “**Medium**” susceptibility rating. Accordingly, a Groundwater Quality Management (GQM) Index of 4 is calculated and a “**Medium**” level groundwater protection is required. It should be noted that due to groundwater being the sole water resource to the landowners and rural communities within the study area, the aquifer can thus be classified as a sole source aquifer in many instances.
- xiii. In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors. The following potential sources have been identified:
- Seepage of poor-quality water and leachate of waste products.
 - Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
 - Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
 - Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.
 - Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
- xiv. The following potential aquifer pathways have been identified:
- Vertical flow through the unsaturated/vadose zone as well as saturated zone to the underlying intergranular and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.
 - Preferential flow-paths include the contact between the depth of weathering and fresh un-weathered rock, fractures, faults, joints and bedding planes. Secondary fractures may also potentially act as transport mechanisms.
 - If not adequately sealed and suitably mitigated, gas production wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

xv. The following potential receptors were identified:

- Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.
- Down-gradient drainages and streams including associated riparian zone aquifer system(s) and baseflow contribution.
- Private or neighbouring boreholes associated with relevant fracture zones and/or structures(s) if intercepted by the pollution plume migration footprint.

xvi. All site characterization information gathered were evaluated and incorporated into the formulation of a conceptual groundwater model. The conceptual model formed the basis for the numerical groundwater model development. The latter was calibrated to an acceptable error margin and applied as groundwater management tool for simulation of management scenarios.

xvii. A scenario was simulated by assigning a point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase. Due to the linear correlation of groundwater elevation and topographical elevation, the simulation indicates that the generated TDS pollution plume will generally mimic topography and will migrate towards the lower laying drainage system. It is evident that regional geological lineaments act as preferred pathways for groundwater flow and contaminant transport mechanisms. It can be noted that conceptual receptors situated within the unconsolidated, riparian zone aquifer, reaches quasi-steady state much quicker than conceptual receptors within the denser Karoo formations. It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~180.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~350.0m during the operational phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer. The TDS mass load contribution within conceptual receptors in close proximity of the production zone ranges between ~980.0mg/l to approximately 1660.0mg/l, which is slightly above the SANS 241:2015 limits while the TDS mass load contribution to existing boreholes in the vicinity of the proposed gas production zone ranges between 350.0mg/l (current background concentration) to a maximum of approximately 800.0mg/l, which is below the SANS 241:2015 limits. It can be observed the mass load contribution is a function of the distance to the source or gas production borehole.

- xviii. A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase. The simulation indicates that the generated CH₄ pollution plume will also mimic topography and will migrate towards the lower laying drainage system. It can be observed that the simulated pollution plume migration is also more sluggish within the denser Karoo formations, reaching a maximum distance of ~150.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~300.0m during the operational production phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation and do not extend beyond the production right area. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone might potentially intersect local drainages i.e., Maselspruit, Merriespruit and Sandrivier including associated drainage systems and riparian zone aquifer. The CH₄ mass load contribution within the conceptual receptors in close proximity of the production zone is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole. It can be observed that the CH₄ mass load contribution ranges between ~0.15mg/l (which is the current background concentration) to a maximum of approximately 0.49mg/l, which is below the EPA safety threshold (2011) of 10.0mg/l.
- xix. A scenario summarises the simulated point source TDS pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated TDS pollution plume will continue to mimic topography during the post-closure phase and will propagate towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~250.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial deposits of the riparian zone is ~450.0m. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems. The TDS mass load contribution within the conceptual receptors in close proximity of the production zone ranges between ~950.0mg/l to approximately >1600.0mg/l, which is slightly above the SANS 241:2015 limits while the TDS mass load contribution to existing boreholes in the vicinity of the proposed gas production boreholes ranges between 380.0mg/l to a maximum of approximately 480.0mg/l, which is below the SANS 241:2015 limits.
- xx. A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH₄) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised after decommissioning. After a simulation period of 100-years, it can be observed that the maximum pollution plume migration distance reached is ~180.0m within the denser Karoo aquifer whereas the maximum pollution plume migration distance reached within the unconsolidated alluvial

deposits of the riparian zone is ~350.0m. It should be noted that the pollution plumes originating from production boreholes situated within the riparian zone will continue migrating to the Maselspruit, Merriespruit and Sandrivier including associated drainage systems. The CH₄ mass load contribution within conceptual receptors in close proximity of the production zone is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.40-3.80mg/l, with the mass load contribution a function of the distance to the source or gas production borehole. It can be observed that the CH₄ mass load contribution ranges between ~0.15mg/l (which is the current background concentration) to a maximum of approximately 0.65mg/l, which is below the EPA safety threshold (2011) of 10.0mg/l.

- xxi. As scenario was simulated evaluating the three site alternatives for the proposed processing plant footprint. It can be observed that the TDS mass load contribution ranges between <350.0mg/l (which is the current background) for Plant locality C, to a maximum of approximately 1700.0mg/l for Plant locality B. Furthermore, it can be observed that processing plant locality B suggest the most impact on the riparian zone aquifer with processing plant locality C indicating the least potential impact. It should however be noted that processing plant locality C it situated in close proximity to a geological lineament which can serve as a potential mechanism and preferred pathway for groundwater flow and contaminant transport.
- xxii. The model results were incorporated into a risk rating matrix to determine the significance of potential groundwater related impacts.
- xxiii. During the construction phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium to high** without implementation of remedial measures and **medium to high** and **medium to low** with implementation of proposed mitigation measures. Potential impacts associated with the construction phase activities include the following:
 - a. Site clearing and vegetation removal may cause increased turbidity and sediment loads in groundwater.
 - b. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads into recharge areas.
 - c. Poor quality leachate including sewage and domestic wastewater emanating from the construction camp may have a negative impact on groundwater quality.
 - d. Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
 - e. Borehole drilling can introduce various potential contaminants including drilling muds/additives and hydrocarbons into host-aquifers which may have a detrimental effect on the water quality.
 - f. Drilling activities can disturb sediments and may result in silt formation in groundwater and can cause siltation within the potable water aquifer.
 - g. Encountering of major water strikes and blow-out during the drilling process may reduce local groundwater levels.
 - h. Groundwater pollution as a result of produced formation water or wastewater spills and

seepage from drilling sumps.

- i. Handling of borehole drilling chips may pose a risk to groundwater contamination.
 - j. Borehole construction in terms of casing installation and concrete works might have a negative impact on groundwater quality.
 - k. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
 - l. Anthropogenic activities and movement related to the construction phase can cause potential groundwater pollution.
 - m. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.
 - n. Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.
 - o. Unplanned releases of formation water.
 - p. Unplanned event such as well explosion can release saline formation water and gasses.
- xxiv. During the operational phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium to high** without implementation of remedial measures and **medium to high** and **medium to low** with implementation of proposed mitigation measures. Potential impacts associated with the operational phase activities include the following:
- a. Inadequate casing or cementing can create a vertical flow pathway between different aquifers/ hydrostratigraphical units or between the production zone and potable aquifer.
 - b. Migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
 - c. Upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase can cause mixing between aquifers.
 - d. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
 - e. Gas production can alter pressure differences and alter hydraulic gradients between different hydrostratigraphical units resulting in modification of local groundwater flow pathways.
 - f. Poor quality leachate may emanate from the gas production zone which may have a negative impact on groundwater quality.
 - g. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
 - h. Operation and maintenance of heavy vehicles as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
 - i. Leaking pipelines may cause contamination of groundwater resources.

- xxv. During the decommissioning phase the environmental significance rating of potential groundwater impacts on down-gradient receptors are rated as **high** and **medium** to **high** without implementation of remedial measures and **medium** to **high** and **medium** to **low** with implementation of proposed mitigation measures. Potential impacts associated with the post-closure and decommissioning phase activities include the following:
- a. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing migration of saline groundwater or groundwater with a different chemical composition originating from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
 - b. Poorly plugged and sealed decommissioned production boreholes can create preferred groundwater flow pathways causing an upward migration of stray formation gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the decommissioning phase can cause mixing between aquifers.
 - c. Multiple gas wells can collectively affect groundwater levels, quality and hydraulic connectivity over a larger area.
 - d. Poor quality leachate may emanate from production zone footprint areas which may have a negative impact on groundwater quality.
 - e. De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
 - f. Site de-establishment and removal of infrastructure can potentially cause increased turbidity and sediment loads in groundwater.

18. RECOMMENDATIONS

The following recommendations are proposed following this investigation:

- i. Mitigation and management measures as set out in the groundwater management plan should be implemented as far as practically possible. It should be noted that the mitigation and management measures recommended in this report should be incorporated into the existing EMPr and do not substitute the existing mitigation measures but rather supplement them.
- ii. It is recommended that the monitoring program and network as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated on a bi-annual basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.
- iii. Any development and/or drilling which takes place within the primary porosity aquifer associated with alluvium material deposited in flood plains must be avoided where possible and restricted if it cannot be avoided. If there are no other alternatives available and drilling within the riparian zone aquifer is necessary, mitigation and management measures should be strictly adhered to.
- iv. The identified hydrogeological sensitive areas and buffer zones delineated as part of this assessment must be adhered to during the construction and operational phase activities. It is recommended that an updated hydrocensus user survey be performed in the vicinity of proposed production boreholes where limited hydrocensus points were identified. The survey should be conducted within a 500.0m radius of each proposed gas production borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas production borehole situated within the Karoo formations in order to verify the presence of other sensitive groundwater receptors and/or private boreholes.
- v. Additional monitoring boreholes should be established within the proposed target areas buffer zone as identified in Section 16 of this report, to evaluate the mass load contribution to sensitive environmental and groundwater receptors. Drilling localities should be determined in consultation with a suitably qualified hydrogeologist and sited means of a geophysical survey to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.
- vi. Newly established monitoring boreholes should be subjected to aquifer hydraulic parameters to supplement and verify existing hydraulic parameters interpreted as part of the first phase drilling and testing run.
- vii. Geological logs and data recording should include major water strikes and depths, water loss or water make volumes and depths as well as blow yields if applicable. Should water from the deeper, fractured aquifer be encountered, a sample should be collected to be subjected for inorganic testing as well as isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.

- viii. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed production borehole drilling be recorded along with associated water levels in order to get a better understanding of the deeper aquifer piezometric head and expected behaviour.
- ix. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial (once every two years) basis as newly gathered site characterisation data and monitoring results become available in order to be applied as a dynamic groundwater management tool for future scenario predictions.
- x. It is recommended that a weather station (i.e., rain gauges) be established at a central collection point on-site in order to keep record of all rainfall events and assess potential climatic changes. The latter should be incorporated into the numerical groundwater flow model update accordingly.
- xi. All preferred groundwater flow pathways which are in direct connection with surface topography such as decommissioned gas production boreholes should be sealed off and rehabilitated according to best practise guidelines.

19. SPECIALIST PROFESSIONAL OPINION

In my professional opinion, the most significant impact of the project on the regional groundwater regime is deterioration of the potable Karoo aquifer water quality as well as modification of the riparian zone primary porosity aquifer associated with alluvium material deposited in flood plains. Groundwater is the sole water resource to the landowners and rural communities within the study area and can thus be classified as a sole source aquifer.

If the recommended mitigation measures be implemented along with management principals as set out in the groundwater management plan (**Section 15** of this Report), the potential impacts associated with the project can be managed. It will be important to adhere to the recommended integrated groundwater monitoring program to assess the regional groundwater qualities which will serve as early warning mechanism in order to pro-actively implement water management and mitigation measures. With a sound groundwater management and monitoring programme as discussed in this report, this phase of the project can be authorised. All mitigation and management measures proposed in the groundwater management plan should be included in the EMPr and closure and rehabilitation plan as an auditable document.

It will be important that the Licensee appoint a suitably qualified and responsible person to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities and ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively. The applicant must however demonstrate that they have the technical and financial means to protect the aquifers during the project, as groundwater is the sole water resource to the landowners and rural communities within the greater study area and its surroundings.

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21. APPENDIX A: RAINFALL DATA (RAINFALL ZONES C4C)

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22. APPENDIX B: GEOPHYSICAL SURVEY FIELD MEASUREMENTS AND PROFILES

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23. APPENDIX C: BOREHOLE GEOLOGICAL LOGS AND CONSTRUCTION

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24. APPENDIX D: AQUIFER TESTING DATASHEETS

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25. APPENDIX E: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

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26. APPENDIX F: D3 ENERGY HENNENMAN EXPLORATION AREA EMPR (ER315)

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27. APPENDIX G: SPECIALIST DECLARATION FORM

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28. APPENDIX H: SPECIALIST CURRICULUM VITAE

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