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MOTUOANE ENERGY EXPLORATION RIGHT EIA HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

May 2026

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

Compiled by:
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REPORT REVIEW AND SIGN OFF

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I, JFW Mostert, hereby declare that:

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

JFW Mostert (Hydrogeologist)

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Executive summary

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 Motuoane Energy (Pty) Ltd gas Exploration Right (ER386).

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 exploration and extraction on sensitive environmental receptors.

Regional setting and site locality

The gas exploration right and greater study area falls within the Lejweleputswa and Fezile Dabi District Municipalities covering a total footprint of ~ 580.0 km^2, stretching over various farms which are situated between the towns of Kroonstad (~5.0km due north), Winburg (~8.0km to the south), Welkom (~7.0km towards the west) and Ventersburg and Aldam (~9.0km to the east), Free State Province of South- Africa.

Project description

The project entails the establishment of five (5) pre-defined drill site locations and associated infrastructure. In addition, the applicant intends to continue drilling within proximity to the geological fault lines which traverse the area. The exact location of the drill sites within these fault corridors is not known at present and will be guided by both the presence of gas resources as well as any potential environmental sensitivities.

Topography

The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. 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 south and east of the study area, with the lowest elevation of 1 300 mamsl in the central-western parts of the study area and the greatest elevation of 1 533 mamsl in the eastern parts of the study area.

Drainage and catchment

The greater study is situated in primary catchment (C) of the Vaal River drainage system which covers a total area of approximately 598.0km^2. The resource management falls under the Vaal Water Management Area (WMA5) (previously Middle Vaal WMA) 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. These include Quaternary Catchments C25B, C42H, C42J and C60H.

The hydrology of the region is characterised by predominately perennial watercourses with the main rivers draining the greater study area in a general western to northwestern direction. The main watercourses within the Middle Vaal WMA are the Mooi, Vet, and Vaal Rivers. The Vaal River is a major tributary of the Orange River, which generally drains in an eastern direction towards the Atlantic Ocean. The primary rivers in and around the study area include the Vals River towards the northeast of the study area, the Sand River in the central parts of the study area, and the Vet River towards the southwest of the study area.

Climate

The study area has a summer rainfall regime, with the majority of the precipitation occurring from October to March (80.02%) as high intensity thunderstorms, while June, July, and August are particularly dry. The mean annual precipitation (MAP) for the study area is estimated at approximately 531.66 mm/a while the 5th percentile of the dataset, which approximately represents a 1:20 year drought, is calculated as 345.32 mm/a and the 95th percentile of the dataset, which approximately represents the 1:20 year flood, is calculated as 760.66 mm/a. The study area falls within evaporation zones 9A, 11A, and 19C. The mean annual evaporation (MAE), measured by Symons Pan, for the study area ranges between 1 540 and 1 750 mm/a.

Regional geology

The regional geology consists of various lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort and Ecca Groups within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. 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. Structural analysis provided by the applicant indicates that five faults run across the study area, four trending NE and one trending SSE. 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), while small portions towards the northwest of the study area are underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0 L/s). Both the Class d2 and Class d3 aquifers consist of primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. 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. The Ecca Group aquifers consist mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, 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.

The study area can be classified as falling under the Northeastern Upper Karoo Region towards the central, eastern and southern areas whereas the northern and northwestern section forming part of the Northeastern Pan Belt Region.

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 and fractured aquifer within the Beaufort Group:** 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 the Ecca Group and pre-Karoo rocks:** 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, sandstone, shales 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. 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 of the Sand - and Doringrivier 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 ~2.01% of MAP i.e. ~10.67 mm/a.

Site investigation

A hydrocensus user survey within the greater study area was conducted where relevant hydrogeological baseline information was gathered. A total of 168 geosites were visited and recorded as part of the hydrocensus user survey which includes surface water and groundwater which are largely applied for livestock watering and domestic water supply purposes.

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.

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 hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. Aquifer tests results confirmed that the permeability of the shales is low and sluggish. The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10E^{-6}$ – $10E^{-1}$ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10E^{-9}$ – $10E^{-6}$ 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 $10E^{-2}$ – $10E^{1}$ m/d. The site characterisation phase indicates that the local transmissivity values range between $5E^{-3}$ – $5E^{-2}$ m/d with a mean value of $2.75E^{-2}$m/d.

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 >34.0m with a mean thickness of approximately ~6.0m.

Artesian conditions were observed at two of the boreholes surveyed namely MRBH 16 and MRBH 98 which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions. With exclusion of the artesian boreholes, 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 6.78 mbgl which is much shallower than the regional average water level of between 15.10 to 26.60mbgl. It is noted that several dynamic water levels were recorded which is confirmed by the relatively high coefficient of variation calculated from the water level data set of >113.0%. The latter suggest a dynamic groundwater environment with a potentially pumped aquifer system.

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 >0.97. 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.

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 (north of the Sandriver and Rietspruit) will be in a general south to southwestern 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 Sandrivier will be in a general north to northwestern direction.

The average groundwater gradient (*i*) of the shallow, intergranular aquifer in the vicinity of proposed exploration 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 0.0017 in a general southeast to northwest orientation.

The expected seepage rate from potential contamination originating at the proposed exploration activities as well as associated infrastructure is estimated at an average of approximately 3.55m/a, with a maximum distance of ~6.18m/a in a general southern direction.

Hydrochemistry

Hydrochemical results of the hydrocensus borehole 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 and groundwater can be described as neutral, saline and hard. Isolated sampling localities i.e., MRBH42, MRBH69, MRBH71 and MRBH92 suggest above limit total dissolved solids as well as associated higher conductivities with main drivers consisting of elevated Calcium (Ca)/Magnesium (Mg)/Sodium (Na)-Chloride (Cl) concentrations. The latter might be indicative of the intermediate, fractured aquifer unit being targeted by the respective borehole(s), sourcing more stagnant groundwater. It is observed that various of the surveyed boreholes indicate elevated Nitrate 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.

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 Aluminium (Al) and Iron (Fe) concentration. Aluminium is usually kept in solution in wetlands or peat-rich catchments while weathering input from high runoff events can also transport Aluminium-rich sediments into surface water.

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.

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 localities MRBH76 and MTBH04 show Sodium-Chloride dominance usually associated with old stagnant water while borehole localities MRBH42, MRBH69, MRBH71 as well as MRBH92 indicate a static and disordinate environment (Calcium-Magnesium-Chloride dominance) which suggest old stagnant, potentially deeper, water that has mixed with more recently recharged water. Borehole localities MRBH12, MRBH24, MRBH82, MTBH03, MTBH05, MTBH06, BH15, BH35 and 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. 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.

Aquifer classification and groundwater management index

According to the aquifer classification map of South Africa the project area is underlain by a "**Minor aquifer**".

According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a "**Moderate**" vulnerability rating.

According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a "**Medium**" susceptibility rating.

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.

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.

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. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.

ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.

iii. Drilling fluids and additives, lubricants, oils, fuels, and grease from machinery, cement and grouting materials, surface runoff carrying sediments or chemicals, contaminated drilling water used during circulation

iv. 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 exploration 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.

Numerical groundwater flow and pollution plume migration model

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 pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas exploration boreholes be jeopardised i.e., leaking boreholes for the exploration 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 in a radial pattern from the gas exploration 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 ~100.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~230.0m during the operational exploration phase.

It can be observed that the TDS mass load contribution ranges between ~900.0mg/l to approximately 1250.0mg/l, which is slightly above the SANS 241:2015 limits, with the mass load contribution a function of the distance to the source or gas exploration borehole. 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer. 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 shales.

A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH_4) gas emanating from the exploration zone should the integrity of the gas exploration boreholes be jeopardised after decommissioning. The simulation indicates that the generated CH_4 pollution plume will generally mimic topography and will migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~90.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~180.0m during the operational exploration phase. It is evident that source term mass load contribution to is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.0-3.0mg/l, with the mass load contribution a function of the distance to the source or gas exploration borehole. 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

A scenario was simulated by assigning a point source pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas exploration 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 migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum distance reached is ~450.0m during the post-closure phase. It can be observed that the TDS mass load contribution remains below the SANS 241:2015 limits ranging between ~950.0mg/l to approximately 600.0mg/l.

The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation, however salt load contribution to the host aquifer is observed. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

A scenario was simulated by assigning a point source pollution plume migration from of stray methane (CH_4) gas emanating from the exploration zone should the integrity of the decommissioned gas exploration boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated CH_4 pollution plume will also mimic topography during the post-closure phase and will migrate in a general radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum distance reached is ~350.0m during the post-closure phase. It is evident that source term mass load contribution to conceptual receptors remains below the EPA safety threshold (2011) of 10.0mg/l ranging between 1.70-2.80mg/l. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

Groundwater impact assessment

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 groundwater quality impacts on down-gradient receptors are rated as **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. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads.
ii. Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.
iii. Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
iv. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.

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

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
iii. Groundwater pollution as a result of wastewater spills and seepage from drilling sumps.
iv. Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.
v. Operation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
vi. Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.
vii. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
viii. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.
ix. Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.

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

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.
iii. Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.
iv. De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.

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. 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.

iii. 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 within a 500.0m radius of each proposed gas exploration borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas exploration borehole situated within the Karoo formations in order to verify the presence of other sensitive groundwater receptors and/or private boreholes. 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.

iv. 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.

v. 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.

vi. Geological exploration 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 ($\delta^{18}O$, $\delta^{2}H$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.

vii. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed exploration drilling be recorded along with associated water levels in order to get a better understanding of the deeper aquifer piezometric head and expected behaviour.

viii. 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.

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 groundwater management tool for future scenario predictions.

x. It is recommended that a weather station (i.e., rain gauges) be established 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 exploration 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**
CBL	**Cement Bond Log**
CMB	**Chloride Mass Balance**
CNG	**Compressed Natural Gas**
CR	**Constant Rate**
CV	**Coefficient of Variation**
b	**Saturated Thickness**
DMR	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs**
EA	**Environmental Authorisation**
EC	**Electrical Conductivity (mS/m)**
EIA	**Environmental Impact Assessment**
EM	**Electro Magnetic**
EMPr	**Environmental Management Programme**
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**
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)**
l/s	**Litre per second**
LoM	**Life of Mine**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute Error**
mamsl	**Metres Above Mean Sea Level**
MAP	**Mean Annual Precipitation**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
mbsl	**Metres Below Static Level**
mcm	**Million Cubic Metres**
ME	**Mean Error**

meq/L	**Mili-equivalents per litre**
mg/l	**Milligrams per litre**
mm/a	**Millimetre per annum**
MPRDA	**Minerals and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
nT	**Nanotesla**
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)**
PEG	**Propelled Energy Generators**
PI	**Pump Inlet**
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**
SDS	**Safety Data Sheet**
SoW	**Scope of Work**
SRTM	**Shuttle Radar Topography Mission**
T	**Transmissivity (m^2/d)**
TCP	**Technical Cooperation Permit**
TDS	**Total Dissolved Solids**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
uPVC	**Un-plasticised Poly Vinyl Chloride**
USGS	**United States Geological Survey**
WGS	**World Geodetic System**
WM	**With Mitigation**
WOM	**Without Mitigation**
WRC	**Water Research Commission**
WUL	**Water Use Licence**

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1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment in support of an Environmental Impact Assessment (EIA) authorisation process to be followed for the proposed Motuoane Energy (Pty) Ltd gas Exploration Right (ER386). The investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts from the proposed gas exploration 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. This will entail a hydrocensus to cover a total buffer zone of 500.0m in the vicinity of each proposed drill site.

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

iii. Development of a conceptual groundwater flow model.

iv. 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.

v. Hydrogeological impact assessment and risk matrix.

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

vii. Compilation of an integrated groundwater monitoring network and protocol.

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-24-048-V1, submitted in November 2024. 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 activities:

i. Hydrocensus user survey (500.0m buffer zone) 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 exploration area.

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 defendable hydrogeological baseline.

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

1.3.3. Phase C: Site characterisation: Siting, drilling and testing of site characterisation and 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. Management the 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 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.

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 exploration 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.

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

ii. Barnard, H. C., 2000. An explanation of the 1:500 000 general Hydrogeological Map. 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 boreholes.
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 zones.
ix. Groundwater divides have been assumed to align with surface water divides and it is assumed that groundwater cannot flow across this type of boundaries.
x. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly[1].

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

2. 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. Formulation 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 documents[2]:

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

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

[2] It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable, 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 gas exploration right and greater study area falls within the Matjhabeng and Moqhaka Local Municipalities, Lejweleputswa and Fezile Dabi District Municipalities covering a total footprint of ~580.0km^2, stretching over various farms which are situated between the towns of Welkom (~7.0km to the west), Virginia (~6.0km to the southwest), Hennenman (situated in the centre of the proposed exploration right area) and Ventersburg (~2.0km to the southeast), Free State Province of South- Africa. Fixed coordinates representing the boundaries of the ER386 are ER386 are 28°13'28.95"S; 26°55'2.76"E in the South, 27°57'37.57"S; 26°48'49.15"E in the West, 27°59'13.57"S; 27°11'13.06"E in the East and 27°46'34.45"S; 26°57'44.05"E in the North, the central coordinates are approximately 27°58'23.27"S; 26°59'38.94"E. (EIMS, 2025). The site is accessible via the N1 national route traversing the greater study area in a general north south direction as well as the R70 secondary route in a southeast-northwest orientation. 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	27°58'23.27"S
Longitude	26°59'38.94"E

4.2. Project description, listed activities and proposed infrastructure

The project entails the establishment of five (5) pre-defined drill site locations and associated infrastructure. In addition, the applicant intends to continue drilling within proximity to the geological fault lines which traverse the area. The exact location of the drill sites within these fault corridors is not known at present and will be guided by both the presence of gas resources as well as any potential environmental sensitivities. Refer to **Figure 4-3** for a general site layout and infrastructure map.

Motuoane Energy proposes to explore all saleable gases including but not limited to Methane, Carbon Dioxide, Helium, and Nitrogen in the licensed area. Due to the large area and complex exploration methodology, the ER will be required for an initial period of three years with the option to renew three additional periods of two years resulting in a total of nine years.

Exploration Right 386 is a consolidation of Technical Cooperation Permit (TCP) 235 and 240 & Exploration Release Area (ERA) 341 which were tenures in 2024 before ER386 application was submitted to PASA on the 8th of October 2024. TCP235 & TCP240 were granted in October 2023 for a 12 Month Term, an ER application was applied for in October 2024. ERA341 was an application previously submitted to PASA which was held up due to changing legislation and subsequently withdrawn. The areas (ERA341, TCP235 and TCP240) were then consolidated to one ER (ER386). Motuoane's application for an exploration right (ER) for hydrocarbons was accepted on the 22nd of October 2024 in terms of Section 79 of the Mineral and Petroleum Resources Development Act (Act 28 of 2002 – MPRDA, as amended). The accepted application for an exploration right (ER386) is located over an area of approximately 58 000 hectares (ha), covering various farm portions in Welkom near the towns of Virginia, Hennenman and Odendaalsrus, Free State Province.

The main activities are core exploration drilling and seismic survey activities. The proposed approach is to first determine and map the geographic extent of all boreholes currently emitting gas on and near the ER area. Then measure rates and monitor pressures where possible and perform gas composition analysis. The geophysical wireline logging of existing boreholes (where possible) will include monitoring of water levels. If no existing gas emitting boreholes are identified near a target area, new drilling activities are proposed within that area using percussion or rotary drilling method. Although up to five (5) target drilling areas (TA) with 500m buffer (1km corridor) within the exploration right may be undertaken over the 9-year period, the current Works Program caters for only three (3) drilling wells. It must be noted that there may be a single, multiple or no drilling activities within some of the target drilling areas. Should more than 3 drilling wells be required within the ER, the current Works Program will be required to be updated accordingly.

The previous TA's, Target Area 3 (ED G), Target Area 4 (ED H), Target Area 5 (ED J), Target Area 6 (ED I), Target Area 7 (ED F) and Target Area 8 (VEG A) as well as seven (7) seismic transects (Transects ED 1 to 5, VEG 1 & 2) which were proposed within the western section of the exploration right on the agricultural fields between Saaiplaas, Bronville, Thabong and Whites have been removed from the current application. The current application entails:

- Two Target Areas; Target Area 1 (RSB D) and Target Area 2 (RSB E) located in the south of ER386, approximately 7km southeast of Meloding;
- Target Area 9 (HF C) and associated transects (Transects HF 1, HF2 and HF7) located approximately 6km west the eastern boundary of ER386 (N1);
- Two Target Areas proposed within the northern section namely, Target Area 10 (GP B) and Target Area 11 (GP A) and three seismic transect (Transect G1, G2 and G3) R34 located between Odendaalsrus and Kroonstad

Each exploration well will have an overall depth of approximately 650m and a maximum width of 350mm, commencing with a 6m x 323mm spud hole section, followed by 80m x 254mm conductor hole section, then an intermediate hole section of 450m x 203mm and finally an open hole section of 650m x 144mm. The actual casing sizes and configurations will vary depending on the specific geological characteristics and functional requirements. Each borehole will be steel cased and have cement barriers to prevent leaks as well as plugged at the end of exploration to prevent groundwater seepage.

The seismic survey activities are proposed throughout the exploration right as and when necessary. Motuoane will search records at the Council for Geoscience and the Petroleum Agency for seismic data that was acquired on the Exploration Right in the past. If no data are available, Motuoane will either acquire its own seismic or telluric data on the property, following proper environmental protocols and with the written permission of the landowner. There were previously sixteen (16) proposed transects for seismic / telluric survey, approximately 100km long around known structures and possible drill locations which have since been revised / reduced to nine (9) preliminary proposed transects for seismic / telluric survey, approximately 70km long around known structures and possible drill locations. Seismic and/or telluric locations and lengths are subject to be changed as knowledge increases. Although the Vibroseis technique is the likely method to be undertaken for the seismic activities. There is also a potential alternative to the Vibroseis known as the Propelled Energy Generators (PEGs), more commonly referred to as the Accelerated Weight Drop Seismic (AWD) which Motuoane may consider over the Vibroseis. It must be noted that there are at least 14 approved renewable energy projects from various applicants located within ER386. Motuoane and the renewable energy applicants will need to discuss the way forward and/or make necessary arrangements to coexist. It should be further noted that majority of the overlaps between the exploration right and the renewable energy developments is largely within TA 3 (EDG) and Transects EDG1 and EDG2 which have since been removed from the current application.

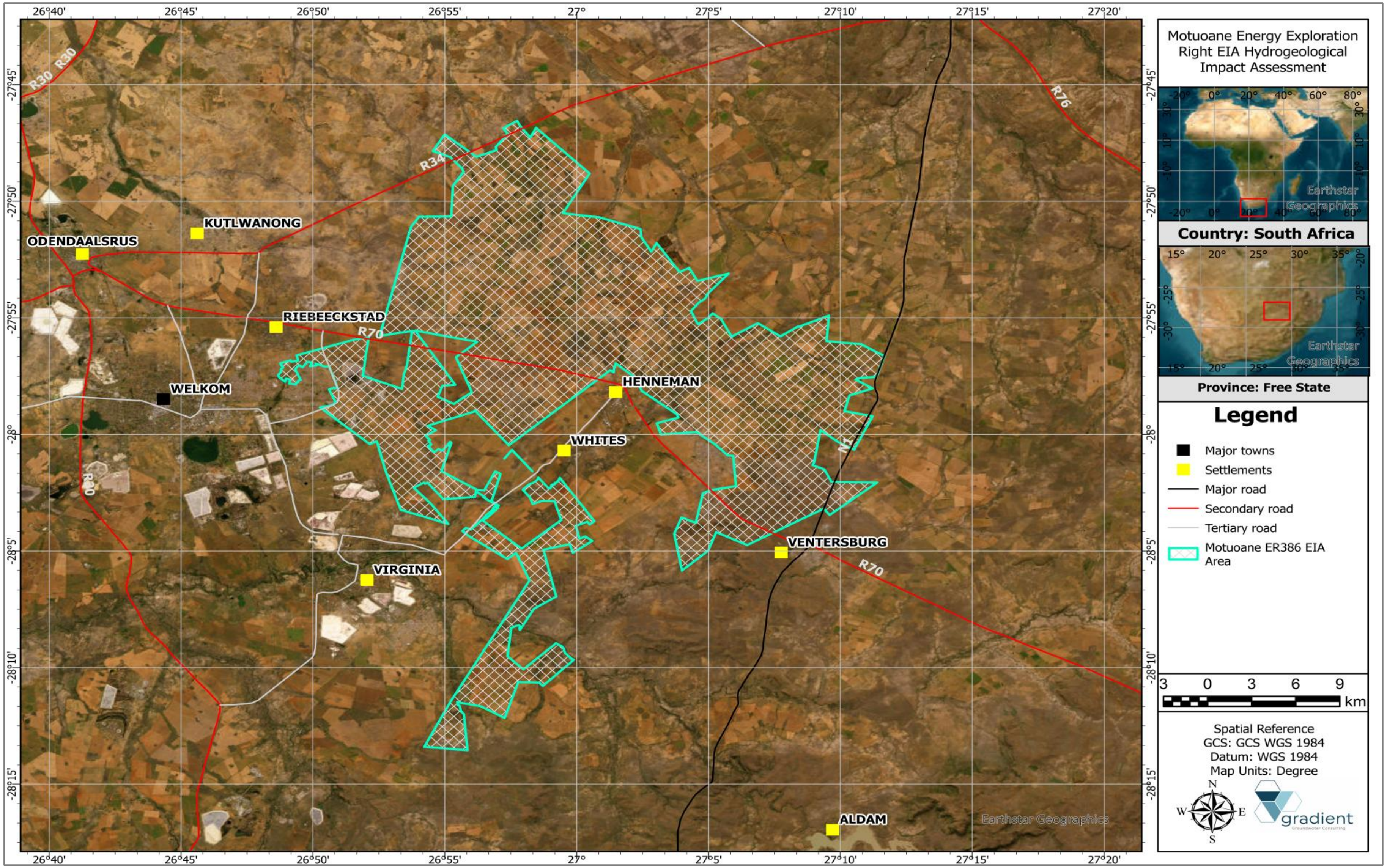


Figure 4-1 **Aerial extent and greater study area.**

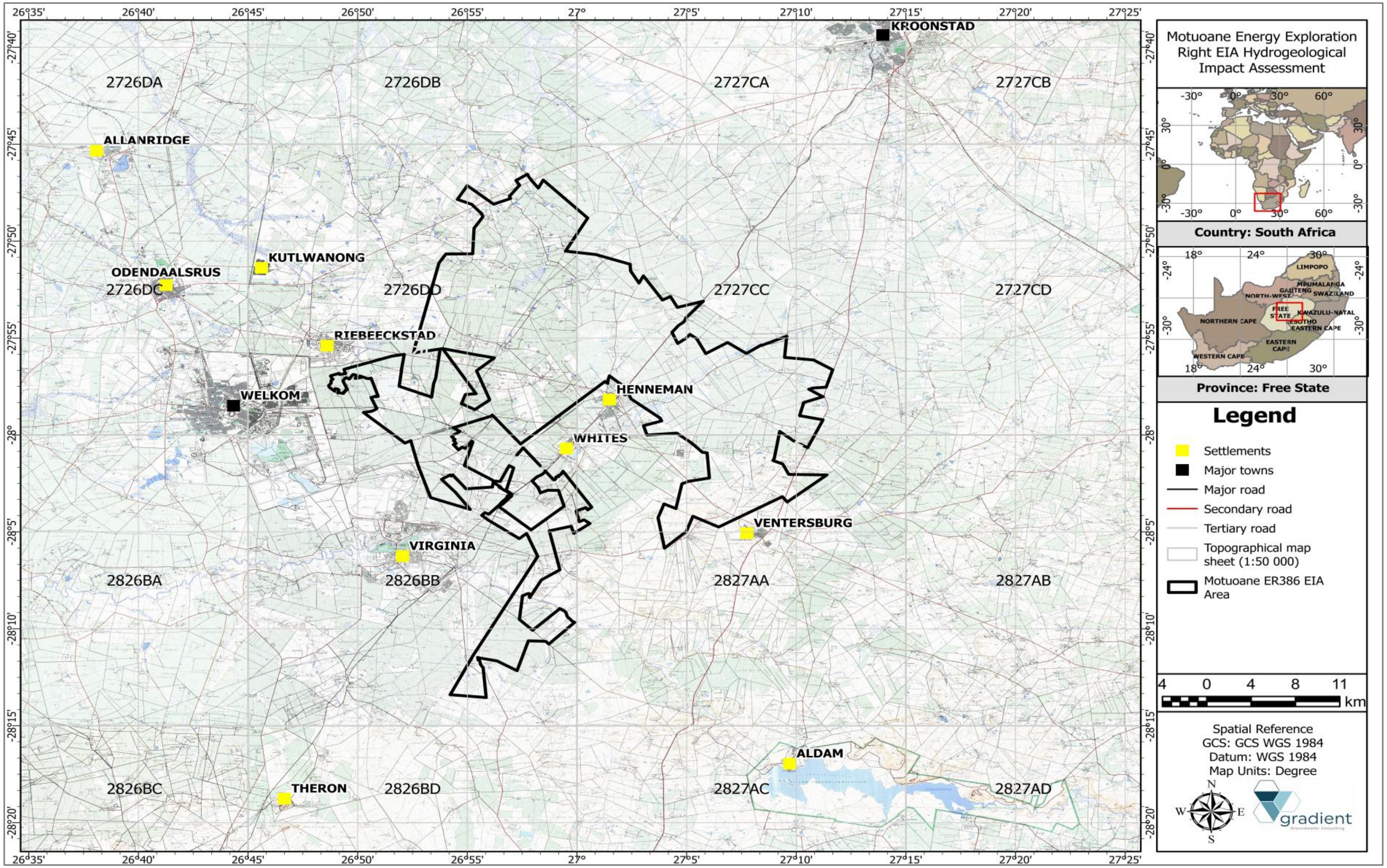


Figure 4-2 **Greater study area (1:50 000 topographical mapsheet 2826 and 2827).**

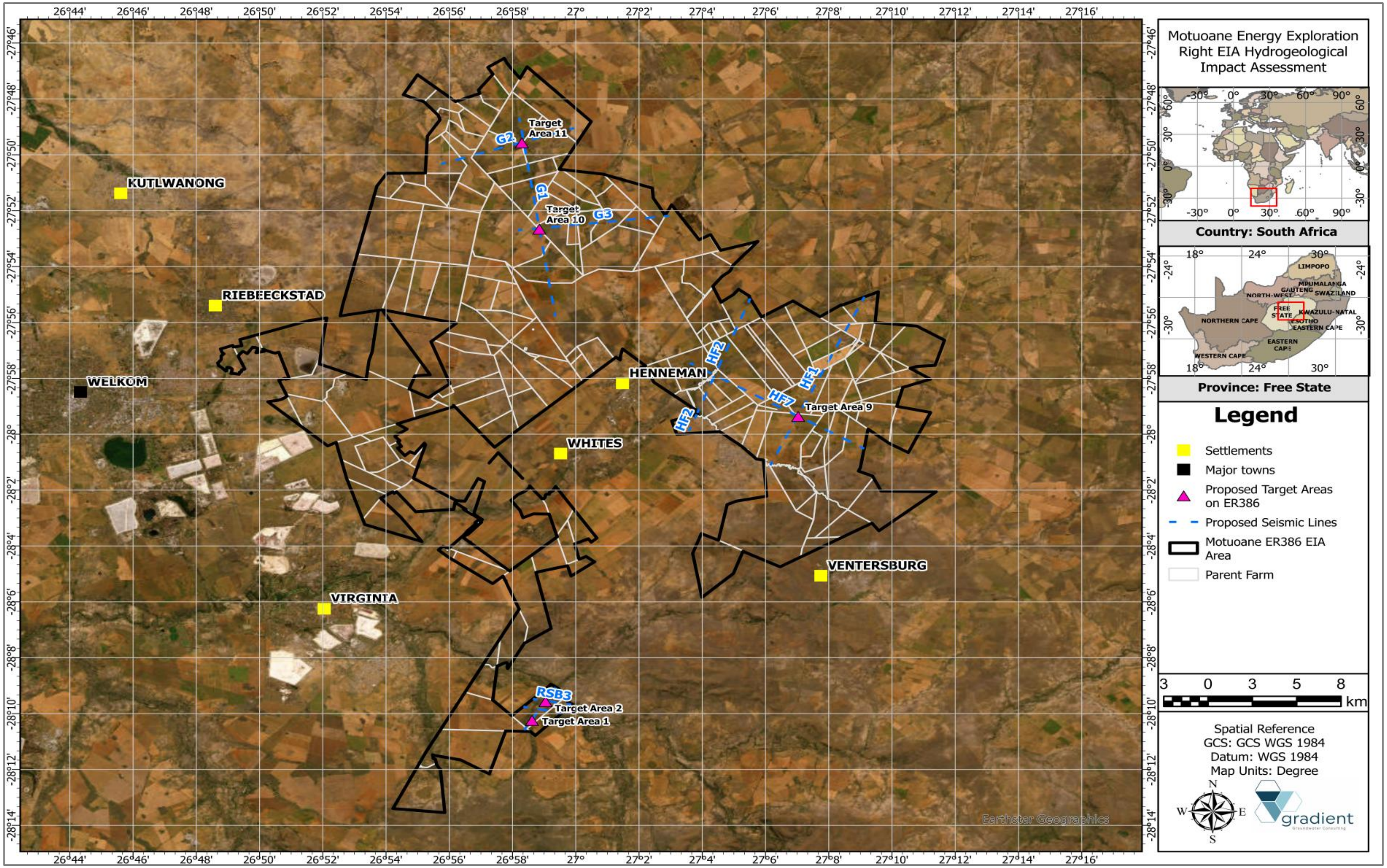


Figure 4-3 **General site layout and infrastructrure map.**

5. PHYSIOGRAPHY

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

5.1. Topography

The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. 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 western perimeter and 30 – 210.0m to the south and northern boundaries. Elevations within the study area range between 1 300 and 1 533 mamsl (based on elevations extracted from the SRTM DEM raster interpolation). Elevations generally increase towards the south and east of the study area, with the lowest elevation of 1 300 mamsl in the central-western parts of the study area and the greatest elevation of 1 533 mamsl in the eastern parts of the study area. Based on calculations performed using GIS, the slope of the study area ranges between 0% (indicating water bodies such as wetlands, pans, and dams) and 45.17% (indicating steep hillslopes), while the average slope is calculated as 3.58% with a standard deviation of 2.35%. **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 northwest 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.

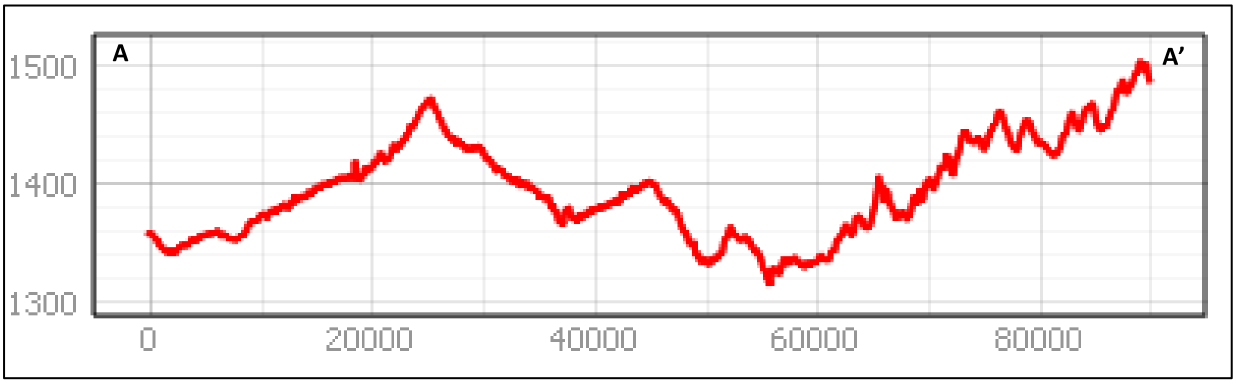


Figure 5-1 **North-South Elevation Profile (refer to Figure 5-4 Slice A-A').**

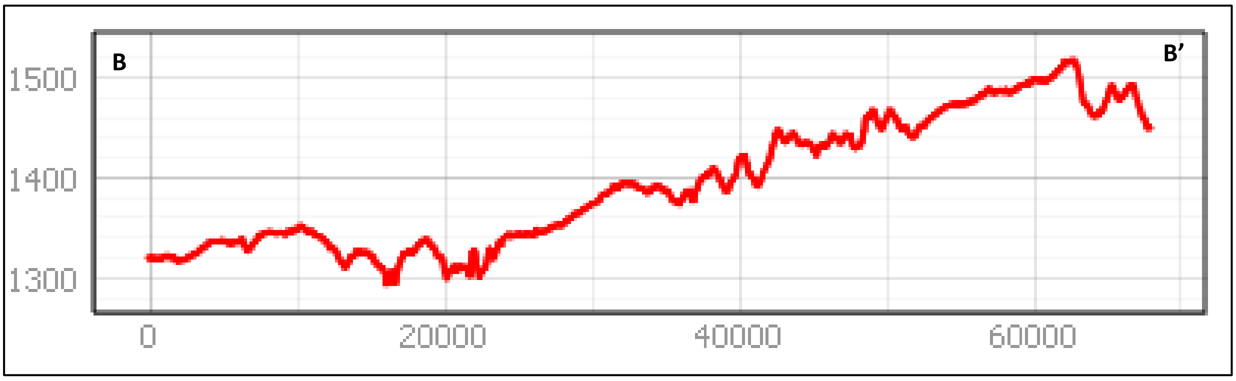


Figure 5-2 **West-East Elevation Profile (refer to Figure 5-4 Slice B-B').**

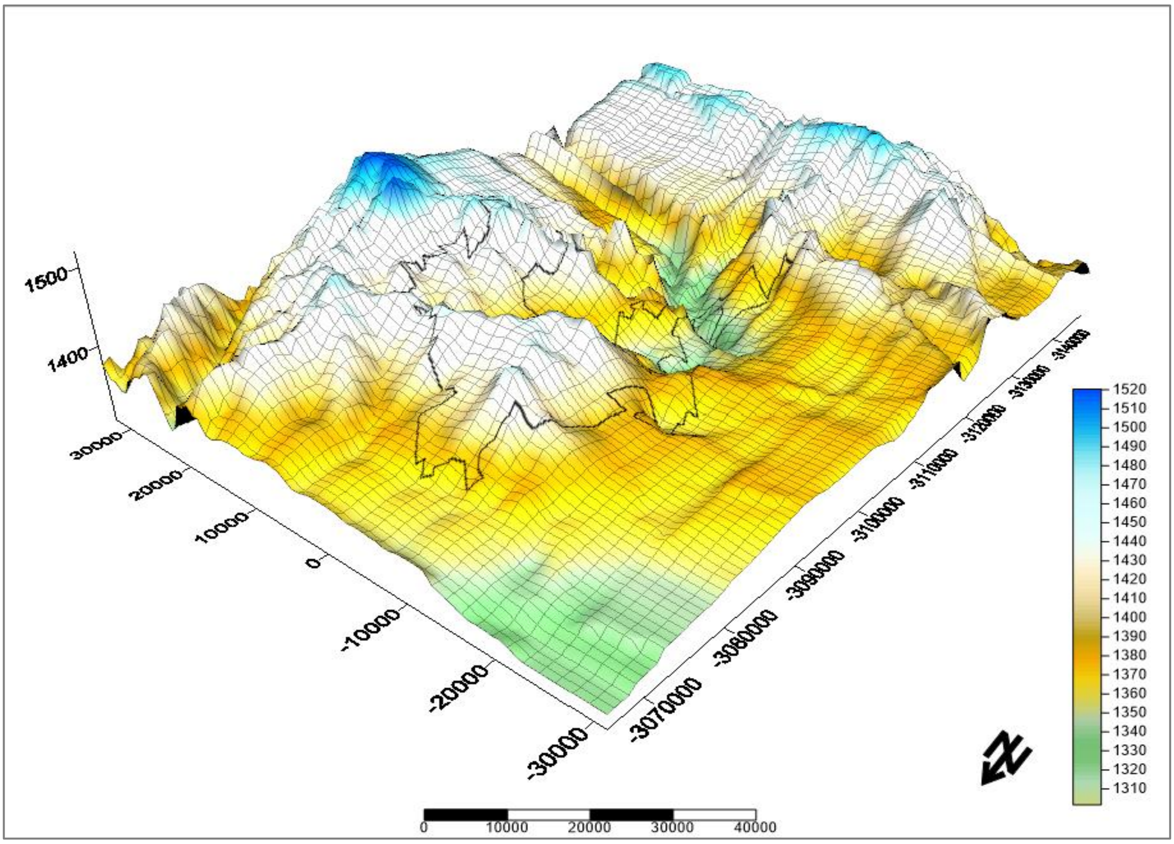


Figure 5-3 Topographical cross-sections of the greater project area.

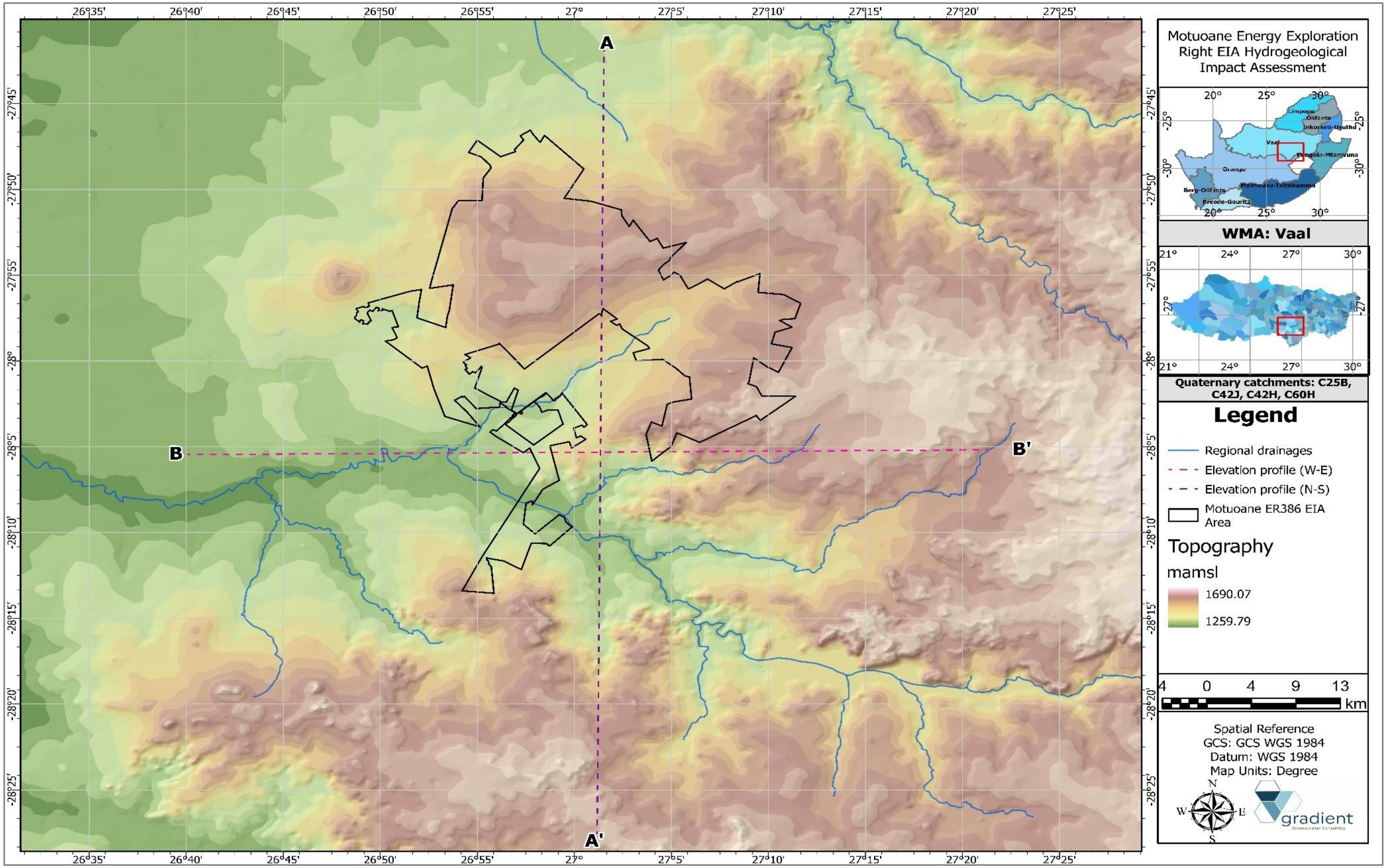


Figure 5-4 **Regional topography and conceptual slice (Refer to Figure 5-1 and Figure 5-2).**

5.2. Drainage and catchment

The greater study is situated in primary catchment (C) of the Vaal River drainage system which covers a total area of approximately 598.0km^2. The resource management falls under the Vaal Water Management Area (WMA5) (previously Middle Vaal WMA[3]) 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. These include Quaternary Catchments C25B, C42H, C42J and C60H. The main watercourses within the Middle Vaal WMA are the Mooi, Vet, 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 primary rivers in and around the study area include the Vals River towards the northeast of the study area, the Sand River in the central parts of the study area, and the Vet River towards the southwest of the study area (WRC, 2016).

The perennial Vals River, a major tributary of the Vaal River, flows across the northeastern extremity of the study area, where it is dammed by the Serfontein Dam, and drains in a northwestern direction. The Serfontein Dam has a surface area of approximately 1.09 km^2. Minor tributaries of the Vals River located within the study area include Blomspruit and Enslinspruit toward the northeast of the study area, Middelspruit and Otterspruit toward the north of the study area, and Sandspruit towards the northwest of the study area. Blomspruit, Middelspruit and Sand Spruit drain in a northwestern direction toward the Vals River, while Enslinspruit and Otterspruit drain toward the north.

The perennial Sand River, a tributary of the Vet River, flows across the central parts of the study area and drains in a western direction. The Sand River is dammed by the Allemanskraal Dam southeast of the study area. The Allemanskraal Dam has a surface area of approximately 28.64 km^2. Minor tributaries of the Sand River located within the study area include Koolspruit, Erasmusspruit, and Rietspruit north of the Sand River and Maselspruit, Merriespruit, and the Doring River south of the Sand River. Koolspruit, Erasmusspruit, and Rietspruit drain in a southwestern direction toward the Sand River, Maselspruit and Merriespruit drain in a northern direction toward the Sand River, and the Doring River drains in a northwest direction toward the Sand River.

The perennial Vet River, a major tributary of the Vaal River, is located towards the southwest of the study area and drains in a northwestern direction. The Vet River is dammed by the Erfenis Dam towards the south of the study area. The Erfenis Dam has a surface area of approximately 32.40 km^2. Minor tributaries of the Vet River located within the study area include Soutspruit and Kromspruit north of the Vet River. Soutspruit drains is a southern direction towards the Vet River, while Kromspruit drains towards the southwest. Surface water drainage overall occurs in a western to northwestern direction within the study area. The mean annual runoff (MAR) for the study area is estimated at approximately 13.16 Mm^3/a, based on MAR data obtained from WR2012 (WRC, 2016). **Table 5-1** provides a summary of relevant climatological and hydrogeological information for the relevant quaternary catchments.

[3] 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 5-1 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
C25B	1 887.67	1.91	509.21	1 750	7.23	C2H	9A
C42H	445.00	9.83	540.00	1 590	10.16	C4C	19C
C42J	1 013.93	26.69	529.79	1 600	21.26	C4C	19C
C60H	1 232.02	19.39	512.75	1 650	2.64	C6B	11A

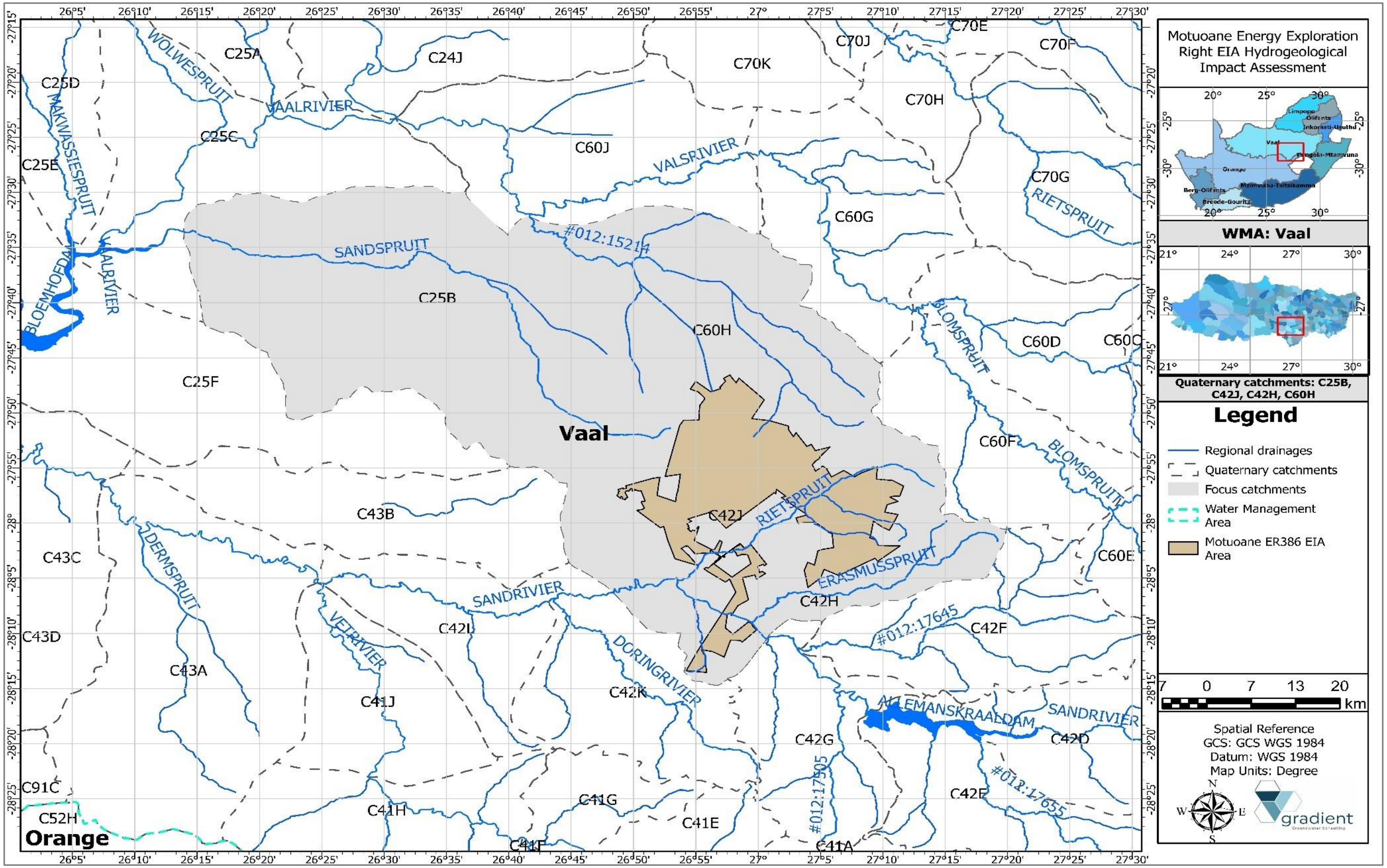


Figure 5-5 **Quaternary catchments and water management area.**

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 Welkom area ranges between 9.7 °C in the winter (July) and 23.3 °C in the summer (January), while the mean annual temperature is 17.7 °C (Climate-Data, 2021). Refer to **Figure 5-6** for the Mean Yearly Temperature Distribution of the greater study area.

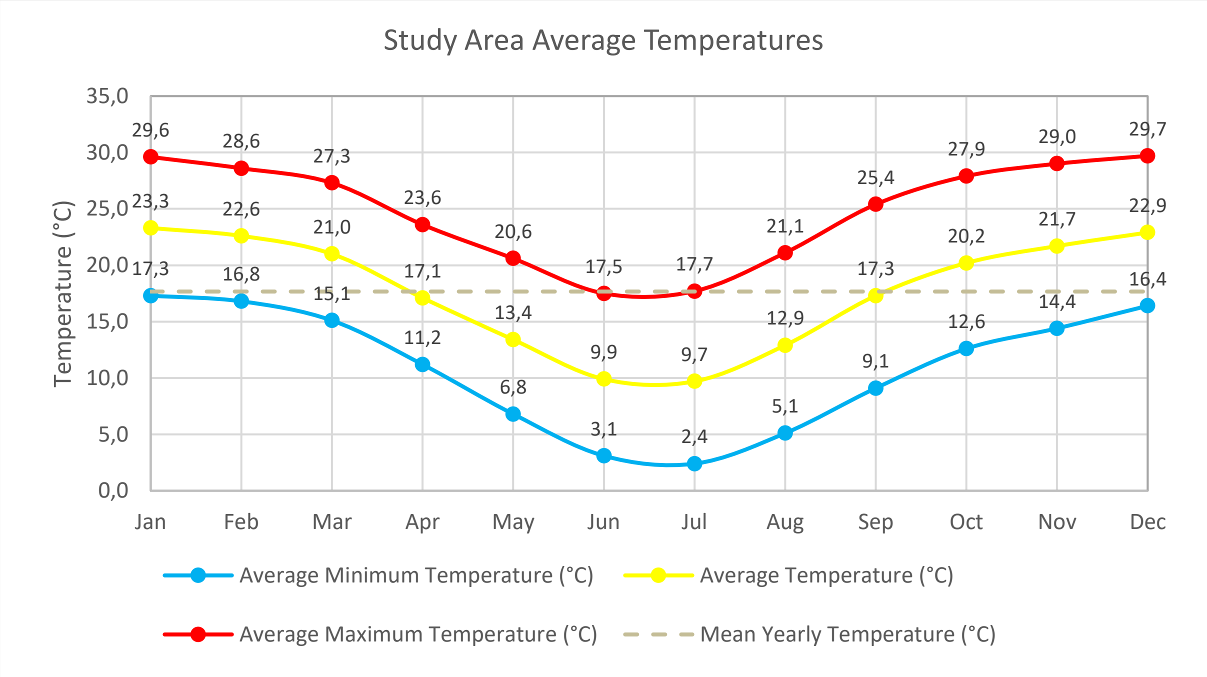


Figure 5-6 Mean Yearly Temperature Distribution of the greater study area, 1991 – 2021 (Climate-Data, 2021).

The mean annual precipitation (MAP) for the study area is estimated at approximately 531.66 mm/a, based on MAP data obtained from WR2012 (WRC, 2016). Using patched monthly precipitation data (ranging from 1920 to 2009), obtained from the WR2012 database (WRC, 2016), the MAP for the study area is calculated as 531.81 mm/a. The 5th percentile of the dataset, which approximately represents a 1:20 year drought, is calculated as 345.32 mm/a. The 95th percentile of the dataset, which approximately represents the 1:20 year flood, is calculated as 760.66 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 (80.02%) as high intensity thunderstorms, while June, July, and 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 zones 9A, 11A, and 19C (WRC, 2016). The mean annual evaporation (MAE), measured by Symons Pan, for the study area ranges between 1 540 and 1 750 mm/a (WRC, 2016).

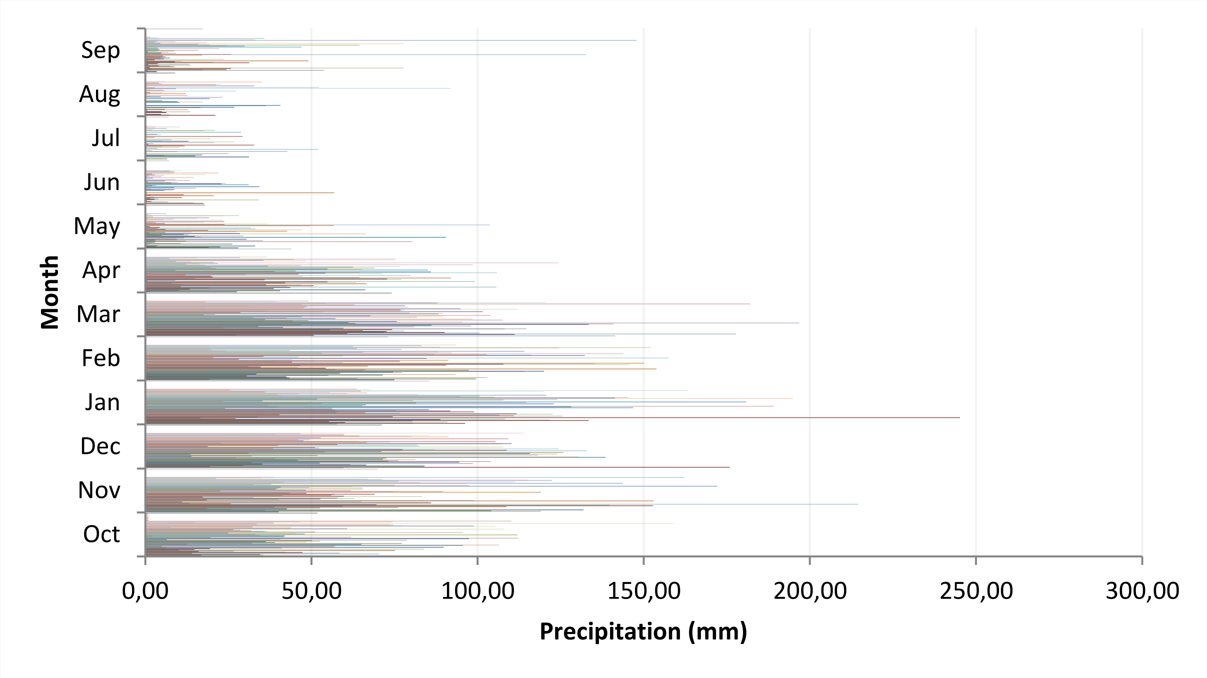


Figure 5-7 **Monthly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

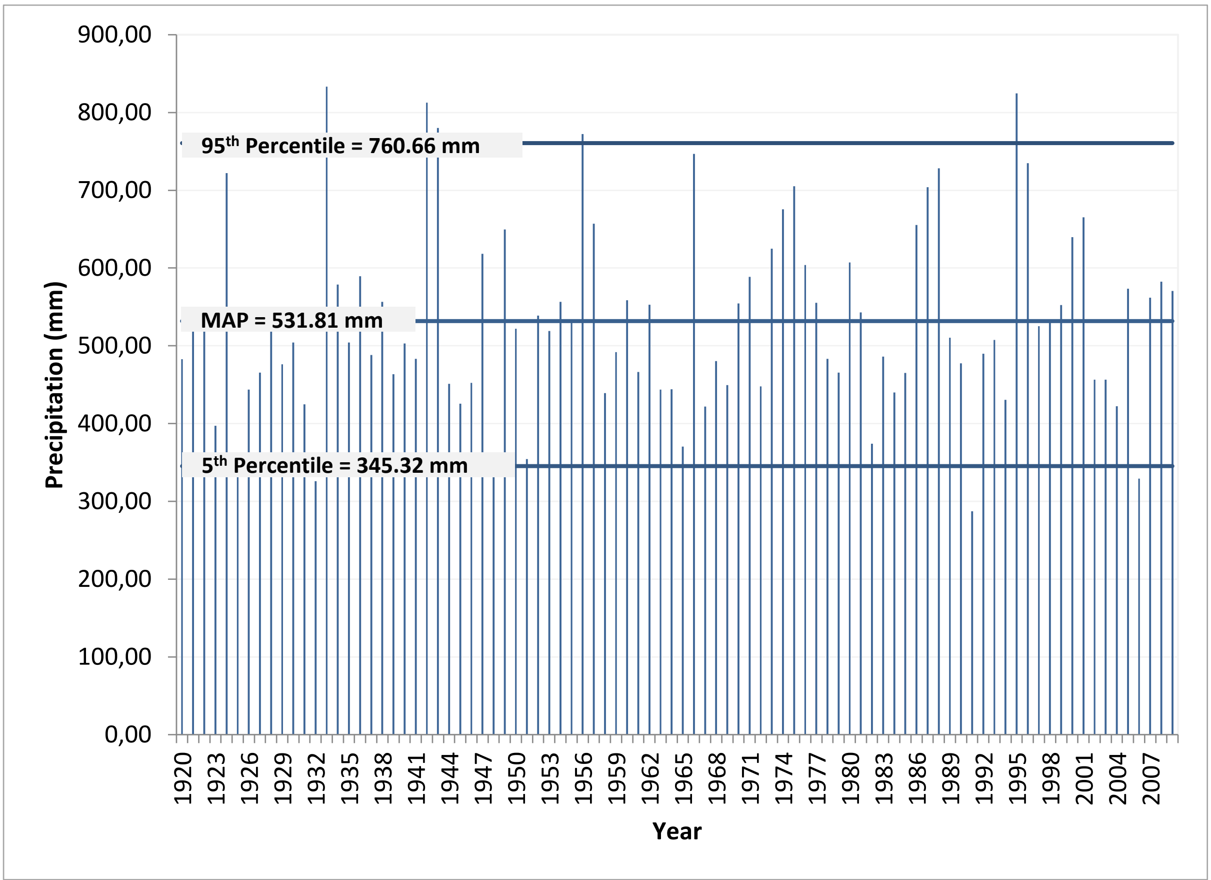


Figure 5-8 **Yearly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

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 2726 Kroonstad and 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; sediments of the Beaufort and Ecca Groups 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 5-2** 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.

The sediments of the Ecca Group were deposited during the Permian Period between approximately 290 and 248 million years ago (Woodford and Chevallier, 2002). The Volksrust Formation within the Ecca Group occurs toward the northwestern parts of the study area. Fluvial and deltaic sediments were supplied to the Volksrust Formation as a result of continental provenance towards the north and northeast of the Karoo Basin (Woodford and Chevallier, 2002). The Volksrust Formation, which interfingers with the overlying Beaufort Group (Woodford and Chevallier) is a primarily argillaceous formation comprising of mudstone, siltstone, and shale.

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). Furthermore, kimberlite and associated alkaline-rich intrusive rocks, including carbonatite and olivine melelitite, intruded into the Karoo Basin between approximately 130 and 70 million years ago (Woodford and Chevallier).

Table 5-2 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	-	Volksrust	-	Mudstone, siltstone, shale

5.3.2. Structural geology

According to the CGS 1:250 000 geological maps (Geological Map Sheet 2726 Kroonstad and Geological Map Sheet 2826 Winburg) dolerite dykes associated with the Karoo Dolerite Suite occur toward the northeast (NS trending), central west (NE trending), and southwest (EW trending) of the study area. 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). Exploration data evaluated suggest dykes are relatively thin, usually not wider than 5.0m while sills may be as thick as 100.0m. The maps further indicate that three kimberlite pipes occur toward in the central west of the study area with a kimberlite dyke (NNW trending) located between the pipes, while another kimberlite dyke (EW trending) occurs in the southwestern parts of the study area. Furthermore, structural analysis provided by the applicant indicates that five faults run across the study area, four trending NE and one trending SSE. 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.

5.3.3. Soils

Soils in the study area were identified using GIS data obtained from WR2012 (WRC, 2016). The data indicates that soils toward the north and northwest of the is classified as Sandy-Loam to Sandy-Clay-Loam (SaLm-SaClLm) with a clay content of 10 to 20%, and soils toward the northeast and toward south of the study area are classified as Sandy-Clay-Loam to Sandy-Clay (SaClLm-SaCl) with a clay content of 20 to 35%.

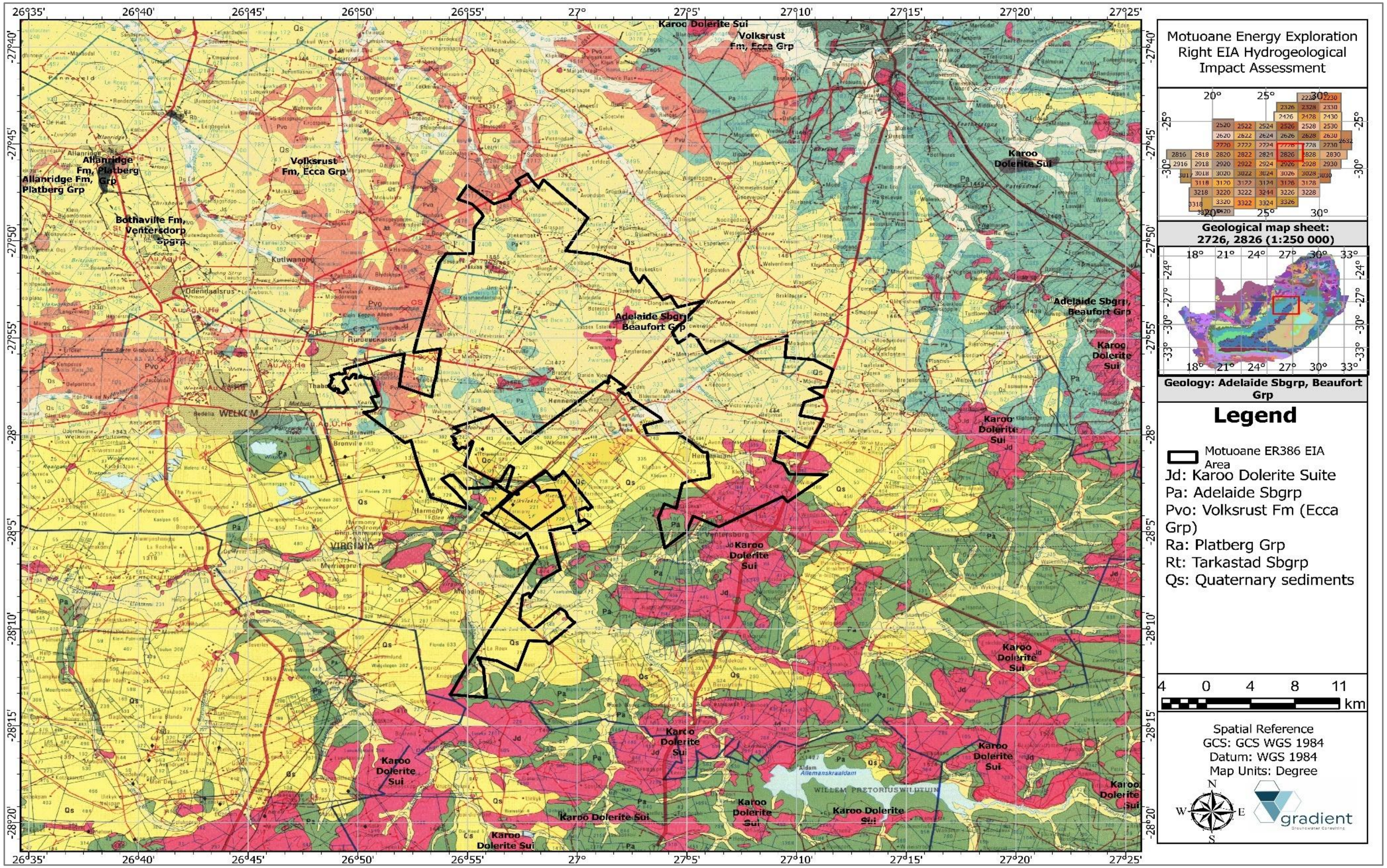


Figure 5-9 **Regional geology and stratigraphy (Geological map sheet 2726: Kroonstad and 2826: Winburg)(1:250 000 scale).**

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

The following sections summarises 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), while small portions towards the northwest of the study area are underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0 L/s). Both the Class d2 and Class d3 aquifers consist of primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. 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. The Ecca Group aquifers consist mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, 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).

According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the Northeastern Upper Karoo Region (Region 30) towards the central, eastern and southern areas whereas the northern and northwestern section forming part of the Northeastern Pan Belt Region (Region 33). Groundwater Region 33 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 Pan Belt Region is <20m while the maximum aquifer thickness within the Northeastern Upper Karoo Region is slightly thicker at 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. The average groundwater level within Groundwater Region 33 is 14.90 mbgl, while the average saturated thickness of the weathered (shallow) and fractured (deeper) zones are 22.60 m and 75.00 m, respectively (WRC, 2016). Groundwater Region 30 comprises of compact, dominantly argillaceous strata of the Ecca Group within the Karoo Supergroup (WRC, 2016). The average groundwater level within Groundwater Region 30 is 18.20 mbgl, while the average saturated thickness of the weathered (shallow) and fractured (deeper) zones are 9.30 m and 185.00 m, respectively (WRC, 2016). 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 and fractured aquifer within the Beaufort Group:** 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 the Ecca Group and pre-Karoo rocks:** 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, sandstone, shales 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 WR2012 (WRC, 2016), the average thickness of the unsaturated zones of Groundwater Region 30 and 33 are 18.20 m and 14.90 m, respectively. According to the 1.0×1.0 km groundwater level grid obtained from WR2012 (WRC, 2016), the thickness of the unsaturated zone ranges between 15.98 to 56.82 m, with an average thickness of 29.48 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). 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 of the Sandrivier, Rietspruit and Erasmuspruit forms a primary aquifer and is directly connected with surface water resources, especially during high flow conditions.

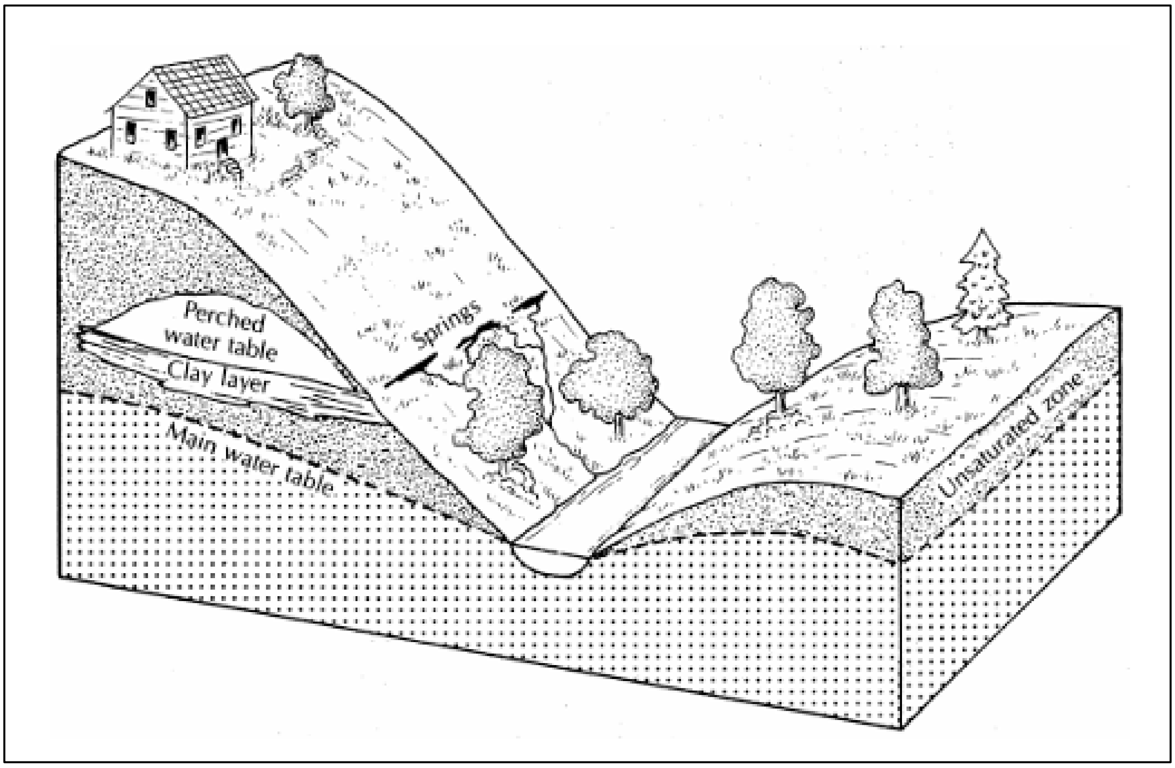


Figure 6-1 Illustration of the Unsaturated Zone (Fetter and Kreamer, 2023).

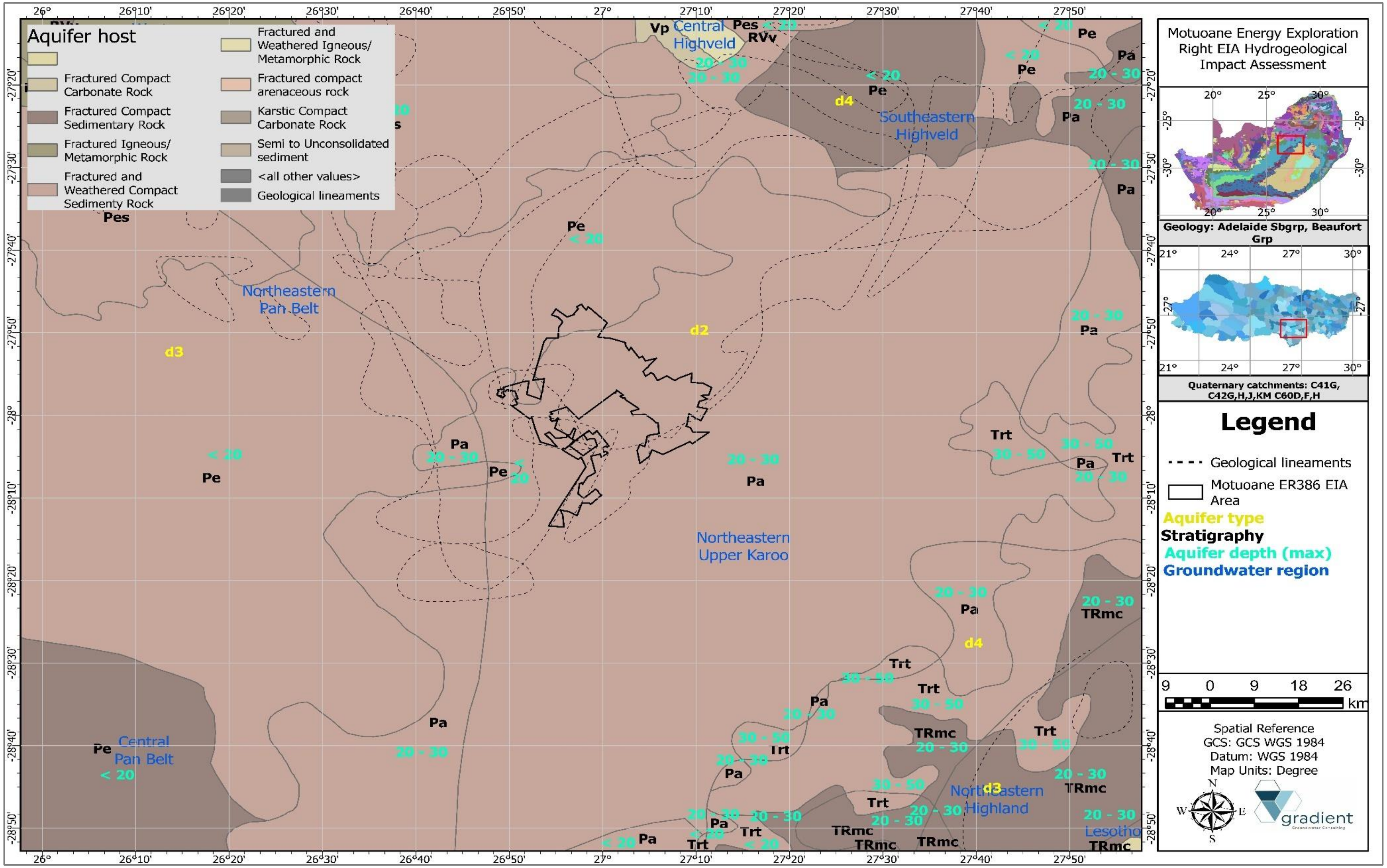


Figure 6-2 **Typical aquifer hosts and groundwater occurrence for the study region (2726 Kroonstad).**

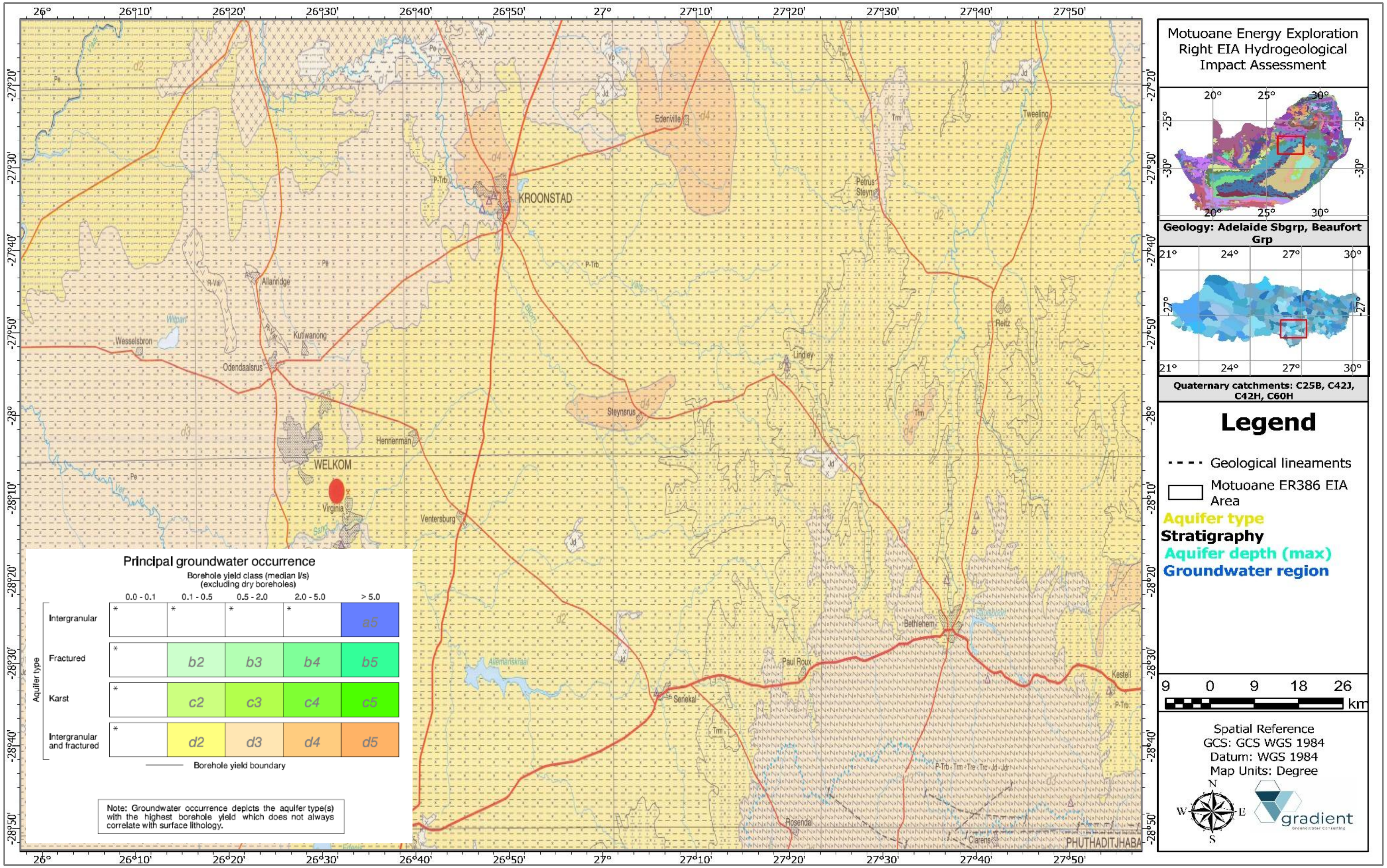


Figure 6-3 **Hydrogeological map of the greater study region (2726 Kroonstad).**

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 (m^3/d).

dh/dl = Hydraulic gradient.

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

The hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10E^{-6}$ – $10E^{-1}$ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10E^{-9}$ – $10E^{-6}$ 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 $10E^{-2}$ – $10E^{1}$ 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 (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

According to the transmissivity GIS data provided by WR2012 (WRC, 2016), the entire study area is underlain by a Class d2 intergranular and fractured aquifer with an average transmissivity of 17.5 m^2/day (WRC, 2016)[4]. The site characterisation phase indicates that the local transmissivity values range between 0.10m^2/d to 1.0m^2/d with a mean value of 0.55m^2/d.

[4] It should be noted that no aquifer tests were conducted to support site representative hydraulic parameters.

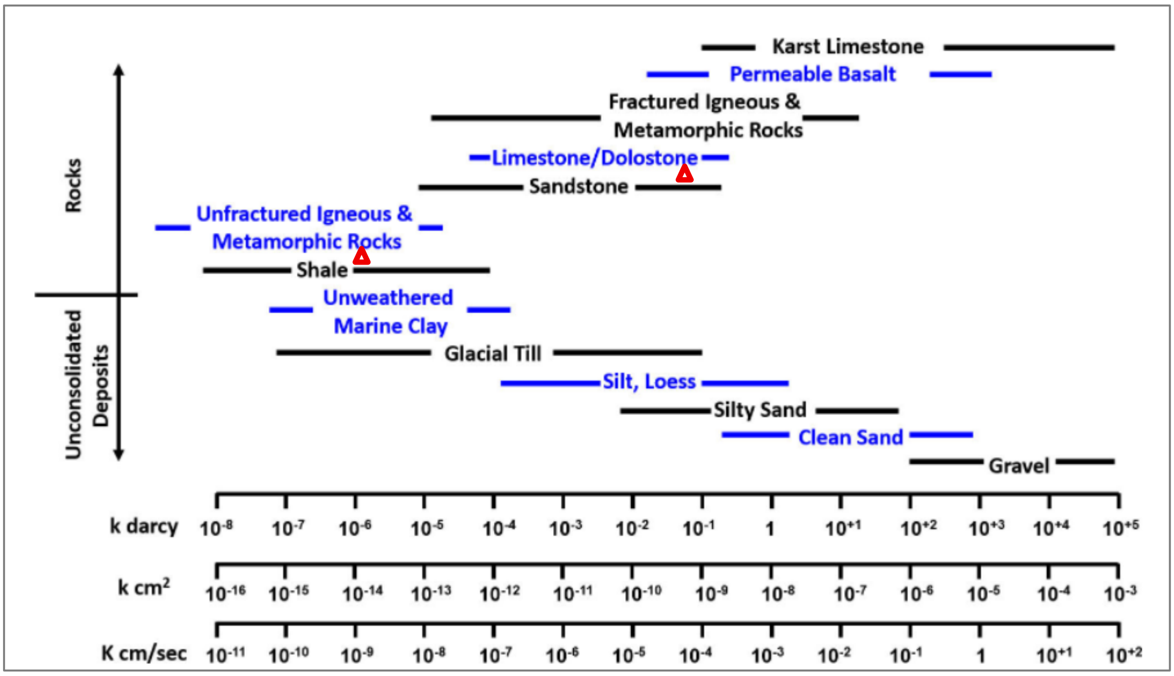


Figure 6-4 **Typical hydraulic conductivity values for on-site hydrostratigraphical units.**

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 $10E^{-5}$ – $10E^{-3}$ (Freeze and Cherry, 1979). Storativity values of the shallow, weathered aquifer will be slightly higher i.e., $10E^{-2}$.

6.5.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. 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 ~2.01% of MAP i.e., ~10.67 mm/a as summarised in **Table 6-1**. According to the 1 × 1 km recharge grid obtained from WR2012, the average recharge in the greater study area ranges is approximately 9.11 mm/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 (CMB) method (**Figure 6-5** to **Figure 6-7** summarises the recharge calculations (CMB methodology) based on the specific geological formation targeted); (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	10.45	1.97	4.00
Geology	12.00	2.26	1.00
Vegter	25.00	4.71	1.00
Harvest Potential	20.00	3.77	1.00
Baseflow	15.00	2.82	1.00
Qualified opinion	10.00	1.88	4.00
Literature (Botha et al., 1998)	17.80	3.35	2.00
Weighted average	**10.67**	**2.01**	**14.00**

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

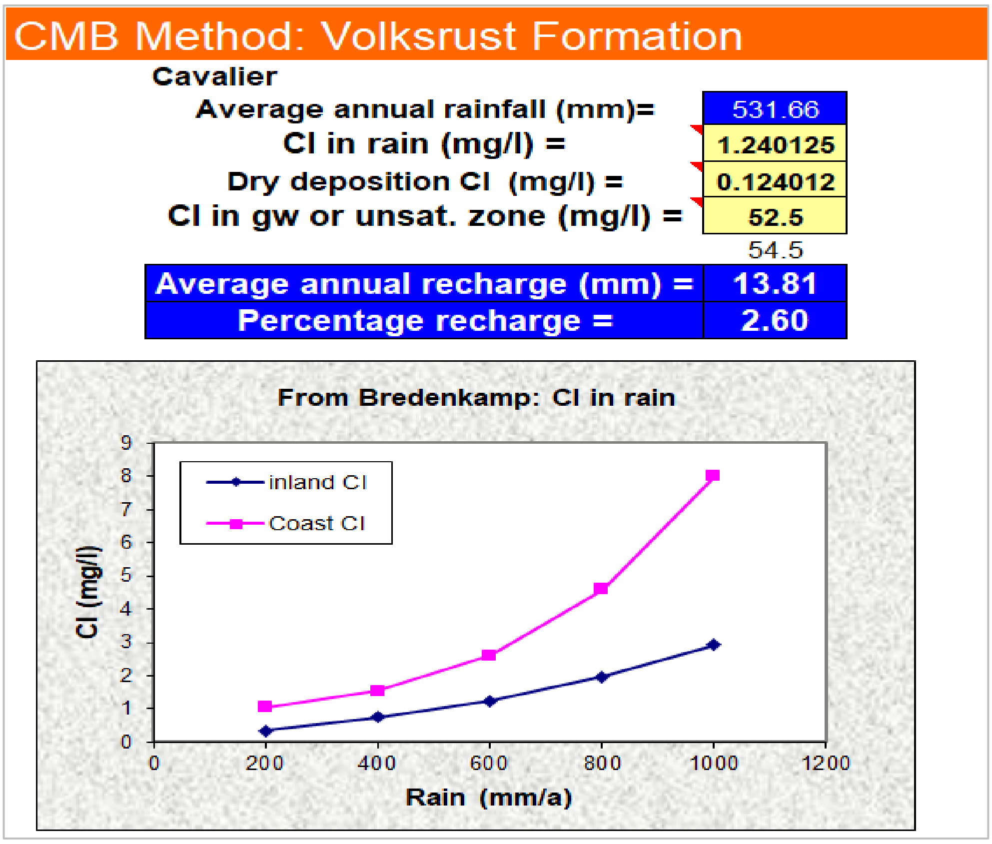


Figure 6-5 Chloride Mass Balance (CMB) method recharge summary: Volksrust Fm, Ecca Grp.

CMB Method: Adelaide SbGrp, Beaufort Grp

Cavalier

Average annual rainfall (mm)=	531.66
Cl in rain (mg/l) =	1.240125
Dry deposition Cl (mg/l) =	0.124012
Cl in gw or unsat. zone (mg/l) =	56.85

Average annual recharge (mm) =	12.76
Percentage recharge =	2.40

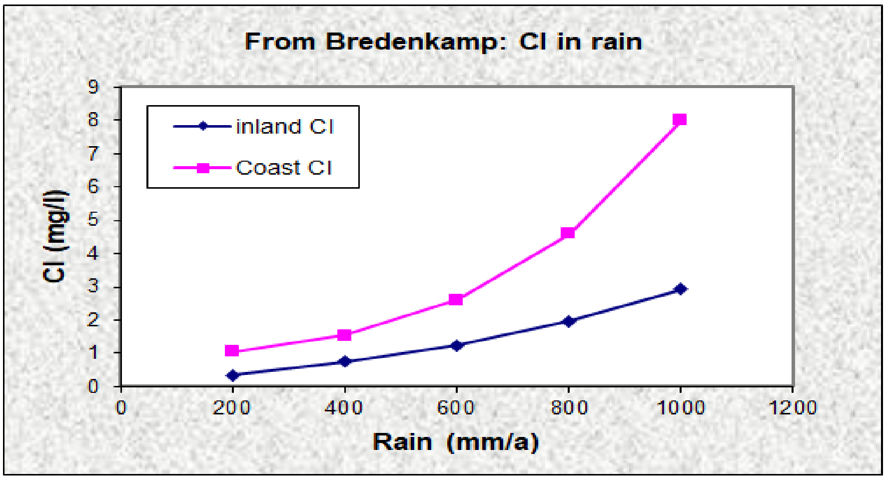


Figure 6-6 **Chloride Mass Balance (CMB) method recharge summary: Adelaide Sbgrp, Beaufort Grp Aquifer.**

CMB Method: Alluvial aquifer

Cavalier

Average annual rainfall (mm)=	531.66
Cl in rain (mg/l) =	1.240125
Dry deposition Cl (mg/l) =	0.124012
Cl in gw or unsat. zone (mg/l) =	28.33

Average annual recharge (mm) =	25.60
Percentage recharge =	4.82

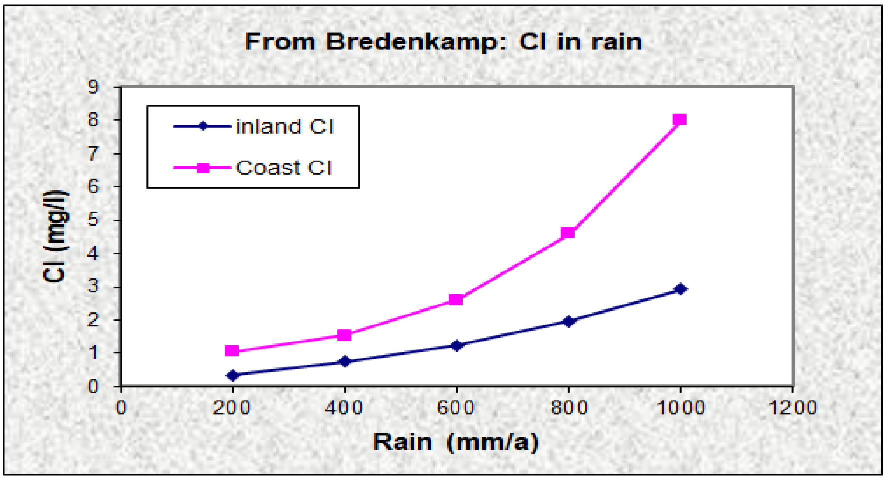


Figure 6-7 **Chloride Mass Balance (CMB) method recharge summary: Riparian zonw/ Alluvial Aquifer.**

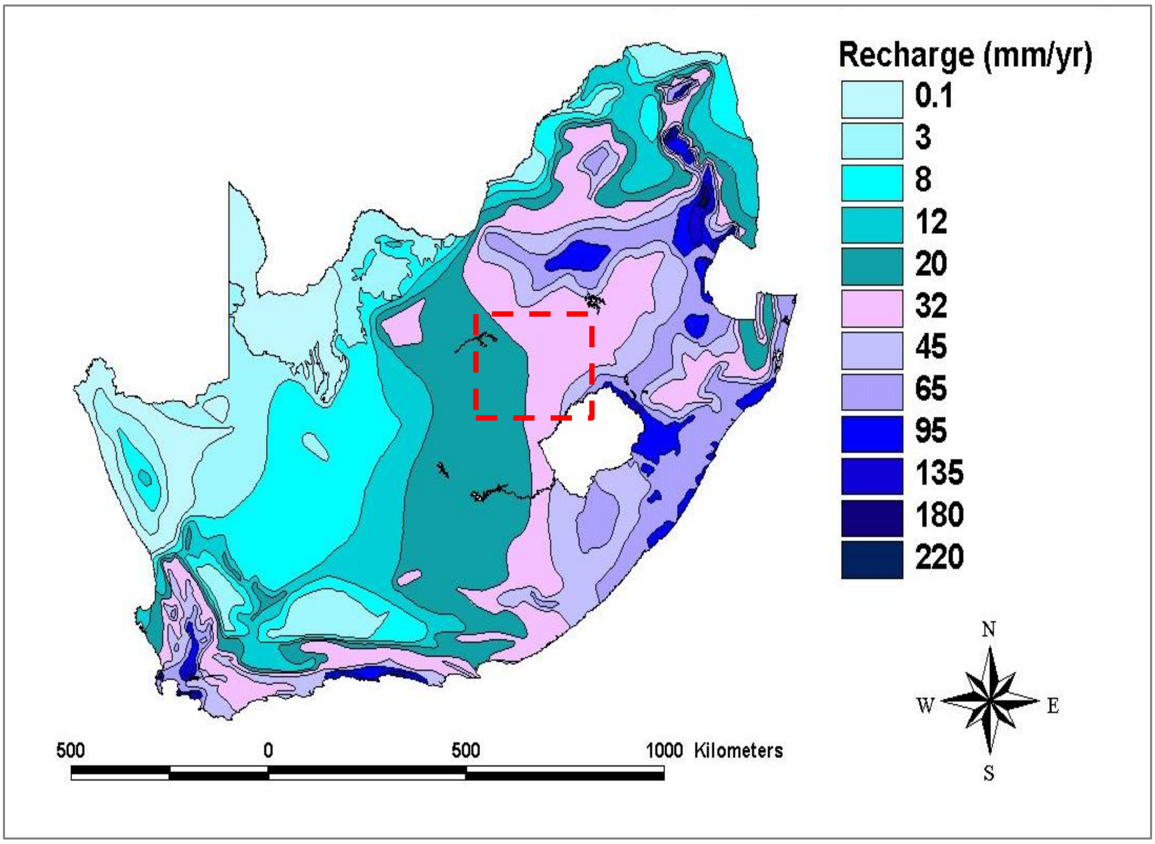


Figure 6-8 **Groundwater recharge distribution in South Africa (After Vegter, 1995).**

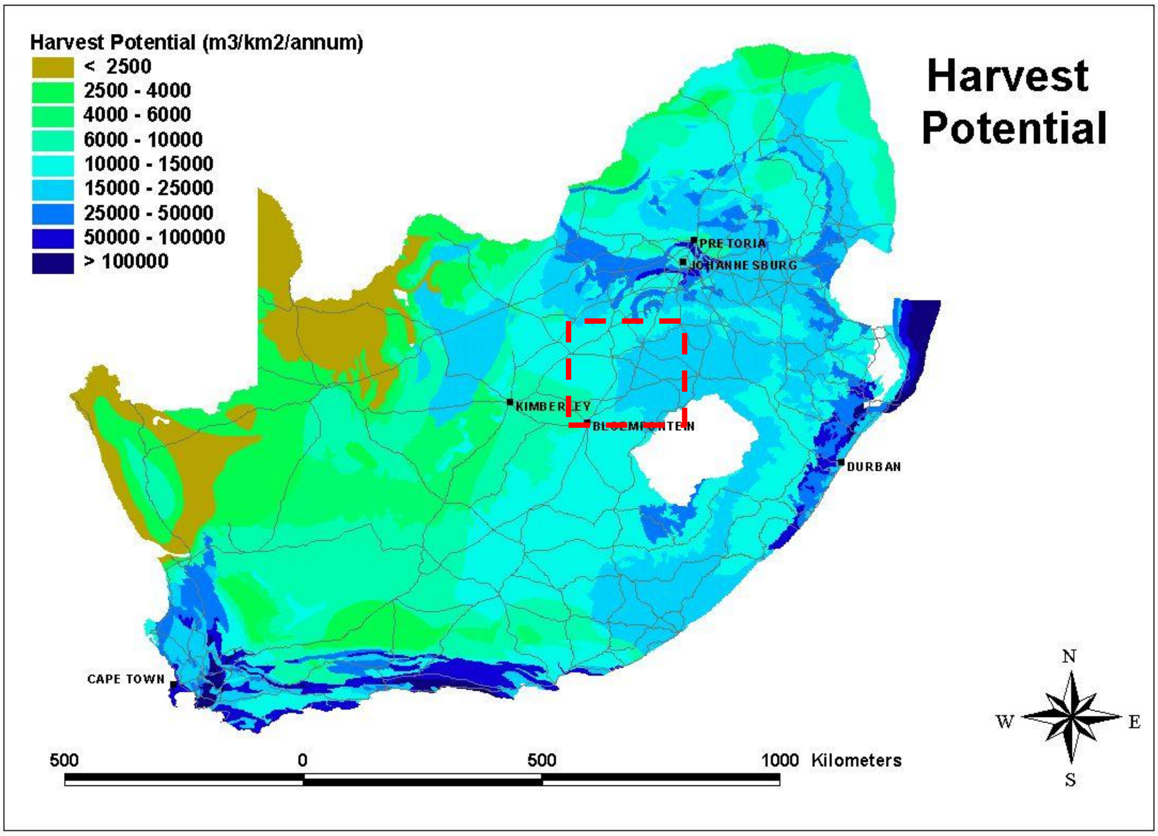


Figure 6-9 **Harvest potential distribution in South Africa (DWS, 2013).**

7. SITE INVESTIGATION

7.1. Hydrocensus user survey

A hydrocensus user survey within the greater study area was conducted during November and December 2025[5] where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater conditions and applications and to identify potential sensitive environmental receptors, i.e., groundwater users in the direct vicinity of the proposed exploration activities. A total of 168 geosites were visited and recorded as part of the hydrocensus user survey which include 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 (>77.58%) while ~22.42% 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 (~33.33%) while water being applied for either domestic and household or domestic and livestock purposes account for >39.40%. A small number of boreholes are also being applied for domestic and gardening purposes (0.61%), wildlife watering (1.21%), irrigation (0.61%) or monitoring purposes (~2.42%). Boreholes which do not have an application and are not currently being utilized account to 22.42% of the total geosites visited. Refer to **Figure 7-3** for a 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 to 43.4%, while 35.20% of boreholes were fitted either with a wind pump or mono pump (0.63%). An average of 20.75% of boreholes are not equipped as indicated in **Figure 7-4**.

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

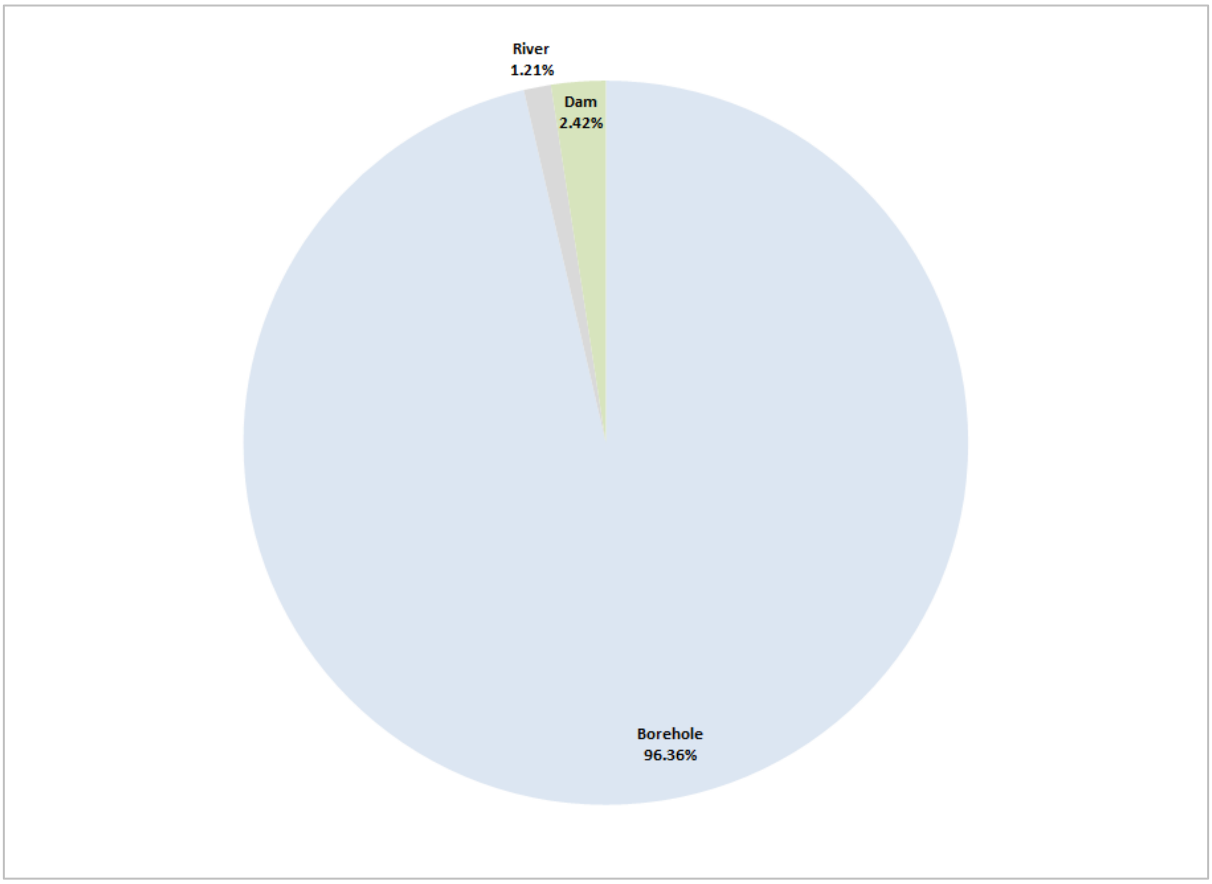


Figure 7-1 Hydrocensus user survey: Geosite type.

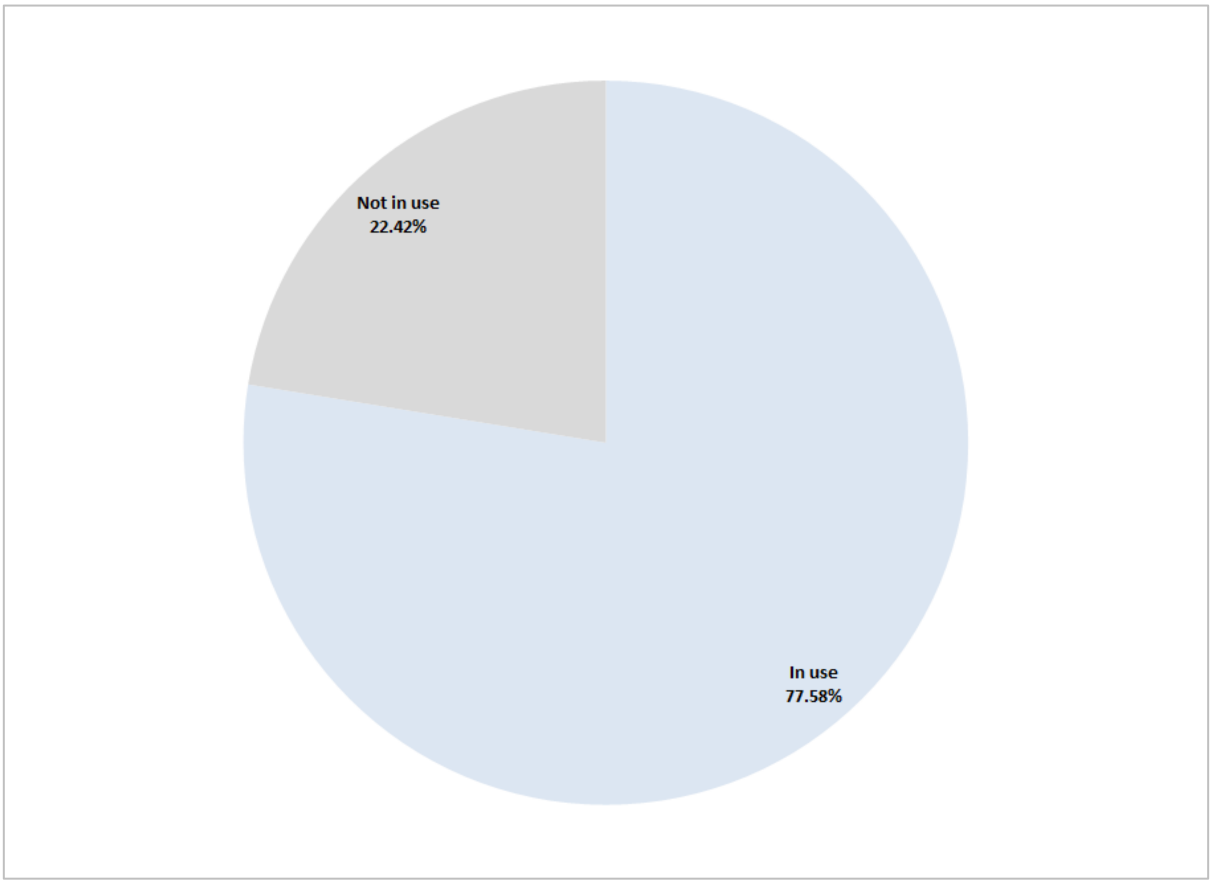


Figure 7-2 Hydrocensus user survey: Geosite status.

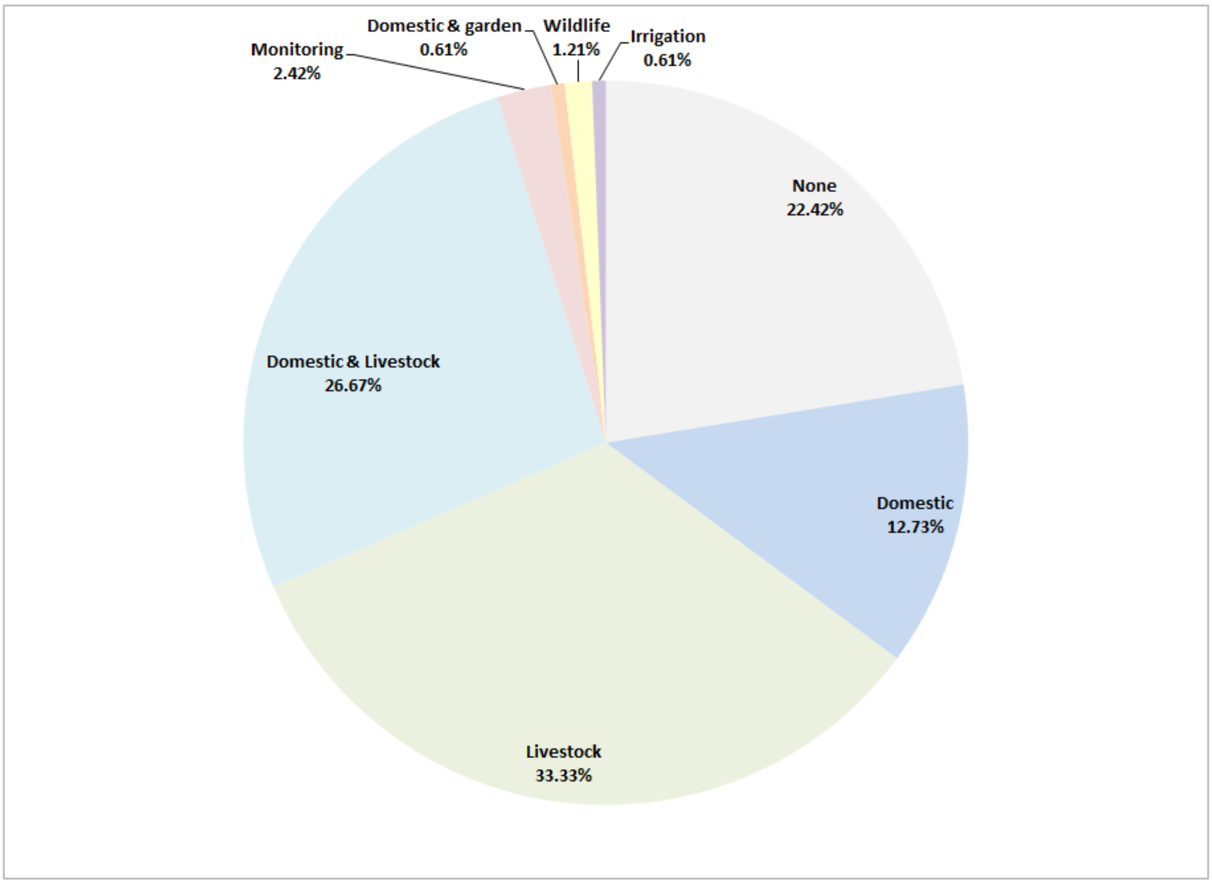


Figure 7-3 Hydrocensus user survey: Groundwater application.

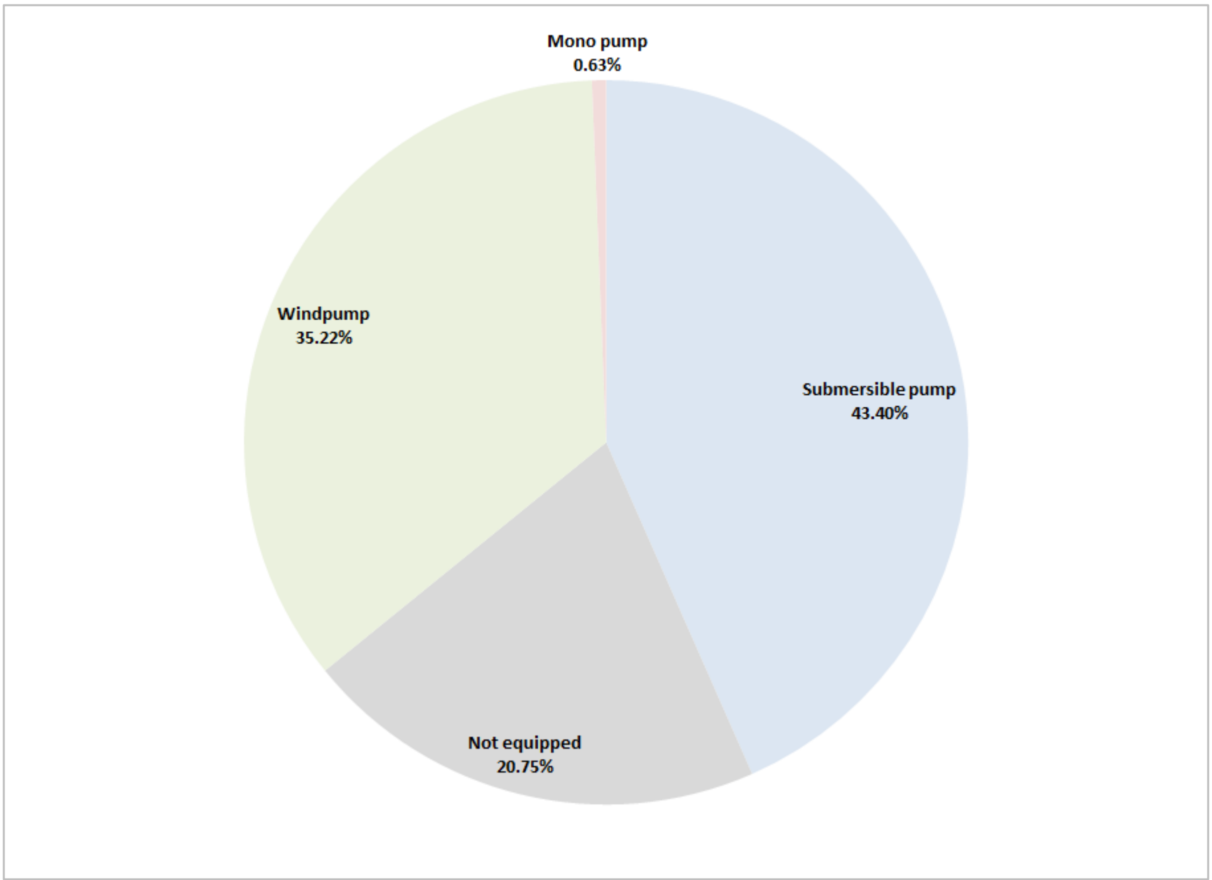


Figure 7-4 Hydrocensus user survey: Equipment type.

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	Property owner**
BH 01	-28.19612	26.97198	3.48	0.00	3.48		Static	Borehole	In Use	Submersible pump	Domestic	
BH 02	-28.19624	26.97227	3.00	0.42	2.58		Static	Borehole	Not in use	Not Equipped	None	
BH 03	-28.15924	26.97866	0.16	0.00	0.16	24.22	Static	Borehole	Not in use	Not Equipped	None	
BH 04	-28.20301	26.96701	3.13	0.00	3.13	48.07	Static	Borehole	Not in use	Not Equipped	None	
BH 05	-28.20883	26.97606			NAWL		Obstructed	Borehole	Not in use	Windpump	None	
BH 06	-28.19168	26.96538	1.77	0.25	1.52	18	Static	Borehole	Not in use	Not Equipped	None	
BH 07	-28.19180	26.94602	5.07	0.37	4.70		Static	Borehole	In Use	Submersible pump	Livestock	
BH 08	-28.17946	26.94019	4.44	0.00	4.44		Static	Borehole	Not in use	Windpump	None	
BH 09	-28.20564	26.91197	5.00	0.29	4.71		Recovering	Borehole	In Use	Submersible pump	Domestic	
BH 10	-28.20552	26.91393	7.00	0.32	6.68	7.22	Static	Borehole	Not in use	Not Equipped	None	
BH 11	-28.20710	26.91369	1.23	0.00	1.23		Static	Borehole	Not in use	Windpump	None	
BH 12	-28.22326	26.91753	4.69	0.00	4.69	4.82	Static	Borehole	Not in use	Not Equipped	None	
BH 13	-28.19279	26.91172	12.25	0.00	12.25		Pumping	Borehole	In Use	Windpump	Livestock	
BH 14	-28.17489	26.90367	10.77	0.00	10.77		Static	Borehole	In Use	Submersible pump	Domestic	
BH 15	-28.19129	27.00830	10.65	0.26	10.39		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 16	-28.19154	27.00855	5.04	0.00	5.04		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 17	-28.19075	27.00879	6.83	0.00	6.83		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 18	-28.19241	27.00700	11.01	0.00	11.01		Recovering	Borehole	In Use	Submersible pump	Domestic	

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	Property owner**
BH 19	-28.17209	26.99396	2.70	0.00	2.70		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 20	-28.28822	26.94036			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
BH 21	-28.28828	26.93973	5.70	0.00	5.70		Pumping	Borehole	In Use	Windpump	Domestic & Livestock	
BH 22	-28.29067	26.94438	9.43	0.00	9.43		Pumping	Borehole	In Use	Windpump	Livestock	
BH 23	-28.29557	26.94153	4.78	0.00	4.78	29.03	Static	Borehole	Not in use	Not Equipped	None	
BH 24	-28.29959	26.91854	9.37	0.00	9.37		Static	Borehole	In Use	Windpump	Domestic & Livestock	
BH 25	-28.30351	26.91989	5.83	0.00	5.83		Static	Borehole	In Use	Submersible pump	Domestic	
BH 26	-28.30663	26.92578		0.00	NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
BH 27	-28.28959	26.92606	9.19	0.00	9.19		Pumping	Borehole	In Use	Windpump	Domestic & Livestock	
BH 28	-28.27021	26.95501	15.88	0.21	15.67		Static	Borehole	In Use	Windpump	Livestock	
BH 29	-28.27592	26.97325	27.59	0.00	27.59		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 30	-28.27869	26.97491	3.97	0.23	3.74		Static	Borehole	In Use	Windpump	Livestock	
BH 31	-28.28107	26.97678	13.41	0.22	13.19		Static	Borehole	In Use	Windpump	Livestock	
BH 32	-28.28990	26.97188	13.94	0.25	13.69		Static	Borehole	In Use	Windpump	Livestock	
BH 33	-28.27489	26.98015	10.36	0.23	10.13		Static	Borehole	In Use	Windpump	Wildlife	
BH 34	-28.29272	26.96305	9.71	0.12	9.59		Pumping	Borehole	In Use	Windpump	Domestic & Livestock	
BH 35	-28.29233	26.96184	25.94	0.24	25.70		Static	Borehole	In Use	Submersible pump	Domestic	
BH 36	-28.28396	26.98823	13.13	0.36	12.77	38.2	Static	Borehole	Not in use	Not Equipped	None	
BH 37	-28.28368	26.99612	12.50	0.20	12.30		Pumping	Borehole	In Use	Windpump	Livestock	
BH 38	-28.27880	26.99982			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
BH 39	-28.27551	26.98851	13.49		13.49		Static	Borehole	Not in use	Windpump	None	
BH 40	-28.23407	26.97477	9.10	0.18	8.92		Static	Borehole	In Use	Submersible pump	Livestock	
BH 41	-28.22767	26.95813	19.97	0.26	19.71		Static	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	Property owner**
BH 42	-28.23039	26.94617	13.00	0.14	12.86		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
BH 43	-28.21135	26.94593			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
BH 44	-28.21711	26.94048	10.54	1.01	9.53	37.24	Static	Borehole	In Use	Not Equipped	Monitoring	
BH 45	-28.24814	26.94961			NAWL		Obstructed	Borehole	In Use	Submersible pump	Livestock	
BH 46	-28.24571	26.96123	14.20	0.00	14.20		Potentially affected by Pumping	Borehole	In Use	Submersible pump	Livestock	
BH 47	-28.24542	26.96122			NAWL		Obstructed	Borehole	In Use	Submersible pump	Livestock	
BH 48	-28.24658	26.96695	5.77	0.40	5.37		Static	Borehole	Not in use	Submersible pump	None	
BH 49	-28.25289	26.96300	1.46	0.10	1.36		Static	Borehole	In Use	Submersible pump	Livestock	
BH 50	-28.25294	26.96446	1.16	0.31	0.85		Static	Borehole	In Use	Submersible pump	Livestock	
BH 51	-28.26969	26.97812	13.30	0.30	13.00		Static	Borehole	Not in use	Not Equipped	None	
BH 52	-28.26691	26.97810	10.85	0.22	10.63		Static	Borehole	In Use	Windpump	Livestock	
BH 53	-28.26583	26.98844	11.89	0.21	11.68	11.89	Static	Borehole	Not in use	Not Equipped	None	
BH 54	-28.25307	26.99084	20.29	0.18	20.11		Static	Borehole	In Use	Submersible pump	Livestock	
BH 55	-28.25229	26.99123	52.79	0.35	52.44		Recovering	Borehole	In Use	Submersible pump	Livestock	
BH 56	-28.24033	26.98329	10.46	0.10	10.36		Pumping	Borehole	In Use	Submersible pump	Livestock	
MRBH 01	-27.97447	27.11229	1.88	0.00	1.88	38.43	Static	Borehole	Not in use	Not Equipped	None	
MRBH 02	-27.97484	27.11264			NAWL		Obstructed	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 03	-27.98252	27.11837	0.99		0.99	1.28	Static	Borehole	Not in use	Not Equipped	None	
MRBH 04	-27.96317	27.12997	1.22	0.30	0.92	15	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	Property owner**
MRBH 05	-27.99751	27.11662	2.06	0.00	2.06		Static	Borehole	Not in use	Submersible pump	None	
MRBH 06	-28.00427	27.11143	25.62	0.00	25.62		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 07	-27.99732	27.16372	11.70	0.14	11.56		Recovering	Borehole	In Use	Submersible pump	Domestic	
MRBH 08	-27.99595	27.16409	1.13	0.19	0.94	46.06	Static	Borehole	Not in use	Not Equipped	None	
MRBH 09	-27.99257	27.16908	1.88	0.37	1.51		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 10	-27.98892	27.15526	4.35	0.24	4.11		Pumping	Borehole	In Use	Windpump	Livestock	
MRBH 11	-27.94613	27.10499	13.21	0.40	12.81		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 12	-27.91435	27.08624	1.00	0.18	0.82	51.01	Static	Borehole	Not in use	Not Equipped	None	
MRBH 13	-27.90099	27.08360	9.59	0.14	9.45	30	Static	Borehole	Not in use	Not Equipped	None	
MRBH 14	-27.93600	27.09331	0.76	0.26	0.50	24.02	Static	Borehole	Not in use	Not Equipped	None	
MRBH 15	-27.94574	27.14457	2.94	0.34	2.60		Recovering	Borehole	In Use	Windpump	Livestock	
MRBH 16	-27.95616	27.15386	0.00	0.00	NAWL		Artesian	Borehole	Not in use	Submersible pump	None	
MRBH 17	-27.94401	27.15858	4.30	0.20	4.10		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 18	-27.94539	27.15752	2.74	0.22	2.52		Static	Borehole	Not in use	Not Equipped	None	
MRBH 19	-27.94542	27.15349	2.95	0.15	2.80		Static	Borehole	In Use	Windpump	Livestock	
MRBH 20	-27.93474	27.12692	4.64	0.00	4.64	27.62	Static	Borehole	Not in use	Not Equipped	None	
MRBH 21	-27.92937	27.13320			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 22	-27.98886	27.14421	0.00	0.00	NAWL		Static	Borehole	Not in use	Not Equipped	None	
MRBH 23	-28.03391	27.16555	1.89	0.16	1.73		Static	Borehole	In Use	Mono pump	Domestic & Livestock	
MRBH 24	-28.01515	27.12539	34.12	0.00	34.12		Static	Borehole	In Use	Submersible pump	Domestic & 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	Property owner**
MRBH 25	-27.91883	27.15684	9.56	0.00	9.56		Potentially affected by Pumping	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 26	-27.91896	27.15694			NAWL		Obstructed	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 27	-27.96348	27.08057			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 28	-27.96966	27.06257	3.81	0.10	3.71		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 29	-27.99116	27.06111	18.00	0.15	17.85		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 30	-27.95291	27.04439	8.36	0.30	8.06		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 31	-27.94353	27.05962			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 32	-27.93060	27.07296	0.72	0.00	0.72		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 33	-27.93188	27.07867	1.63	0.14	1.49		Static	Borehole	In Use	Windpump	Livestock	
MRBH 34	-27.93916	27.06846	0.87	0.00	0.87		Static	Borehole	In Use	Windpump	Livestock	
MRBH 35	-27.91421	27.15065	4.75	0.27	4.48		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 36	-27.91273	27.15526	5.30	0.00	5.30		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 37	-27.88290	27.05334	6.57	0.11	6.46		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 38	-27.88931	27.06377	3.34	0.37	2.97		Static	Borehole	In Use	Windpump	Livestock	
MRBH 39	-27.88977	27.06191	3.81	0.26	3.55		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 40	-27.86061	27.01692	1.60	0.00	1.60		Recovering	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 41	-27.87161	27.01829	2.62	0.16	2.46		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 42	-27.85103	27.01240	2.54	2.54	NAWL		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 43	-27.89182	26.99726	1.65	0.41	1.24		Static	Borehole	In Use	Windpump	Livestock	
MRBH 44	-27.88341	26.99032			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 45	-27.87008	26.99530	2.10	0.38	1.72		Static	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 46	-27.87271	26.98714			NAWL		Obstructed	Borehole	In Use	Windpump	Domestic	

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	Property owner**
MRBH 47	-27.91207	26.95290			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 48	-27.92234	26.96354			NAWL		Obstructed	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 49	-27.89696	26.96312			NAWL		Obstructed	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 50	-27.89106	26.96381			NAWL		Obstructed	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 51	-27.89039	26.96517	0.54	0.20	0.34		Static	Borehole	In Use	Windpump	Livestock	
MRBH 52	-27.88737	26.97165	1.70	0.33	1.37		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 53	-27.88729	26.97215	1.00	0.22	0.78		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 54	-27.87657	26.95393	1.77	0.10	1.67		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 55	-27.86797	26.94948	3.00	0.31	2.69		Static	Borehole	In Use	Windpump	Livestock	
MRBH 56	-27.85681	26.94673	4.26	0.17	4.09		Static	Borehole	In Use	Windpump	Domestic	
MRBH 57	-27.85373	26.94912	3.41	0.30	3.11		Static	Borehole	In Use	Windpump	Livestock	
MRBH 58	-27.85663	26.94859	1.87	0.16	1.71		Static	Borehole	In Use	Windpump	Livestock	
MRBH 59	-27.85877	26.96865	1.00	0.27	0.73		Static	Borehole	In Use	Windpump	Livestock	
MRBH 60	-27.85242	26.92022	6.74	0.50	6.24		Static	Borehole	In Use	Windpump	Livestock	
MRBH 61	-27.85574	26.97672			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 62	-27.85537	26.97762	1.20	0.30	0.90		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 63	-27.83674	26.96503			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 64	-27.83849	26.95769	4.47	0.30	4.17		Pumping	Borehole	In Use	Windpump	Livestock	
MRBH 65	-27.83814	26.99071	2.06	0.20	1.86		Static	Borehole	In Use	Submersible pump	Livestock	
MRBH 66	-27.82690	26.99616	1.25	0.18	1.07		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 67	-27.82701	26.98546	0.63	0.00	0.63		Static	Borehole	Not in use	Not Equipped	None	
MRBH 68	-27.82928	26.97909	1.00	0.27	0.73		Static	Borehole	Not in use	Not Equipped	None	
MRBH 69	-27.79737	26.95395	4.21	0.24	3.97		Static	Borehole	In Use	Submersible pump	Domestic & 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	Property owner**
MRBH 70	-27.94777	27.00071	8.72	0.00	8.72		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 71	-27.95181	27.00055	2.67	0.00	2.67		Static	Borehole	Not in use	Not Equipped	None	
MRBH 72	-27.86503	27.00092	2.00	0.14	1.86		Static	Borehole	Not in use	Windpump	None	
MRBH 73	-27.86111	27.00034	4.69	0.33	4.36		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 74	-27.86334	27.00234	1.69	0.24	1.45		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 75	-27.87911	27.00489	0.91	0.06	0.85		Static	Borehole	Not in use	Not Equipped	None	
MRBH 76	-27.91542	26.92172	1.14	0.16	0.98		Static	Borehole	In Use	Windpump	Livestock	
MRBH 77	-27.80887	26.98933			NAWL		Obstructed	Borehole	In Use	Windpump	Livestock	
MRBH 78	-27.93483	26.92256	5.72	0.10	5.62		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 79	-27.93526	26.92232	6.10	0.00	6.10		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 80	-27.93615	26.92136	4.00	0.39	3.61		Static	Borehole	In Use	Submersible pump	Livestock	
MRBH 81	-27.93546	26.91854	3.43	0.44	2.99		Static	Borehole	In Use	Submersible pump	Domestic & Garden	
MRBH 82	-27.93561	26.92615	9.89	0.24	9.65		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 83	-27.95482	26.92270	12.33	0.47	11.86		Static	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 84	-27.95358	26.92245	9.08	0.29	8.79		Static	Borehole	Not in use	Not Equipped	None	
MRBH 85	-27.82049	26.92249	5.44	0.16	5.28		Static	Borehole	Not in use	Not Equipped	None	
MRBH 86	-27.97991	26.92125	5.21	0.00	5.21		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 87	-28.01670	26.92110	5.05	0.33	4.72		Static	Borehole	In Use	Submersible pump	Domestic	
MRBH 88	-28.03292	26.89683	2.85	0.00	2.85		Static	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 89	-28.03391	26.89601	3.36	0.20	3.16		Static	Borehole	In Use	Windpump	Domestic	

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	Property owner**
MRBH 90	-28.03389	26.89580	3.65	0.00	3.65		Static	Borehole	Not in use	Not Equipped	None	
MRBH 91	-28.03719	26.89469	3.55	0.40	3.15		Static	Borehole	In Use	Windpump	Domestic & Livestock	
MRBH 92	-28.06826	26.90842	7.52	0.15	7.37		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 93	-27.90584	27.03180	20.52	0.25	20.27		Static	Borehole	In Use	Windpump	Wildlife	
MRBH 94	-27.91148	27.02501	2.00	0.60	1.40		Static	Borehole	In Use	Submersible pump	Livestock	
MRBH 95	-27.90584	27.02247	0.75	0.10	0.65		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 96	-27.95109	26.95801	7.00	0.00	7.00		Static	Borehole	In Use	Submersible pump	Irrigation	
MRBH 97	-27.95122	26.95832	7.06	0.10	6.96		Static	Borehole	Not in use	Not Equipped	None	
MRBH 98	-27.92696	26.96163	0.00	0.30	0.00		Artesian	Borehole	Not in use	Not Equipped	None	
MRBH 99	-27.94754	26.98978			NAWL		Bees	Borehole	In Use	Submersible pump	Domestic & Livestock	
MRBH 100	-27.94735	26.98988	1.42	0.00	1.42		Static	Borehole	In Use	Submersible pump	Domestic & Livestock	
MTBH01	-27.98028	27.11779	1.85	0.20	1.65	120	Static	Borehole	In Use	Not Equipped	Monitoring	
MTBH02	-27.82267	26.97051	1.25	0.20	1.05	120	Static	Borehole	In Use	Not Equipped	Monitoring	
MTBH03	-28.24108	26.97378	13.08	0.20	12.88	120	Static	Borehole	In Use	Not Equipped	Monitoring	
MTBH04	-28.21098	26.95767	8.14	0.20	7.94	120	Static	Borehole	In Use	Not Equipped	Monitoring	
MTBH05	-28.28627	26.97008	13.29	0.20	13.09	120	Static	Borehole	In Use	Not Equipped	Monitoring	
MTBH06	-28.22438	26.93892	4.86	0.20	4.66	120	Static	Borehole	In Use	Not Equipped	Monitoring	
SW 01	-28.20727	26.91736	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock	
SW 02	-28.29012	26.93968	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock	
SW 03	-28.27852	26.97496	n/a	n/a	n/a	n/a	n/a	Dam	In Use	n/a	Livestock	
SW 04	-27.97173	26.90652	n/a	n/a	n/a	n/a	n/a	River	In Use	n/a	Livestock	
SW 05	-27.91525	27.15967	n/a	n/a	n/a	n/a	n/a	Rietspruit (Upstream)	In Use	n/a	Livestock	
SW 06	-27.91686	27.02100	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 of the hydrocensus geosites surveyed.**

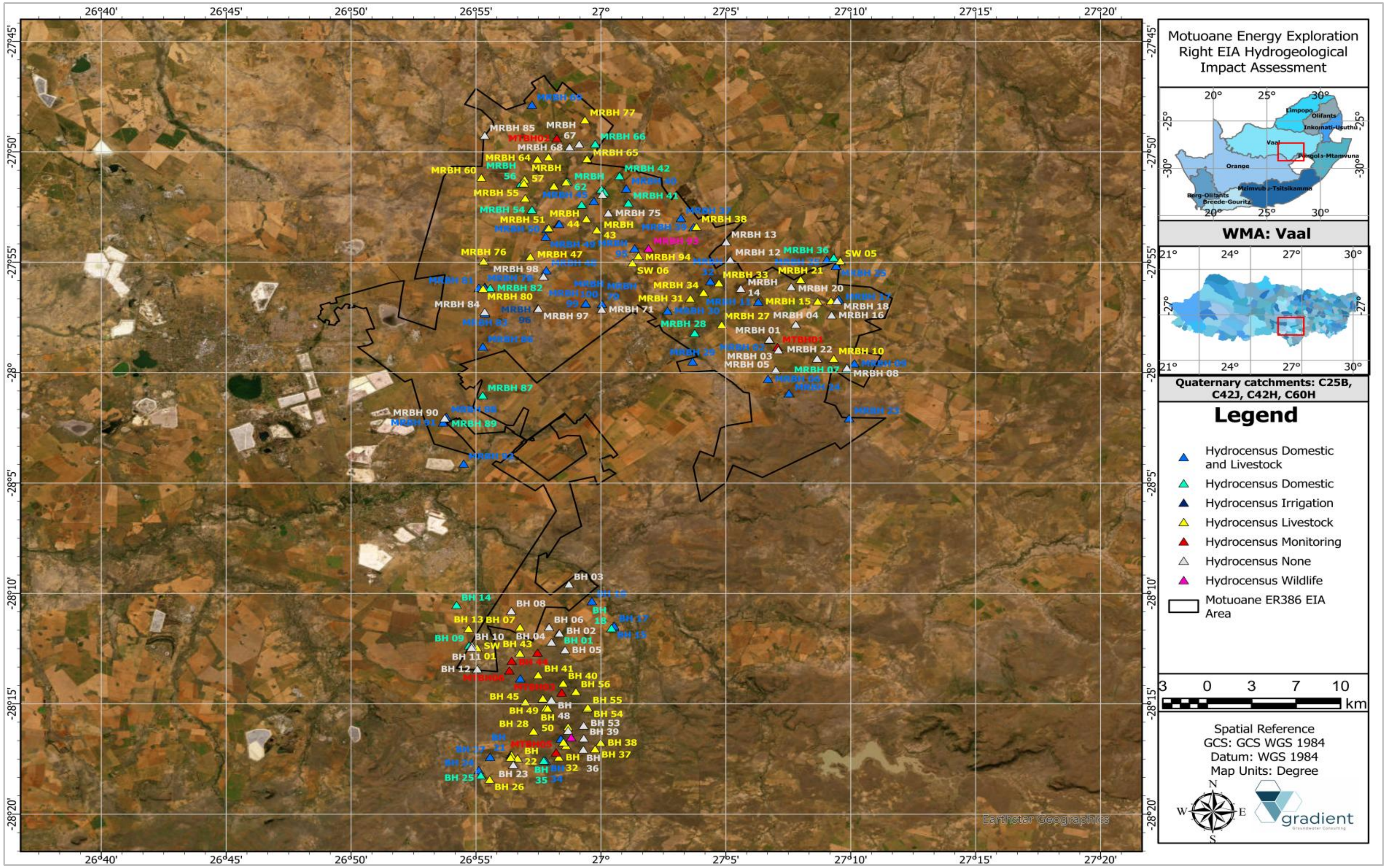


Figure 7-6 **Spatial distribution map indicating groundwater status and application.**

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 week 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		Approximate Length (m)	Potential target	Station spacing (m)	Drilling target	Approximate orientation
	Latitude	Longitude					
Traverse 01	-27.974865	27.128883	900.00	SW-NE striking lineament	10.00	MTBH01	W-E
Traverse 02	-27.971852	27.114019	650.00	W-E striking lineament	10.00	n/a	SW-NE
Traverse 02a	-27.974865	27.128883	600.00	W-E striking lineament	10.00	n/a	S-N
Traverse 03	-27.823385	26.968678	640.00	NW-SE striking lineament	10.00	MTBH02	SW-NE
Traverse 04	-27.821203	26.969845	600.00	NW-SE striking lineament	10.00	n/a	N-S
Traverse 05	-27.810811	26.966487	600.00	N-W 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 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 reginal geological lineaments in relations to proposed infrastructure and activities.**

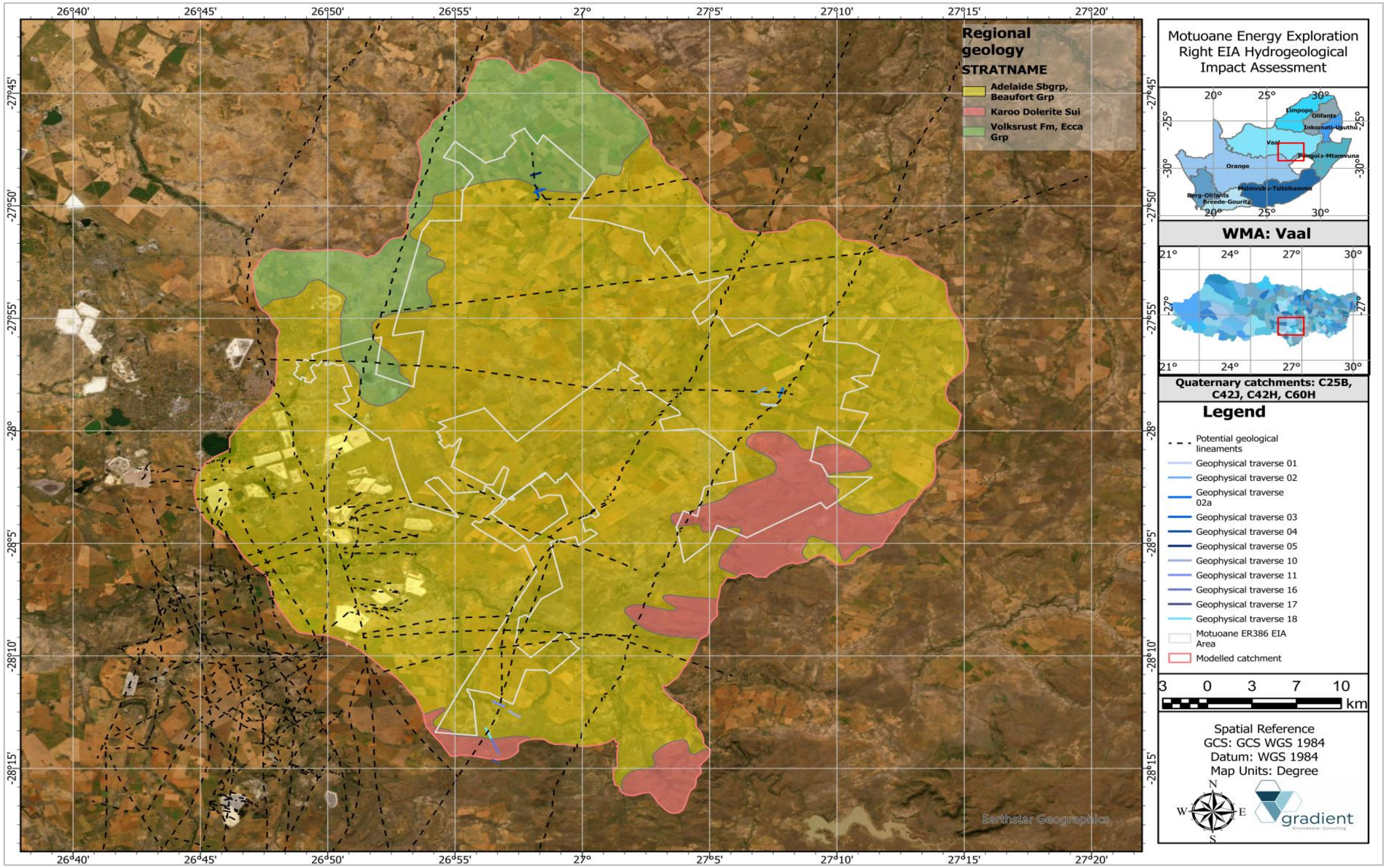


Figure 8-2 **Geophysical traverse array in relation to regioanl geology as well as potential geological lineaments.**

8.1.1. Traverse 01

Traverse 01 was surveyed over a lateral distance of 900.0m (10 m-station spacing) and was conducted in an approximate west-east orientation targeting a southwest-northeast striking geological lineament. A prominent magnetic low zone can be observed between stations 40.0-70.0m and again at stations 800.0 – 900.0m. The second magnetic anomaly was caused by interference by a communication tower and, as such, was not considered. Accordingly, the first anomaly was identified as drilling position MTBH01, targeting a potential dyke 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 03

Traverse 03 was surveyed over a lateral distance of 640.0m (10 m- station spacing) and was conducted in an approximate southwest-northeast orientation targeting a northwest-southeast striking geological lineament. A prominent increase in the measured magnetic field followed by a sharp decrease can be observed between stations 140.0-180.0m and again between station 280.0-310.0m. The magnetic low at the first anomaly is associated with a sharp 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 170.0m was identified as drilling position MTBH02. Refer to **Figure 8-4** for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.3. 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 8-5** 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.

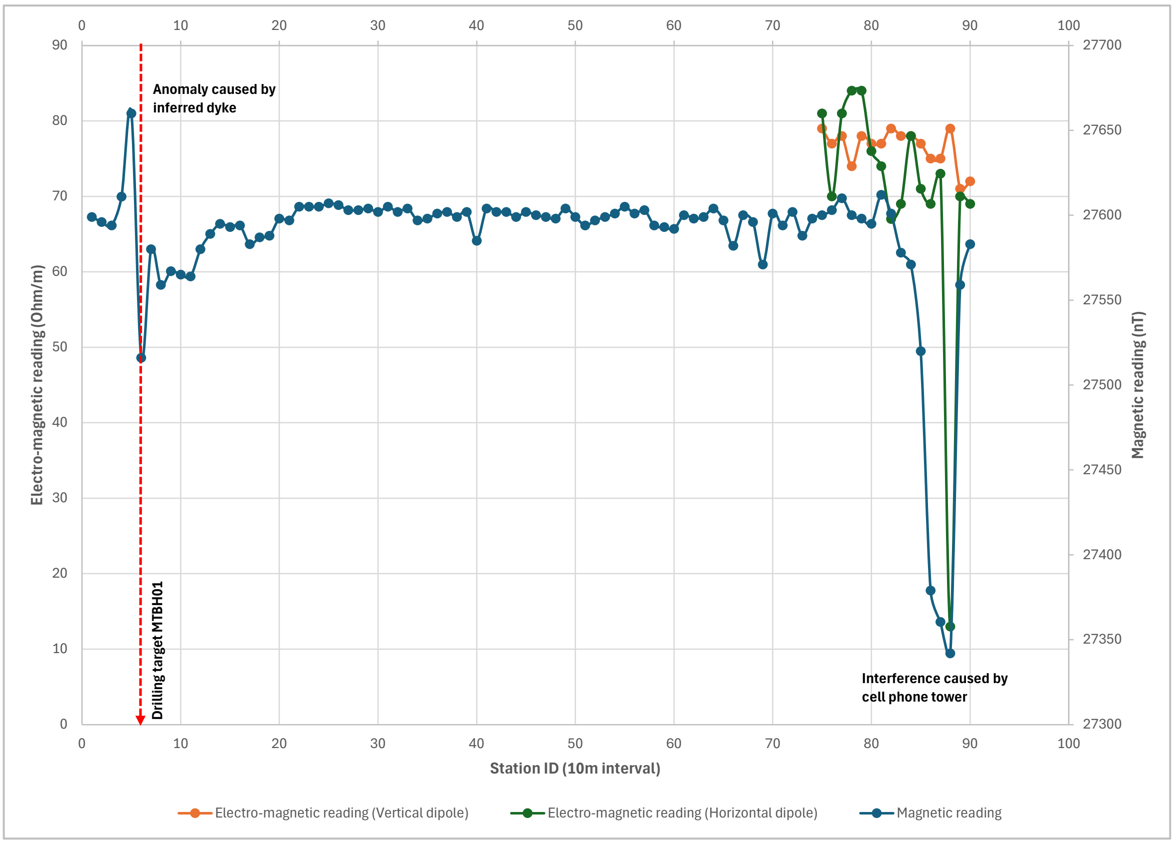


Figure 8-3 **Geophysical traverse 01: Magnetic curve as well as electro-magnetic profile with relevant information.**

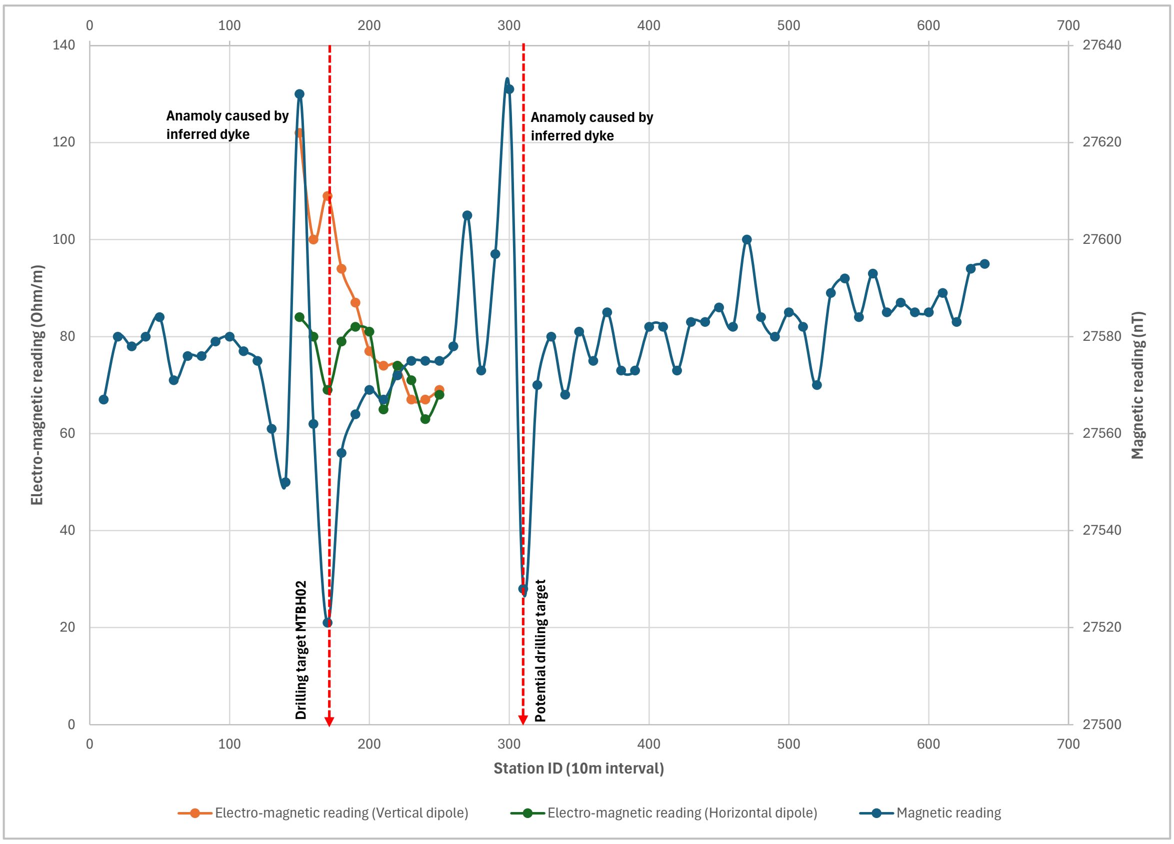


Figure 8-4 **Geophysical traverse 03: Magnetic curve as well as electro-magnetic profile with relevant information.**

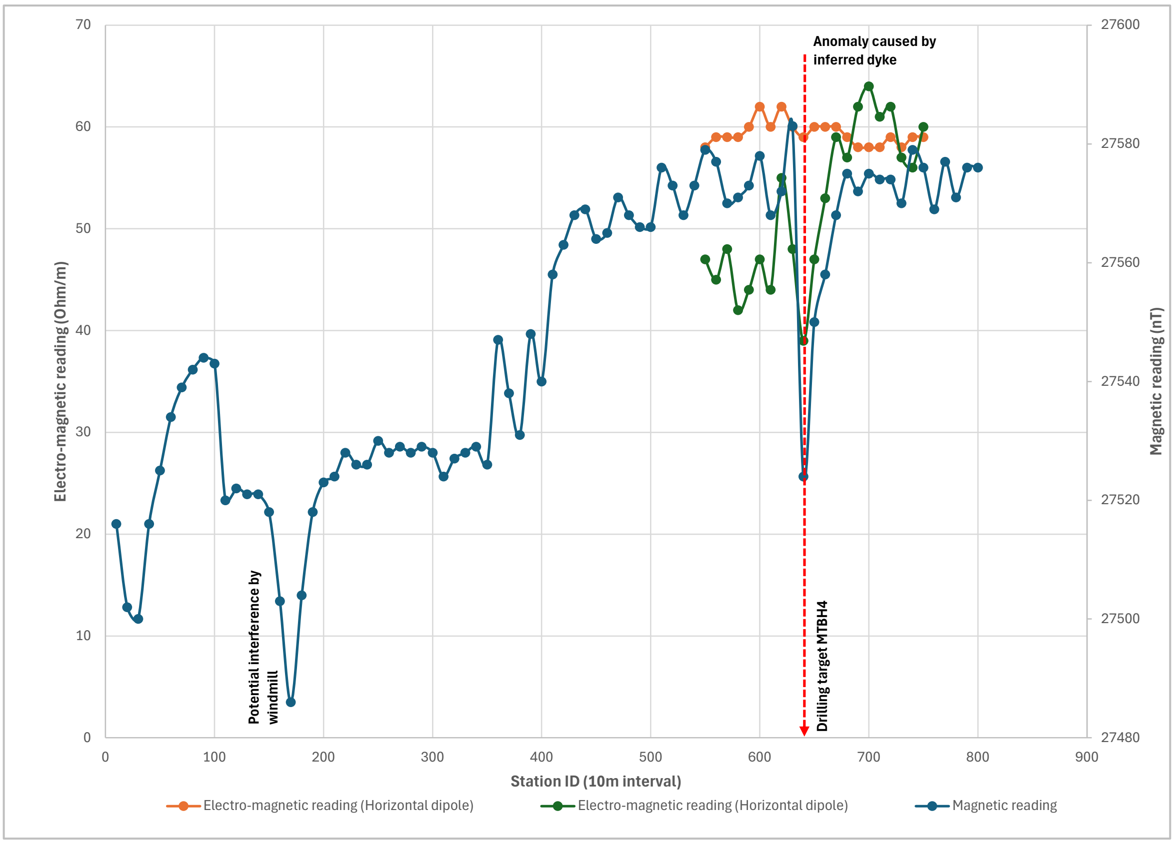


Figure 8-5 **Geophysical traverse 10: Magnetic curve as well as electro-magnetic profile with relevant information.**

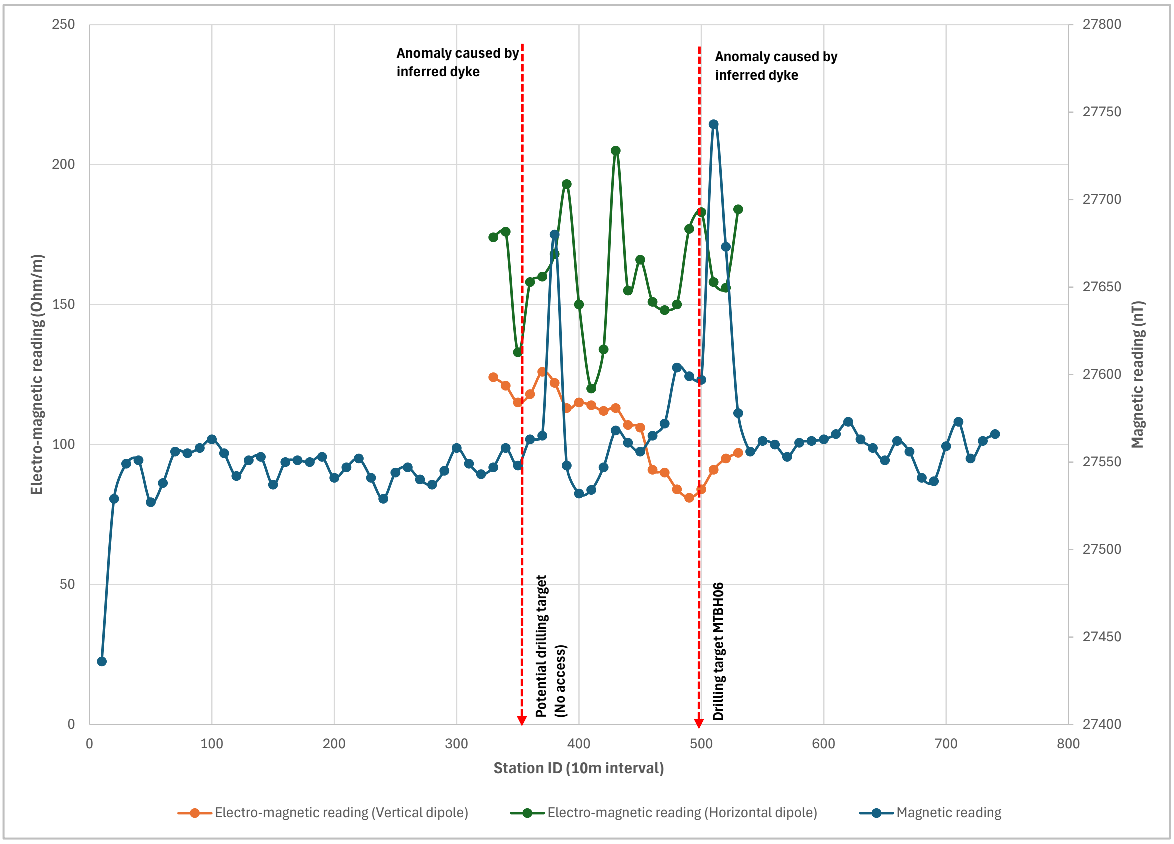


Figure 8-6 **Geophysical traverse 18: Magnetic curve as well as electro-magnetic profile with relevant information.**

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
MTBH01	-27.9803	27.11779	Fractured aquifer (confined)	Site characterisation and monitoring
MTBH02	-27.8227	26.97051	Fractured aquifer (confined)	Site characterisation and monitoring
MTBH04	-28.211	26.95767	Fractured aquifer (confined)	Site characterisation and monitoring
MTBH06	-28.2244	26.93892	Fractured aquifer (confined)	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)
MTBH01	120.00	1.42	219.0mm(0-18m); 165.0mm (18m-EOH)	Steel (starter = 18m) uPVC (EOH)	165.0mm (0-EOH)	200.00	60/96	0.55
MTBH02	120.00	1.65	250.0mm(0-18m); 165.0mm (18m-EOH)	Steel (starter = 18m) uPVC (EOH)	165.0mm (0-EOH)	200.00	Seepage (19)	None
MTBH04	120.00	12.88	219.0mm(0-6m); 165.0mm (6m-EOH)	Steel (starter = 6m) uPVC (EOH)	165.0mm (0-EOH)	200.00	Seepage (60)	0.33
MTBH06	120.00	13.09	219.0mm(0-6m); 165.0mm (6m-EOH)	Steel (starter = 6m) uPVC (EOH)	165.0mm (0-EOH)	200.00	16/30/60/102	0.33

Notes: EOH = End of Hole.

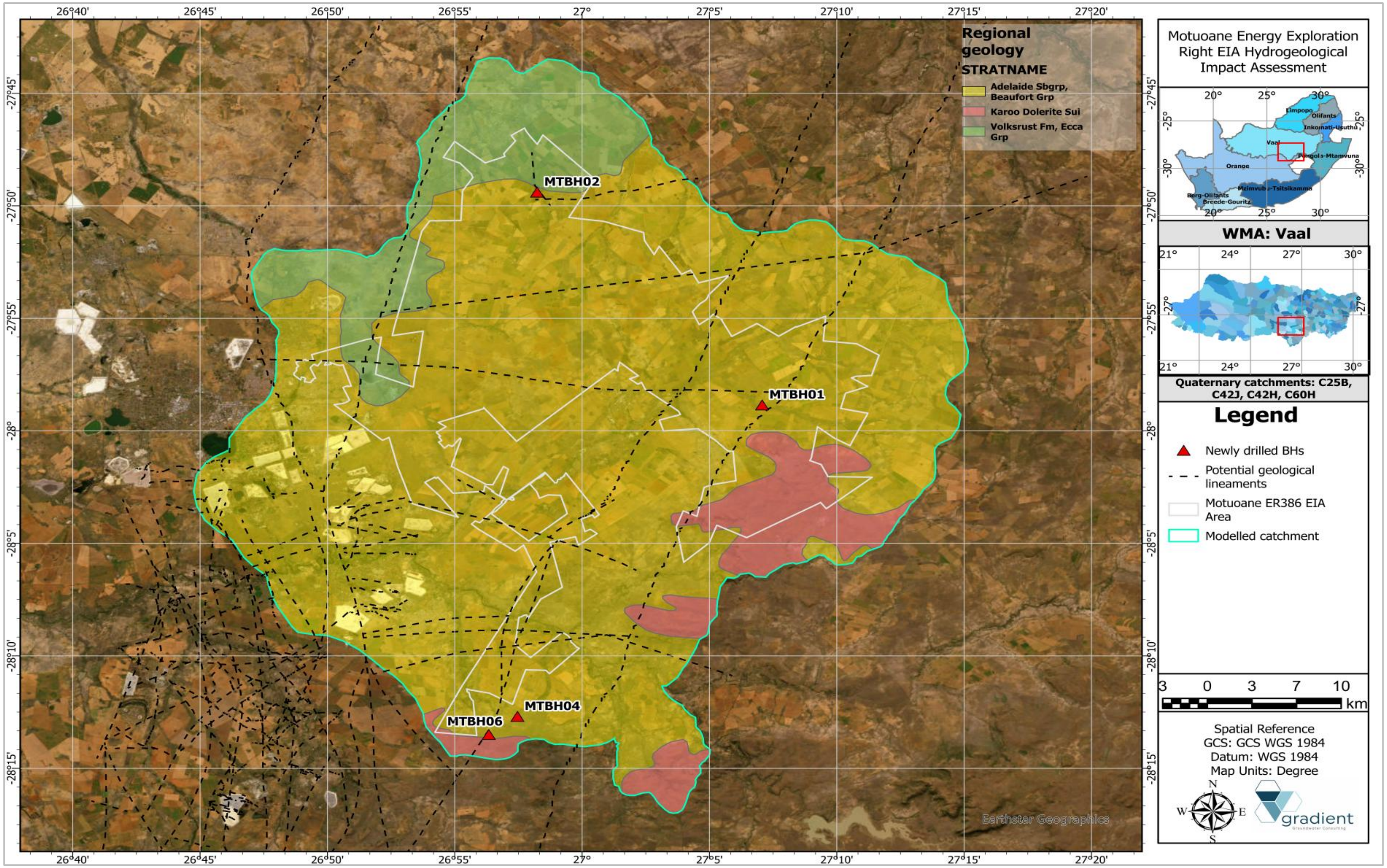


Figure 8-7 **Map depicting new drilled site characterisation borehole positions in relation to regional geology and inferred geological lineaments.**

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

8.2.1. Drilling locality MTBH01

Borehole locality MTBH01 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 18.0mbgl 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 thick yellow clay layer followed by black shale of the Beaufort Group formations to the end of the hole (EOH). A major water strike was encountered at a depth of between 60.0m as well as 96.0m (final blow yield = 0.55l/s) After borehole development, the static water level was recorded at 1.42mbgl.

8.2.2. Drilling locality MTBH02

Borehole locality MTBH02 was drilled at a 165.0mm (6.50") diameter to a depth of 120.0mbgl. The borehole was reamed to a diameter of 250.0mm (10.0") due to unstable drilling conditions with the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 18.0mbgl 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 thick yellow clay layer followed by black shale of the Beaufort Group to a depth of 84.0mbgl and interlaminated sandstone and shale to the EOH. Seepage water was encountered at the shale and sandstone contact at a depth of approximately 84.0mbgl, however the volume was too little to determine a blow yield. After borehole development, the static water level was recorded at 1.65mbgl.

8.2.3. 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.

8.2.4. 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 (m^2/d).

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

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

Equation 8-1 Transmissivity (Cooper-Jacob).

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

where:

T = Transmissivity (m^2/d).

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

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)
MTBH01	0.55	CR	0.50	360.00	1.42	95.00	93.58	27.45	29.33	0.15	0.25	0.50	0.80
MTBH02	None	CR	0.20	360.00	1.65	95.00	93.35	17.67	18.93	0.15	0.20	0.30	0.50
MTBH04	0.33	CR	0.20	480.00	12.88	95.00	82.12	47.77	58.17	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 (m²/d)	Recovery Transmissivity (m²/d)	Early Transmissivity (m²/d)	Late Transmissivity (m²/d)	Transmissivity (m²/d)	Hydraulic conductivity (m/d)
MTBH01	Geological lineament	1.03	0.93	1.13	0.24	1.03	0.07
MTBH02	Volksrust formation	0.59	0.54	0.51	0.47	0.55	0.04
MTBH04	Beaufort Group formation	0.11	0.11	0.58	0.08	0.26	0.02
MTBH06	Karoo Dolerite Suite	0.03	0.03	0.05	0.04	0.04	0.00

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 MTBH01

Borehole MTBH01 was subjected to four calibration step tests of 0.15l/s, 0.25l/s, 0.50l/s and 0.80l/s followed by a constant rate test at a yield of 0.50l/s for a duration of 6 hours until radial flow conditions were observed. A maximum drawdown depth of 27.45 meter below static level (mbsl) was reached during the pump test duration, representing ~29.33% of available drawdown utilised. Borehole recovery observed was not good with the borehole not reaching pre-testing water levels within the recovering time. The Cooper Jacob method indicated the best data fit and are assumed to be the most representative of the confined aquifer behaviour which were selected to estimate the aquifer parameters. An average transmissivity of 1.03m²/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.

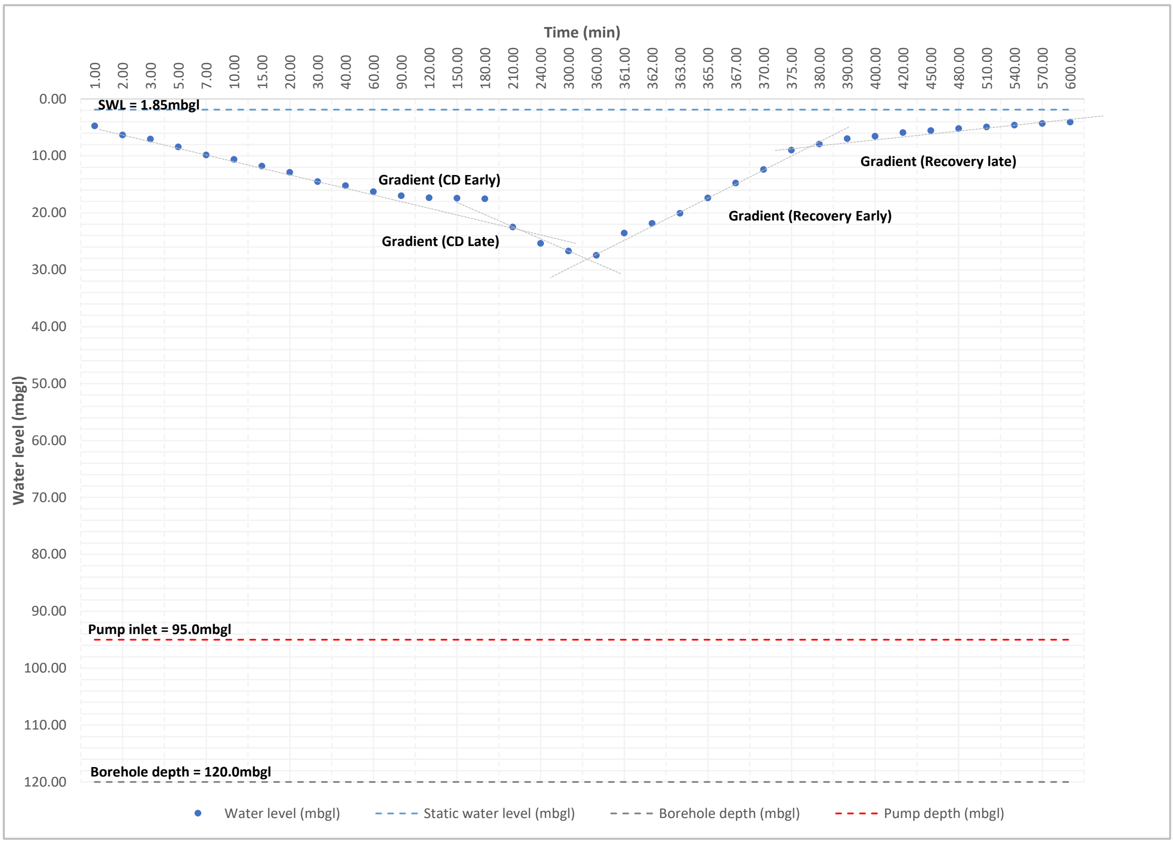


Figure 8-8 **Aquifer tests: MTBH01 water level drawdown and recovery scattered plot.**

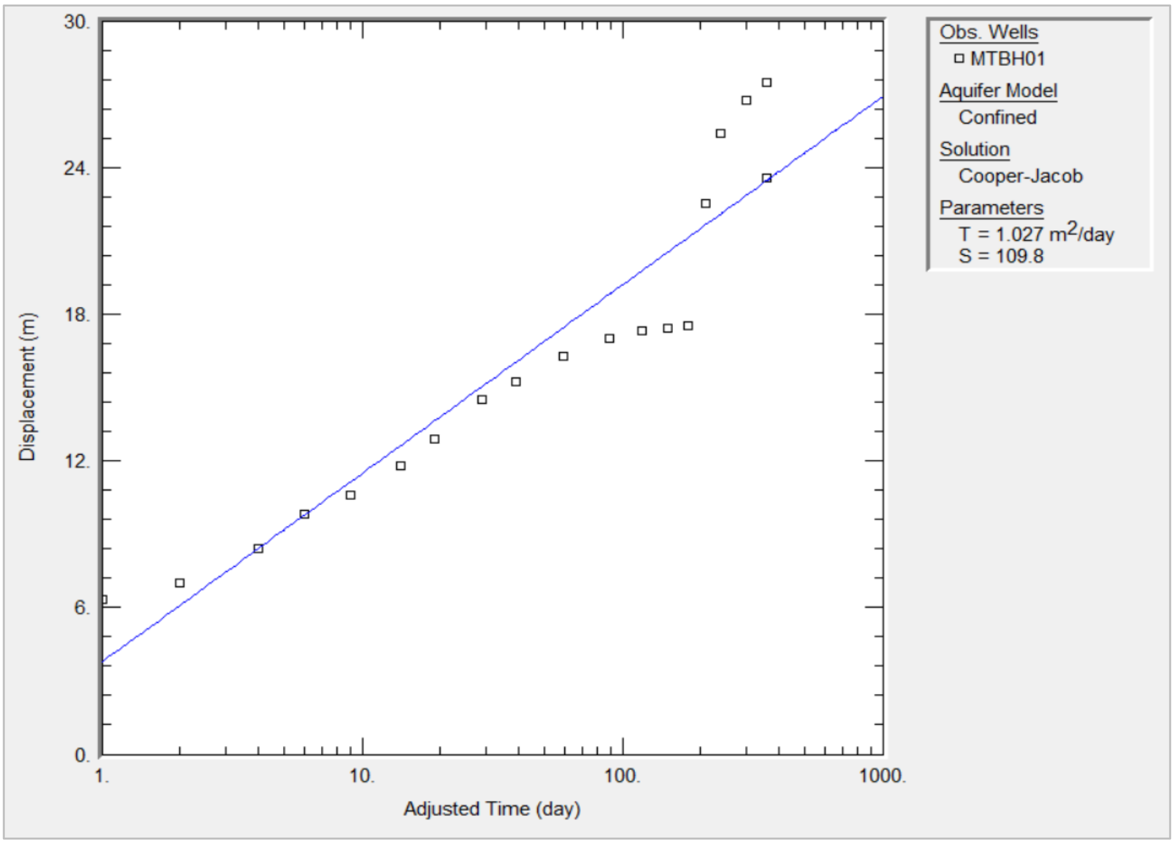


Figure 8-9 Aquifer tests: Cooper-Jacob method displacement time curve for MTBH01.

8.3.2. Constant Rate Test borehole MTBH02

Borehole MTBH02 was subjected to four calibration step tests of 0.15l/s, 0.20l/s, 0.30l/s and 0.50l/s followed by a constant rate test at a yield of 0.20l/s for a duration of 6 hours until radial flow conditions were observed. A maximum drawdown depth of 17.67 mbsl was reached during the pump test duration, representing ~19.0% of available drawdown utilised. Borehole recovery observed was not good with the borehole not reaching pre-testing water levels within the recovering time. The Cooper Jacob method indicated the best data fit and are assumed to be the most representative of the confined aquifer behaviour which were selected to estimate the aquifer parameters. An average transmissivity of 0.55m^2/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 Cooper-Jacob method displacement time curve fitment.

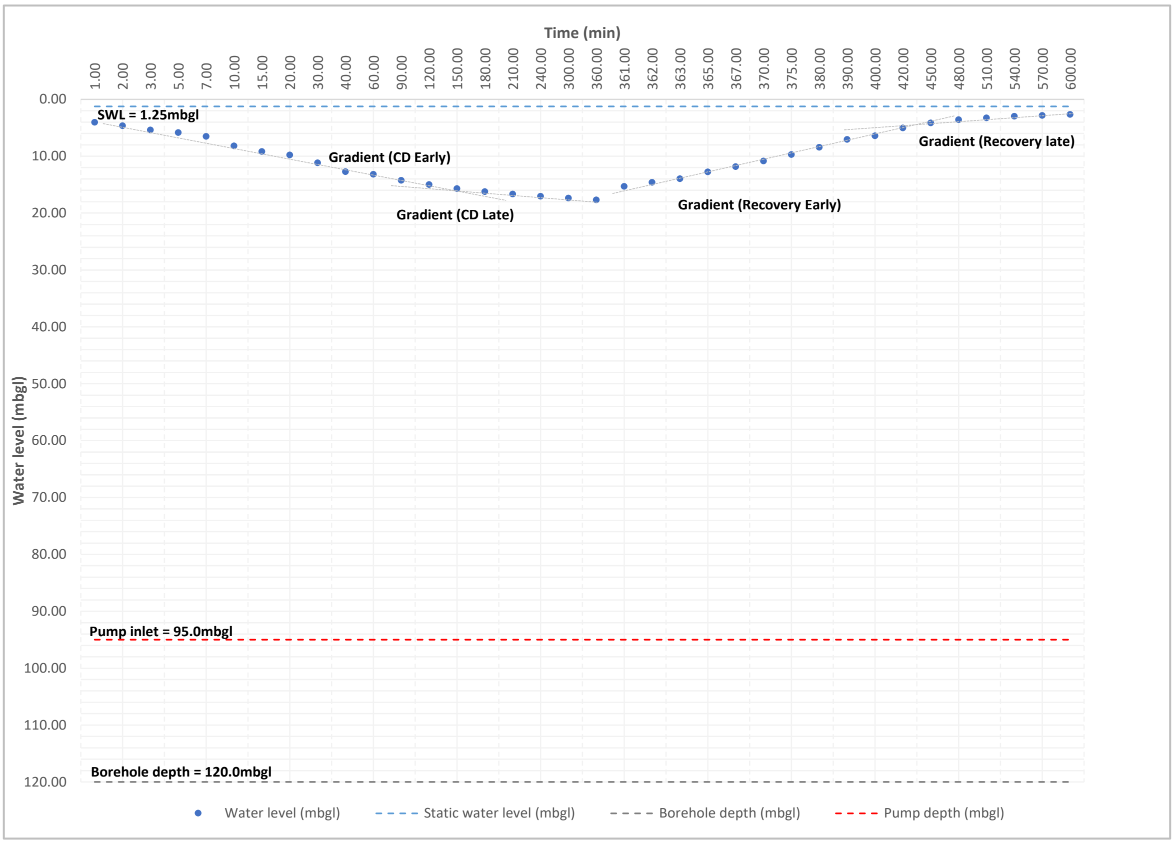


Figure 8-10 Aquifer tests: MTBH02 water level drawdown and recovery scattered plot.

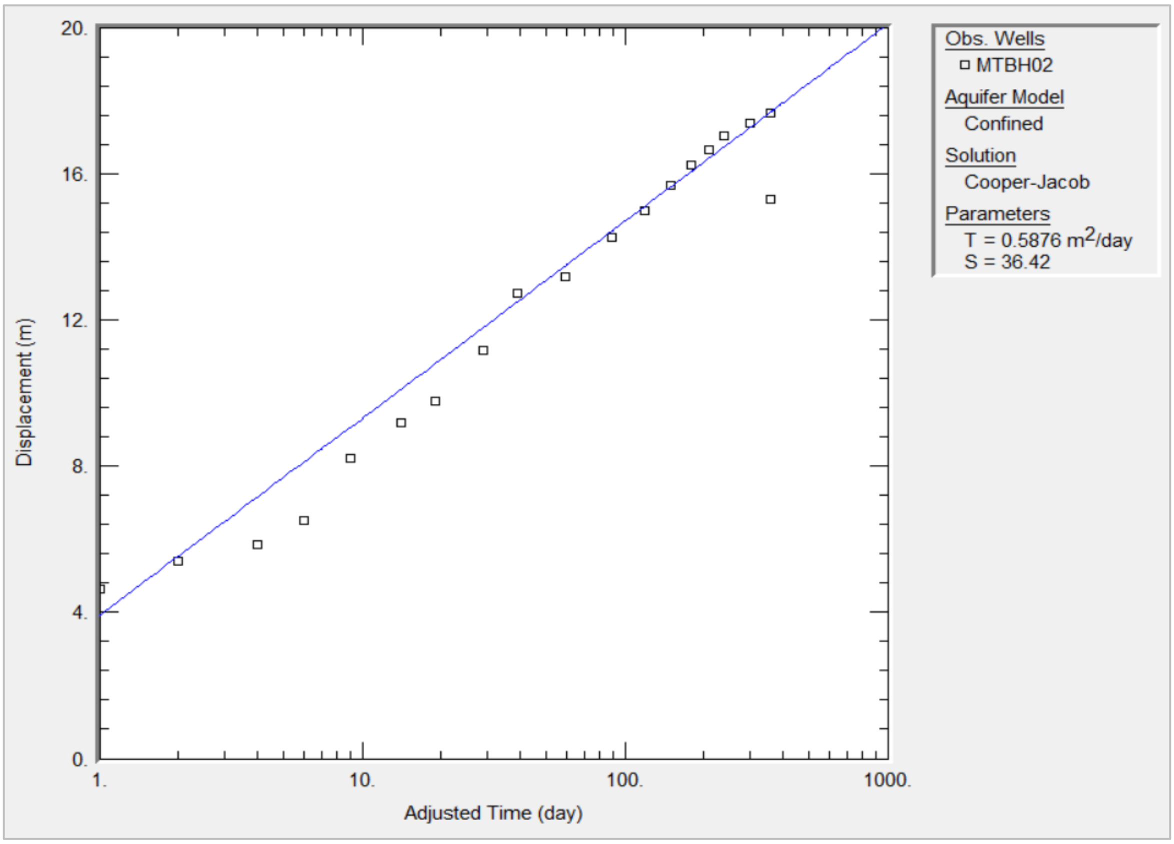


Figure 8-11 Aquifer tests: Cooper-Jacob method displacement time curve for MTBH02.

8.3.3. Constant Rate Test borehole MTBH04

Only one calibration step tests 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 until radial flow conditions were observed. A maximum drawdown depth of 47.77 mbsl 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. The Theiss method represented the best data fit and are assumed to be the most representative of the confined aquifer behaviour which were selected to estimate the aquifer parameters. An average transmissivity of 0.26m^2/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.

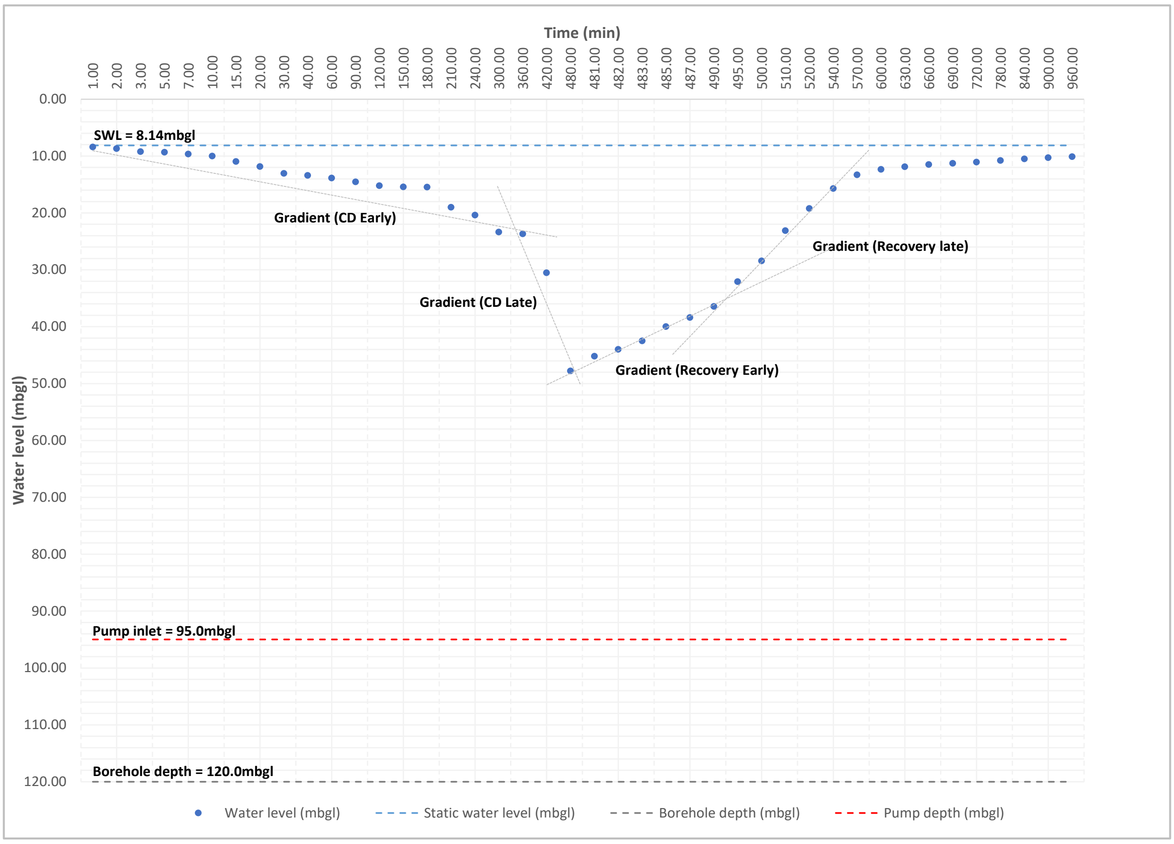


Figure 8-12 **Aquifer tests: MTBH04 water level drawdown and recovery scattered plot.**

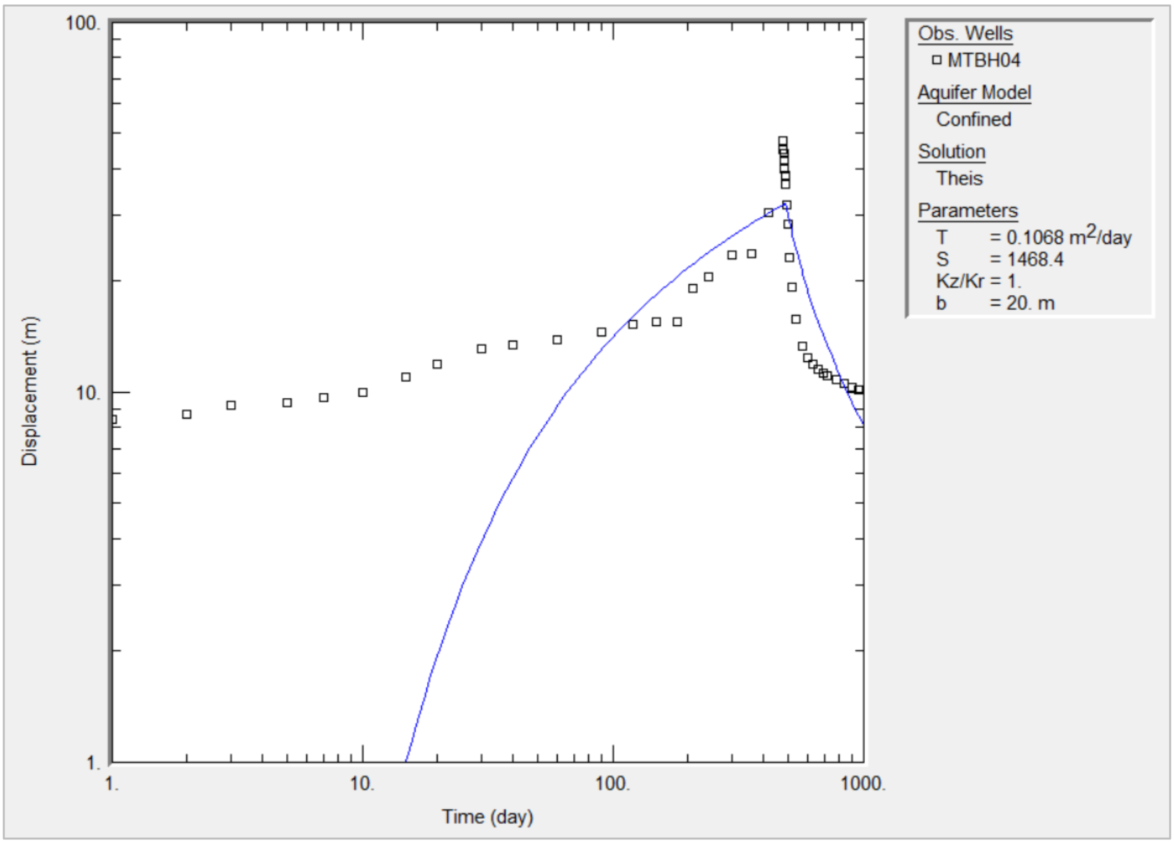


Figure 8-13 **Aquifer tests: Theis method displacement time curve for MTBH04.**

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. The Cooper Jacob method indicated the best data fit and are assumed to be the most representative of the confined aquifer behaviour which were selected to estimate the aquifer parameters. An average transmissivity of 0.04m^2/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.

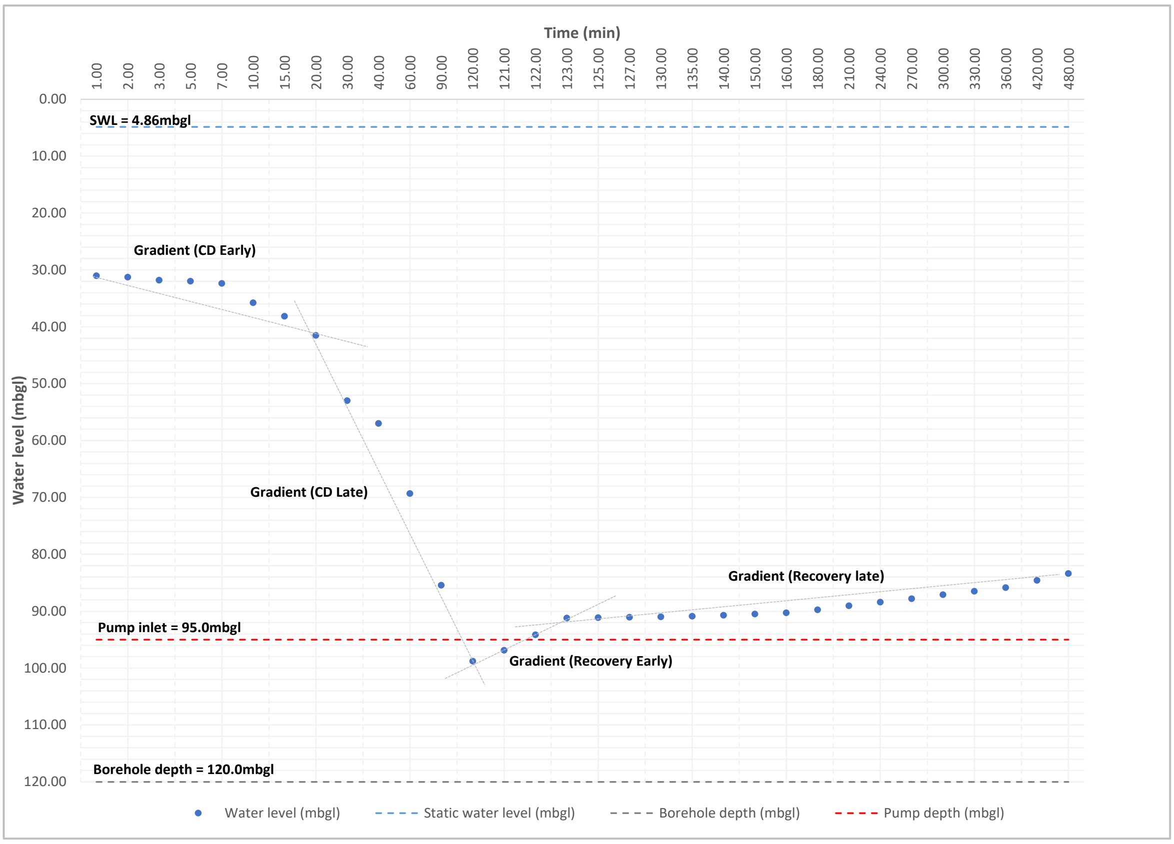


Figure 8-14 **Aquifer tests: MTBH06 water level drawdown and recovery scattered plot.**

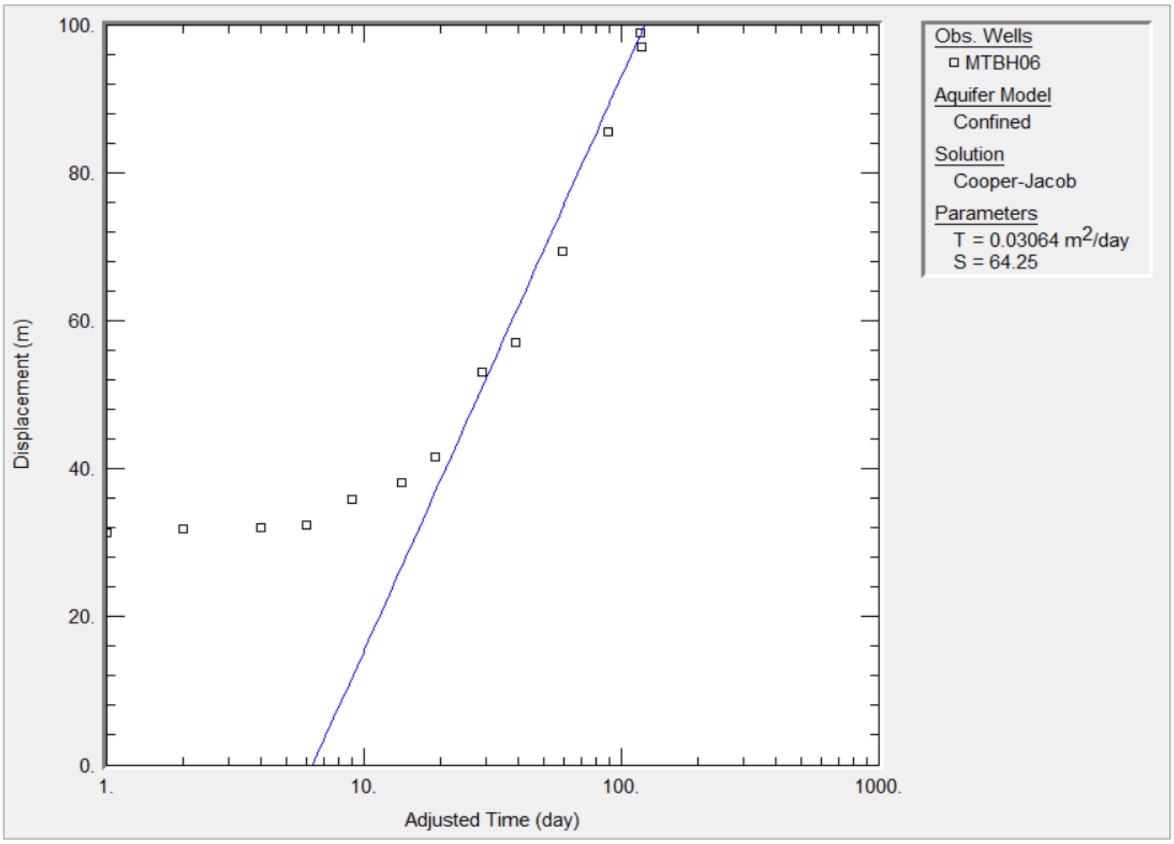


Figure 8-15 **Aquifer tests: Cooper-Jacob method displacement time curve for MTBH06.**

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 >34.0m with a mean thickness of approximately ~6.0m. 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**.

Artesian conditions were observed at two of the boreholes surveyed namely MRBH 16 and MRBH 98 which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions. With exclusion of the artesian boreholes, the minimum water level was recorded at 0.16mbgl (BH03), while the deepest water level was measured at borehole locality BH55 (52.44mbgl)[6]. The average water level is calculated at 6.78 mbgl which is much shallower than the regional average water level of between 15.10 to 26.60mbgl (Aquiworx, 2014). From statistical evaluation the 95th percentile of this data set is calculated at 19.74mbgl with the standard deviation of 7.73m. It is noted that several dynamic water levels were recorded which is confirmed by the relatively high coefficient of variation calculated from the water level data set of >113.0%. The latter suggest a dynamic groundwater environment with a potentially pumped aquifer system.

[6] 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
MRBH 04	1420.68	0.92	1419.76
MRBH 07	1435.94	11.56	1424.38
MRBH 09	1439.87	1.51	1438.36
MRBH 10	1426.53	4.11	1422.42
MRBH 11	1399.33	12.81	1386.52
MRBH 12	1419.96	0.82	1419.14
MRBH 13	1439.62	9.45	1430.17
MRBH 14	1399.11	0.50	1398.61
MRBH 16	1419.24	0.00	1419.24
MRBH 15	1406.79	2.60	1404.19
MRBH 19	1416.55	2.80	1413.75
MRBH 24	1433.86	34.12	1399.74
MRBH 28	1380.75	3.71	1377.04
MRBH 29	**1387.41**	**17.85**	**1369.56**
MRBH 30	1398.71	8.06	1390.65
MRBH 32	1404.37	0.72	1403.65
MRBH 33	1401.24	1.49	1399.75
MRBH 34	1398.73	0.87	1397.86
MRBH 35	1402.75	4.48	1398.27
MRBH 37	1453.51	6.46	1447.05
MRBH 39	1460.54	3.55	1456.99
MRBH 40	1415.31	1.60	1413.71

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
MRBH 41	1423.67	2.46	1421.21
MRBH 43	1451.11	1.24	1449.87
MRBH 45	1424.83	1.72	1423.11
MRBH 52	1451.25	1.37	1449.88
MRBH 53	1451.30	0.78	1450.52
MRBH 54	1440.00	1.67	1438.33
MRBH 55	1440.00	2.69	1437.31
MRBH 56	1449.95	4.09	1445.86
MRBH 59	1423.56	0.73	1422.83
MRBH 60	1434.76	6.24	1428.52
MRBH 64	1418.09	4.17	1413.92
MRBH 65	1407.45	1.86	1405.59
MRBH 66	1399.68	1.07	1398.61
MRBH 67	1399.19	0.63	1398.56
MRBH 69	1380.23	3.97	1376.26
MRBH 70	1426.22	8.72	1417.50
MRBH 71	1423.70	2.67	1421.03
MRBH 73	1420.00	4.36	1415.64
MRBH 74	1420.00	1.45	1418.55
MRBH 75	1437.53	0.85	1436.68
MRBH 76	1420.04	0.98	1419.06
MRBH 78	1421.69	5.62	1416.07
MRBH 79	1421.95	6.10	1415.85
MRBH 81	1419.42	2.99	1416.43
MRBH 82	1427.30	9.65	1417.65
MRBH 83	1429.12	11.86	1417.26
MRBH 84	1429.51	8.79	1420.72
MRBH 85	1399.59	5.28	1394.31
MRBH 86	1400.44	5.21	1395.23
MRBH 87	1360.32	4.72	1355.60
MRBH 88	1363.42	2.85	1360.57
MRBH 89	1363.87	3.16	1360.71
MRBH 91	1364.15	3.15	1361.00
MRBH 92	1335.21	7.37	1327.84
MRBH 93	1459.92	20.27	1439.65
MRBH 94	1443.51	1.40	1442.11
MRBH 95	1457.86	0.65	1457.21
MRBH 96	1454.02	7.00	1447.02
MRBH 98	1443.06	0.00	1443.06
MRBH 100	1438.78	1.42	1437.36
MTBH01	1409.06	1.42	1407.64
MTBH02	1399.99	1.65	1398.34
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	**1410.05**	**6.78**	**1403.26**
Minimum	**1324.88**	**0.00**	**1324.72**
Maximum	**1460.54**	**52.44**	**1457.21**
5th Percentile	**1342.22**	**0.65**	**1335.26**
95th Percentile	**1451.41**	**19.74**	**1447.19**
Standard deviation	**30.58**	**7.73**	**31.29**
Coefficient of Variation (CV)	**2.17**	**113.93**	**2.23**
Correlation		**0.97**	

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

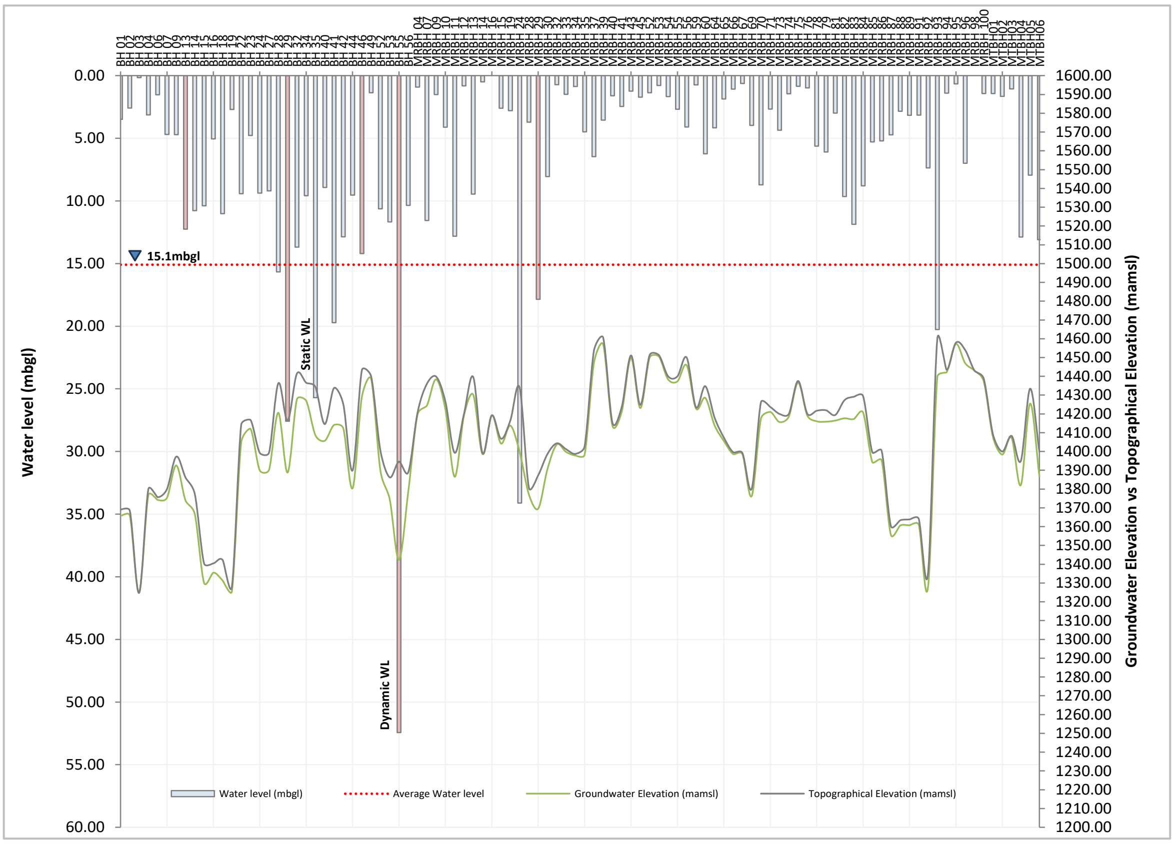


Figure 9-1 **Bar chart indicating regional water level summar.**

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 >0.97 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 (north of the Sandriver and Rietspruit) will be in a general south to southwestern 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 Sandrivier will be in a general north to northwestern direction as depicted in **Figure 9-3**.

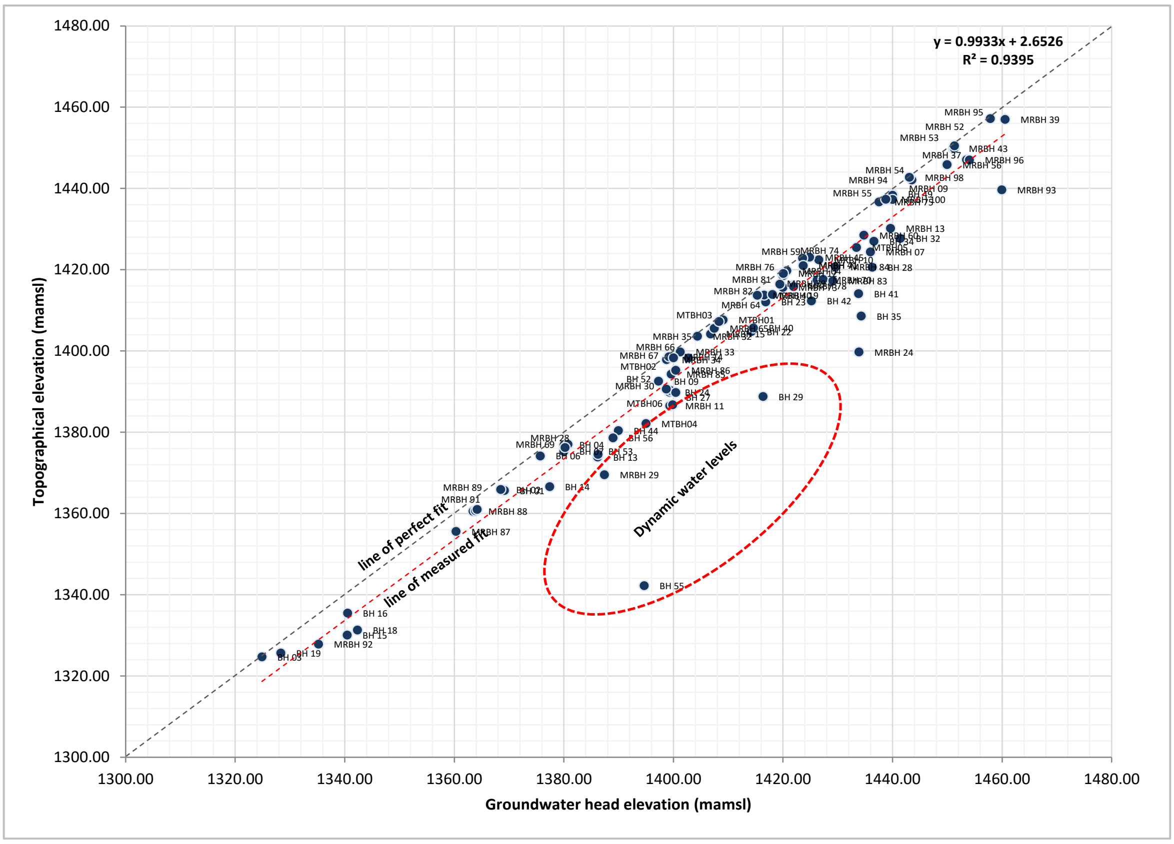


Figure 9-2 **Topographical elevation vs. groundwater elevation correlation graph.**

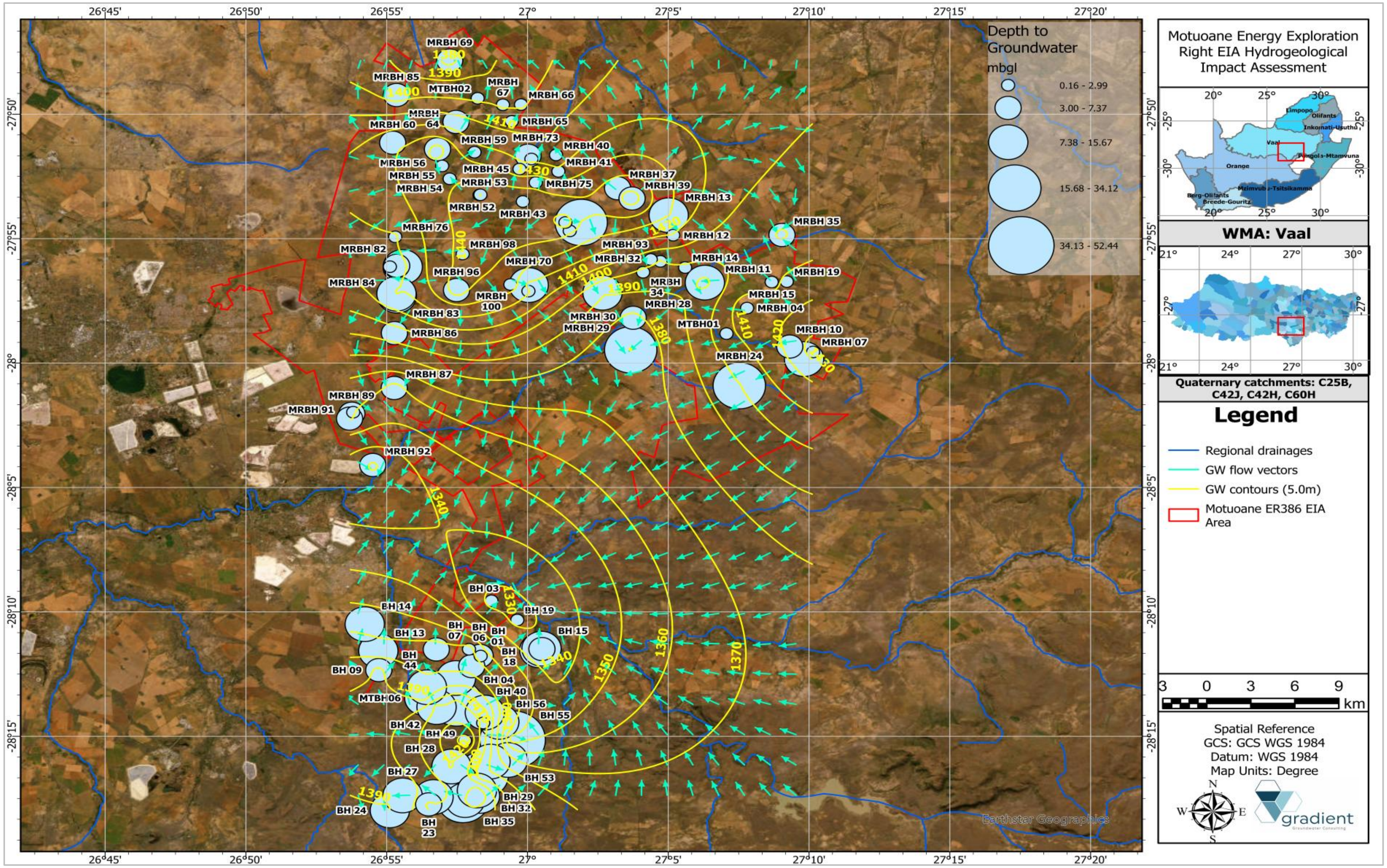


Figure 9-3 **Regional groundwater flow direction and depth to groundwater.**

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.

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

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points...

The average groundwater gradient (*i*) of the shallow, intergranular aquifer in the vicinity of proposed exploration 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 0.0017 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)
N to S	0.005
E to W	0.002
SW to NE	0.004
SE to NW	0.0017
Minimum	**0.002**
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 porosity[7] (**Equation 9-3**). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

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

Equation 9-2 Darcy flux.

$$v = Ki$$

Equation 9-3 Seepage velocity.

$$v = \frac{Ki}{ø}$$

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

The expected seepage rate from potential contamination originating at the proposed exploration activities as well as associated infrastructure is estimated at an average of approximately 3.55m/a, with a maximum distance of ~6.18m/a in a general southern direction as summarised in **Table 9-3** below[8].

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	0.0047	0.180	0.00085	0.05	0.0170	6.1868
E to W	0.0015	0.180	0.00028	0.05	0.0055	2.0215
SW to NE	0.0044	0.180	0.00078	0.05	0.0157	5.7290
SE to NW	0.0017	0.180	0.00031	0.05	0.0061	2.2338
Minimum	**0.0015**	**0.180**	**0.00028**	**0.05**	**0.0055**	**2.0215**
Maximum	**0.0047**	**0.180**	**0.00085**	**0.05**	**0.0170**	**6.1868**
Standard deviation	**0.0015**	**0.000**	**0.00026**	**0.00**	**0.0053**	**1.9234**
Geometric Mean	**0.0027**	**0.180**	**0.00049**	**0.05**	**0.0097**	**3.5569**

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

10. HYDROCHEMISTRY

To assess future impacts of the proposed gas exploration 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 NO_3^-.

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.

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

Table 10-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
MRBH 02	8.505	8.505	2.13%
MRBH 04	7.693	7.693	-0.64%
MRBH 07	10.661	10.661	-1.33%
MRBH 09	14.491	14.491	0.63%
MRBH 10	8.105	8.105	2.15%
MRBH 11	13.739	13.739	2.73%
MRBH 12	5.206	5.206	0.21%
MRBH 13	11.115	11.115	2.05%
MRBH 14	8.651	8.651	2.53%
MRBH 15	8.572	8.572	1.18%
MRBH 16	8.217	8.217	0.60%
MRBH 19	9.122	9.122	-0.16%
MRBH 21	9.899	9.899	2.21%
MRBH 24	9.082	9.082	-0.04%
MRBH 26	12.506	12.506	3.03%
MRBH 27	10.664	10.664	2.10%
MRBH 28	12.573	12.573	1.77%
MRBH 29	9.999	9.999	0.35%
MRBH 30	6.280	6.280	1.40%
MRBH 31	9.233	9.233	2.94%
MRBH 32	8.364	8.364	1.65%
MRBH 34	15.330	15.330	2.62%
MRBH 35	10.891	10.891	2.85%
MRBH 37	10.855	10.855	2.97%
MRBH 39	9.342	9.342	0.91%
MRBH 40	9.917	9.917	1.87%
MRBH 41	6.054	6.054	2.02%
MRBH 42	21.035	21.035	2.79%
MRBH 43	10.143	10.143	2.91%
MRBH 44	8.295	8.295	0.44%
MRBH 45	7.193	7.193	-0.38%
MRBH 46	15.370	15.370	2.95%
MRBH 47	9.405	9.405	2.33%
MRBH 48	6.654	6.654	1.77%
MRBH 56	9.528	9.528	2.64%
MRBH 59	8.721	8.721	0.27%
MRBH 60	10.920	10.920	2.85%
MRBH 61	9.090	9.090	0.97%
MRBH 63	10.172	10.172	1.93%
MRBH 64	15.253	15.253	1.20%
MRBH 65	11.621	11.621	2.48%
MRBH 66	13.762	13.762	3.00%
MRBH 67	3.720	3.720	0.63%
MRBH 69	25.160	25.160	2.17%
MRBH 70	8.830	8.830	2.15%
MRBH 71	98.824	98.824	-0.26%
MRBH 73	8.187	8.187	1.17%
MRBH 75	6.486	6.486	2.17%
MRBH 76	16.052	16.052	2.87%
MRBH 81	13.762	13.762	2.84%
MRBH 82	8.927	8.927	2.18%
MRBH 83	13.200	13.200	2.69%
MRBH 85	20.713	20.713	0.97%
MRBH 86	8.817	8.817	0.69%

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
MRBH 87	11.548	11.548	1.90%
MRBH 89	11.182	11.182	-1.20%
MRBH 91	12.496	12.496	-0.41%
MRBH 92	34.139	34.139	2.21%
MRBH 93	5.872	5.872	2.91%
MRBH 94	6.235	6.235	1.18%
MRBH 96	7.868	7.868	2.81%
MRBH 98	6.491	6.491	2.66%
MRBH 100	6.225	6.225	2.26%
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%
MTBH01	9.330	9.330	2.53%
MTBH02	13.340	13.340	1.26%
MTBH03	9.544	9.544	2.69%
MTBH04	10.436	10.436	2.39%
MTBH05	8.409	8.409	0.11%
MTBH06	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 and hard. The groundwater quality is impacted by the geological formations, which were deposited in shallow marine environments and are therefore naturally saline.

Isolated sampling localities i.e., MRBH42, MRBH69, MRBH71 and MRBH92 suggest above limit total dissolved solids (TDS) as well as associated higher conductivities (EC) with main drivers consisting of elevated Calcium (Ca)/Magnesium (Mg)/Sodium (Na)-Chloride (Cl) concentrations. The latter might be indicative of the intermediate, fractured aquifer unit being targeted by the respective borehole(s), sourcing more stagnant groundwater. Potential over-abstraction can also introduce more saline matrix water being sourced due to turbulent flow conditions instead of water being sourced from fractures via laminar flow conditions.

It is noted that newly drilled monitoring boreholes (MTBH01) and MTBH06 also indicate elevated Aluminium (Al) concentrations. The latter can be ascribed to natural geochemical processes as Aluminium is abundant in feldspars and clay minerals observed on site.

It is observed that most of the boreholes 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 10-2** for a spatial distribution map of nitrate concentrations within the northern catchment of the Sandriver while **Figure 10-3** shows a spatial distribution map of nitrate concentrations within the southern catchment of the Sandriver.

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 Aluminium (Al) and Iron (Fe) concentration. Aluminium is usually kept in solution in wetlands or peat-rich catchments while weathering input from high runoff events can also transport Aluminium-rich sediments into surface water.

Table 10-7 to **Table 10-16** summarises groundwater quality analysis for the hydrocensus samples analysed whereas **Table 10-17** 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 10-4** and **Figure 10-5** shows spatial distribution of the total inorganic hydrochemical content per catchment zone. Refer to Appendix E for water quality analysis laboratory certificates.

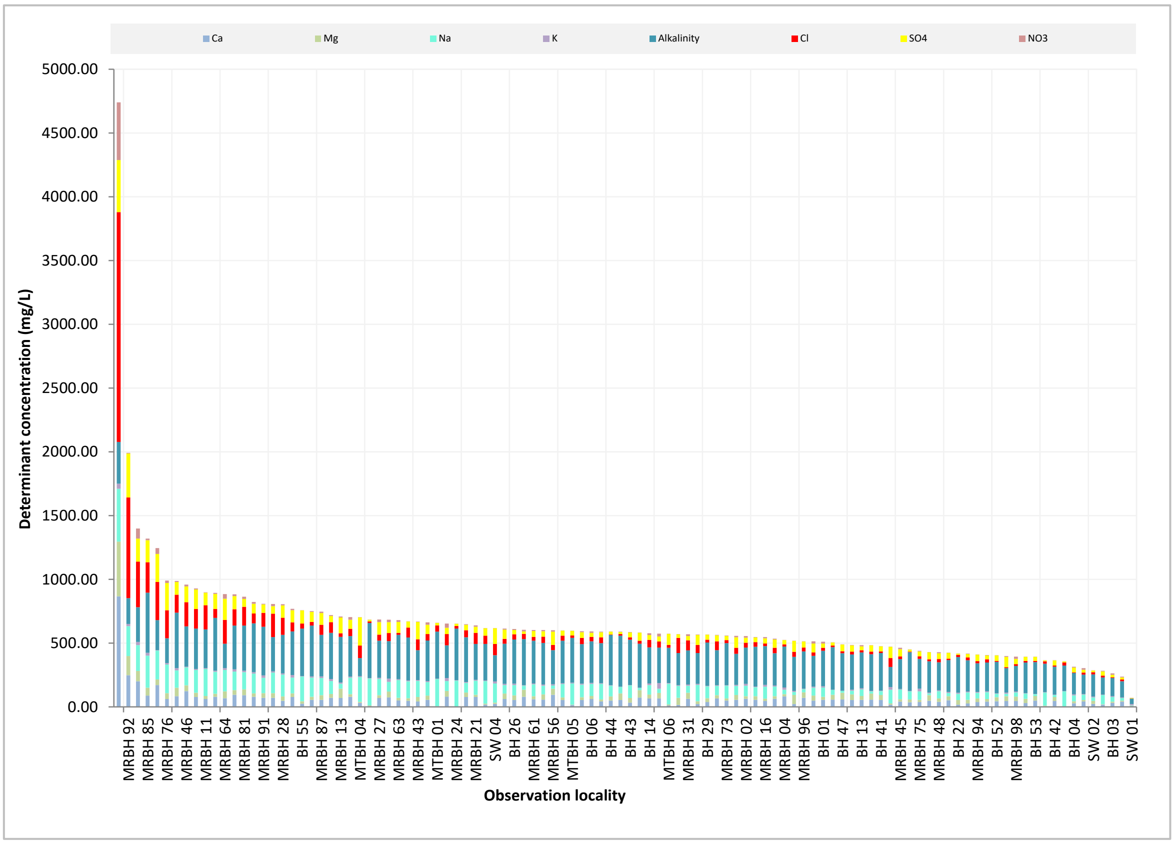


Figure 10-1 **Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of hydrocensus samples analysed.**

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

Determinant	Unit	Risk	SANS 241:2015 limits	MRBH 02	MRBH 04	MRBH 07	MRBH 09	MRBH 10	MRBH 11	MRBH 12	MRBH 13	MRBH 14	MRBH 15
Physical determinants													
Colour	-	-	-	Clear	Brownish	Clear	Clear	Clear	Clear	Rusty	Brownish	Brownish	Yellowish
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	8.03	7.64	7.73	7.66	7.83	7.98	8.62	7.83	8.05	7.97
EC	mS/m	Aesthetic	≤170.0	90.70	69.70	97.50	143.00	81.20	136.00	49.50	102.00	78.60	83.80
TDS		Aesthetic	≤ 1 200.0	485.40	400.21	600.72	830.62	457.33	786.35	277.99	595.87	465.18	485.81
Total Alkalinity	CaCO3/l	-	-	285.00	322.00	317.00	316.00	253.00	304.00	223.00	356.75	333.92	241.00
Total Hardness	mg/l	-	-	243.49	280.86	274.33	330.67	245.64	252.50	32.98	474.08	217.54	147.44
Anions													
Cl	mg/l	Aesthetic	≤300.0	38.00	17.20	51.40	154.00	43.10	189.00	18.30	28.10	39.77	63.70
SO_4	mg/l	Acute health	≤500.0	38.60	33.00	72.50	153.00	64.40	98.90	7.45	124.00	39.70	79.50
F	mg/l	Acute health	≤1.50	<0.09	<0.09	0.10	0.12	<0.09	0.19	0.67	<0.09	<0.09	0.16
NO_3< N	mg/l	Acute health	≤12.0	12.70	0.96	18.60	7.93	6.52	2.23	<0.35	8.27	<0.35	3.62
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	83.00	34.10	106.00	179.00	75.90	213.00	103.00	40.70	105.00	128.00
K	mg/l	Aesthetic	≤50.0	13.80	17.60	9.08	8.11	7.95	5.87	3.02	9.48	5.74	8.72
Ca	mg/l	Aesthetic	≤150.0	64.20	82.30	56.10	78.50	64.40	62.20	5.64	69.80	54.30	22.60
Mg	mg/l	Operational	70.0	20.20	18.30	32.60	32.70	20.60	23.60	4.59	72.80	19.90	22.10
Ba	mg/l	Operational	0.7	<0.01	0.28	0.11	0.03	0.04	0.03	<0.01	<0.01	0.10	<0.01
B	mg/l	Operational	2.4	0.08	0.06	0.08	0.11	0.07	0.32	0.35	0.03	0.10	0.09
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	0.11	<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	0.15	<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	MRBH 16	MRBH 19	MRBH 21	MRBH 24	MRBH 26	MRBH 27	MRBH 28	MRBH 29	MRBH 30	MRBH 31
Physical determinants													
Colour	-	-	-	Clear	Yellowish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Yellowish
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**	8.07	8.38	7.66	8.84	8.09	7.77	7.84	8.23	8.28	8.13
EC	**mS/m**	**Aesthetic**	**≤170.0**	77.90	84.90	94.10	84.50	116.00	97.10	124.00	97.90	57.60	89.50
TDS		**Aesthetic**	**≤ 1 200.0**	459.02	499.34	566.57	490.66	721.25	637.30	717.31	537.25	327.33	507.83
Total Alkalinity	**CaCO3/l**	-	-	304.00	310.00	281.00	405.00	383.00	292.00	302.00	337.00	245.00	266.00
Total Hardness	**mg/l**	-	-	192.81	227.73	264.77	5.34	310.28	265.21	265.12	203.69	184.47	352.13
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	21.10	49.10	86.10	20.60	77.40	47.10	134.00	78.30	22.90	79.40
SO_4	**mg/l**	**Acute health**	**≤500.0**	41.20	44.10	48.60	17.70	75.20	98.00	97.60	47.20	27.00	34.20
F	**mg/l**	**Acute health**	**≤1.50**	0.14	<0.09	<0.09	0.34	<0.09	<0.09	0.10	<0.09	0.30	<0.09
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	9.21	8.31	11.20	<0.35	**14.80**	**20.00**	9.20	0.42	2.03	**13.00**
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**	93.10	98.40	111.00	**205.00**	155.00	128.00	171.00	134.00	59.40	55.70
K	**mg/l**	**Aesthetic**	**≤50.0**	14.40	8.22	7.36	2.02	11.00	8.26	9.28	5.11	5.90	10.30
Ca	**mg/l**	**Aesthetic**	**≤150.0**	47.20	53.60	78.00	1.00	79.90	69.60	47.30	47.60	27.70	64.50
Mg	**mg/l**	**Operational**	**70.0**	18.20	22.80	17.00	0.69	26.90	22.20	35.70	20.60	28.00	46.40
Ba	**mg/l**	**Operational**	**0.7**	<0.01	0.03	0.09	0.07	0.04	0.02	0.08	0.08	<0.01	0.10
B	**mg/l**	**Operational**	**2.4**	0.11	0.07	0.07	0.07	0.11	0.08	0.09	0.09	0.03	0.03
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	MRBH 32	MRBH 34	MRBH 35	MRBH 37	MRBH 39	MRBH 40	MRBH 41	MRBH 42	MRBH 43	MRBH 44
Physical determinants													
Colour	-	-	-	Clear	Yellowish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Yellowish
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**	8.12	8.07	7.65	7.85	7.85	7.50	7.70	7.39	8.03	7.72
EC	**mS/m**	**Aesthetic**	**≤170.0**	73.90	138.00	100.00	101.00	92.20	92.60	55.30	**213.00**	96.00	76.30
TDS		**Aesthetic**	**≤ 1 200.0**	479.98	838.01	644.80	632.91	539.37	529.52	323.36	**1303.77**	584.84	435.91
Total Alkalinity	**CaCO3/l**	-	-	242.00	436.00	319.00	295.00	279.00	352.00	226.00	236.00	233.00	312.00
Total Hardness	**mg/l**	-	-	287.19	485.90	280.88	375.23	345.12	339.88	190.54	613.53	250.20	254.72
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	28.00	140.00	55.80	62.00	46.80	54.50	26.50	299.00	85.60	36.80
SO_4	**mg/l**	**Acute health**	**≤500.0**	69.00	100.00	71.50	86.70	40.80	43.00	29.80	220.00	137.00	36.00
F	**mg/l**	**Acute health**	**≤1.50**	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.13	<0.09	0.18	<0.09
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	**17.94**	7.26	**19.90**	**19.20**	**21.90**	5.89	1.99	**44.50**	2.21	3.48
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**	61.20	136.00	131.00	76.20	32.90	76.20	52.70	**225.00**	127.00	71.20
K	**mg/l**	**Aesthetic**	**≤50.0**	7.39	16.80	6.99	24.90	43.70	5.19	6.52	4.32	6.78	5.18
Ca	**mg/l**	**Aesthetic**	**≤150.0**	50.20	84.10	80.00	75.40	67.30	77.90	42.50	**171.00**	43.80	56.00
Mg	**mg/l**	**Operational**	**70.0**	39.30	67.00	19.70	45.40	43.00	35.30	20.50	45.30	34.20	27.90
Ba	**mg/l**	**Operational**	**0.7**	0.01	0.05	0.04	0.02	0.02	0.08	0.07	0.11	0.01	0.03
B	**mg/l**	**Operational**	**2.4**	0.05	0.08	0.06	0.06	0.11	0.03	0.07	0.10	0.17	0.05
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	MRBH 45	MRBH 46	MRBH 47	MRBH 48	MRBH 56	MRBH 59	MRBH 60	MRBH 61	MRBH 63	MRBH 64
Physical determinants													
Colour	-	-	-	Clear	Clear	Clear	Brownish	Clear	Clear	Clear	Clear	Clear	Yellowish
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**	7.95	7.84	8.04	7.99	7.81	7.90	7.99	7.95	8.00	7.81
EC	**mS/m**	**Aesthetic**	**≤170.0**	66.90	149.00	81.90	63.30	85.00	81.10	105.00	83.20	94.80	143.00
TDS		**Aesthetic**	**≤ 1 200.0**	406.16	881.98	512.35	369.51	534.69	467.28	615.51	496.62	588.33	935.15
Total Alkalinity	**CaCO3/l**	-	-	233.00	317.00	314.00	219.00	268.00	276.00	398.00	335.00	347.54	192.00
Total Hardness	**mg/l**	-	-	183.12	501.53	334.70	211.00	433.60	271.22	235.37	251.24	216.53	396.29
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	20.50	190.00	38.10	25.50	40.80	68.30	30.00	30.10	16.10	186.00
SO_4	**mg/l**	**Acute health**	**≤500.0**	57.70	124.00	73.60	46.40	104.00	48.00	78.20	46.11	85.70	166.00
F	**mg/l**	**Acute health**	**≤1.50**	0.09	<0.09	0.11	0.09	<0.09	<0.09	<0.09	<0.09	0.13	<0.09
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	10.30	**14.10**	6.89	7.97	11.70	3.44	6.39	7.85	**13.50**	**36.90**
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**	76.30	140.00	65.40	56.90	24.50	73.00	151.00	92.90	139.00	167.00
K	**mg/l**	**Aesthetic**	**≤50.0**	4.79	4.26	10.20	6.39	9.54	4.96	9.24	6.25	6.35	14.30
Ca	**mg/l**	**Aesthetic**	**≤150.0**	42.00	124.00	62.30	40.80	96.30	66.40	56.00	61.20	50.60	68.00
Mg	**mg/l**	**Operational**	**70.0**	19.00	46.60	43.50	26.50	46.90	25.60	23.20	23.90	21.90	55.00
Ba	**mg/l**	**Operational**	**0.7**	0.04	0.14	0.05	0.02	<0.01	0.02	<0.01	0.04	<0.01	<0.01
B	**mg/l**	**Operational**	**2.4**	0.05	0.11	0.05	0.05	<0.01	0.04	0.18	0.09	0.05	0.04
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**	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-11 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	MRBH 65	MRBH 66	MRBH 67	MRBH 69	MRBH 70	MRBH 71	MRBH 73	MRBH 75	MRBH 76	MRBH 81
Physical determinants													
Colour	-	-	-	Clear	Clear	Clear	Clear	Clear	Brownish	Clear	Rusty	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	7.98	7.74	7.85	7.57	7.98	6.98	8.01	7.85	7.95	7.84
EC	mS/m	Aesthetic	≤170.0	105.00	130.00	36.60	**253.00**	84.80	**891.00**	78.30	59.70	162.00	133.00
TDS		Aesthetic	≤ 1 200.0	670.07	800.54	208.85	**1565.93**	502.42	**6159.68**	439.44	367.98	981.76	778.83
Total Alkalinity	CaCO3/l	-	-	342.00	342.00	128.00	272.00	244.00	327.80	330.33	234.00	195.00	355.00
Total Hardness	mg/l	-	-	313.88	386.12	138.48	833.83	292.95	3931.52	197.15	166.90	343.58	416.44
Anions													
Cl	mg/l	Aesthetic	≤300.0	70.60	129.00	12.80	**359.00**	48.50	**1800.91**	22.60	20.40	220.10	145.90
SO_4	mg/l	Acute health	≤500.0	95.40	102.00	15.80	179.00	81.00	409.00	33.20	37.90	212.64	62.59
F	mg/l	Acute health	≤1.50	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.11	0.14	<0.09
NO_3< N	mg/l	Acute health	≤12.0	10.72	**15.40**	6.51	**80.10**	**12.20**	**451.69**	3.23	5.82	**19.70**	**16.54**
PO_4	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	0.16	0.07	0.07	<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	123.00	146.00	19.80	**203.00**	71.80	**415.00**	98.60	65.90	**225.00**	135.00
K	mg/l	Aesthetic	≤50.0	20.70	18.40	4.19	24.40	7.16	39.80	4.67	21.00	11.00	11.20
Ca	mg/l	Aesthetic	≤150.0	78.70	95.10	42.30	**202.00**	56.30	**867.00**	49.60	39.30	61.90	92.40
Mg	mg/l	Operational	70.0	28.50	36.10	7.98	**80.00**	37.00	**429.00**	17.80	16.70	45.90	45.10
Ba	mg/l	Operational	0.7	<0.01	0.05	<0.01	0.09	0.11	0.17	0.05	<0.01	<0.01	0.08
B	mg/l	Operational	2.4	0.11	0.12	<0.01	0.11	0.05	0.01	0.06	0.05	0.20	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	0.06	<0.01	<0.01
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	**0.67**	<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	0.33	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-12 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	MRBH 82	MRBH 83	MRBH 85	MRBH 86	MRBH 87	MRBH 89	MRBH 91	MRBH 92	MRBH 93	MRBH 94
Physical determinants													
Colour	-	-	-	Clear	Clear	Rusty	Clear	Clear	Clear	Rusty	Clear	Clear	Brownish
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**	8.18	7.97	7.71	8.06	7.77	7.87	7.80	7.51	8.46	7.94
EC	**mS/m**	**Aesthetic**	**≤170.0**	87.20	131.00	**183.00**	83.00	108.00	106.00	118.00	**347.00**	52.20	57.40
TDS		**Aesthetic**	**≤ 1 200.0**	507.91	765.20	1172.12	483.56	657.03	600.57	674.71	**1928.32**	299.33	331.32
Total Alkalinity	**CaCO3/l**	-	-	287.00	269.00	472.00	316.00	326.32	362.00	381.00	202.00	240.82	226.00
Total Hardness	**mg/l**	-	-	74.61	331.06	475.91	174.66	286.11	302.31	328.59	1239.45	216.32	213.91
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	65.40	183.00	239.00	44.40	79.00	84.40	109.00	**790.00**	12.60	16.60
SO_4	**mg/l**	**Acute health**	**≤500.0**	58.14	58.71	172.00	40.30	91.80	47.80	66.40	345.00	31.40	50.20
F	**mg/l**	**Acute health**	**≤1.50**	0.41	0.39	<0.09	<0.09	0.12	<0.09	0.13	<0.09	<0.09	0.10
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	0.69	**18.04**	11.90	5.28	11.00	7.15	4.88	4.50	0.56	2.60
PO_4	**mg/l**	**Acute health**	**≤5.0**	<0.03	<0.03	<0.03	<0.03	0.48	0.15	0.13	0.08	<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**	177.00	161.00	**251.00**	122.00	135.00	101.00	121.00	**234.00**	40.90	44.00
K	**mg/l**	**Aesthetic**	**≤50.0**	4.78	9.53	22.90	4.02	12.90	16.20	19.20	18.00	3.10	6.02
Ca	**mg/l**	**Aesthetic**	**≤150.0**	18.40	71.40	89.50	42.90	56.20	71.10	71.40	**249.00**	29.90	38.50
Mg	**mg/l**	**Operational**	**70.0**	6.96	37.10	61.30	16.40	35.40	30.30	36.50	**150.00**	34.40	28.60
Ba	**mg/l**	**Operational**	**0.7**	0.02	0.17	<0.01	0.07	<0.01	0.01	0.03	0.05	<0.01	<0.01
B	**mg/l**	**Operational**	**2.4**	0.39	0.64	0.12	0.13	0.14	0.10	0.11	0.12	0.01	0.04
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	0.21	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10-13 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	MRBH 96	MRBH 98	MRBH 100	BH 01	BH 03	BH 04	BH 06	BH 07	BH 09	BH 13
Physical determinants													
Colour	-	-	-	Clear	Rusty	Clear	Clear	Clear	Rusty	Clear	Clear	Yellowish	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	7.91	7.72	7.94	8.13	8.08	8.00	8.01	7.92	7.97	8.12
EC	mS/m	Aesthetic	≤170.0	73.50	61.40	57.70	72.20	40.60	46.20	82.10	113.00	88.10	66.40
TDS		Aesthetic	≤ 1 200.0	406.84	372.05	347.20	450.74	240.15	270.51	496.03	669.91	503.60	407.94
Total Alkalinity	CaCO3/l	-	-	292.00	201.00	192.00	277.00	143.00	168.00	326.00	256.00	362.00	281.00
Total Hardness	mg/l	-	-	355.22	257.68	268.33	238.58	119.46	139.11	253.15	386.98	426.18	266.83
Anions													
Cl	mg/l	Aesthetic	≤300.0	30.60	14.10	6.81	24.10	5.13	5.31	34.50	88.40	41.40	18.20
SO_4	mg/l	Acute health	≤500.0	47.00	41.20	81.20	33.70	20.20	37.50	32.70	49.43	18.90	29.00
F	mg/l	Acute health	≤1.50	<0.09	<0.09	<0.09	0.09	<0.09	0.19	0.14	<0.09	<0.09	0.10
NO_3< N	mg/l	Acute health	≤12.0	2.42	**16.90**	6.95	**14.40**	10.10	6.34	9.97	**34.28**	**12.74**	10.20
PO_4	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.09	<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	24.30	34.30	19.40	72.70	36.70	46.50	94.50	77.30	31.20	51.40
K	mg/l	Aesthetic	≤50.0	4.12	6.08	10.00	10.10	5.65	7.06	8.12	23.60	3.34	8.52
Ca	mg/l	Aesthetic	≤150.0	72.50	46.30	47.10	55.80	32.80	28.50	61.80	80.60	80.30	55.90
Mg	mg/l	Operational	70.0	42.30	34.50	36.60	24.10	9.12	16.50	24.00	45.10	54.80	30.90
Ba	mg/l	Operational	0.7	<0.01	<0.01	0.01	0.05	0.01	0.02	0.05	0.27	<0.01	<0.01
B	mg/l	Operational	2.4	0.02	0.02	0.02	0.03	<0.01	0.01	0.04	<0.01	<0.01	0.03
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 10-14 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 14	BH 15	BH 19	MTBH01	MTBH02	MTBH03	MTBH04	MTBH05	MTBH06	BH 20
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**	7.94	8.29	8.12	8.82	7.52	7.93	7.80	7.71	8.06	8.06
EC	**mS/m**	**Aesthetic**	**≤170.0**	90.40	42.50	49.10	86.20	121.00	88.80	107.00	75.70	75.40	58.00
TDS		**Aesthetic**	**≤ 1 200.0**	510.64	250.85	285.98	517.03	756.34	518.80	649.97	458.45	476.67	330.44
Total Alkalinity	**CaCO3/l**	-	-	283.00	134.00	150.94	369.36	415.00	431.00	143.00	352.00	276.00	251.00
Total Hardness	**mg/l**	-	-	292.99	60.97	154.24	16.72	295.30	37.57	116.38	53.34	60.84	261.80
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	59.30	14.80	16.80	49.00	69.30	13.50	98.20	18.40	21.90	11.00
SO_4	**mg/l**	**Acute health**	**≤500.0**	37.80	32.70	21.40	18.40	119.00	13.10	222.00	36.80	87.80	45.80
F	**mg/l**	**Acute health**	**≤1.50**	0.10	0.78	0.09	1.80	<0.09	**4.13**	**2.14**	1.04	**2.20**	0.10
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	**13.40**	5.48	**12.40**	<0.35	7.57	<0.35	<0.35	<0.35	1.37	1.27
PO_4	**mg/l**	**Acute health**	**≤5.0**	<0.03	<0.03	<0.03	<0.03	0.29	<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**	73.30	71.40	42.40	**213.00**	172.00	**212.00**	194.00	165.00	164.00	25.20
K	**mg/l**	**Aesthetic**	**≤50.0**	13.10	3.59	5.29	3.16	8.68	3.16	5.61	6.22	4.40	7.89
Ca	**mg/l**	**Aesthetic**	**≤150.0**	67.20	18.10	43.30	4.47	80.00	7.46	31.60	14.50	11.50	52.40
Mg	**mg/l**	**Operational**	**70.0**	30.40	3.83	11.20	1.35	23.20	4.60	9.10	4.16	7.80	31.80
Ba	**mg/l**	**Operational**	**0.7**	0.04	<0.01	0.06	<0.01	0.21	0.09	0.02	0.03	0.02	0.02
B	**mg/l**	**Operational**	**2.4**	0.06	0.24	<0.01	0.70	0.13	0.52	0.35	0.24	0.69	<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	**0.99**	0.13	<0.01	0.07	<0.01	**1.85**	<0.01
Fe	**mg/l**	**Acute health**	**2.0**	<0.01	<0.01	<0.01	0.41	0.04	<0.01	<0.01	<0.01	0.77	<0.01
Mn	**mg/l**	**Operational**	**0.4**	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.06	<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 10-15 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 22	BH 25	BH 26	BH 27	BH 28	BH 29	BH 32	BH 34	BH 35	BH 38
Physical determinants													
Colour	-	-	-	Clear	Clear	Clear	Yellowish	Yellowish	Clear	Yellowish	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**	7.81	7.81	8.28	8.52	7.95	8.06	8.10	8.00	9.25	7.85
EC	**mS/m**	**Aesthetic**	**≤170.0**	56.50	89.40	86.40	87.80	71.40	76.40	60.50	67.70	49.80	67.10
TDS		**Aesthetic**	**≤ 1 200.0**	308.51	503.95	498.81	472.10	415.64	436.74	336.90	386.27	285.00	374.64
Total Alkalinity	**CaCO3/l**	-	-	280.00	325.00	346.00	253.24	268.00	341.00	245.00	277.47	201.00	334.00
Total Hardness	**mg/l**	-	-	197.72	314.46	284.40	266.85	349.55	217.20	303.77	316.94	1.77	300.99
Anions													
Cl	**mg/l**	**Aesthetic**	**≤300.0**	18.20	49.50	42.30	118.56	40.30	21.00	15.60	21.90	24.20	12.80
SO_4	**mg/l**	**Acute health**	**≤500.0**	9.50	43.10	32.90	28.40	84.30	40.50	55.90	48.30	6.98	22.80
F	**mg/l**	**Acute health**	**≤1.50**	0.14	0.10	0.20	0.20	0.10	0.16	<0.09	<0.09	**6.88**	<0.09
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	<0.35	8.89	7.48	0.59	1.10	1.07	1.28	3.30	<0.35	0.65
PO_4	**mg/l**	**Acute health**	**≤5.0**	<0.03	<0.03	<0.03	<0.03	0.12	0.05	0.04	<0.03	0.03	<0.03
NH_3	**mg/l**	**Acute health**	**≤1.5**	1.10	<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**	48.70	67.70	81.20	94.00	23.70	94.80	14.40	29.20	121.00	37.20
K	**mg/l**	**Aesthetic**	**≤50.0**	7.32	10.20	11.10	5.10	7.48	2.38	5.50	7.43	2.19	2.35
Ca	**mg/l**	**Aesthetic**	**≤150.0**	18.00	57.00	53.70	16.00	22.40	38.50	48.10	54.20	0.51	58.20
Mg	**mg/l**	**Operational**	**70.0**	37.10	41.80	36.50	55.10	**71.30**	29.40	44.60	44.10	0.12	37.80
Ba	**mg/l**	**Operational**	**0.7**	<0.01	0.01	0.04	<0.01	0.01	0.04	<0.01	<0.01	<0.01	0.13
B	**mg/l**	**Operational**	**2.4**	0.03	0.04	0.04	0.04	<0.01	0.12	<0.01	<0.01	0.59	0.05
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 10-16 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (Cont.).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 40	BH 41	BH 42	BH 43	BH 44	BH 45	BH 47	BH 49	BH 52	BH 53	BH 55	BH 56
Physical determinants															
Colour	-	-	-	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Rusty	Greyish	Clear
Temperature	°C	-	-	21.00	21.00	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**	7.08	7.51	7.73	7.94	7.81	7.98	8.00	7.88	8.00	7.94	7.93	7.78
EC	**mS/m**	**Aesthetic**	**≤170.0**	59.70	65.70	51.70	75.60	71.60	66.00	68.30	75.60	53.60	54.50	98.90	77.00
TDS		**Aesthetic**	**≤ 1 200.0**	328.93	360.00	279.69	452.48	432.50	373.32	378.01	446.92	304.68	292.28	609.89	437.77
Total Alkalinity	**CaCO3/l**	-	-	304.00	296.00	219.00	356.00	396.00	289.00	293.89	345.00	248.00	250.00	372.00	400.00
Total Hardness	**mg/l**	-	-	181.41	302.76	247.71	234.85	260.98	337.70	362.80	423.87	240.10	274.66	143.84	351.86
Anions															
Cl	**mg/l**	**Aesthetic**	**≤300.0**	5.45	12.90	9.30	18.30	3.63	19.50	16.60	22.50	6.90	9.30	40.30	12.00
SO_4	**mg/l**	**Acute health**	**≤500.0**	15.10	40.20	39.10	39.20	21.20	49.50	52.50	64.10	42.50	31.10	103.00	16.80
F	**mg/l**	**Acute health**	**≤1.50**	0.34	<0.09	<0.09	0.26	0.27	<0.09	<0.09	<0.09	0.19	<0.09	0.58	0.11
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	<0.35	0.63	0.73	2.10	<0.35	1.33	1.29	0.42	<0.35	<0.35	<0.35	2.16
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	<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	<0.45	<0.45
Cations and metals															
Na	**mg/l**	**Aesthetic**	**≤200.0**	63.40	29.50	16.10	99.00	83.90	18.50	13.60	17.70	28.20	13.60	194.00	50.20
K	**mg/l**	**Aesthetic**	**≤50.0**	2.93	2.30	2.26	2.49	2.87	1.90	1.64	1.63	1.87	1.89	2.54	2.34
Ca	**mg/l**	**Aesthetic**	**≤150.0**	36.70	53.80	46.10	33.20	49.60	57.40	59.70	74.10	44.70	49.80	26.60	54.00
Mg	**mg/l**	**Operational**	**70.0**	21.80	40.90	32.20	36.90	33.30	47.20	51.90	58.00	31.20	36.50	18.80	52.70
Ba	**mg/l**	**Operational**	**0.7**	0.09	0.17	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
B	**mg/l**	**Operational**	**2.4**	0.20	<0.01	<0.01	0.05	0.03	<0.01	<0.01	<0.01	0.08	<0.01	0.22	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	<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	<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	<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	<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	<0.003	<0.01
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	<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	0.08	<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	<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	<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	<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	<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	<0.01	<0.01

Table 10-17 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	CaCO3/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

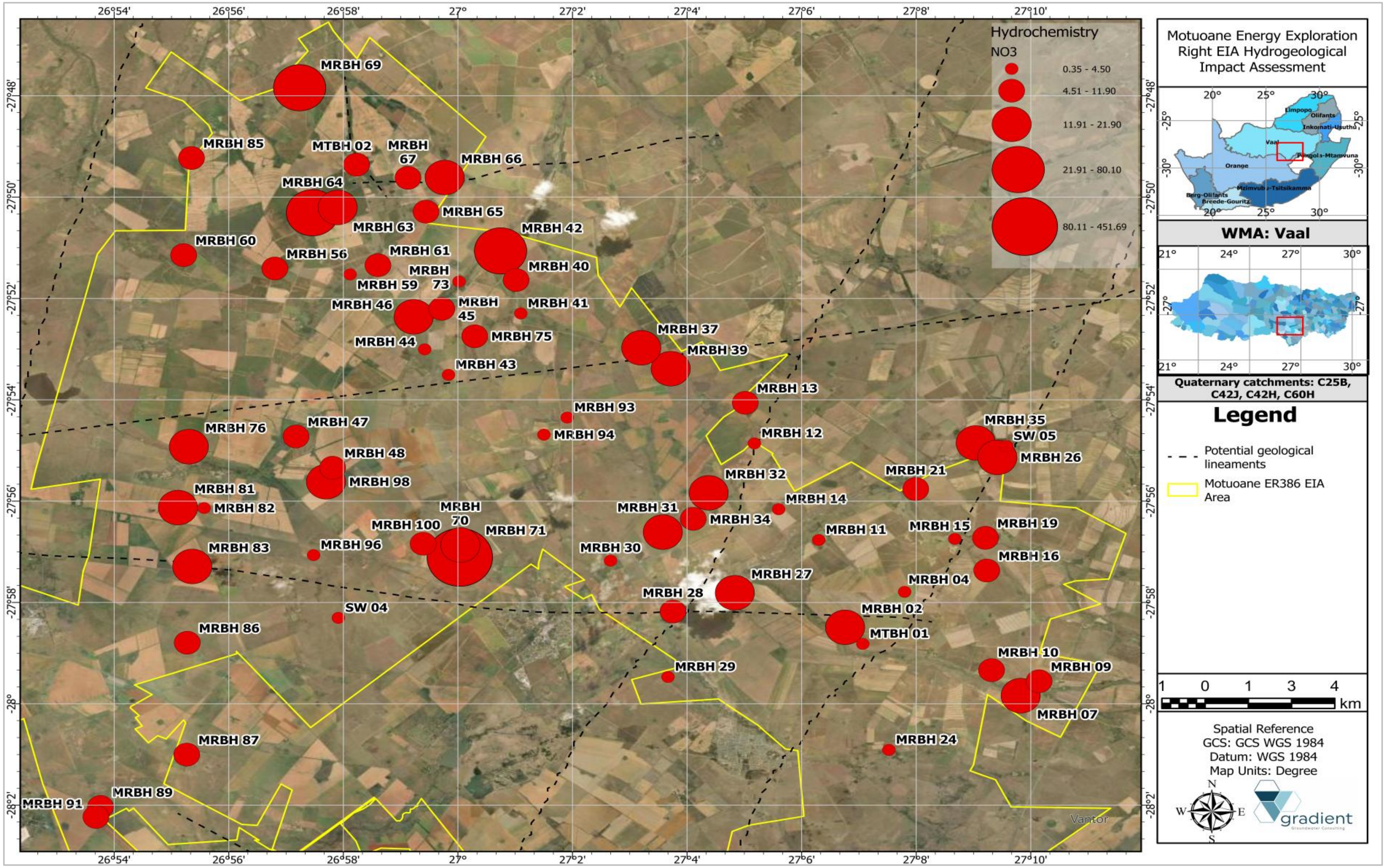


Figure 10-2 Nitrate (NO_3) spatial distribution within the northen catchment of the Sandriver.

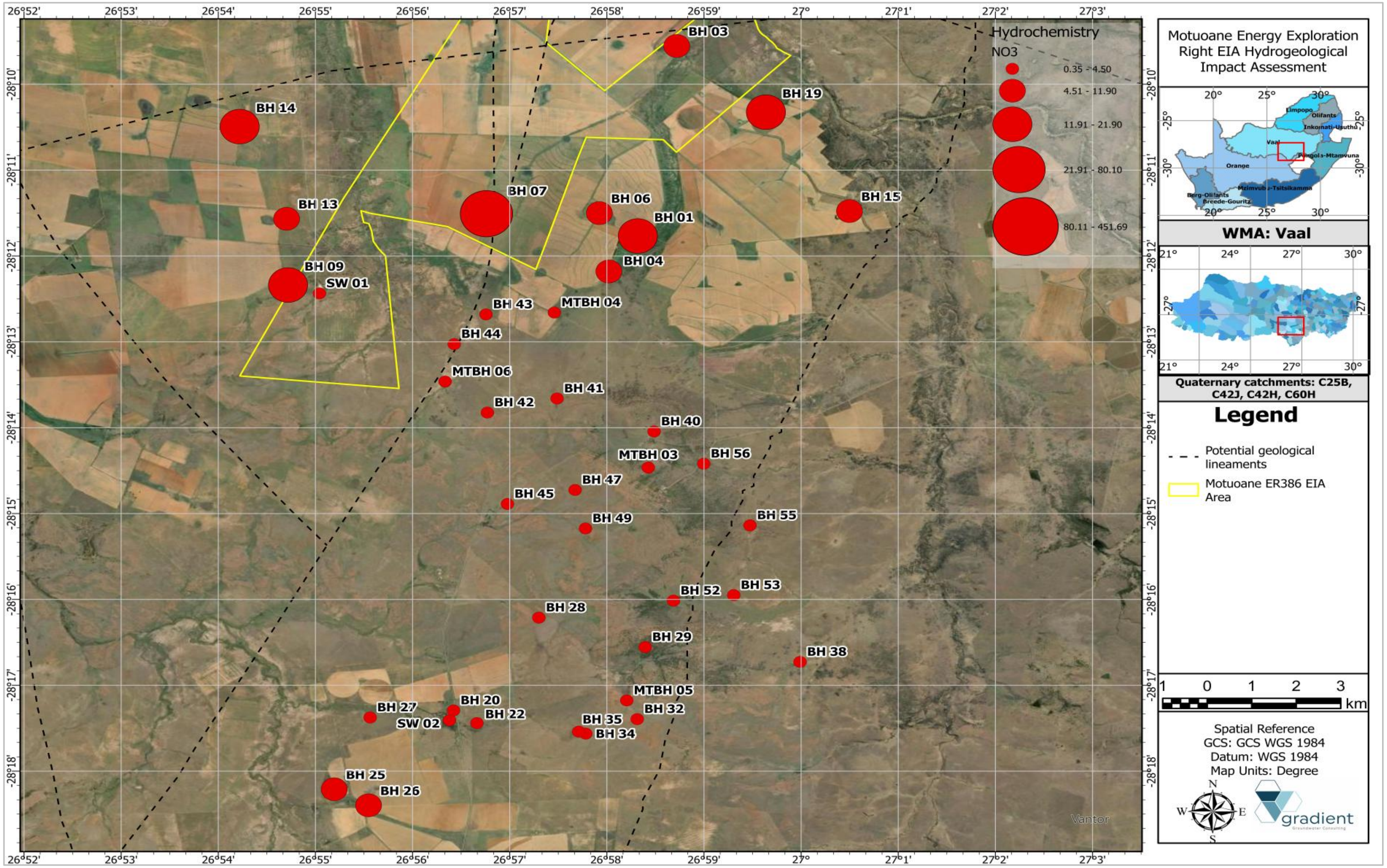


Figure 10-3 **Nitrate (NO3) spatial distribution within the southern catchment of the Sandriver.**

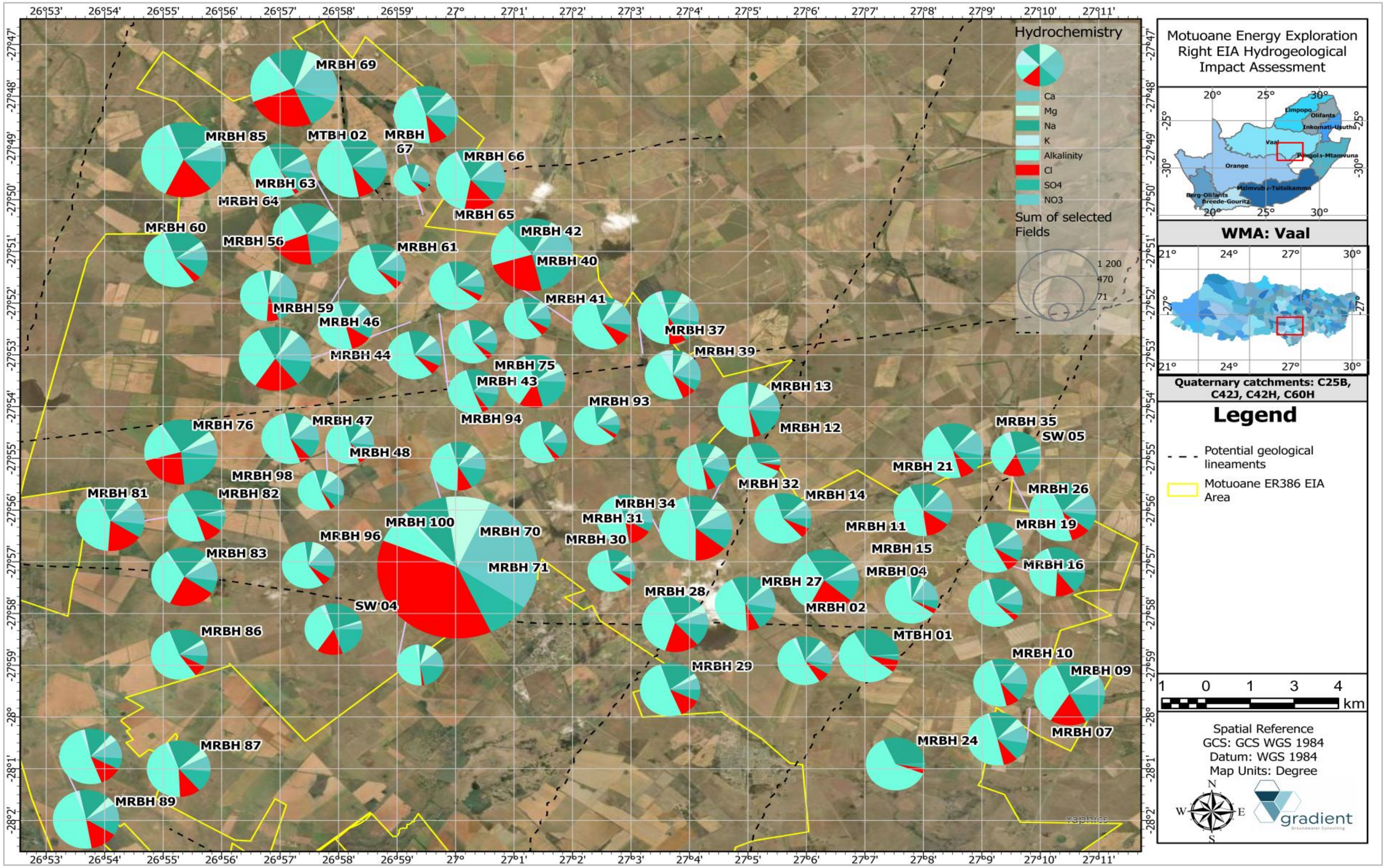


Figure 10-4 **Hydrochemical analysis spatial distribution within the northen catchment of the Sandriver.**

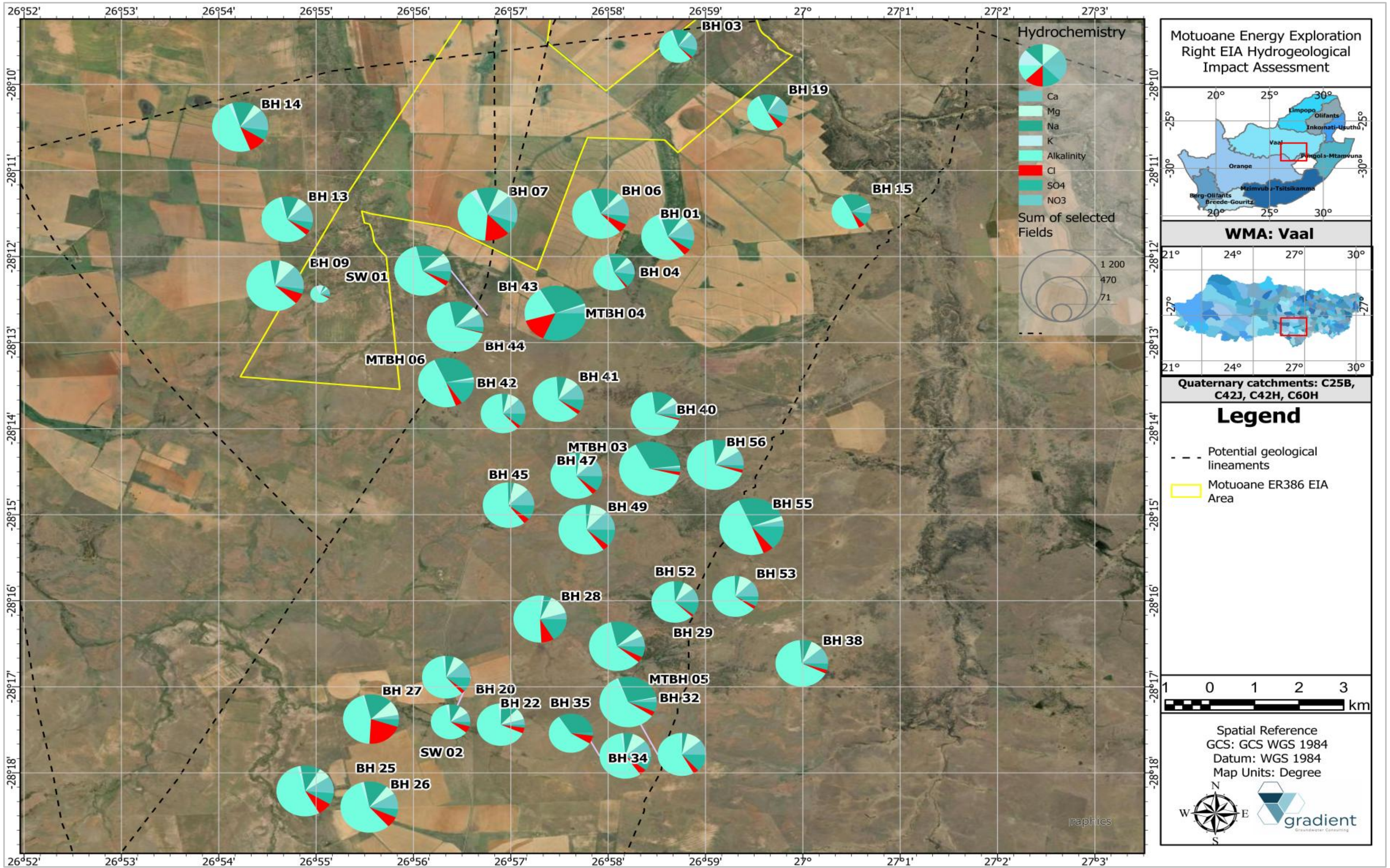


Figure 10-5 **Hydrochemical analysis spatial distribution within the southern catchment of the Sandriver.**

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 10-18** for a summary of the analysis results with **Figure 10-6** 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 10-18 Hydrochemistry: Site characetrisation borehole dissolved methane and ethane compared to U.S. Department of the Interior guidelines.

Determinant	Unit	Risk	U.S. Department of the Interior	MTBH02	MTBH03	MTBH04	MTBH05	MTBH06
Methane	**mg/l**	**Acute health**	**≤ 10.0 mg/l**	0.120	9.500	0.039	0.490	0.022
Ethane	**mg/l**	**Acute health**	**-**	<0.0130	0.032	<0.0130	<0.0130	<0.0130

Figure 10-6 **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 10-7**. 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 10-8** to **Figure 10-12** depict piper diagrams developed from the groundwater quality analysis results while **Figure 10-13** indicate 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 localities MRBH76 and MTBH04 show Sodium-Chloride dominance usually associated with old stagnant water while borehole localities MRBH42, MRBH69, MRBH71 as well as MRBH92 indicate a static and disordinate environment (Calcium-Magnesium-Chloride dominance) which suggest old stagnant, potentially deeper, water that has mixed with more recently recharged water. Borehole localities MRBH12, MRBH24, MRBH82, MTBH03, MTBH05, MTBH06, BH15, BH35 and 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.

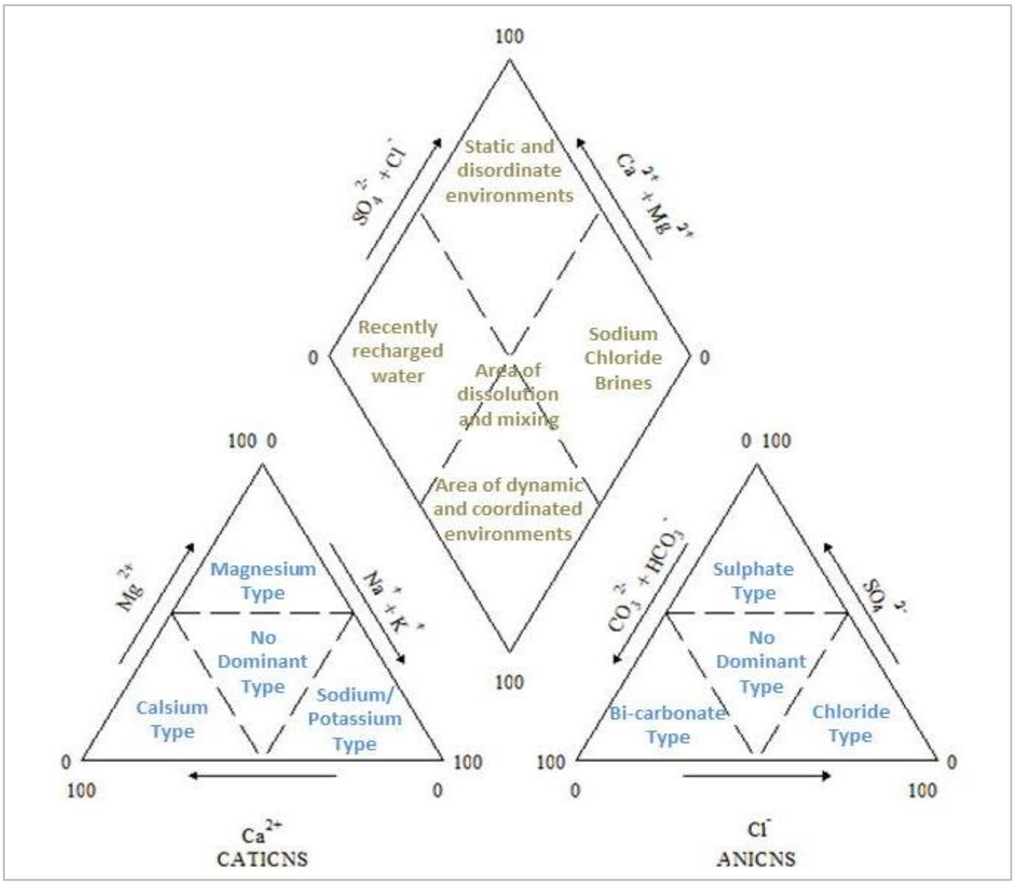


Figure 10-7 **Piper diagram indicating classification for anion and cation facies in terms of ion percentages**

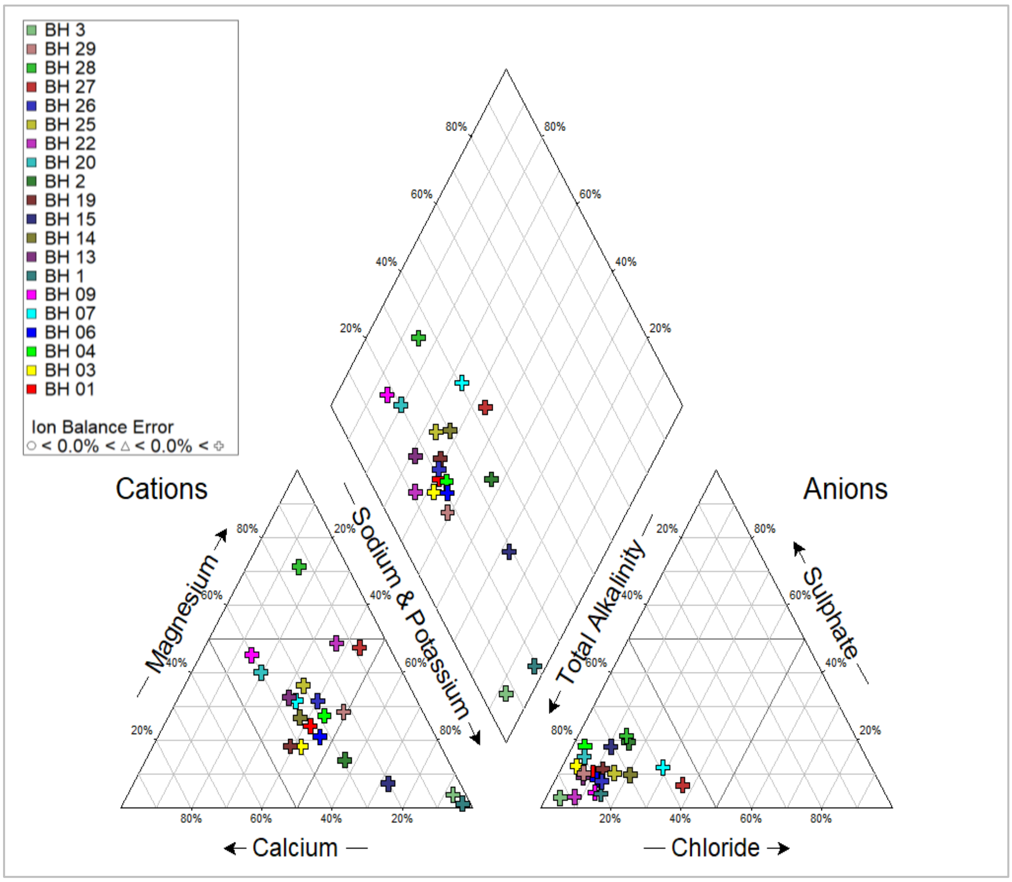


Figure 10-8 **Piper diagram indicating major anions and cations of groundwater samples analysed.**

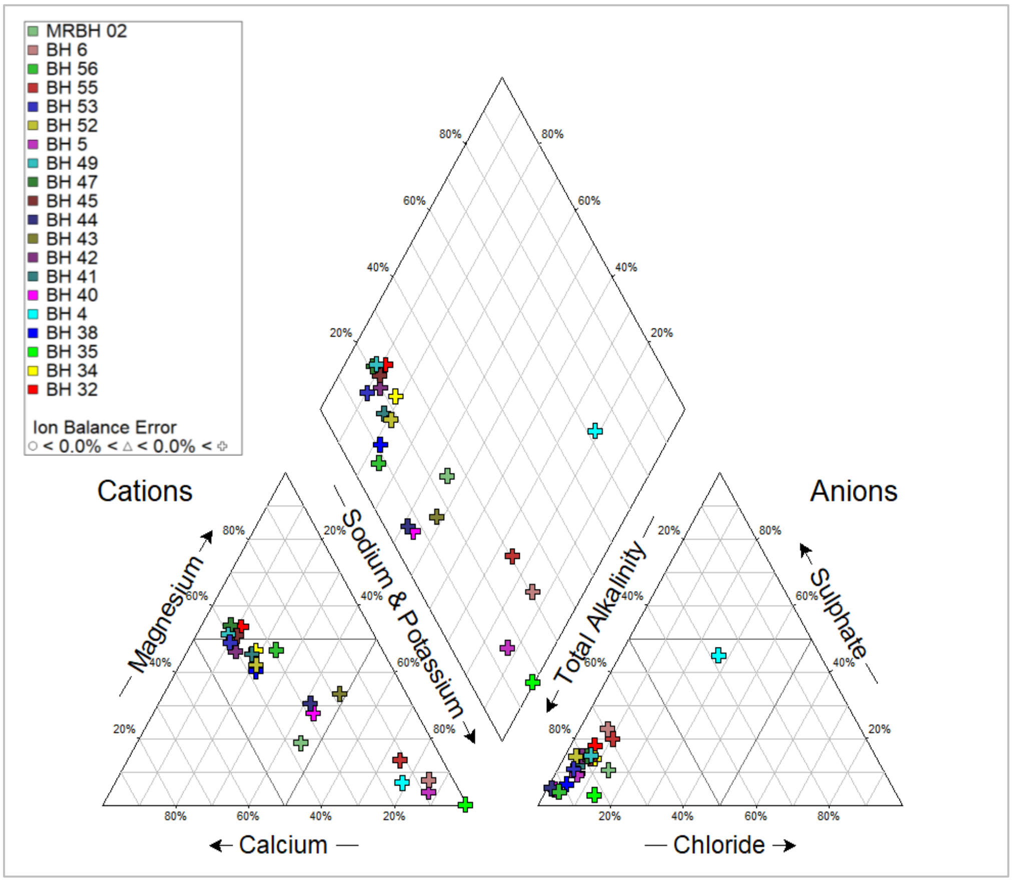


Figure 10-9 **Piper diagram indicating major anions and cations of groundwater samples analysed.**

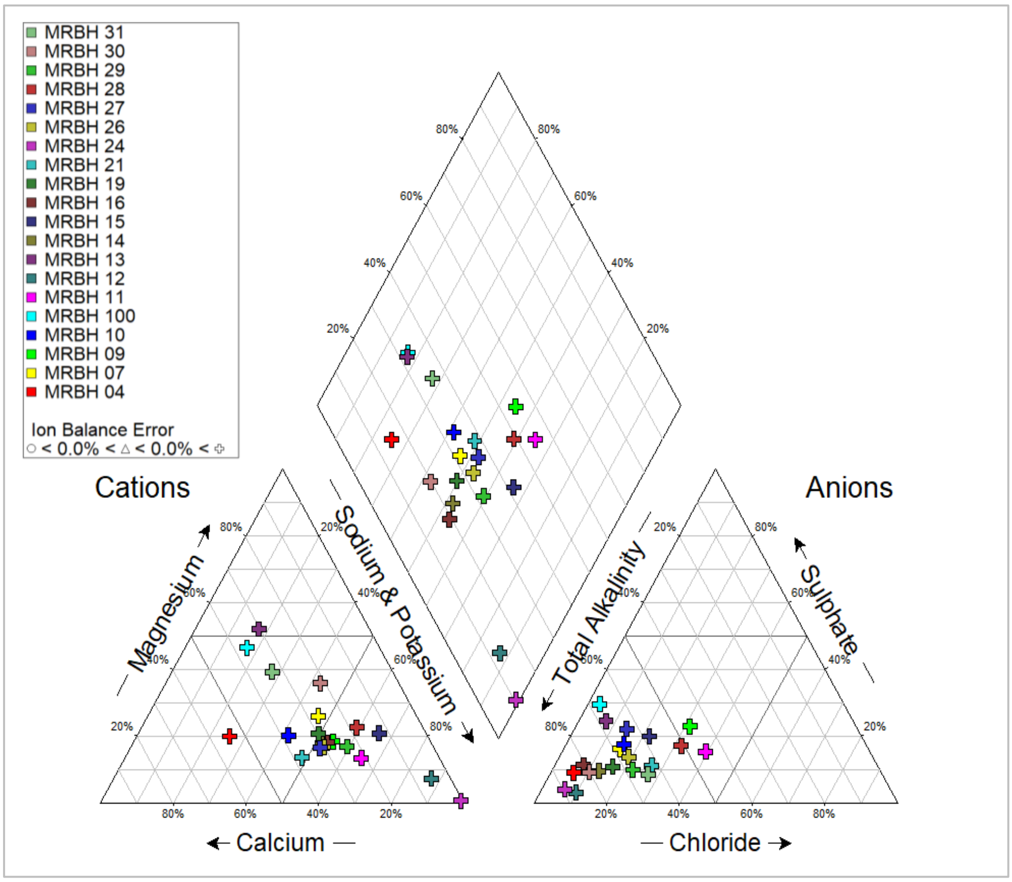


Figure 10-10 **Piper diagram indicating major anions and cations of groundwater samples analysed.**

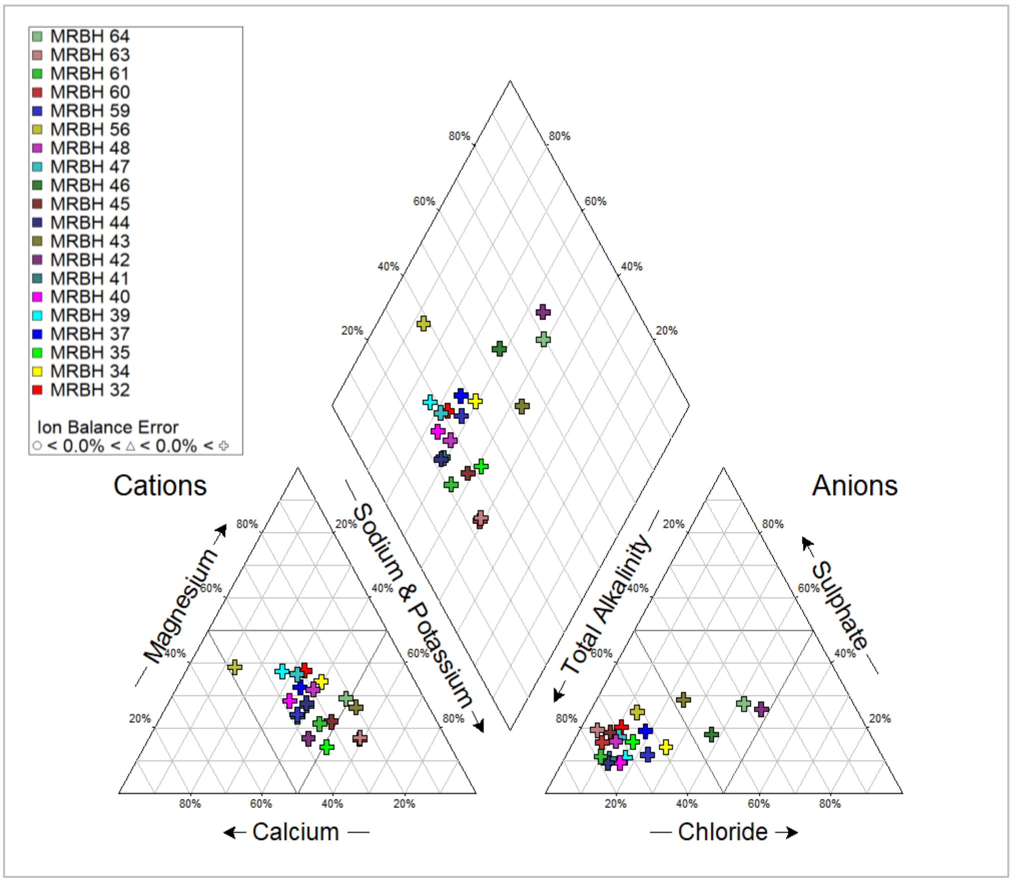


Figure 10-11 **Piper diagram indicating major anions and cations of groundwater samples analysed.**

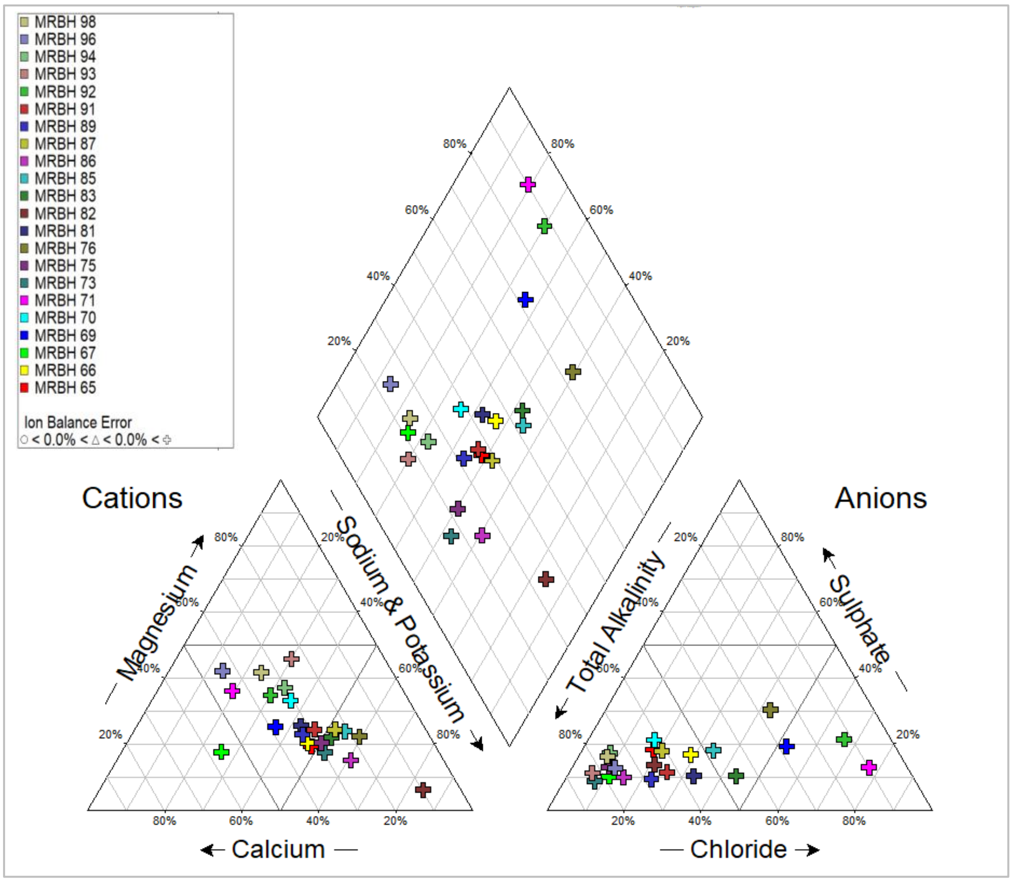


Figure 10-12 **Piper diagram indicating major anions and cations of groundwater samples analysed.**

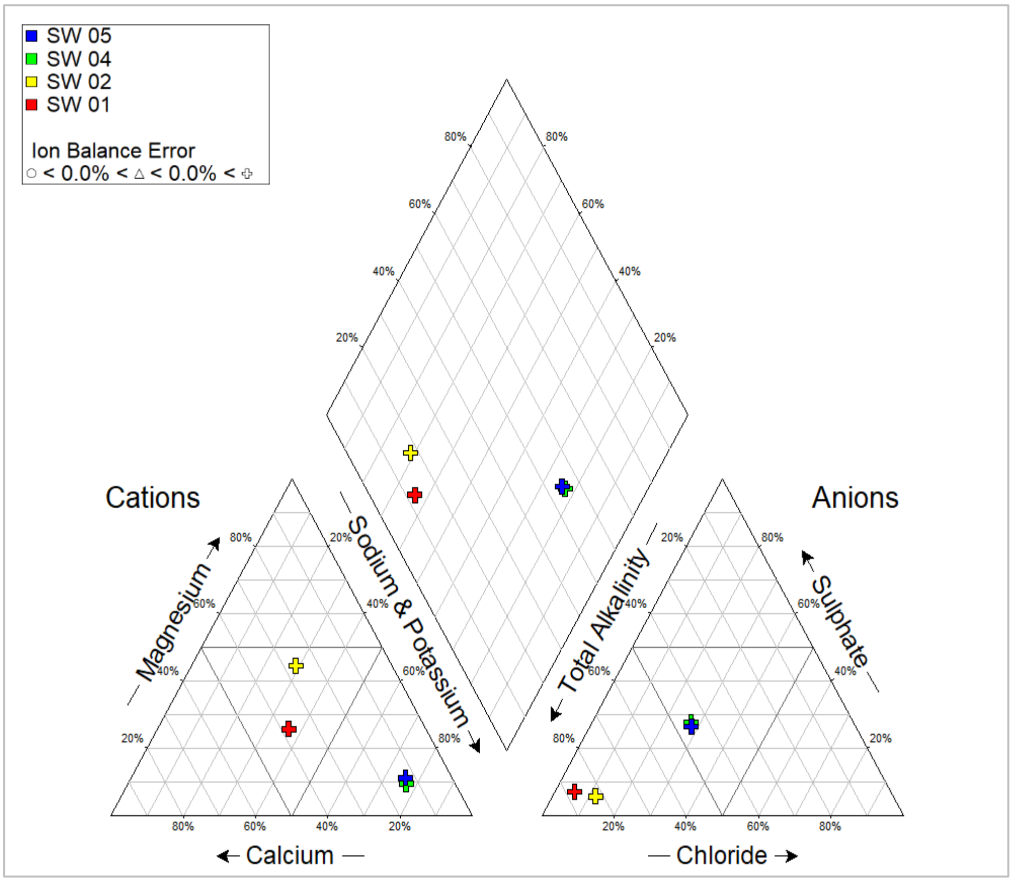


Figure 10-13 **Piper diagram indicating major anions and cations of surface water samples analysed.**

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 10-14** to **Figure 10-18** depicts Stiff diagrams compiled from the hydrocensus groundwater sampling analysis.

It is evident that the following borehole localities BH55, MRBH09, MRBH11, MRBH24, MRBH42, MRBH46, MRBH64, MRBH69, MRBH71, MRBH76, MRBH85 as well as MRBH92 indicate a different ion composition and geometry compared 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 suggest a more dominant Sodium/Potassium dominance which also and may also represent a deeper aquifer unit being.

Figure 10-19 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.

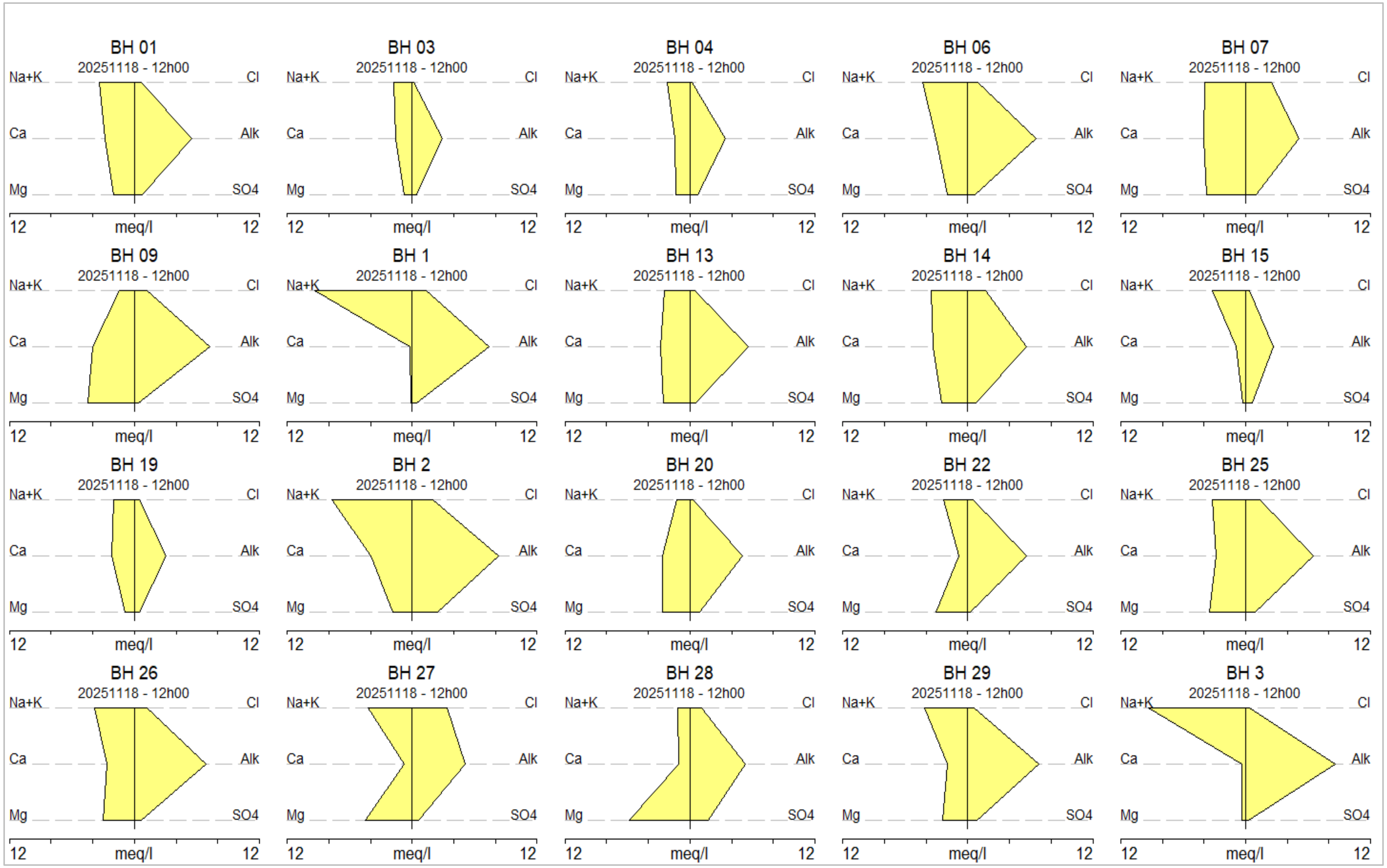


Figure 10-14 **Stiff diagrams representing the groundwater samples analysed.**

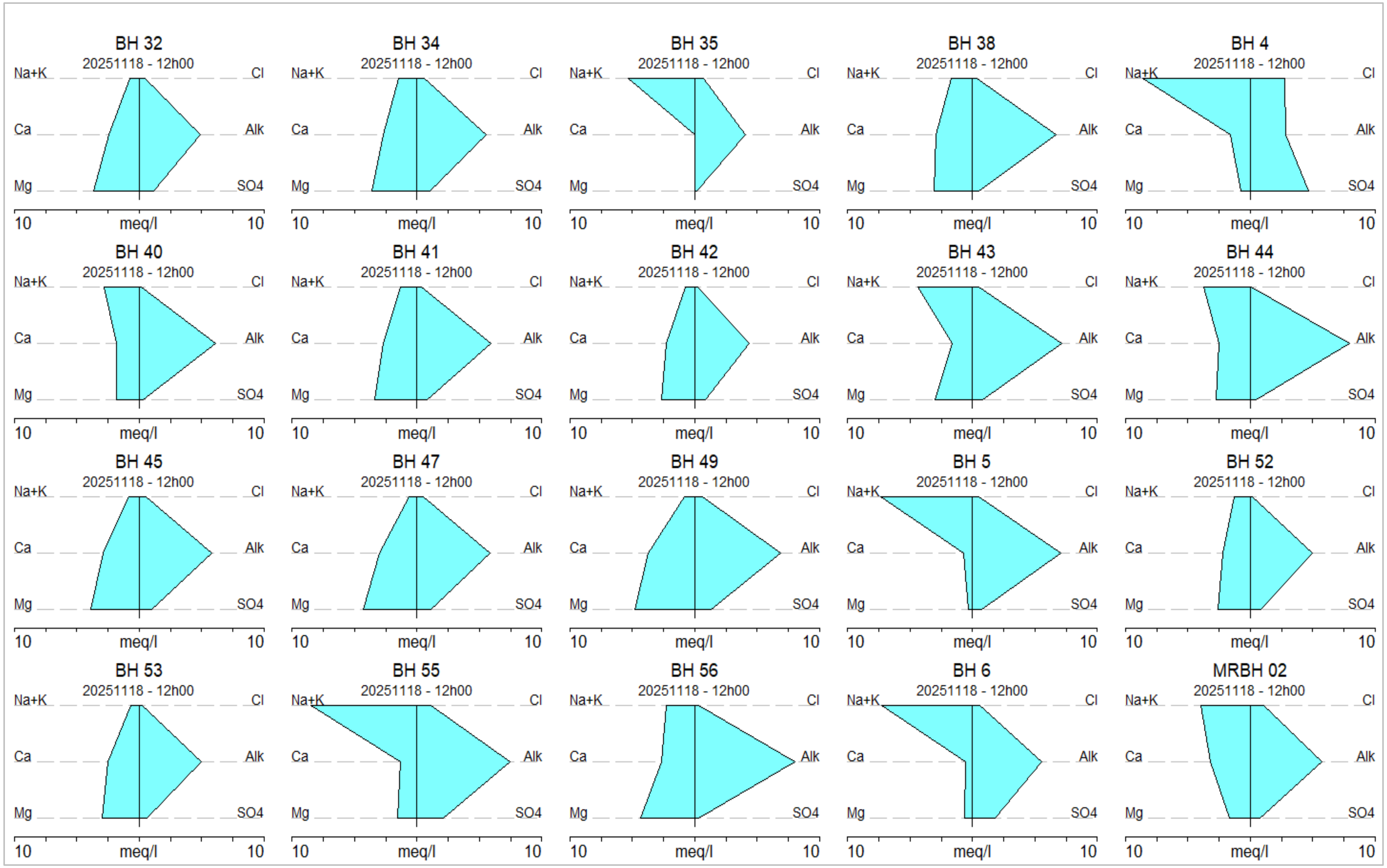


Figure 10-15 Stiff diagrams representing the groundwater samples analysed.

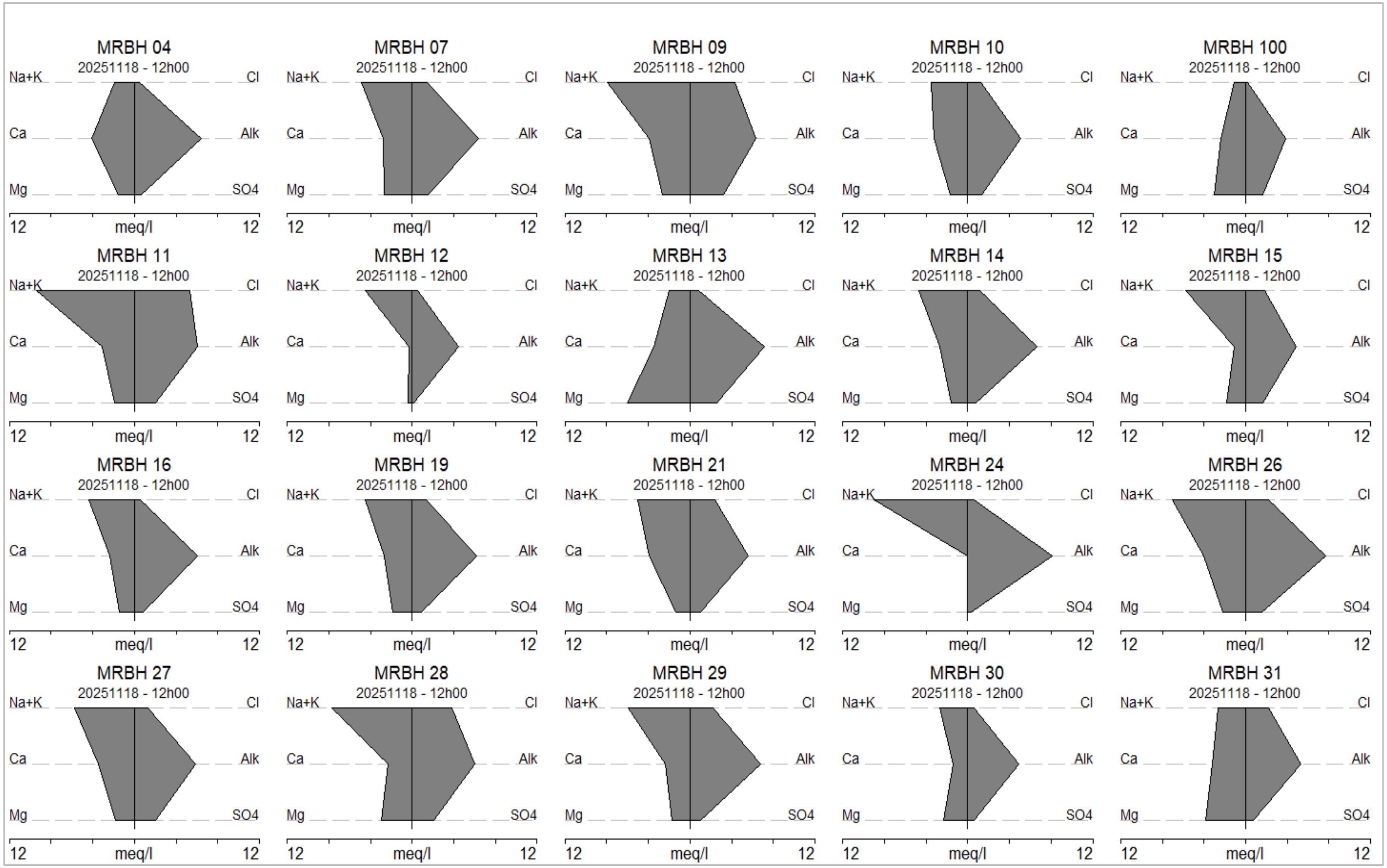


Figure 10-16 **Stiff diagrams representing the groundwater samples analysed.**

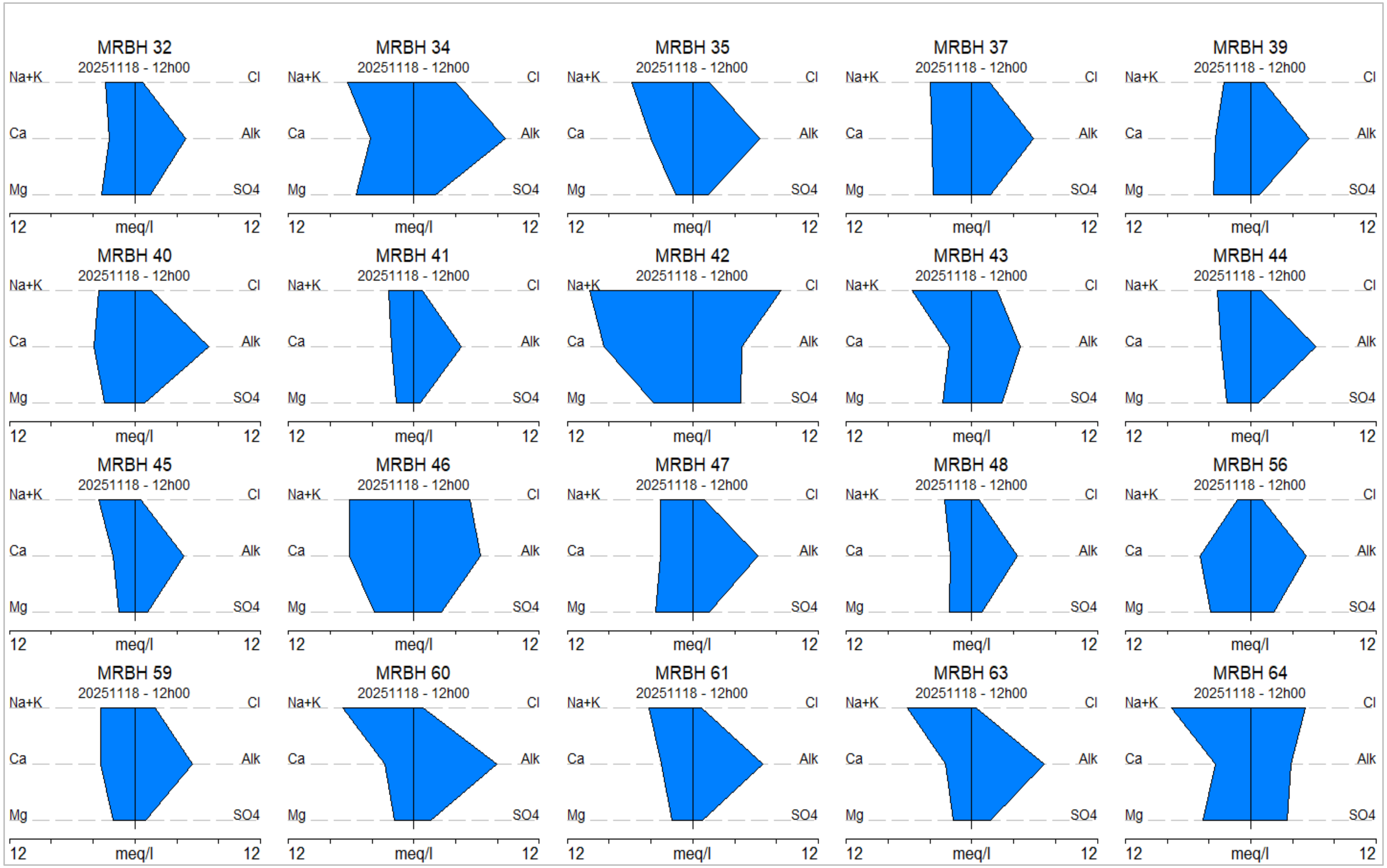


Figure 10-17 **Stiff diagrams representing the groundwater samples analysed.**

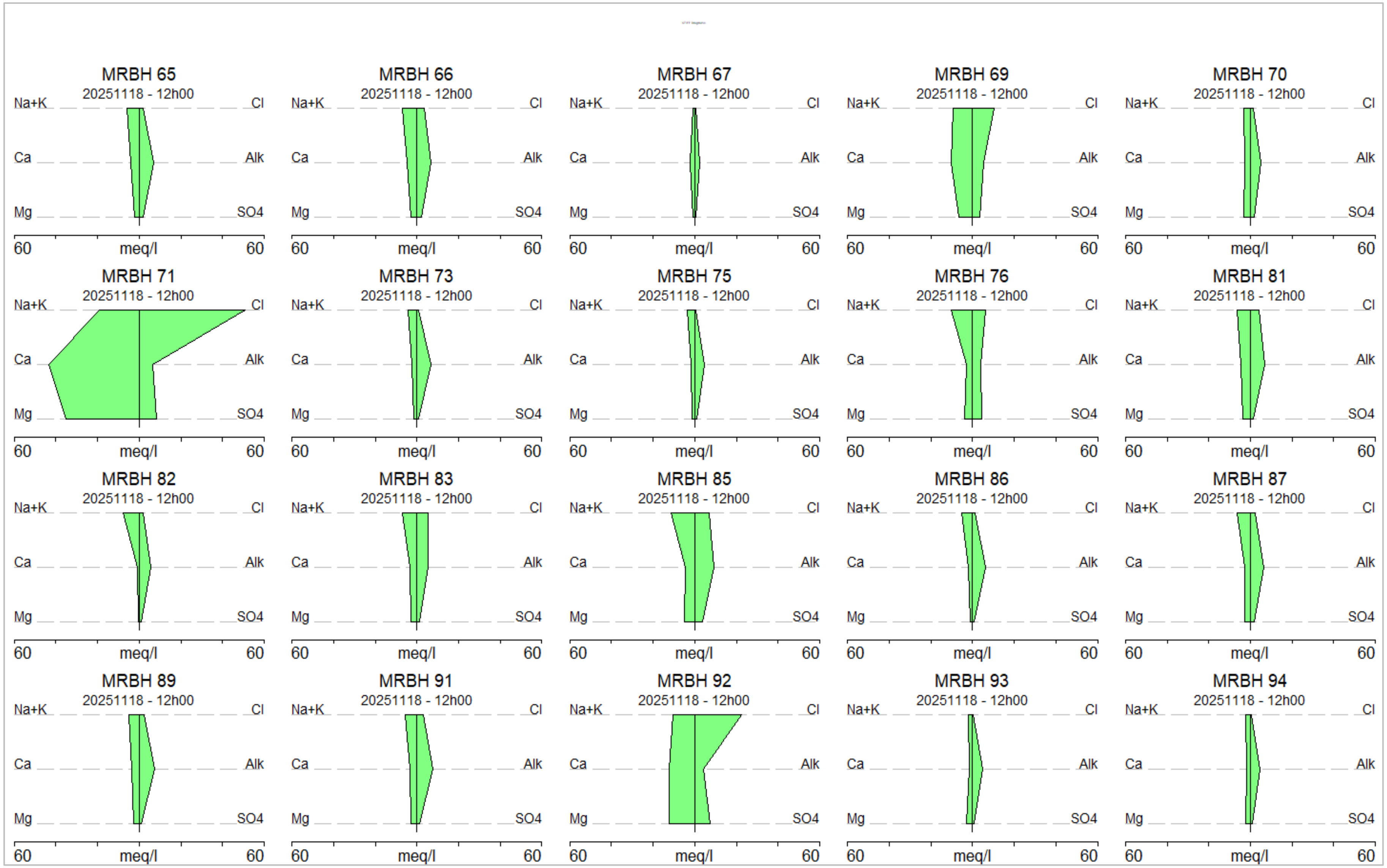


Figure 10-18 **Stiff diagrams representing the groundwater samples analysed.**

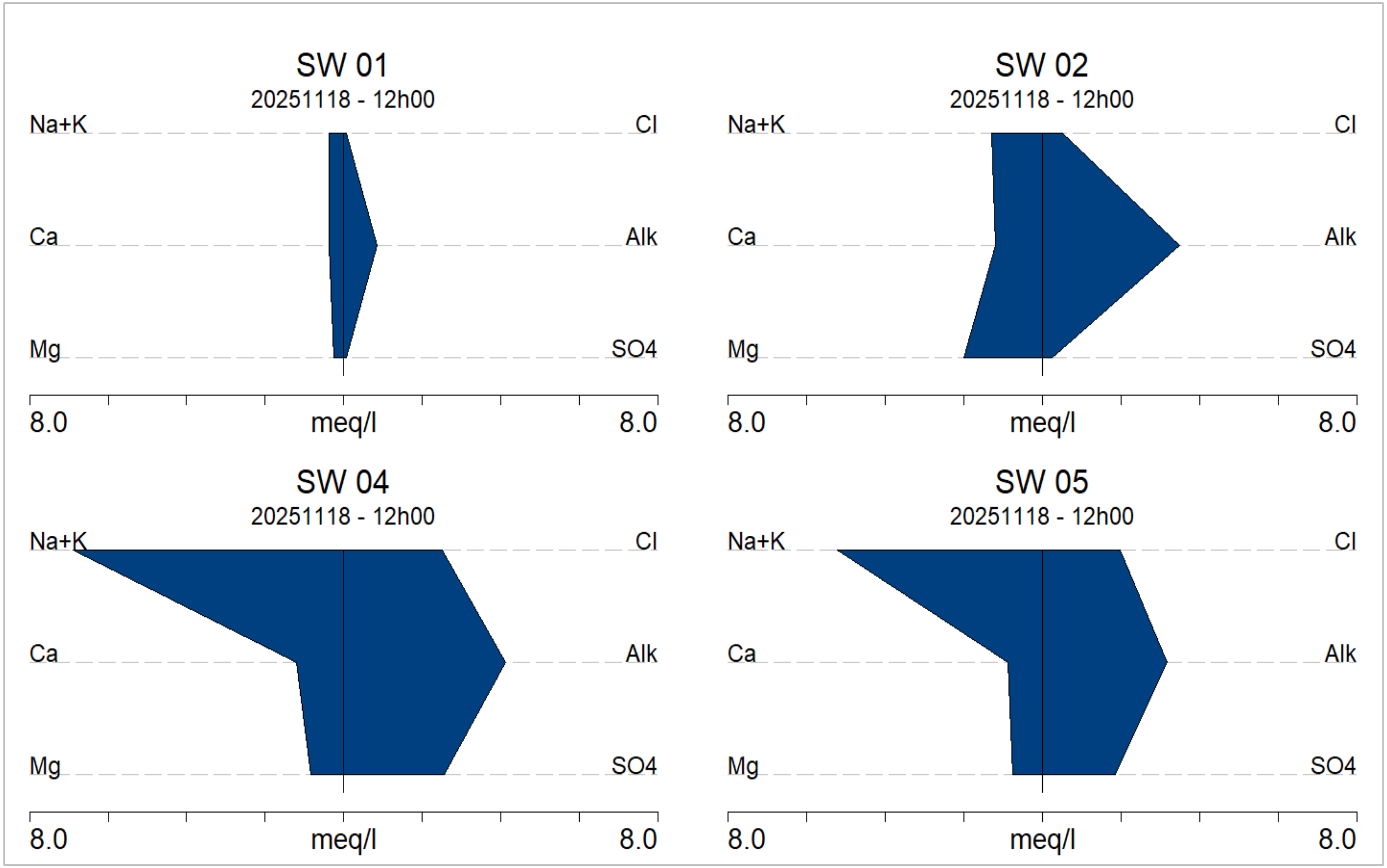


Figure 10-19 Stiff diagrams representing the surface water samples analysed.

10.5.3. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems as depicted in **.** 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.

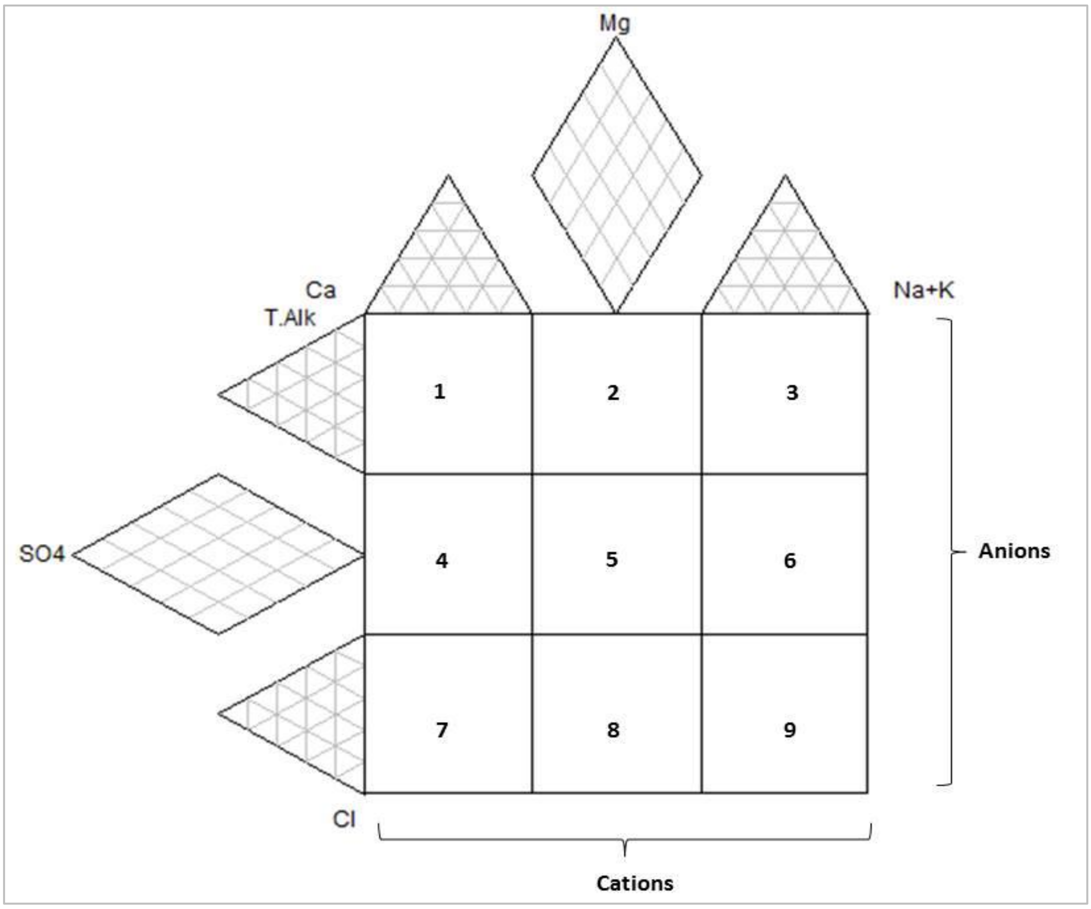
Field 09: Seawater or very old stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.), or water that has moved a long time and/or distance through the aquifer and has undergone significant ion exchange.

Most groundwater samples analysed can be classified as either Field01/ Field 02 i.e., mostly fresh, clean and relatively young with HCO3- and CO3 dominance evident indicative of an unimpacted groundwater environment or Field 03 (often associated with Na ion exchange between groundwater and aquifer material).

Borehole localities MRBH42, MRBH46 and MRBH64 can be classified as Field05, suggesting old stagnant NaCl dominated water that has mixed with clean water.

Borehole localities MRBH09, MRBH11, MRBH43, MRBH76, MRBH83 and MRBH85 can be classified as Field06, suggesting old stagnant NaCl dominated water that has mixed with clean water. Borehole localities MRBH69, MRBH71 and MRBH92 can be classified as Field08 (old stagnant NaCl-dominated water). The latter suggests more stagnant and older water which may indicate a deeper aquifer or hydrostratigraphical units being targeted (refer to **Figure 10-21** to **Figure 10-24**). **Figure 10-26** 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 HCO3- and CO3 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 10-20 Extended Durov diagramindicating major anions and cations.



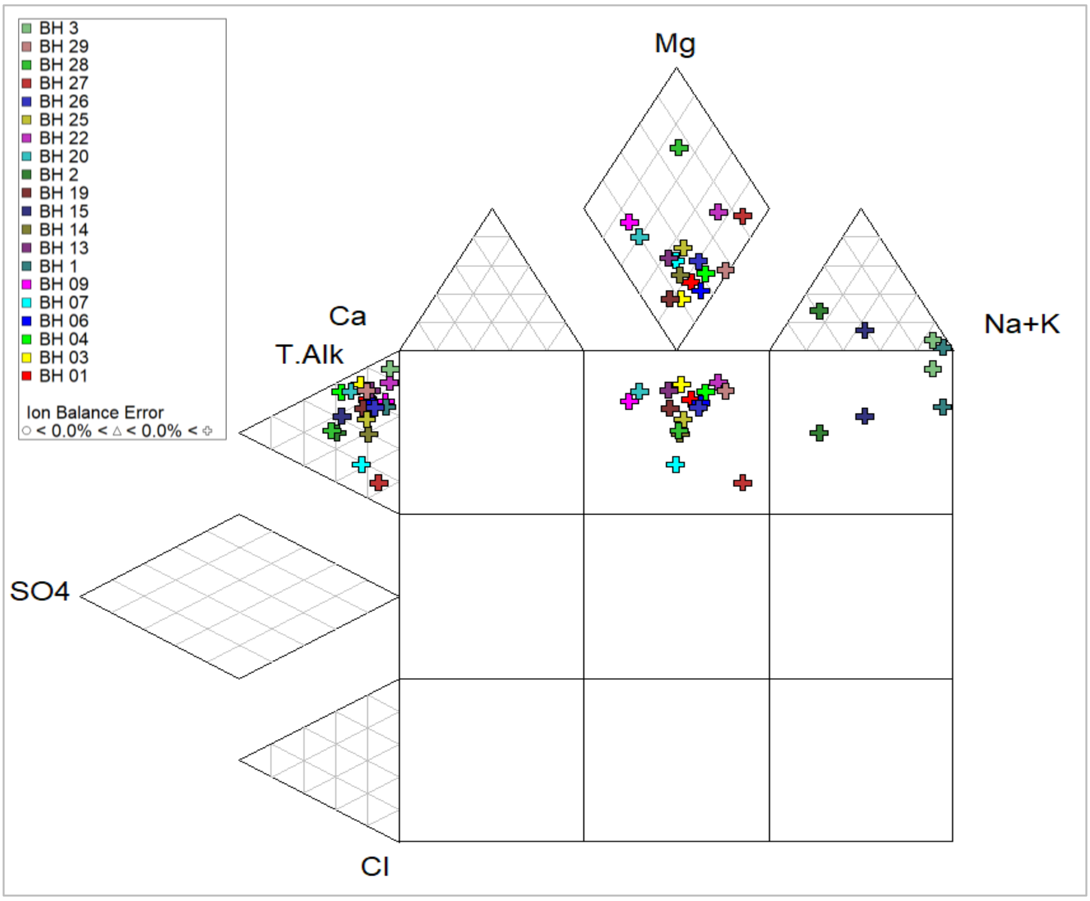


Figure 10-21 Extended Durov diagram of groundwater samples analysed.

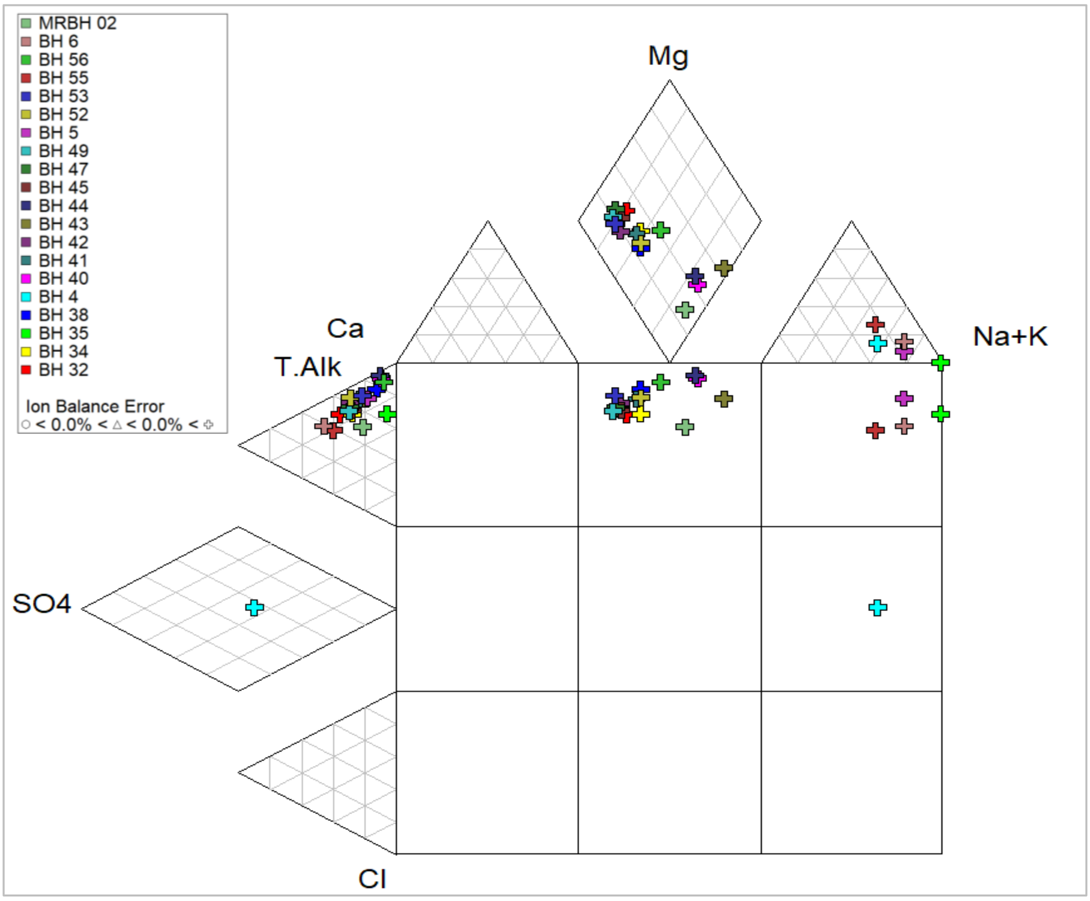


Figure 10-22 Extended Durov diagram of groundwater samples analysed.

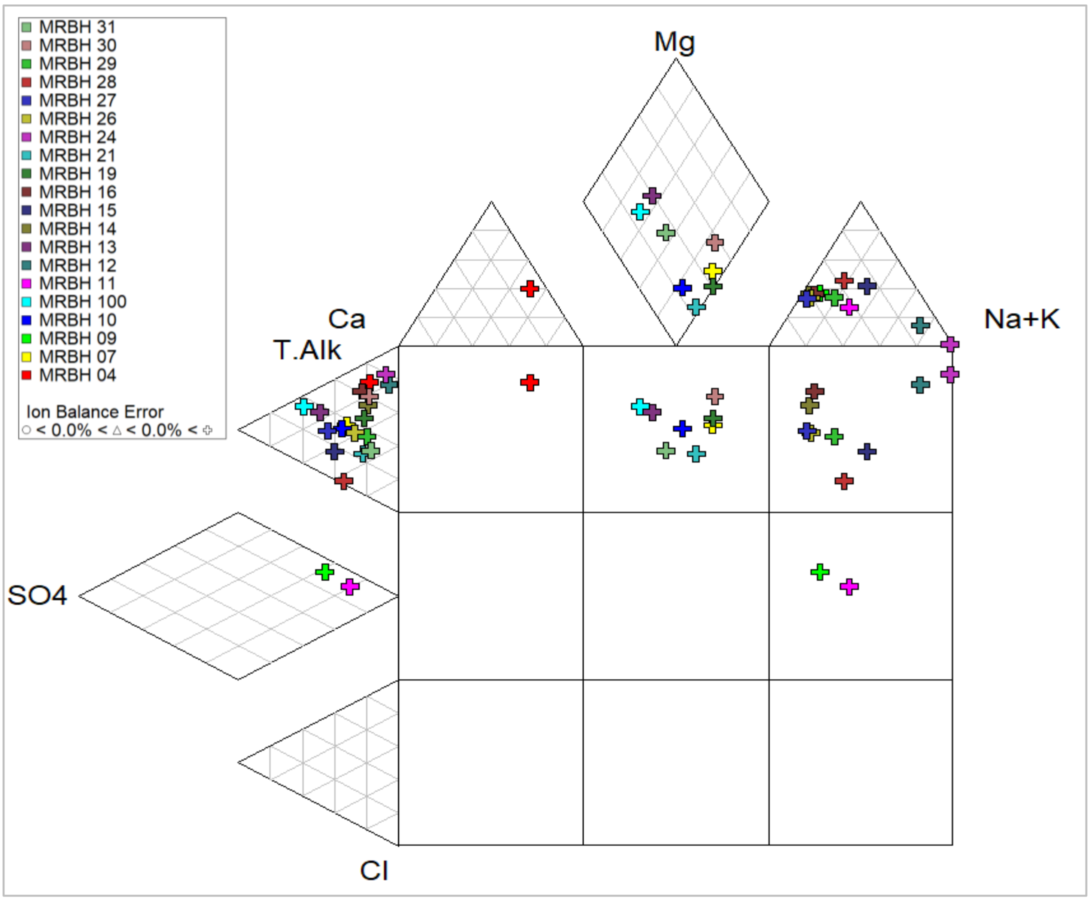


Figure 10-23 **Extended Durov diagram of groundwater samples analysed.**

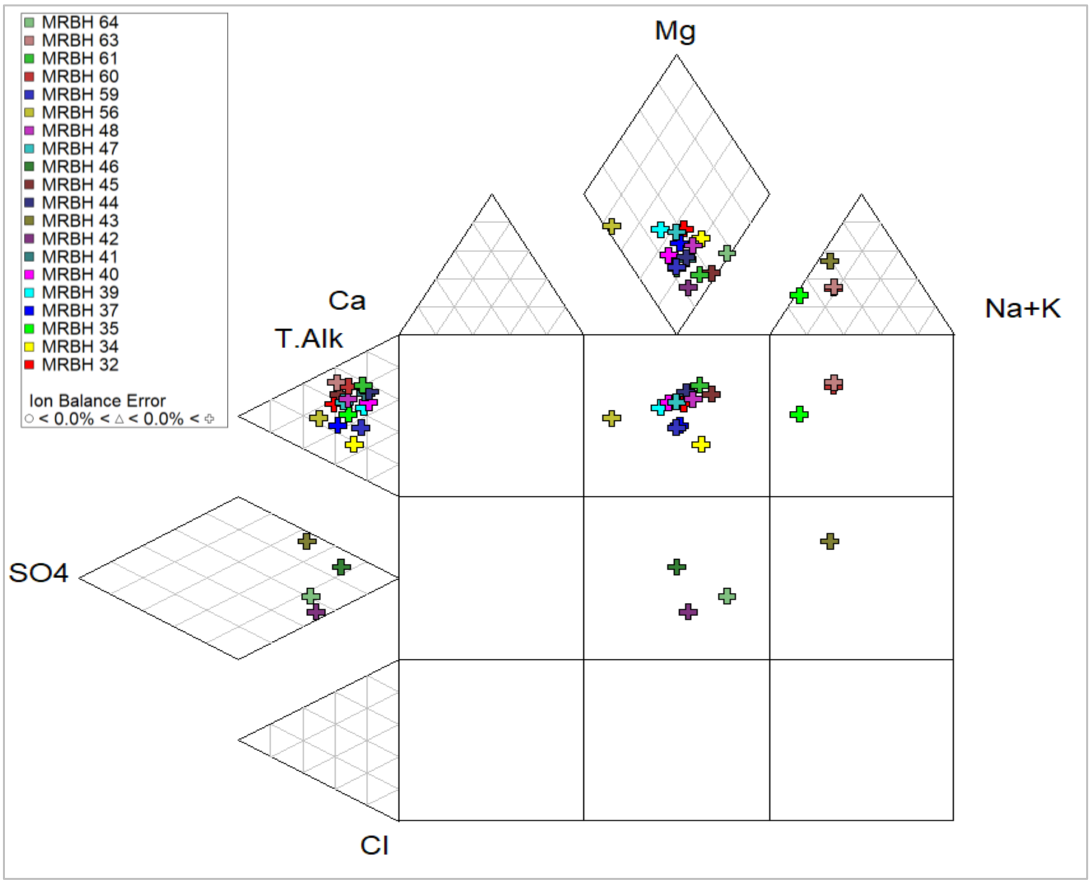


Figure 10-24 **Extended Durov diagram of groundwater samples analysed.**

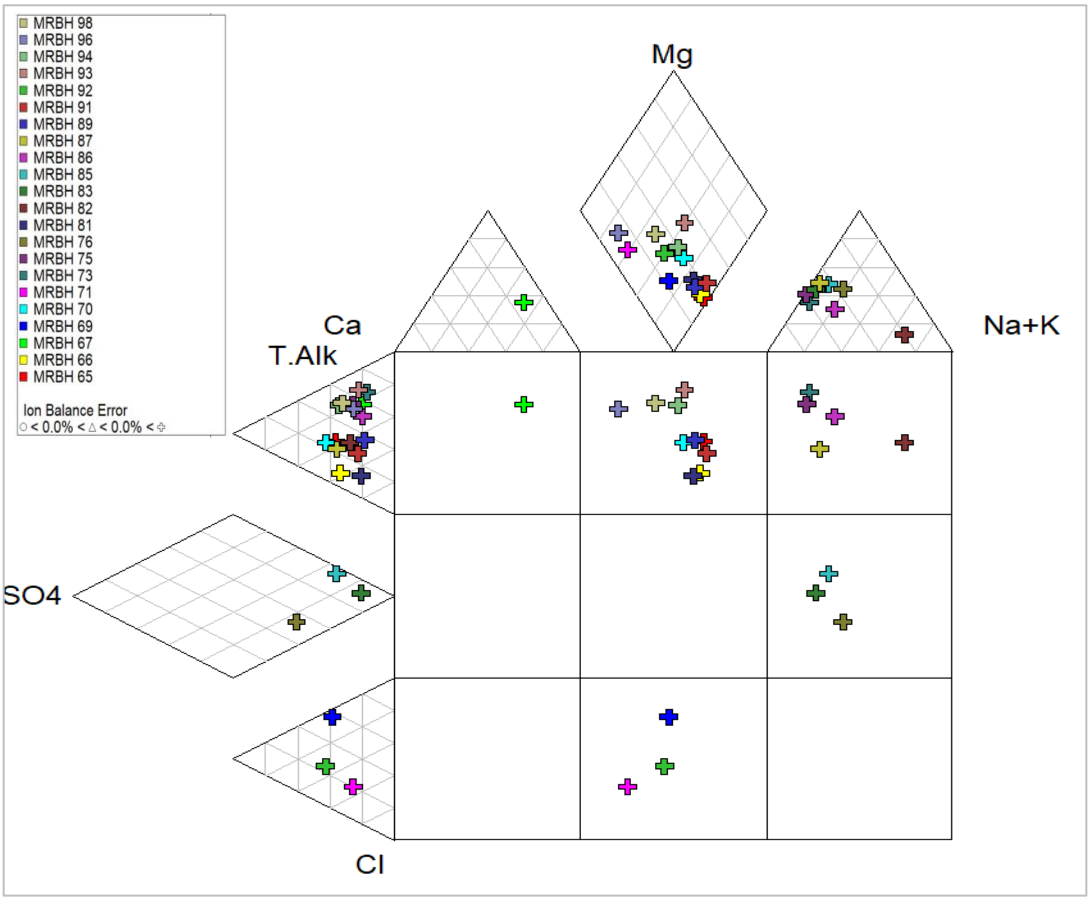


Figure 10-25 **Extended Durov diagram of groundwater samples analysed.**

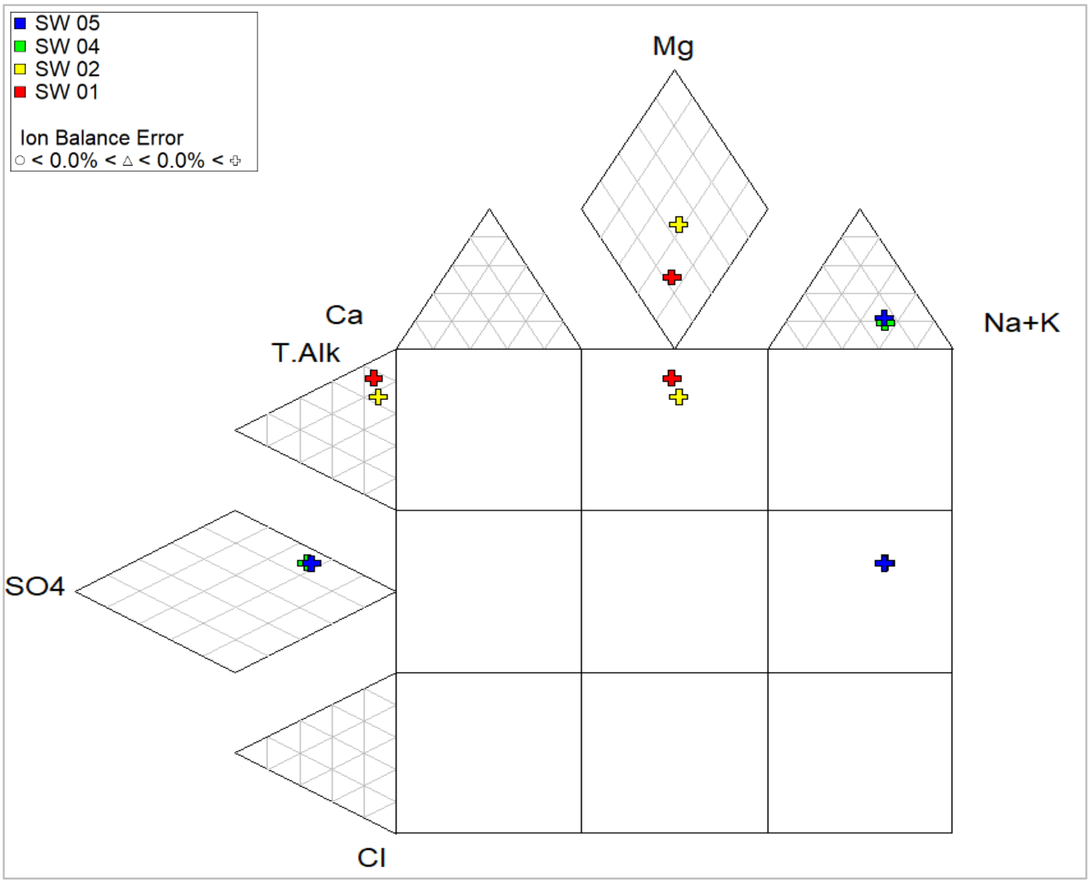


Figure 10-26 **Extended Durov diagram of surface water samples analysed. .**

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 GMQ Index.

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

11.1. Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). Aquifer classification forms a very useful planning tool which can be applied to guide the management of groundwater systems. According to the aquifer classification map of South Africa the project area is underlain by a “**Minor 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, Nett 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).

$$Di = DrD\lambda + RrR\lambda + ArA\lambda + Sr\,S\lambda + TrT\lambda + IrI\lambda$$

where:

D = Depth to Water Table

R = Recharge

A = Aquifer media.

S = Soil media.

T = Topographic aspect.

I = Impact of vadose zone media.

C = Conductivity.

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)

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

Net Recharge (R_R)

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

Aquifer Media (A_R)

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

Soil Media (S_R)

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

Topography (T_R)

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

Impact of the vadose zone (I_R)

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

Table 11-5 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		
	> 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) = 154				

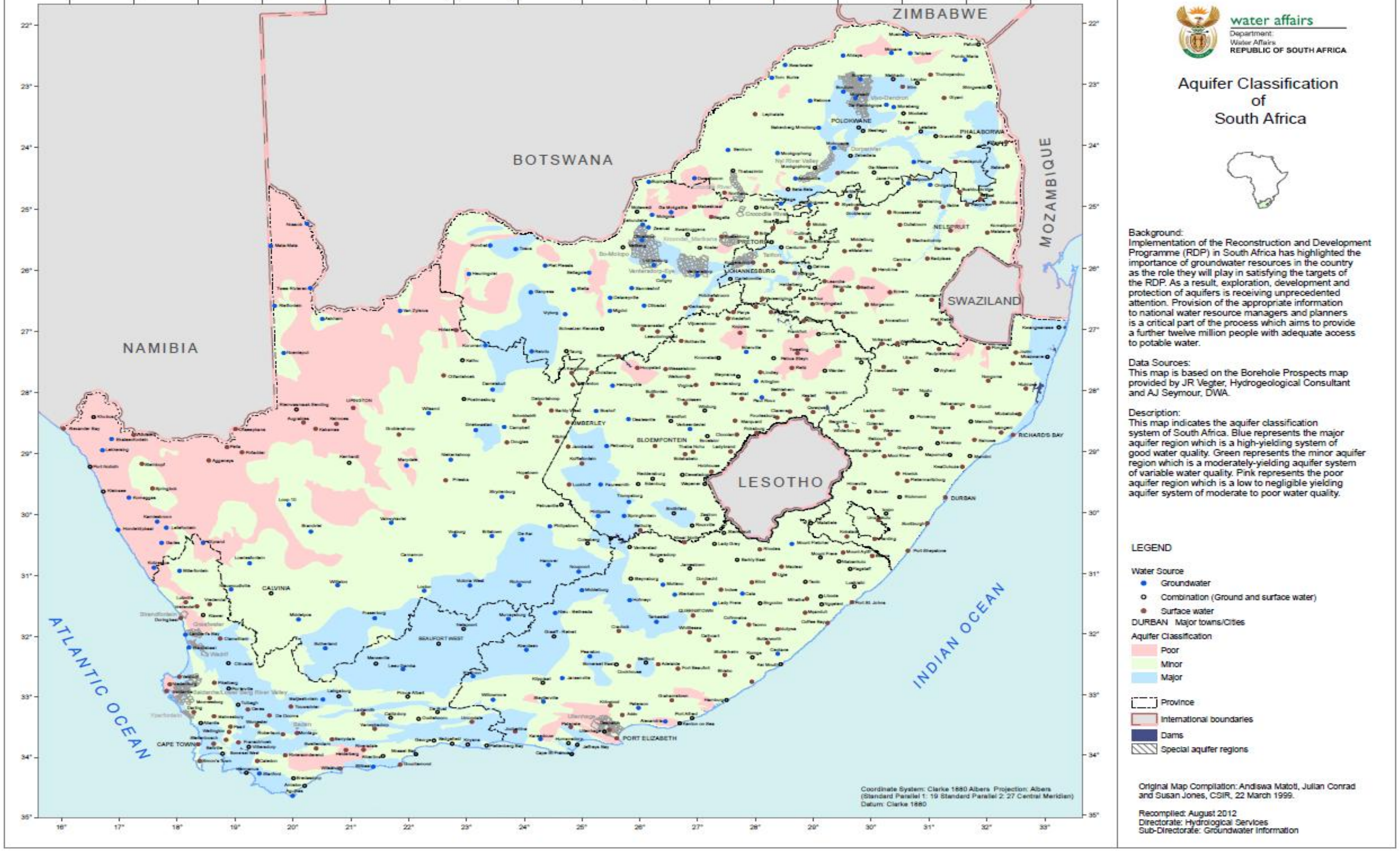


Figure 11-1 **Aquifer classification of South Africa (DWS, 2013).**

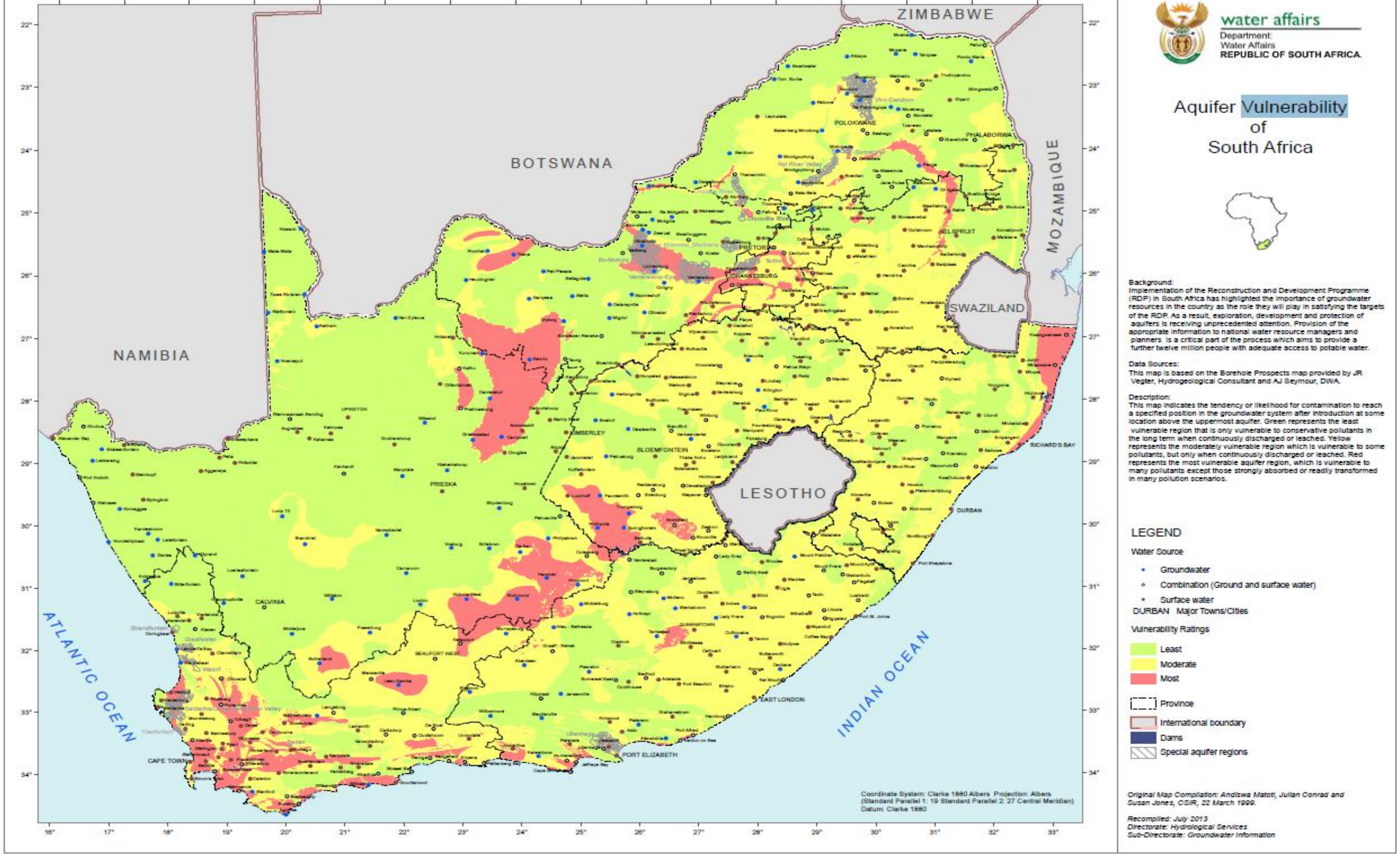


Figure 11-2 Aquifer vulnerability of South Africa (DWS, 2013).

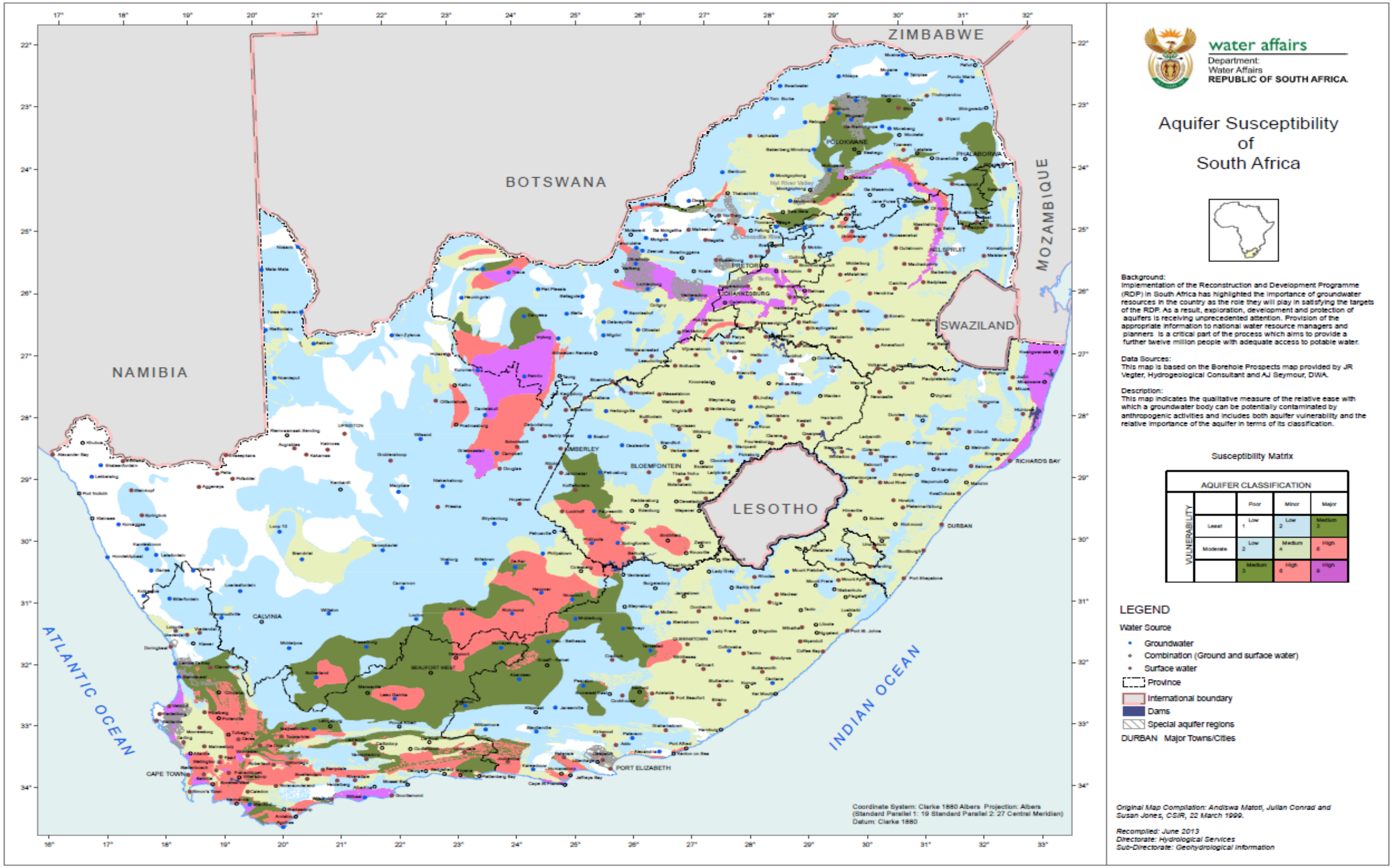


Figure 11-3 **Aquifer Susceptibility of South Africa (DWS, 2013).**

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**).

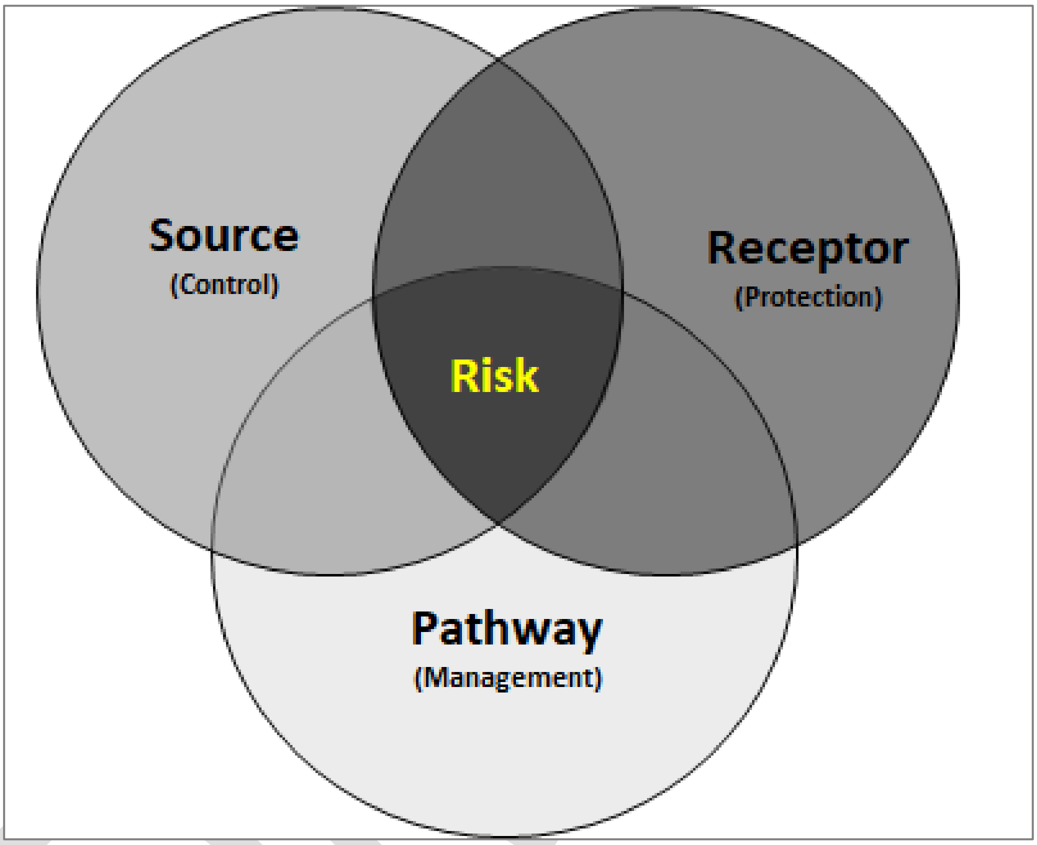


Figure 11-4 Source pathway receptor principle.

11.5.1. Potential sources

The following potential sources have been identified:

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.

ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.

iii. Drilling fluids and additives, lubricants, oils, fuels, and grease from machinery, cement and grouting materials, surface runoff carrying sediments or chemicals, contaminated drilling water used during circulation

iv. 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 exploration and exploration 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:

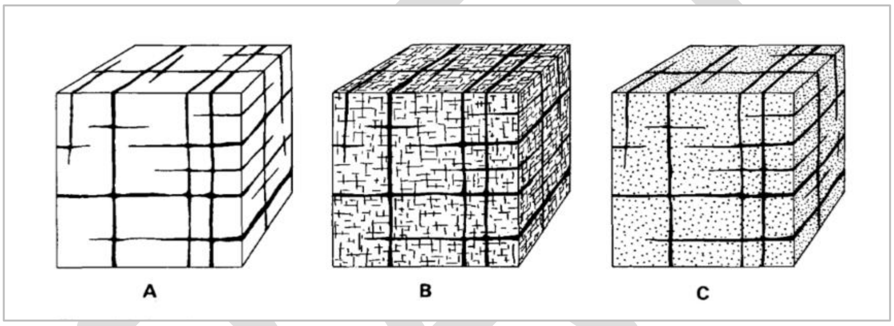
i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.

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. The weathered zone aquifer and secondary rock aquifer in the area could be classified as double porosity aquifers. **Figure 12-2** depicts a south- north cross section of the study area with relevant information included (Refer to **Figure 13-2** for spatial reference).



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

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

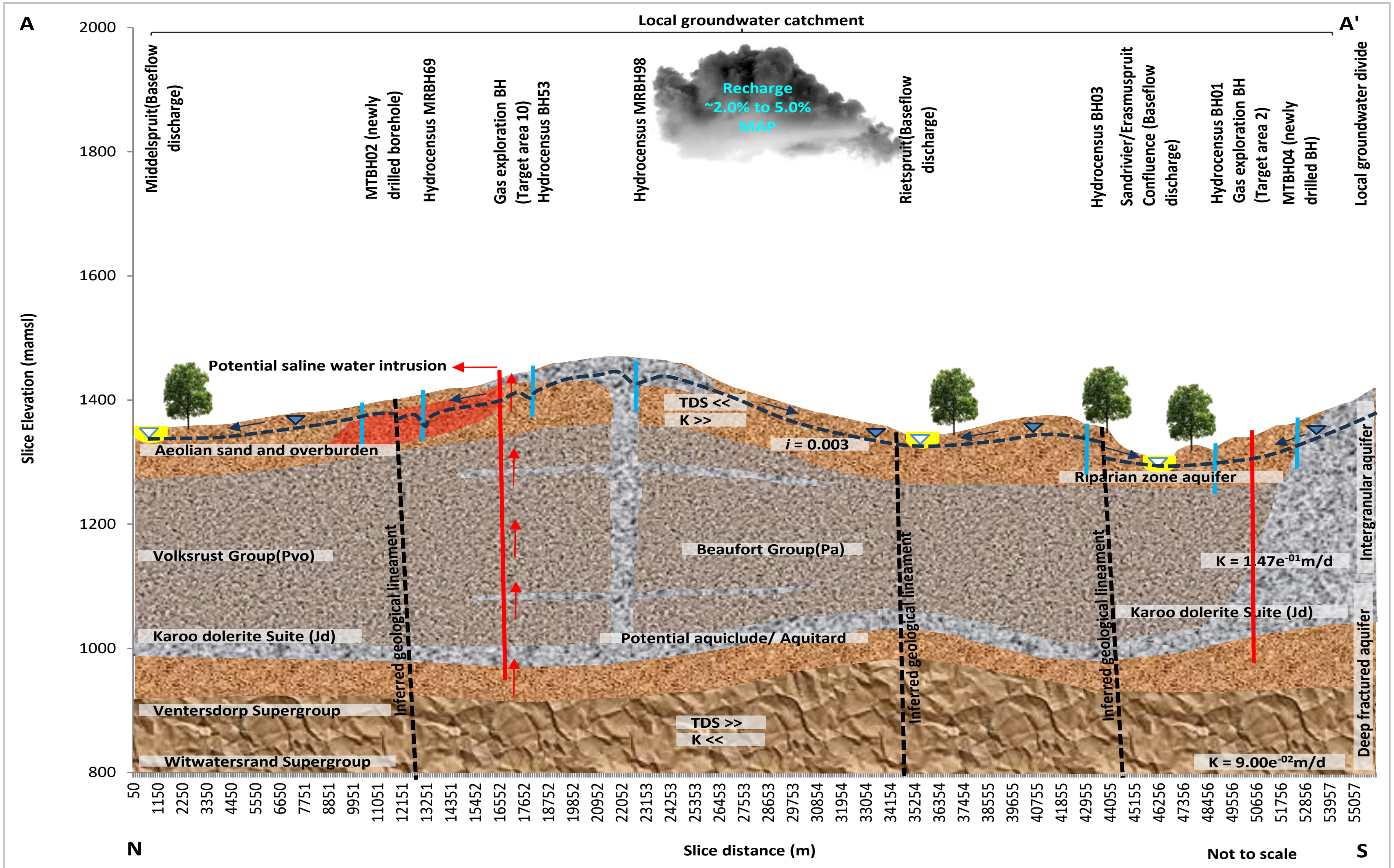


Figure 12-2 **Hydrogeological conceptual model: South- North cross section (A'-A') (Refer to Figure 13-2).**

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.

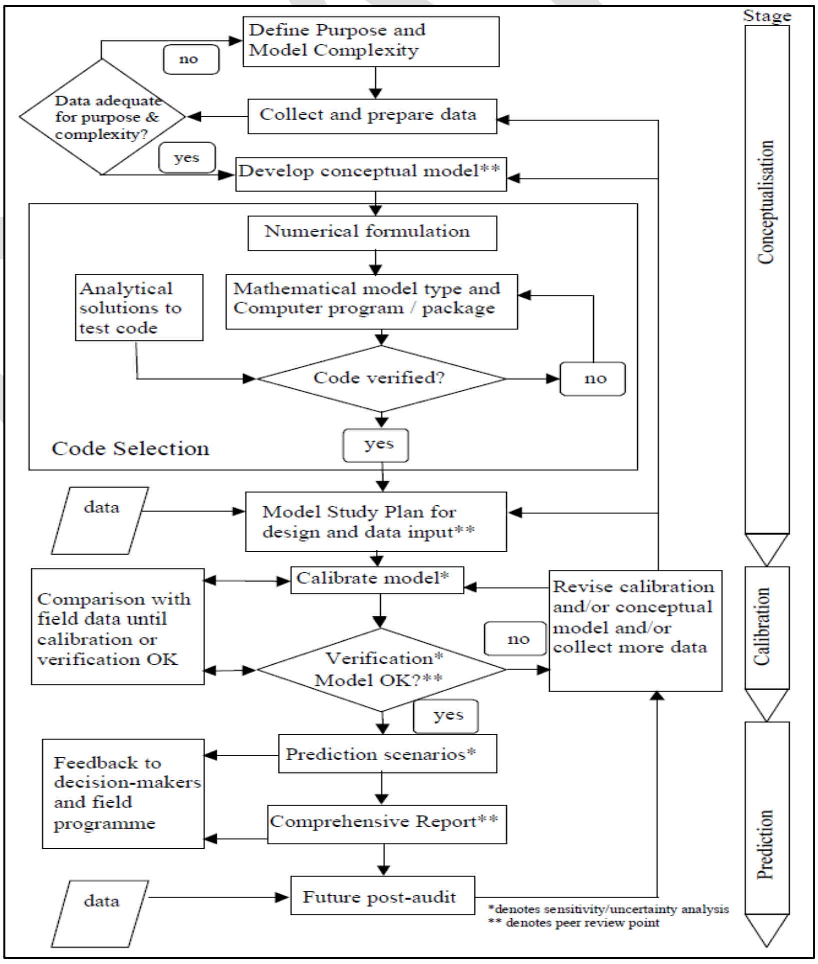


Figure 13-1 **Workflow numerical groundwater flow model development.**

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.

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

where:

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

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

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

The piezometric gradient, which can be measured from site 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 m^3/m^2/d) and K is the hydraulic conductivity, D the aquifer thickness and dh/dl the piezometric gradient. Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small error (usually <10.0 % of the aquifer thickness).

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: 24987.28[m] and Y: -3067829.89[m] using triangular prism type of elements. The model has a width of 49848.6[m], height of 62008[m], depth of 682.49[m] and spans an area of $1.76e^{+09}m^2$ with a volume of $\sim 7.91e^{+11}m^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e., discharge zones and no-flow zones (**Figure 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 five layers i.e., six slices, 518 433 triangular prism elements per layer, a total of 2 592 165 elements for the model domain, with 259 616 nodes per slice a total of 1 557 696 nodes for the model domain. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 0.8%.
- Interior holes: 0.
- Obtuse angled triangles: 0.60% > 120°, 5.10% > 90°.

13.3.3. Model layers

The groundwater model consists of five layers (six 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 = ~20.0m).

ii. **Layer 02:** A shallow, intergranular aquifer (unconfined to semi-confined) occurring in the transitional soil and weathered bedrock formations of the Karoo Supergroup (Ecca and Beaufort Group shales and sandstones) rocks underlain by more consolidated bedrock (Average thickness = ~100.0m).

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 (Ecca and Beaufort Group shales (may also potentially act as an aquitard)) (Average thickness = ~250.0m).

iv. **Layer 04:** Karoo Dolerite Suite (Sill) which may potentially act as an aquitard (Average thickness = 30.0m).

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 Ventersdorp and Witwatersrand Supergroups (Average thickness = ~150.0m).

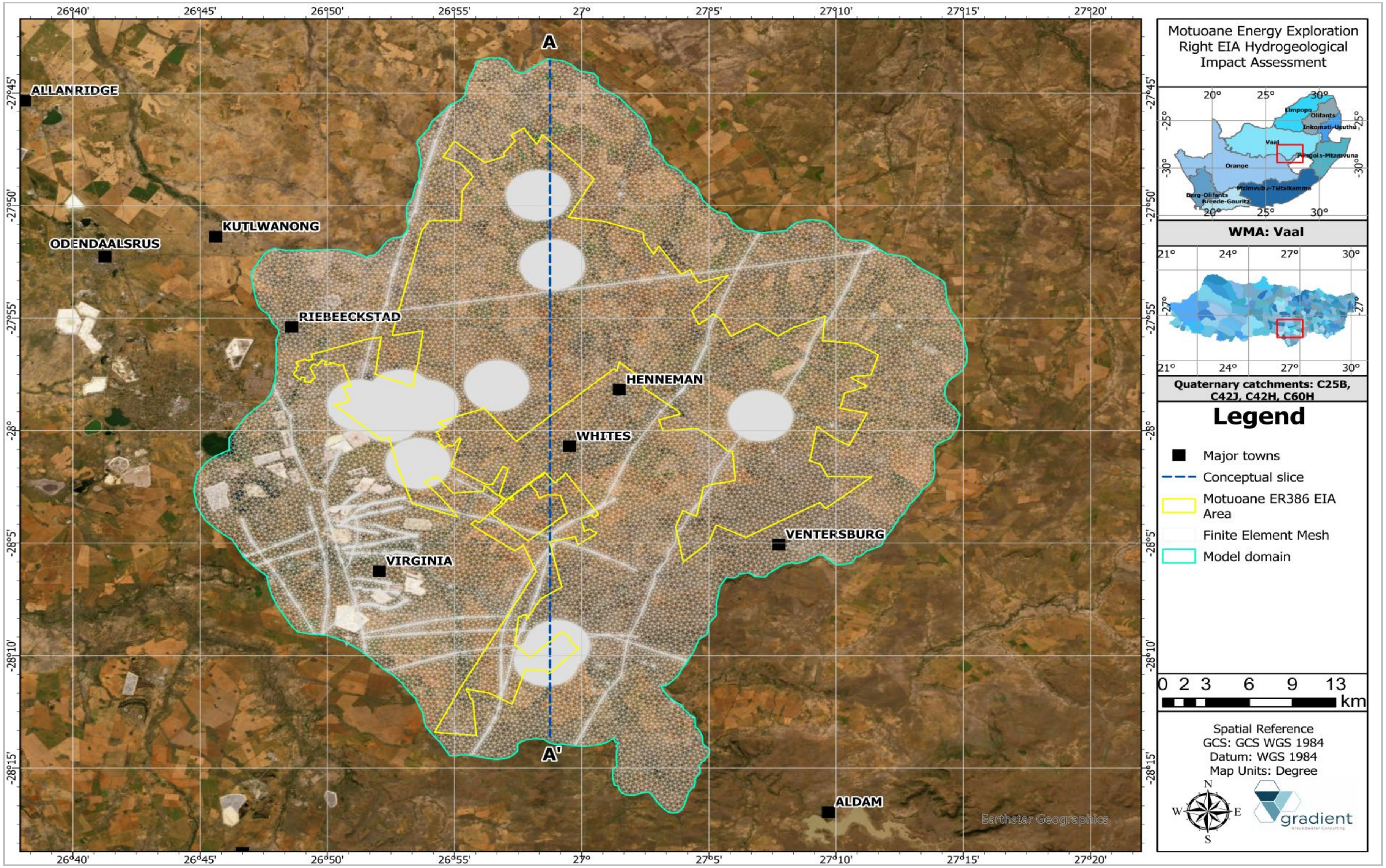


Figure 13-2 **Model domain: Aerial extent.**

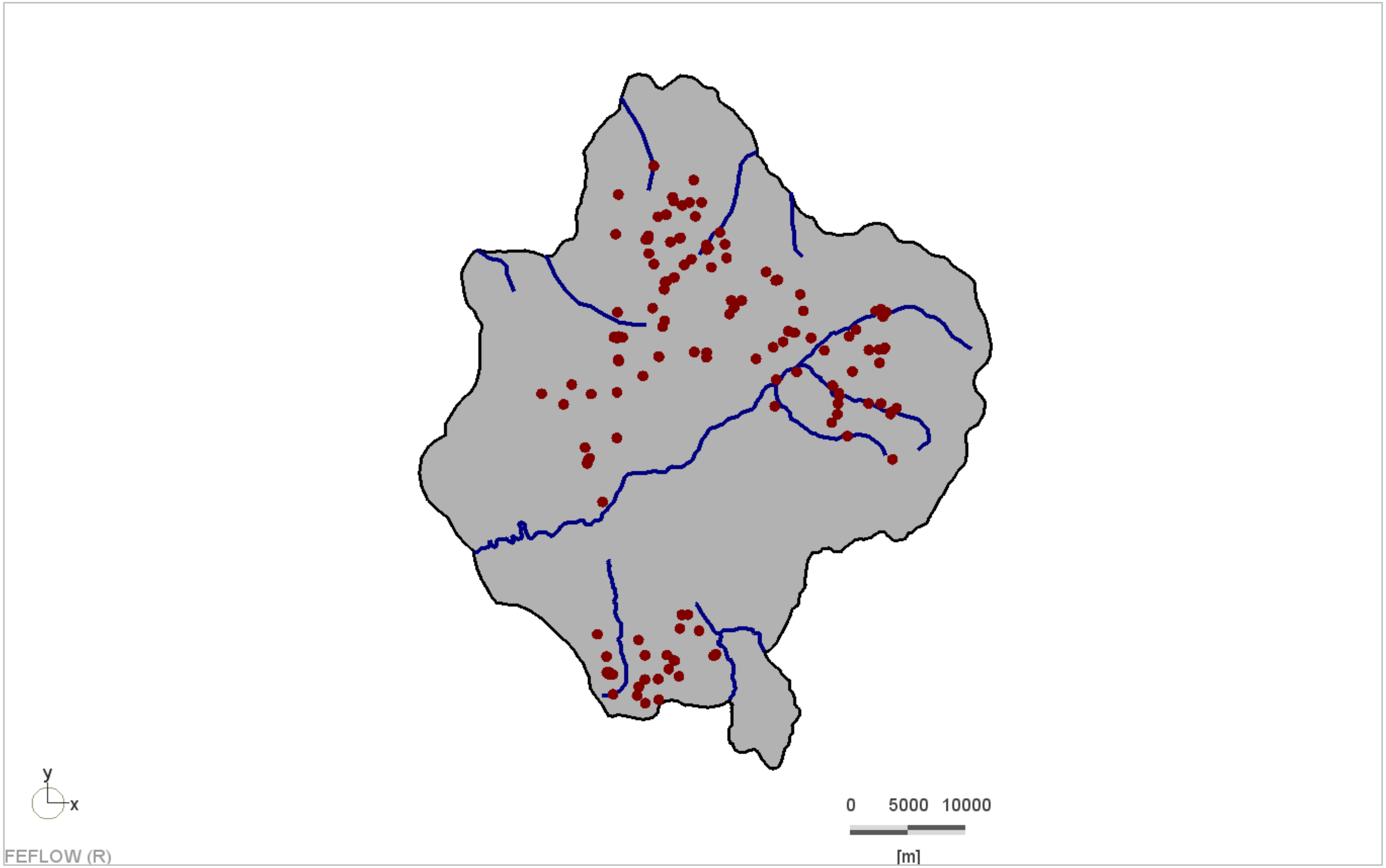


Figure 13-3 **Model domain: Supermesh view.**

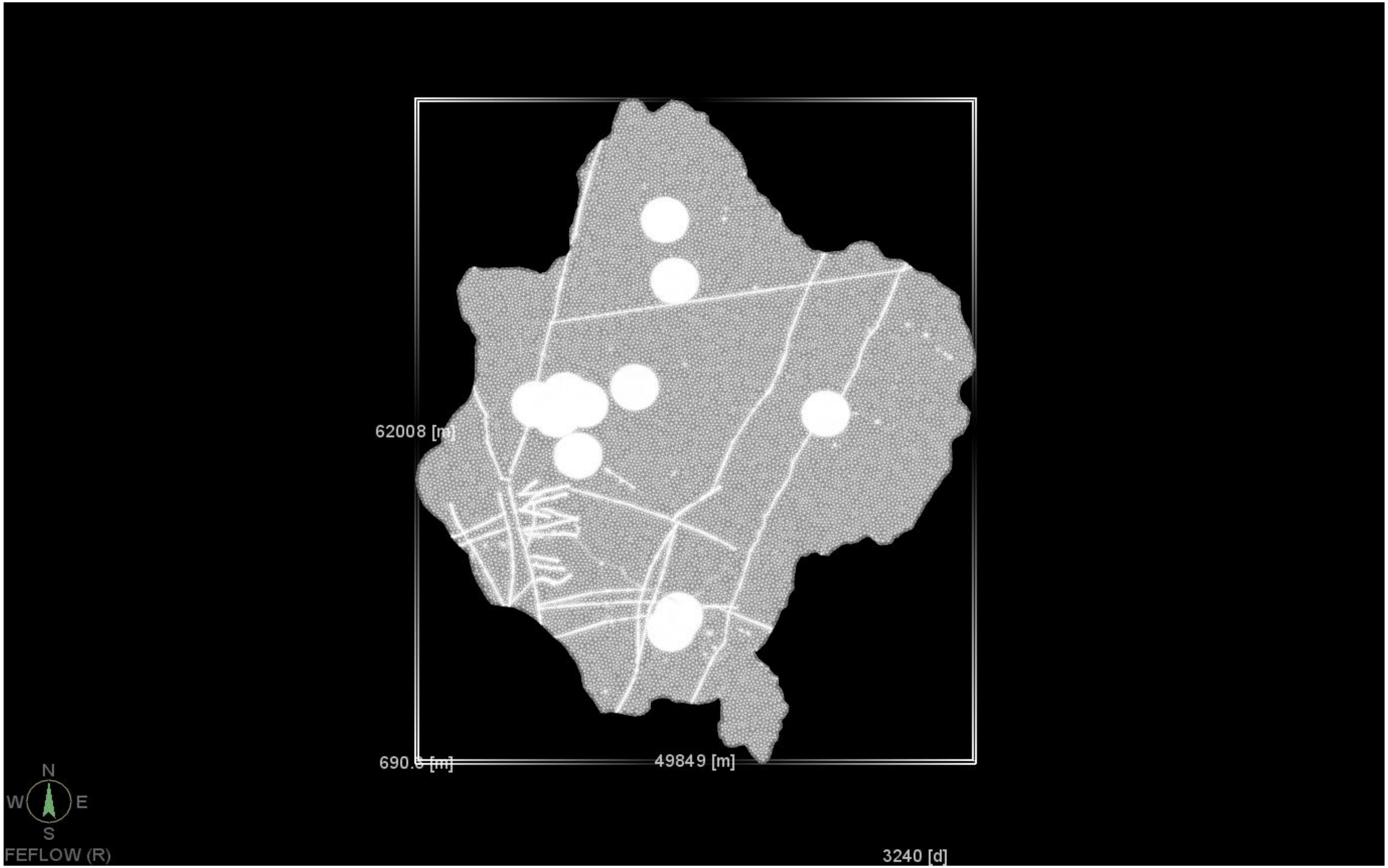


Figure 13-4 **Model domain 3-D FEM mesh in a plan view depicting a plan-view orientation .**

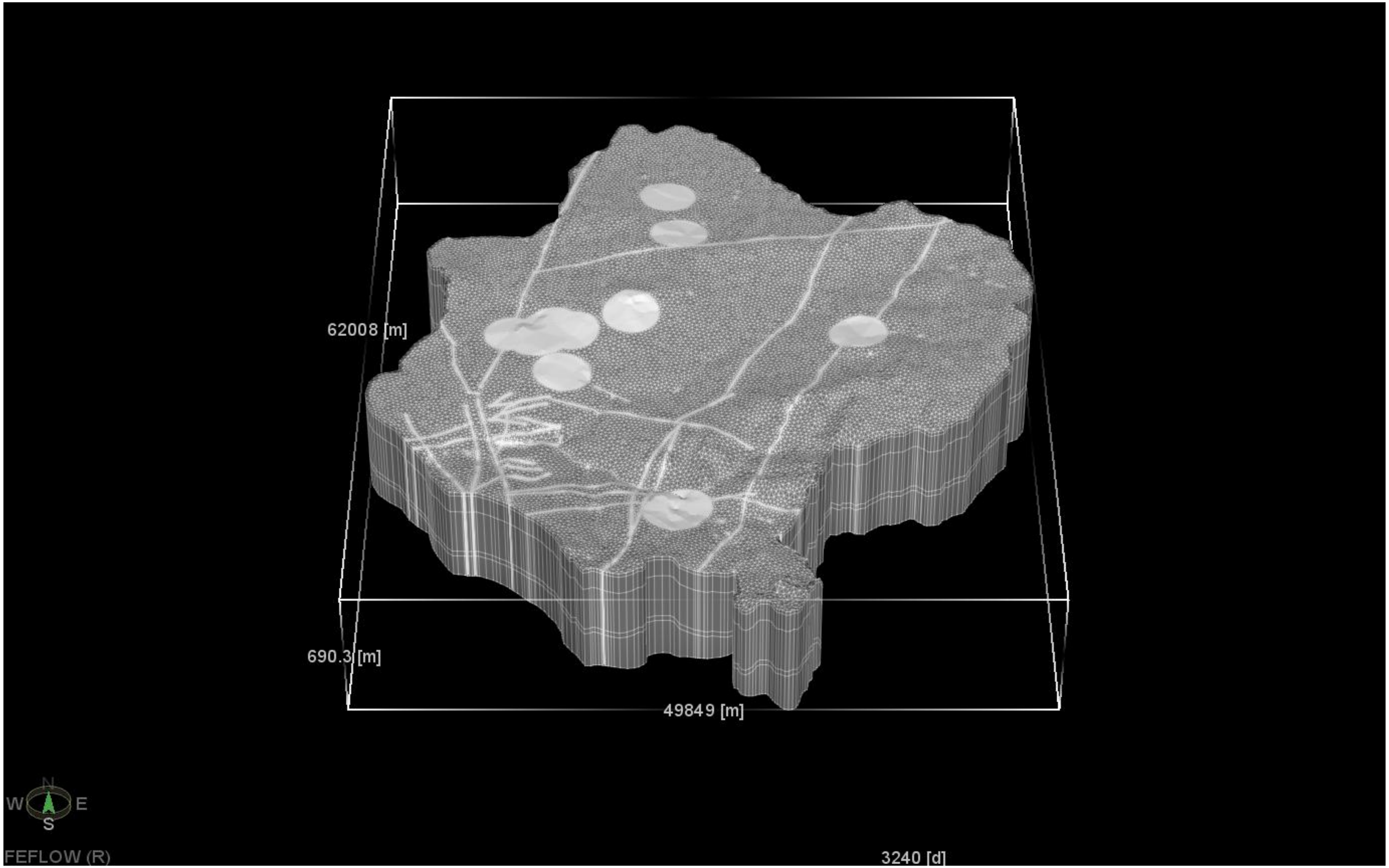


Figure 13-5 **Model domain 3-D FEM mesh depicting a plan view and cross sectional view in a south-north orientation.**

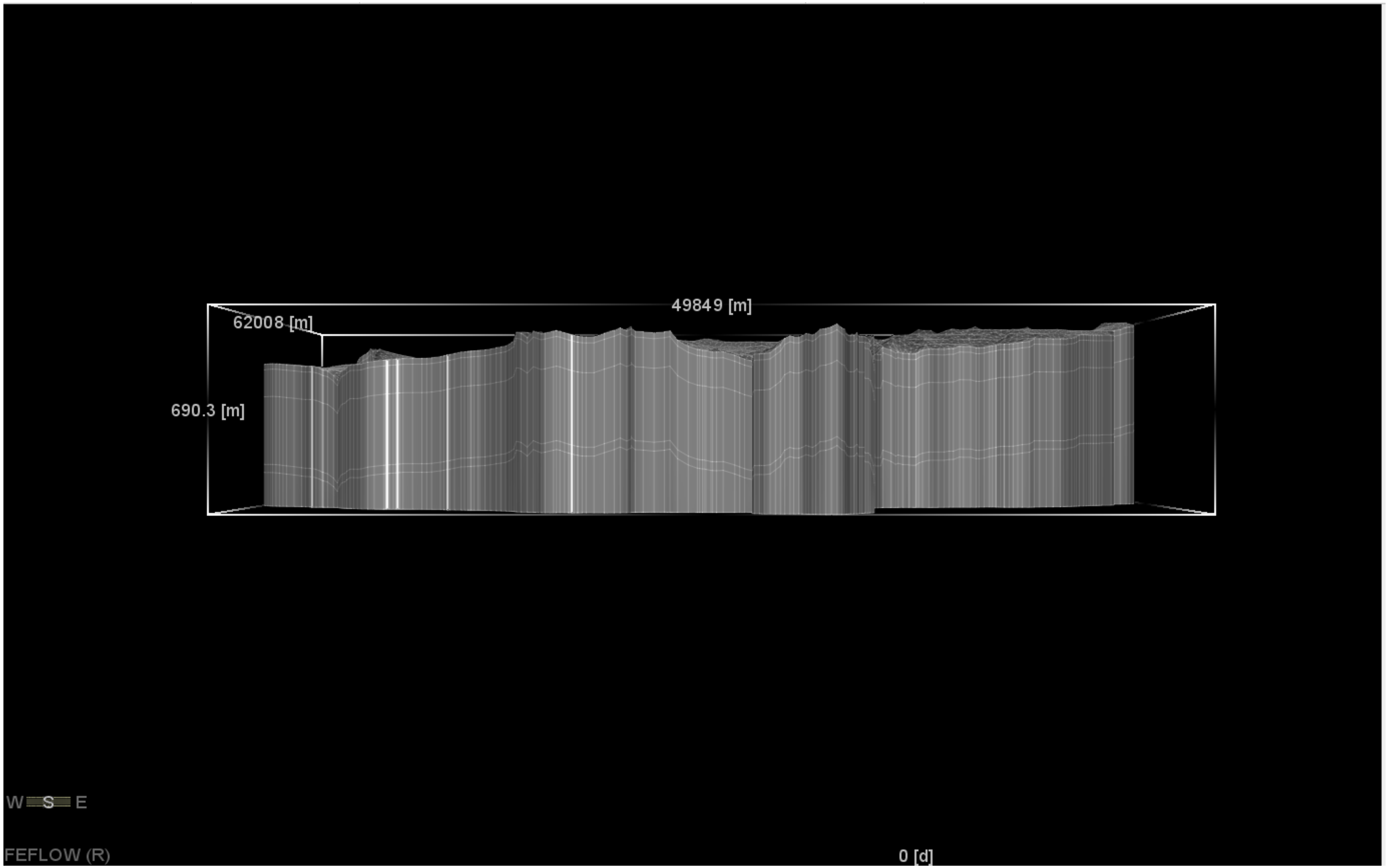


Figure 13-6 **Model domain 3-D FEM mesh view depicting a cross sectinal view in a south-north orientation.**

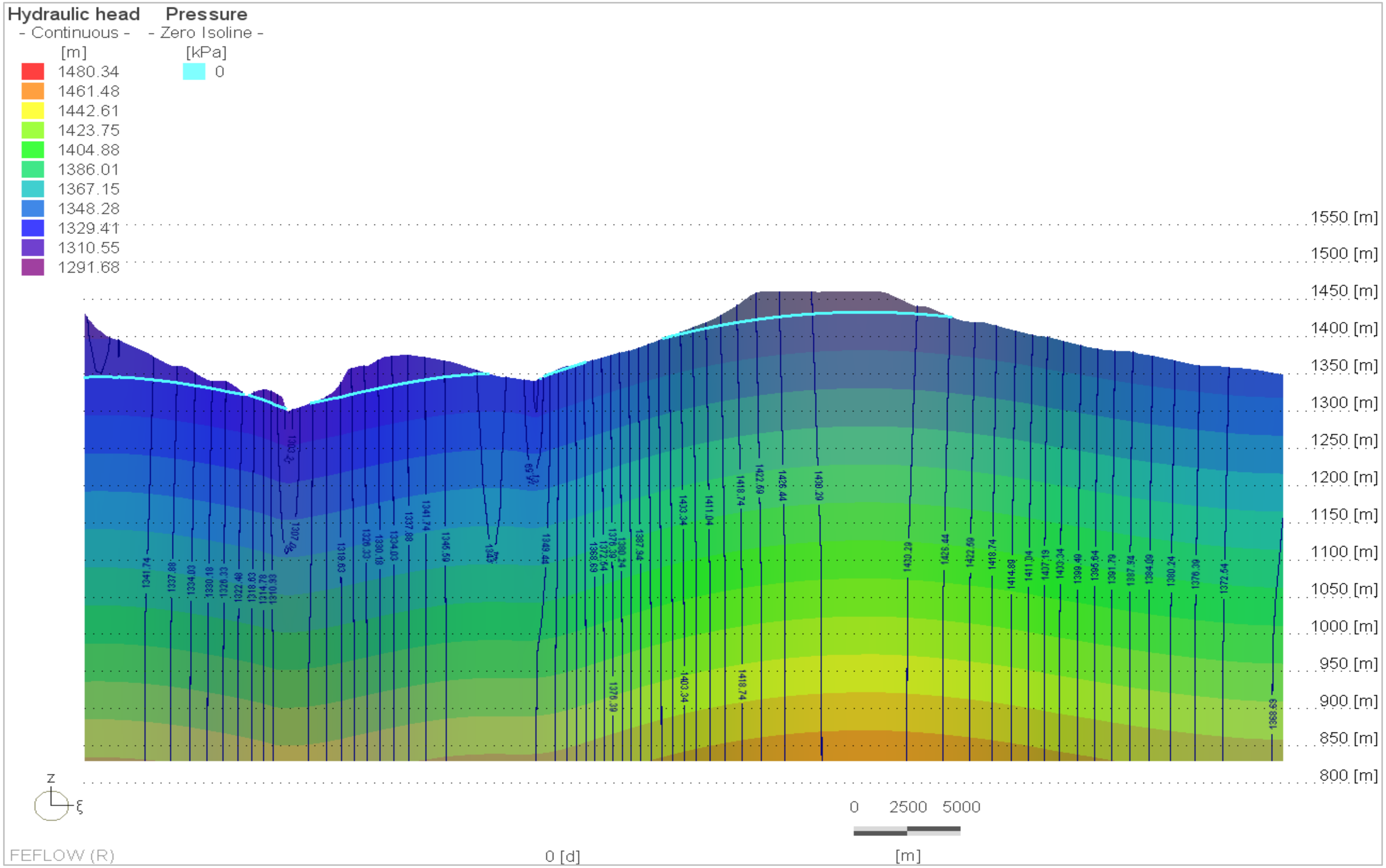


Figure 13-7 **Model domain 3-D FEM mesh view (cross sectional view southwest-northeast orientation of conceptual slice A-A').**

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 is 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, Sandspruit, Ritspruit as well as the Erasmusspruit were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[9]. **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 values[10] 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 $1.47E^{-01}$m/d ranging from $2.00E^{-00}$m/d for loose alluvial deposit sediments associated with local drainages, $1.80E^{-01}$m/d for the weathered Beaufort Group formations, $2.50E^{-01}$m/d for the weathered Ecca Group formations, $1.00E^{-02}$m/d for the more competent Karoo dolerite formations to $1.00E^{00}$m/d for the more permeable geological lineaments[11] traversing the study area. The average hydraulic conductivity for the deeper, fractured aquifer is calculated at $9.00E^{-02}$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.

[9] Refer to “gaining stream” assumption.

[10] 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.

[11] 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 formations, ~14.0mm/a assigned for Ecca Group formations 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. Also refer to Section 6.5.4 of this report.

13.4.3. Storativity and specific storage

Specific storage values were assigned per hydrostratigraphical units and ranges between $1.00E^{-06}$ for denser Karoo dolerite formations to $1.00E^{-02}$ 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), 1.0-3.0% (Weathered Beaufort Group and Ecca Group aquifer) 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} m^2/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

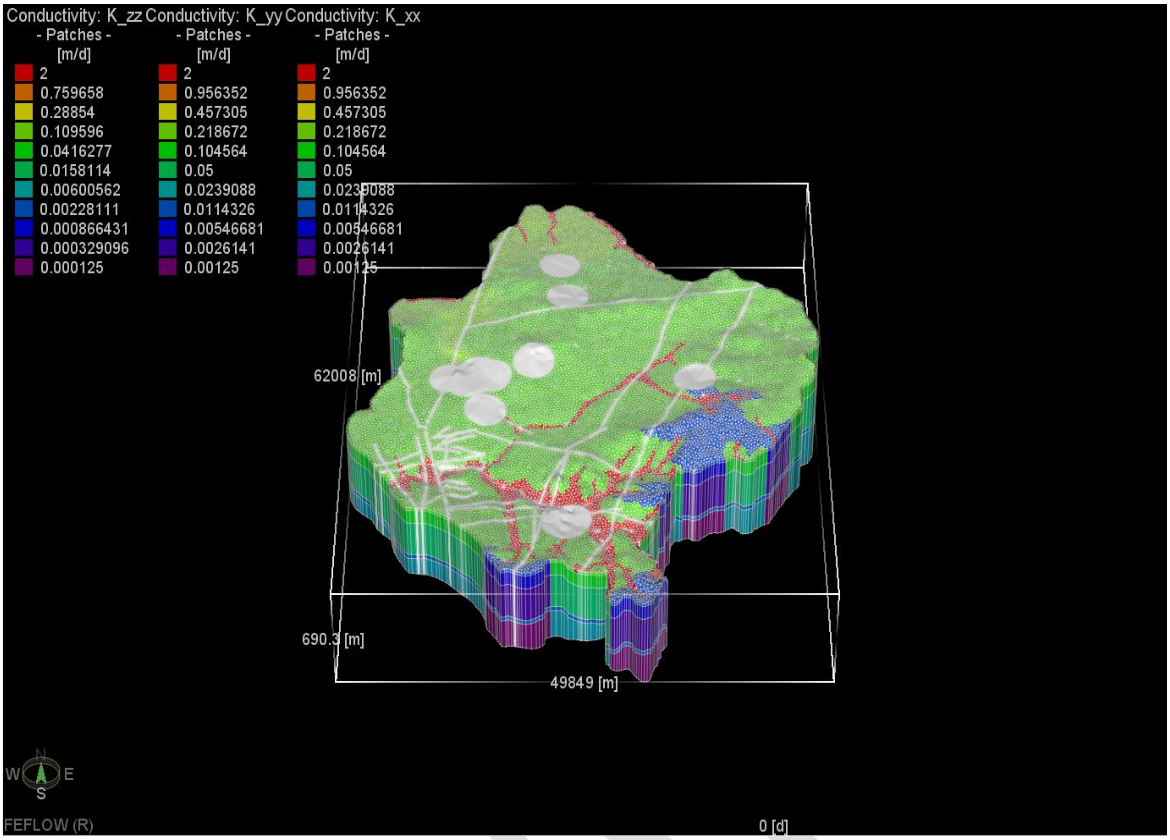


Figure 13-8 **Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.**

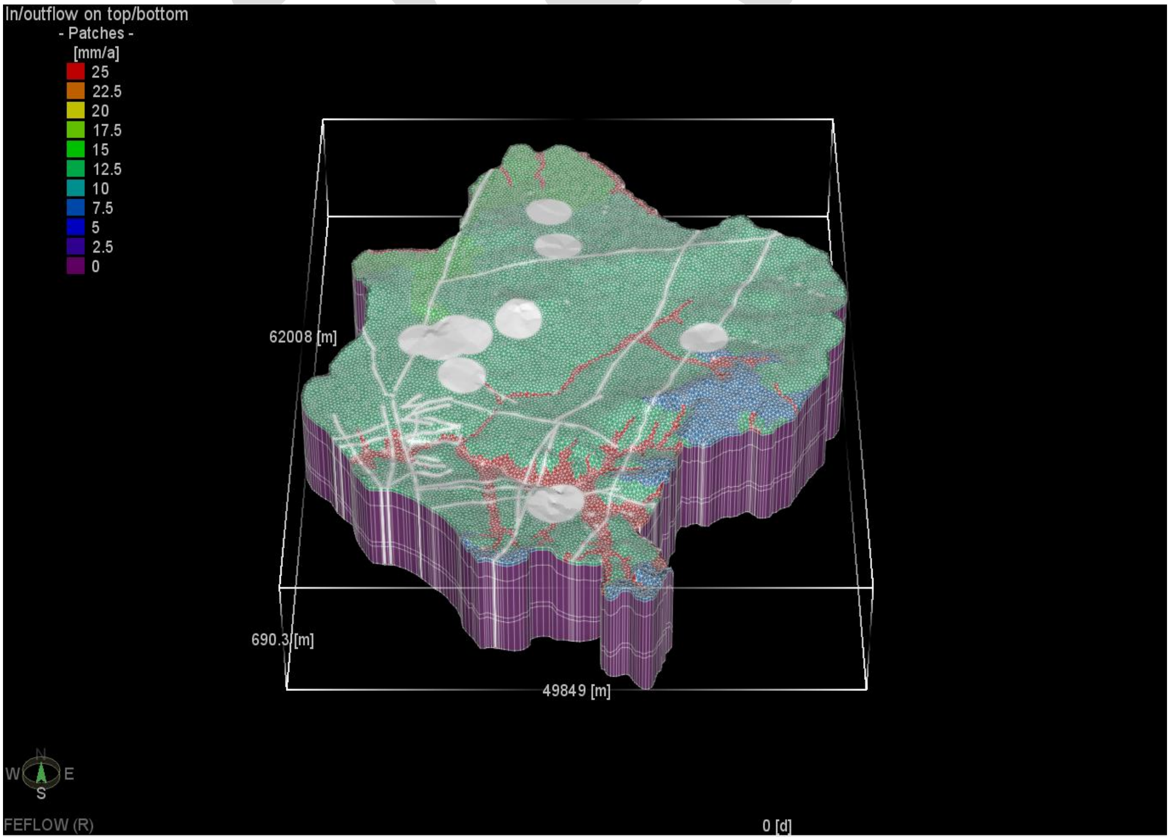


Figure 13-9 **Model development: Numerical groundwater flow model: Recharge distribution.**

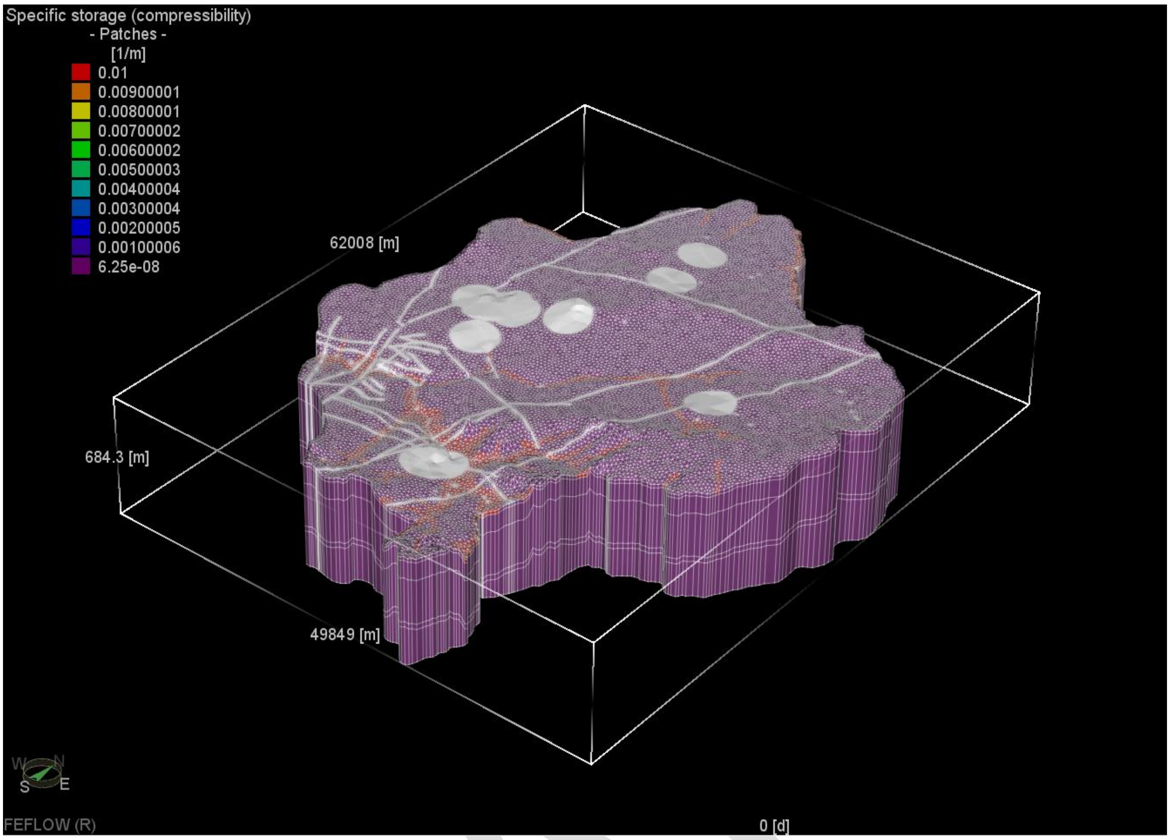


Figure 13-10 **Model development: Numerical groundwater flow model: Specific storage distribution.**

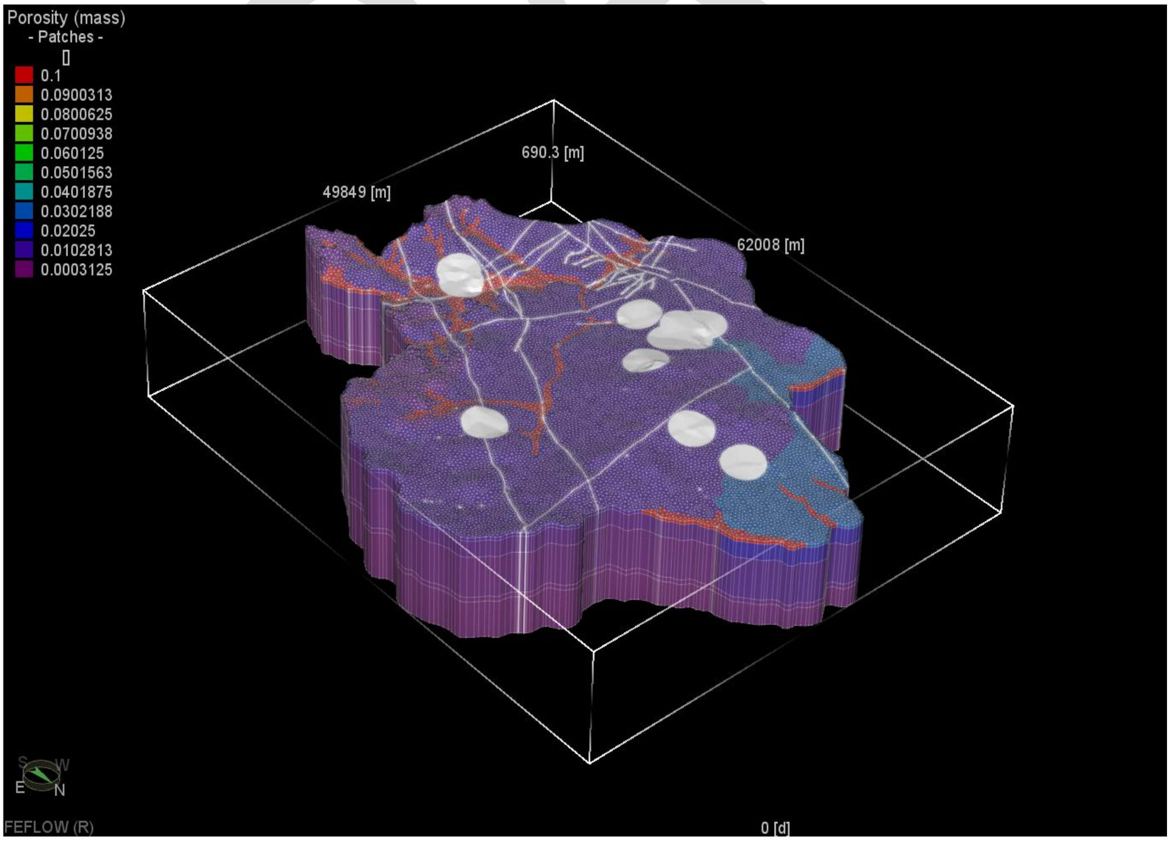


Figure 13-11 **Model development: Numerical groundwater flow model: Porosity distribution.**

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

Model Layer	Hydrostratigraphic unit	Approximate layer thickness (m)	Hydraulic Conductivity (K)		Recharge (Re)	Specific storage (Sc)	Porosity (n)
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)	In/Outflow on top/bottom (mm/a)	Sc (1/m)	
Layer 01	Alluvial deposits	20.00	2.00E+00	2.00E+00	25.0	1.00E-02	1.00E-01
	Volksrust Fm, Ecca Grp		2.50E-01	2.50E-02	14.0	1.00E-04	3.00E-02
	Adelaide Sbgrp, Beaufort Grp		1.80E-01	1.80E-02	12.0	1.00E-05	1.00E-02
	Karoo Dolerite Suite		1.00E-02	1.00E-03	8.0	1.00E-06	5.00E-03
	Geological lineaments		1.00E+00	1.00E-01	18.0	1.00E-03	7.50E-02
Layer 02	Volksrust Fm, Ecca Grp	100.00	1.25E-01	1.25E-02	0.0	5.00E-05	1.50E-02
	Adelaide Sbgrp, Beaufort Grp		9.00E-02	9.00E-03		5.00E-06	5.00E-03
	Karoo Dolerite Suite		5.00E-03	5.00E-04		5.00E-07	2.50E-03
	Geological lineaments		5.00E-01	5.00E-02		5.00E-04	3.75E-02
Layer 03	Volksrust Fm, Ecca Grp	250.00	6.25E-02	6.25E-03	0.0	2.50E-05	7.50E-03
	Adelaide Sbgrp, Beaufort Grp		4.50E-02	4.50E-03		2.50E-06	2.50E-03
	Karoo Dolerite Suite		2.50E-03	2.50E-04		2.50E-07	1.25E-03
	Geological lineaments		2.50E-01	2.50E-02		2.50E-04	1.88E-02
Layer 04	Karoo Dolerite Suite (Sill)	30.00	1.00E-02	1.00E-03	0.0	1.25E-06	6.25E-04
Layer 06	Witwatersrand Supergroup Quartzite	150.00	1.25E-03	1.25E-04	0.0	1.25E-07	6.25E-05

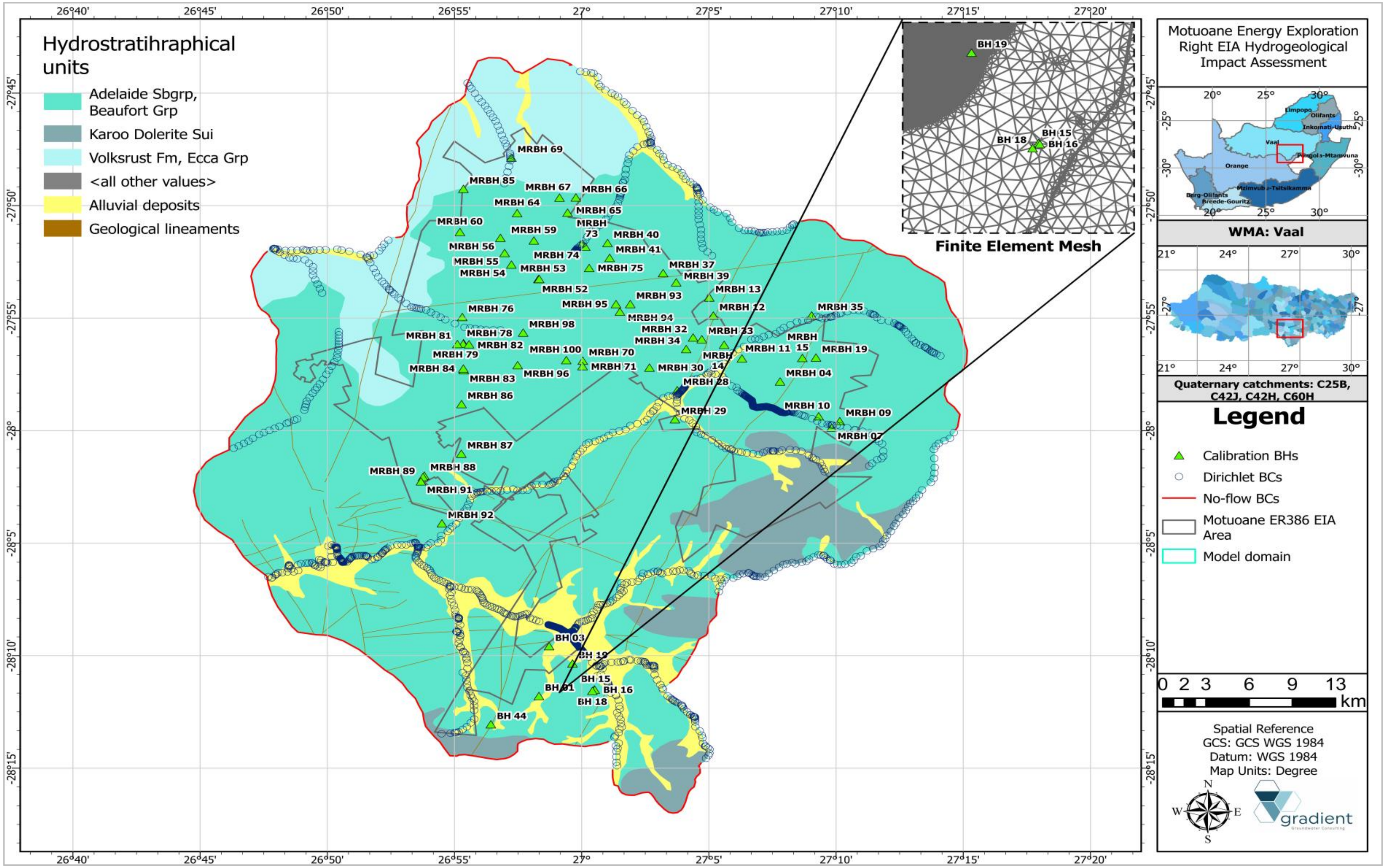


Figure 13-12 **Hydrostratigraphic units and model boundary conditions.**

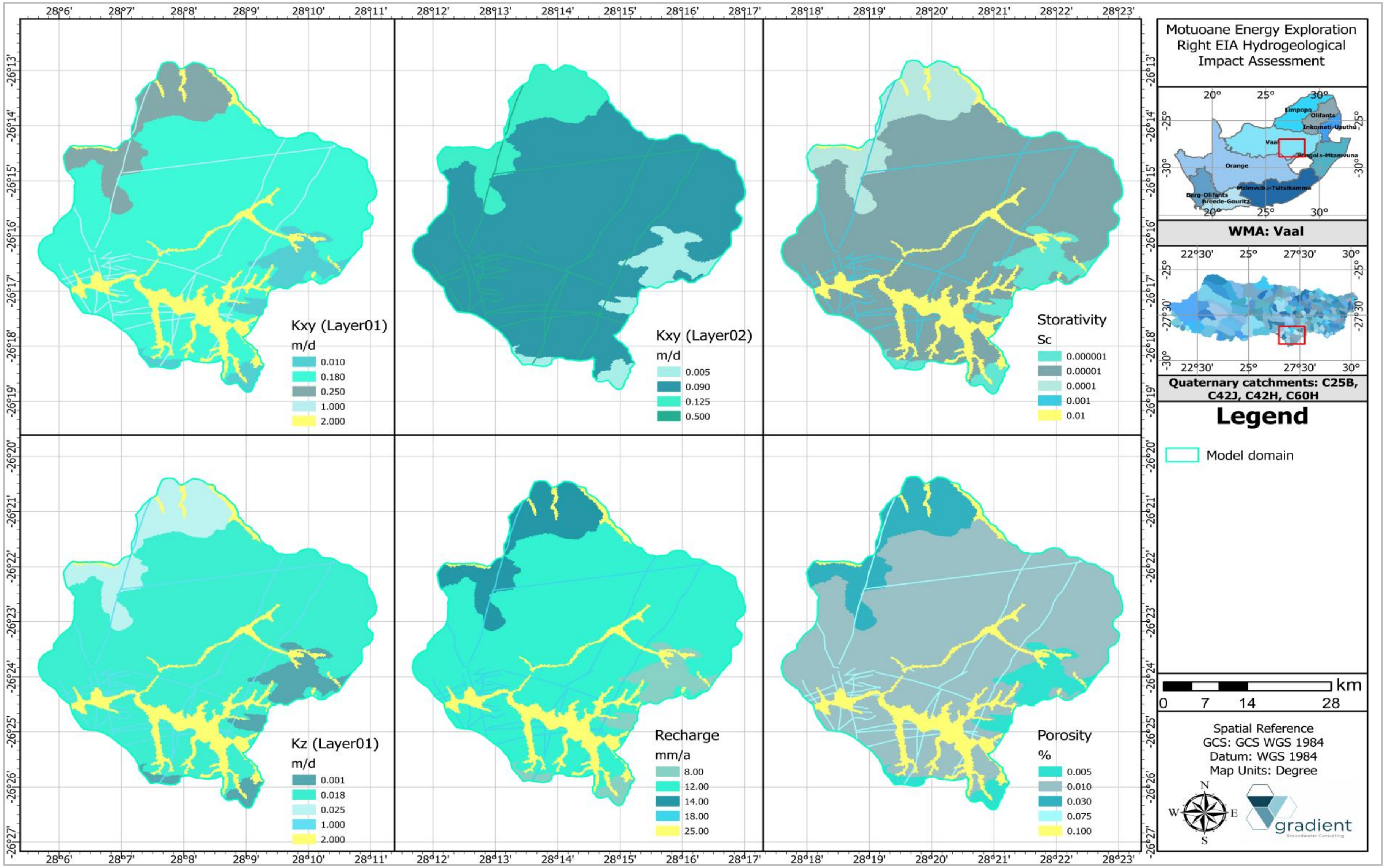


Figure 13-13 **Numerical groundwater flow model: Hydraulic properties.**

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 ~0.94 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): 1.12m.

ii. Mean Absolute Error (MAE): 9.64m.

iii. Normalised Root Mean Square Deviation (NRMSD): 9.17% 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	1341.79	23.79	23.79	565.87
BH 03	1324.83	0.16	1324.67	1319.32	5.35	5.35	28.64
BH 15	1340.47	10.39	1330.08	1325.30	4.78	4.78	22.90
BH 16	1340.46	5.04	1335.42	1325.26	10.16	10.16	103.21
BH 18	1342.23	11.01	1331.22	1326.59	4.63	4.63	21.48
BH 19	1328.26	2.70	1325.56	1322.31	3.25	3.25	10.60
BH 44	1389.94	9.53	1380.41	1354.37	26.04	26.04	678.19
MRBH 04	1420.71	0.92	1419.79	1419.60	0.19	0.19	0.04
MRBH 07	1435.99	11.56	1424.43	1437.03	-12.60	12.60	158.68
MRBH 09	1439.84	1.51	1438.33	1439.92	-1.59	1.59	2.52
MRBH 10	1426.62	4.11	1422.51	1430.25	-7.74	7.74	59.85
MRBH 11	1399.31	12.81	1386.50	1401.91	-15.41	15.41	237.31
MRBH 12	1419.97	0.82	1419.15	1422.57	-3.42	3.42	11.71
MRBH 13	1439.65	9.45	1430.20	1427.90	2.31	2.31	5.31
MRBH 14	1399.07	0.50	1398.57	1407.21	-8.64	8.64	74.62
MRBH 15	1406.77	2.60	1404.17	1423.30	-19.13	19.13	365.84
MRBH 19	1416.61	2.80	1413.81	1427.38	-13.57	13.57	184.01

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)
MRBH 28	1380.75	3.71	1377.04	1382.59	-5.55	5.55	30.78
MRBH 29	1387.42	17.85	1369.57	1387.89	-18.32	18.32	335.70
MRBH 30	1398.65	8.06	1390.59	1407.84	-17.25	17.25	297.42
MRBH 32	1404.46	0.72	1403.74	1416.02	-12.28	12.28	150.87
MRBH 33	1401.28	1.49	1399.79	1413.78	-13.99	13.99	195.69
MRBH 34	1398.73	0.87	1397.86	1410.92	-13.05	13.05	170.43
MRBH 35	1402.79	4.48	1398.31	1411.61	-13.30	13.30	176.89
MRBH 37	1453.50	6.46	1447.04	1429.72	17.32	17.32	299.91
MRBH 39	1460.54	3.55	1456.99	1430.18	26.82	26.82	719.04
MRBH 40	1415.26	1.60	1413.66	1420.58	-6.92	6.92	47.89
MRBH 41	1423.68	2.46	1421.22	1426.62	-5.40	5.40	29.12
MRBH 52	1451.19	1.37	1449.82	1431.28	18.54	18.54	343.69
MRBH 53	1451.26	0.78	1450.48	1431.31	19.17	19.17	367.49
MRBH 54	1440.00	1.67	1438.33	1427.77	10.56	10.56	111.60
MRBH 55	1440.00	2.69	1437.31	1425.65	11.66	11.66	136.00
MRBH 56	1449.96	4.09	1445.87	1422.84	23.03	23.03	530.43
MRBH 59	1423.42	0.73	1422.69	1424.46	-1.77	1.77	3.14
MRBH 60	1434.80	6.24	1428.56	1417.43	11.13	11.13	123.92
MRBH 64	1418.03	4.17	1413.86	1416.50	-2.64	2.64	6.97
MRBH 65	1407.47	1.86	1405.61	1412.81	-7.20	7.20	51.80
MRBH 66	1399.67	1.07	1398.60	1405.71	-7.11	7.11	50.57
MRBH 67	1399.16	0.63	1398.53	1407.65	-9.12	9.12	83.16
MRBH 69	1380.23	3.97	1376.26	1383.31	-7.05	7.05	49.67
MRBH 70	1426.11	8.72	1417.39	1421.08	-3.69	3.69	13.58
MRBH 71	1423.66	2.67	1420.99	1418.94	2.05	2.05	4.19
MRBH 73	1420.00	4.36	1415.64	1420.32	-4.68	4.68	21.90
MRBH 74	1420.00	1.45	1418.55	1422.00	-3.45	3.45	11.93
MRBH 75	1437.46	0.85	1436.61	1429.67	6.94	6.94	48.15
MRBH 76	1420.04	0.98	1419.06	1417.12	1.94	1.94	3.76
MRBH 78	1421.64	5.62	1416.02	1416.81	-0.79	0.79	0.62
MRBH 79	1421.90	6.10	1415.80	1416.68	-0.88	0.88	0.77
MRBH 81	1419.47	2.99	1416.48	1415.27	1.21	1.21	1.46
MRBH 82	1427.30	9.65	1417.65	1417.98	-0.33	0.33	0.11
MRBH 83	1429.20	11.86	1417.34	1412.97	4.38	4.38	19.14
MRBH 84	1429.60	8.79	1420.81	1413.26	7.55	7.55	57.02
MRBH 85	1399.61	5.28	1394.33	1408.14	-13.81	13.81	190.74
MRBH 86	1400.38	5.21	1395.17	1402.22	-7.05	7.05	49.73
MRBH 87	1360.33	4.72	1355.61	1374.37	-18.76	18.76	351.83
MRBH 88	1363.30	2.85	1360.45	1361.00	-0.55	0.55	0.30
MRBH 89	1363.80	3.16	1360.64	1360.20	0.44	0.44	0.20
MRBH 91	1364.10	3.15	1360.95	1357.33	3.62	3.62	13.13
MRBH 92	1335.26	7.37	1327.89	1325.24	2.65	2.65	7.01
MRBH 93	1459.93	20.27	1439.66	1431.61	8.05	8.05	64.80
MRBH 94	1443.53	1.40	1442.13	1431.35	10.78	10.78	116.23
MRBH 95	1457.83	0.65	1457.18	1432.28	24.90	24.90	620.26
MRBH 96	1454.00	7.00	1447.00	1420.28	26.72	26.72	714.12
MRBH 98	1443.03	0.30	1442.73	1428.06	14.67	14.67	215.30
MRBH 100	1438.75	1.42	1437.33	1422.25	15.08	15.08	227.41
Average	**1409.88**	**4.57**	**1405.32**	**1404.20**	**1.12**	**9.64**	**147.64**
Minimum	**1324.83**	**0.16**	**1324.67**	**1319.32**	**-19.13**	**0.19**	**0.04**
Maximum	**1460.54**	**20.27**	**1457.18**	**1439.92**	**26.82**	**26.82**	**719.04**
Correlation			**0.94**				
∑					**72.71**	**626.75**	**9596.66**
1/n					**1.12**	**9.64**	**147.64**
Root Mean Square Deviation (RMSD)					**1.06**	**3.11**	**12.15**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**9.17**

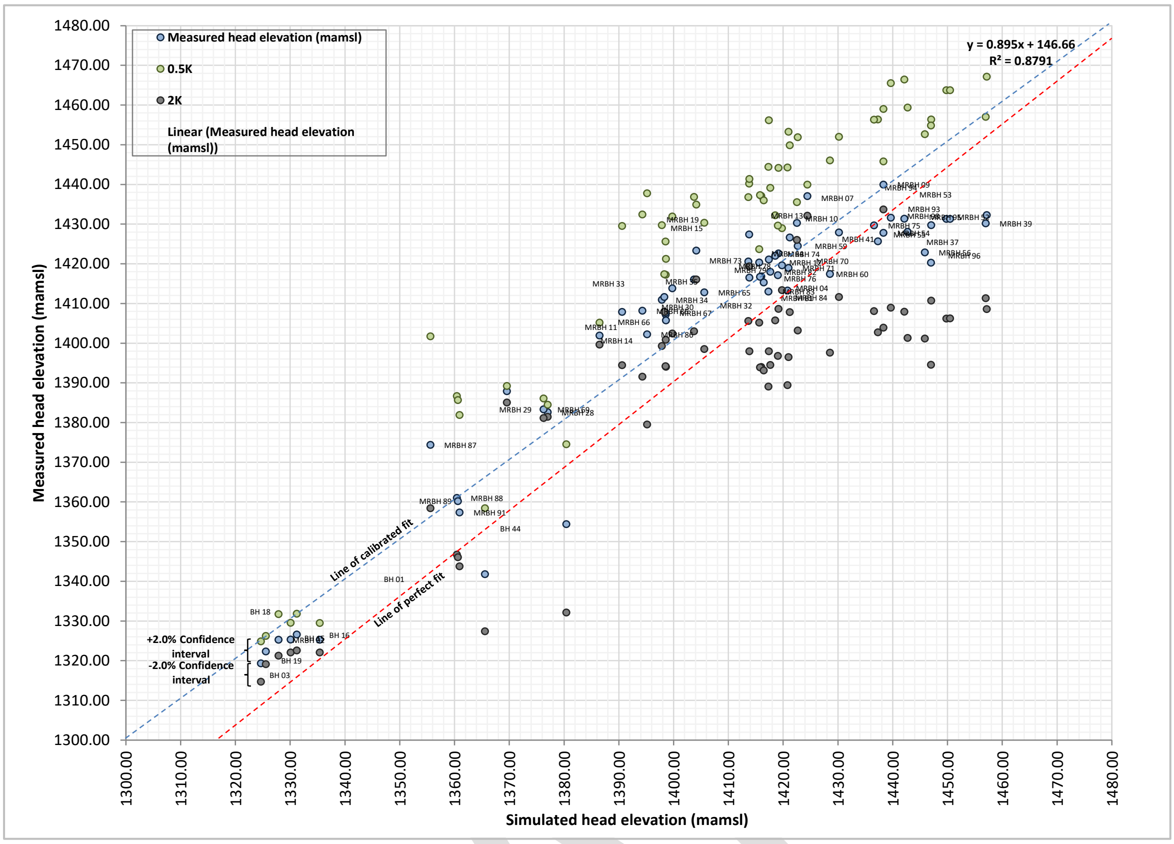


Figure 13-14 **Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.**

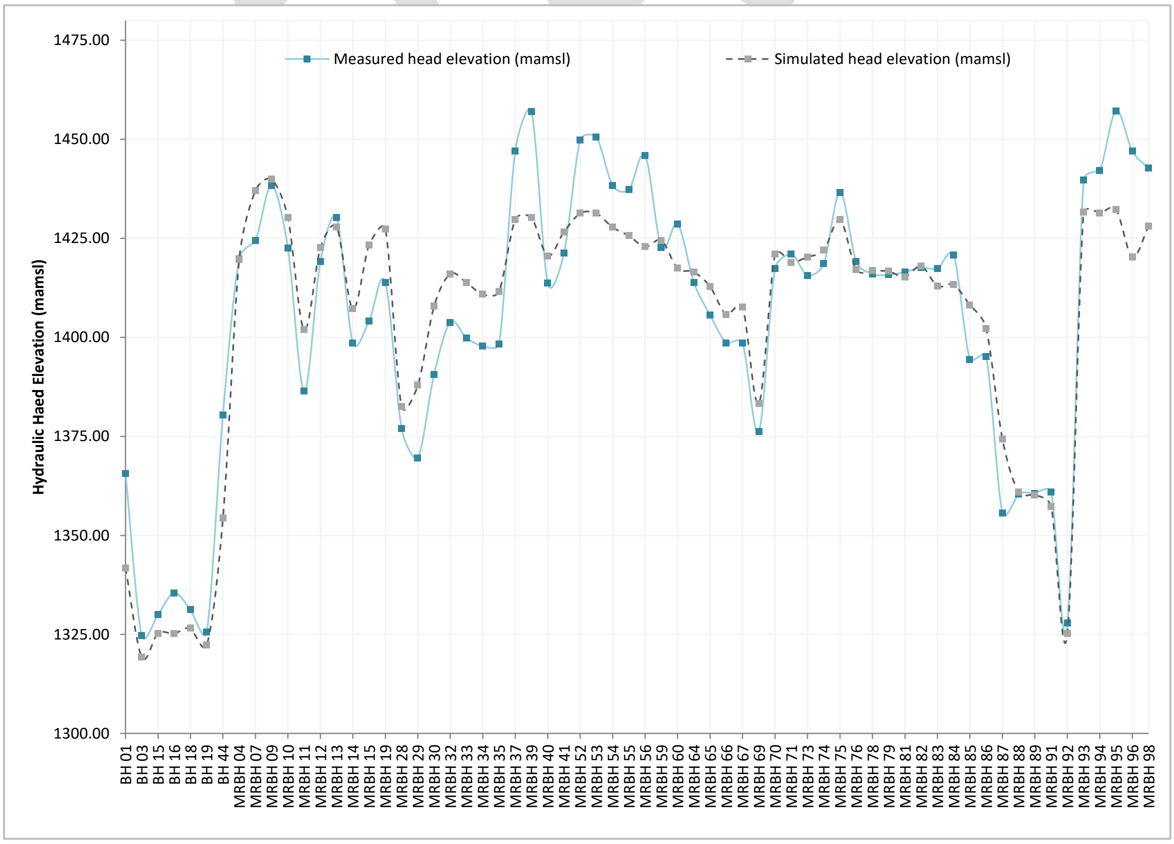


Figure 13-15 **Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.**

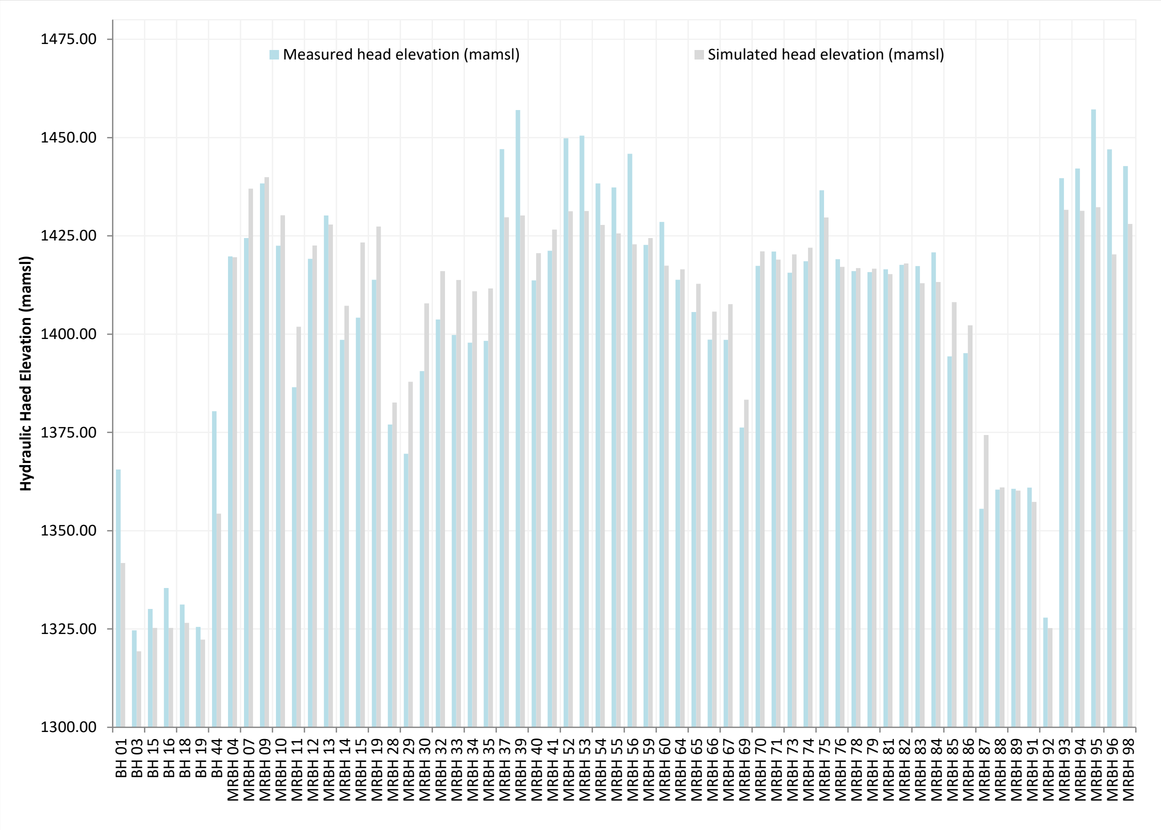


Figure 13-16 **Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.**

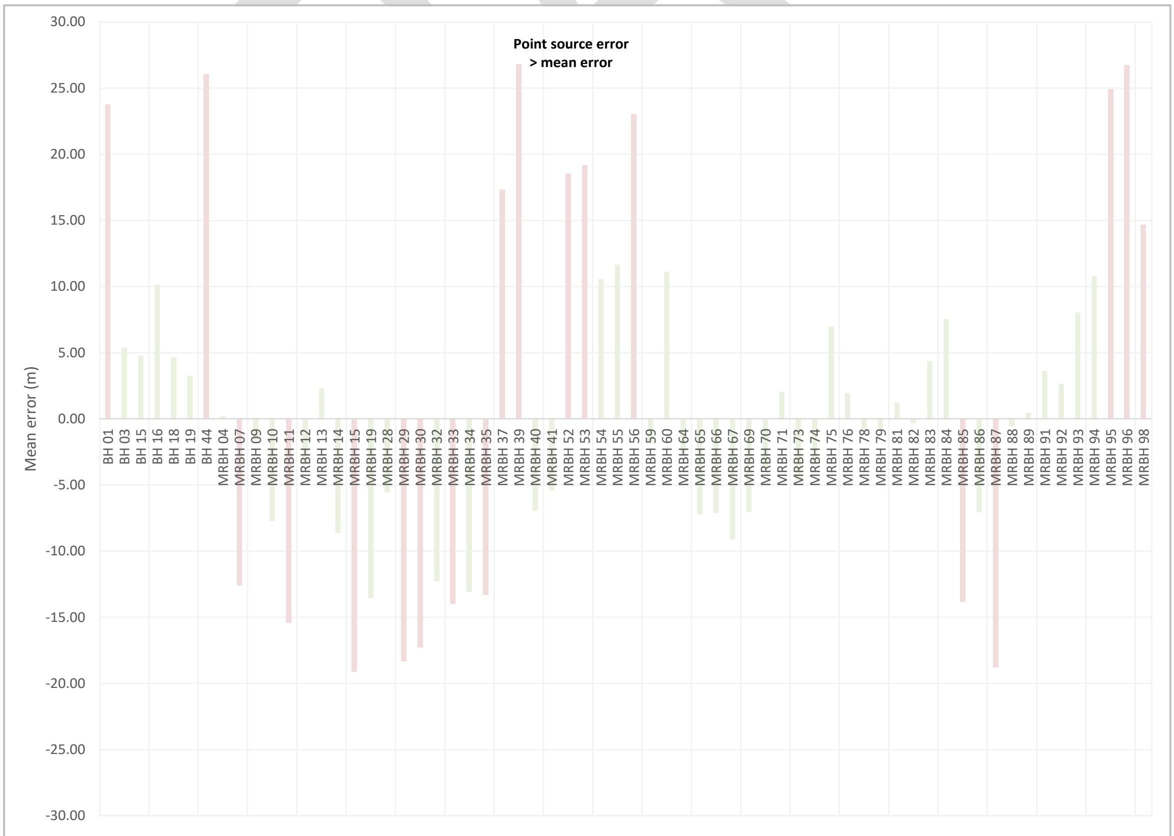


Figure 13-17 **Model steady state calibration: Bar-chart of simulated vs. measured hydraulic head elevation.**

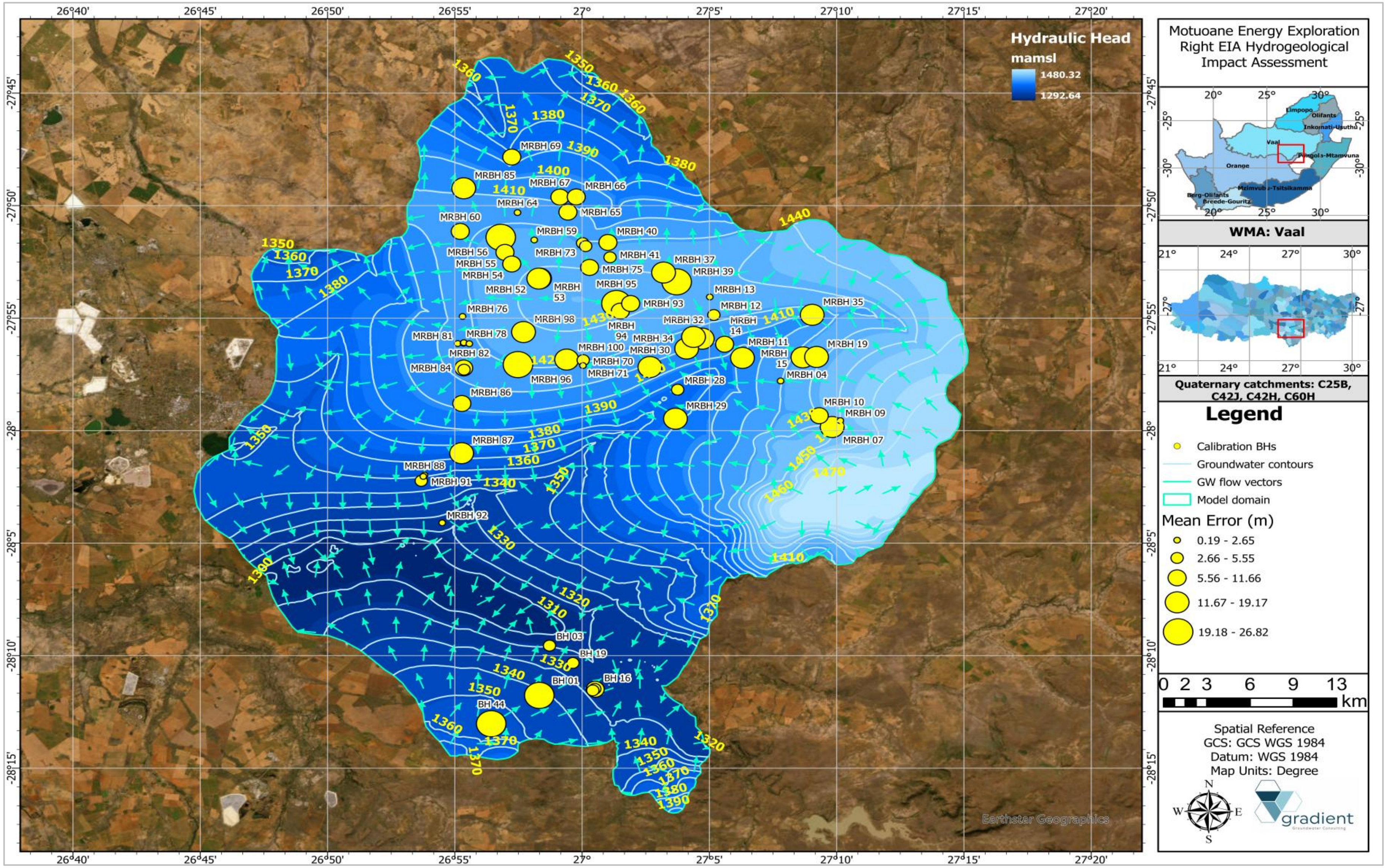


Figure 13-18 **Model calibration: steady state hydraulic heads and groundwater flow direction.**

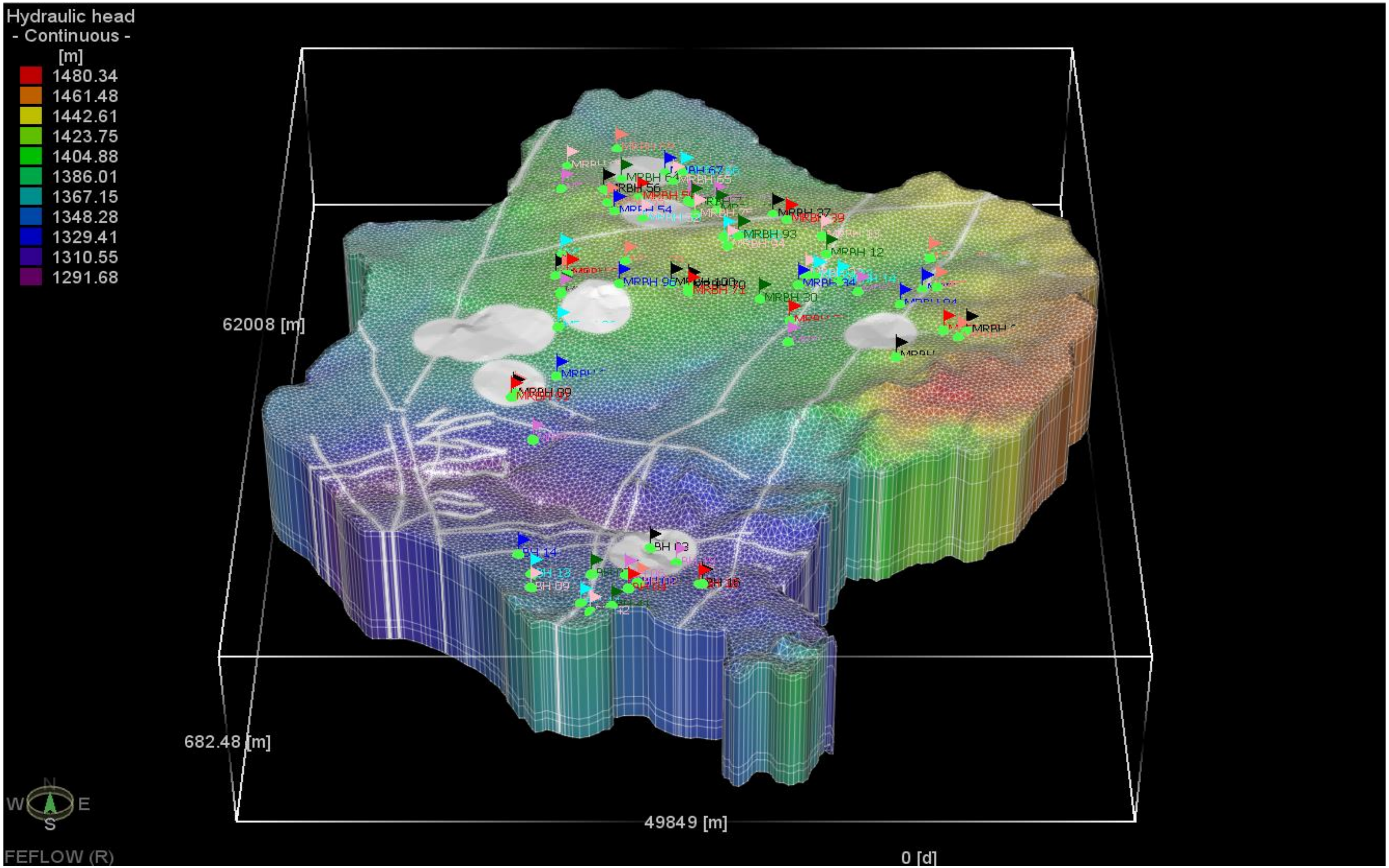


Figure 13-19 Model calibration: steady state hydraulic head distribution.

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 hydraulic conductivity and an increase in recharge as observed in **Figure 13-20**, **Figure 13-21** and **Figure 13-22**[12].

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

Parameter	Scenario: Base Case	Scenario: -50.0% of calibrated K-value	Scenario: +50.0% of calibrated K-value	Scenario: -50.0 of calibrated recharge	Scenario: +50.0% of calibrated recharge
Correlation	0.94	0.95	0.86	0.86	0.95
Mean Error	1.12	-18.59	16.29	16.74	-17.64
Mean Abs Error	9.64	19.19	19.02	19.38	18.33
RMSD	12.15	22.07	23.89	24.32	21.15
NRMSD	9.17%	16.66%	18.03%	18.35%	15.96%

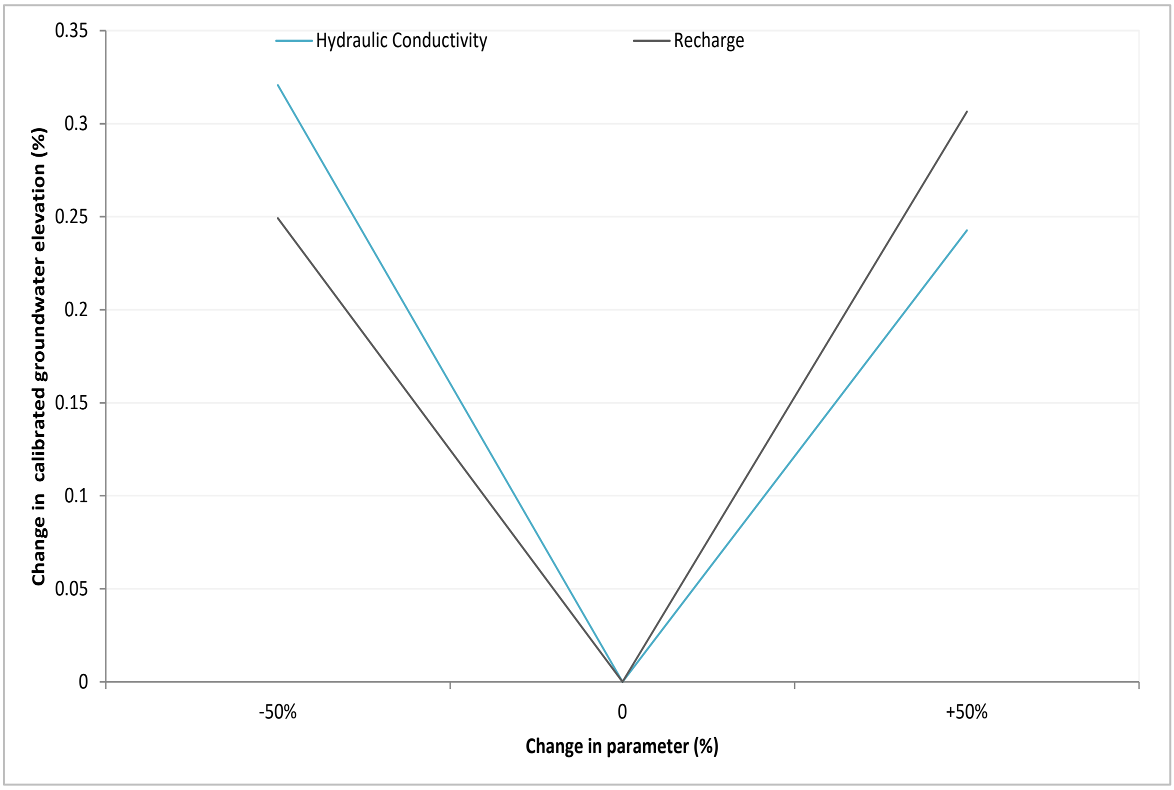


Figure 13-20 Model steady state calibration: sensitivity analysis for monitoring locality BH15.

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

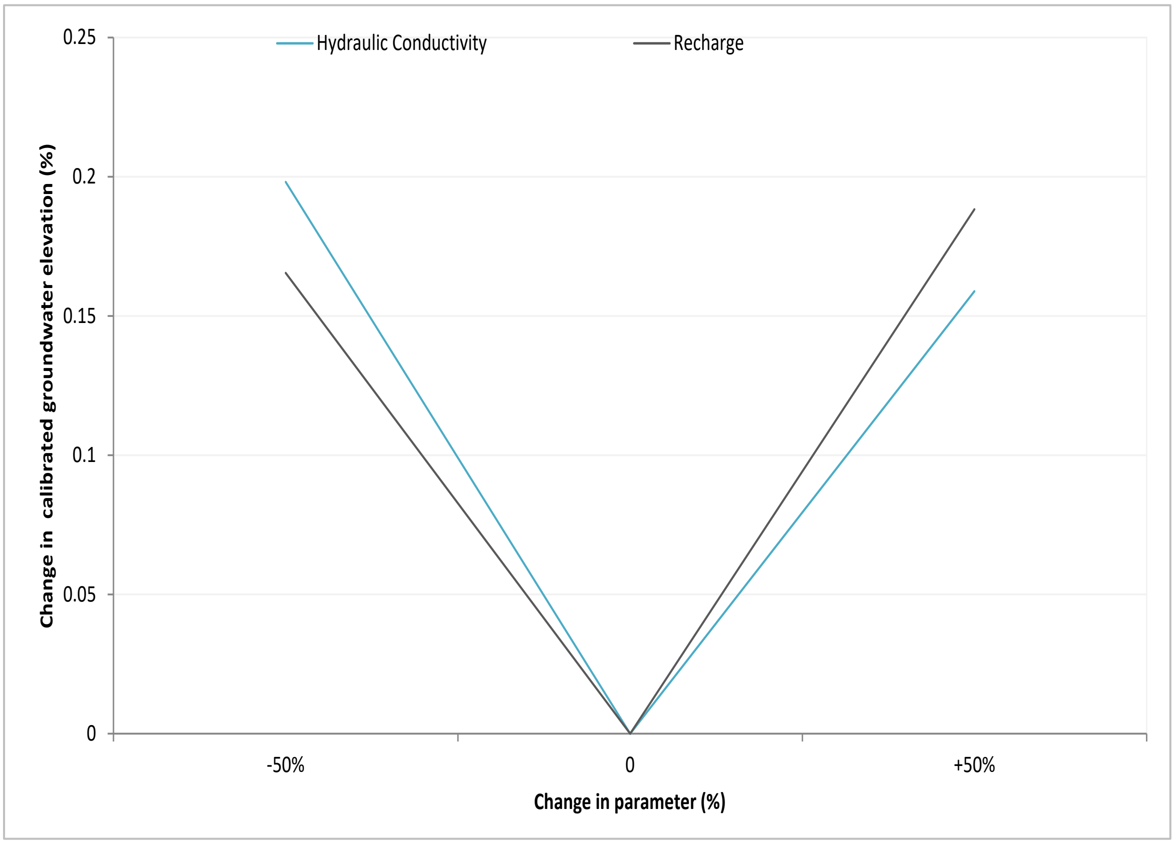


Figure 13-21 Model steady state calibration: sensitivity analysis for monitoring locality MRBH69.

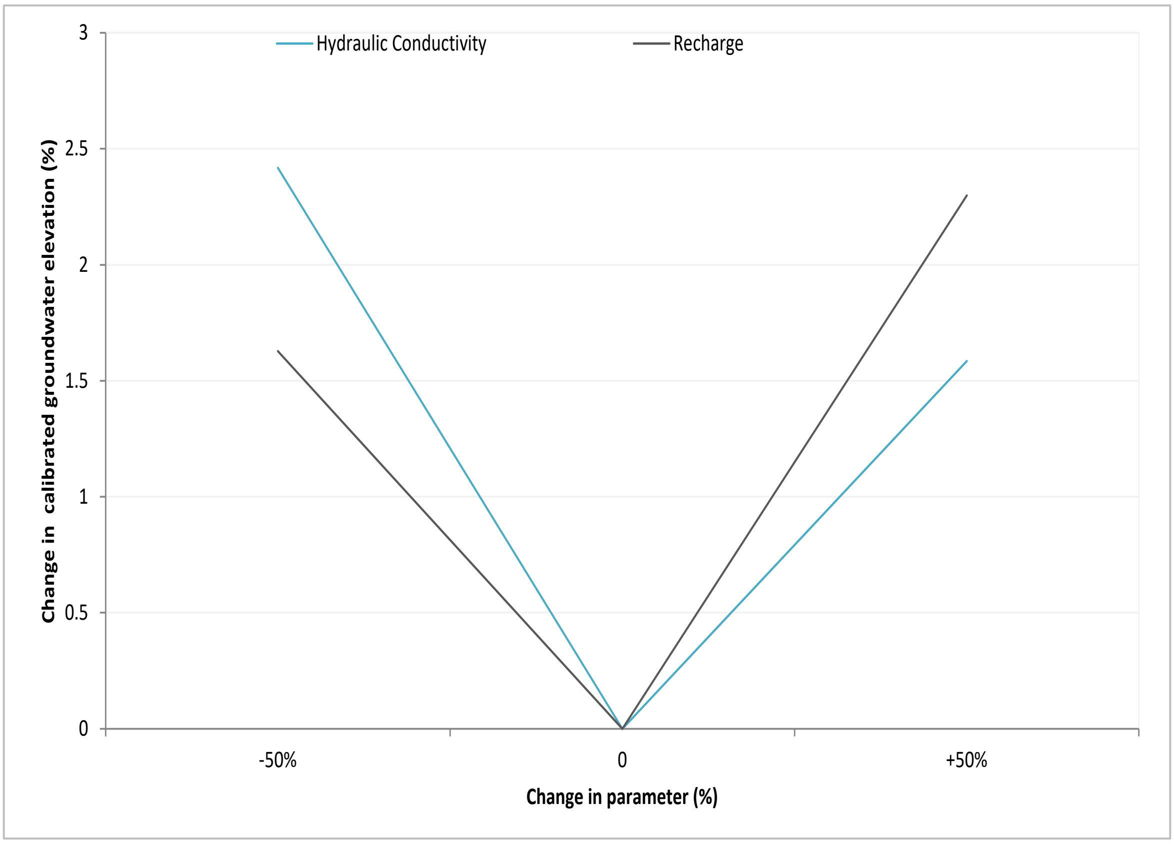


Figure 13-22 Model steady state calibration: sensitivity analysis for monitoring locality MRBH71.

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.

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

where:

h = hydraulic head [L]

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

S = storage coefficient

t = time [T]

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

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

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.

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

where:

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

n = porosity of saturated zone;

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

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

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

$n\rho\Gamma$ = mass of pollutant added to the water (or leaving it) as a result of chemical interactions among species inside the water, or by various decay phenomena[13];

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

p = density of pollutant;

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

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

[13] 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 exploration 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 exploration boreholes. The explorational drilling of gas 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 exploration 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 exploration phase.

iii. **Scenario 03:** Migration of stray methane (CH_4) gas emanating from the exploration zone to the overlying, potable aquifer(s) during the operations gas exploration phase.

iv. **Scenario 03:** Migration of stray methane (CH_4) gas emanating from the exploration zone to the overlying, potable aquifer(s) during the operations gas exploration 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 exploration zone to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios).

Table 13-4 Summary of model stress-periods.

Stress period	Description
Year01 – Year9	Gas exploration operational phase
Year 10 – Year 60	50-years post closure
Year 61 – Year 111	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 $6.37E^{+04}m^3/d$, while the largest loss to the groundwater system is via groundwater contribution to baseflow, $6.36E^{+04}m^3/d$. Water captured as storage equates to $4.63E^{+02}m^3/d$ while water released from storage is calculated as $6.79E^{+04}m^3/d$. The imbalance of the delineated aquifer unit, ignoring internal transfer, is calculated at $1.21E^{+02}m^3/d$.

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)	6.37E+04	0.00E+00	6.37E+04
Dirichlet/ Drain conductance (m^3/d)	0.00E+00	6.36E+04	-6.36E+04
Storage Capture(-)/Release(+)(m^3/d)	4.63E+02	6.79E+02	-2.16E+02
Imbalance ignoring internal transfer (m^3/d)	1.21E+02	0.00E+00	1.21E+02
Total (m^3/d)	**6.43E+04**	**6.43E+04**	**0.00E+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 exploration phase

This scenario summarises the simulated point source pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas exploration boreholes be jeopardised i.e., leaking boreholes for the exploration phase (9-year period).

It should be noted that, due care will be taken to ensure that exploration 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).

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 in a radial pattern from the gas exploration 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 ~100.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~230.0m during the operational exploration 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated 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 exploration boreholes (positioned 50m and 100m from the respective boreholes). It can be observed that the TDS mass load contribution ranges between ~900.0mg/l to approximately 1250.0mg/l, which is slightly above the SANS 241:2015 limits, with the mass load contribution a function of the distance to the source or gas exploration 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 shales.

Figure 13-24 indicates the simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of target area 11 with **Figure 13-25** showing the simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of target areas 1 and 2.

Figure 13-26 indicates the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target areas 10 and 11 while **Figure 13-27** depicts the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the riparian zone aquifer in the vicinity of target areas 1 and 2 for the operational phases.

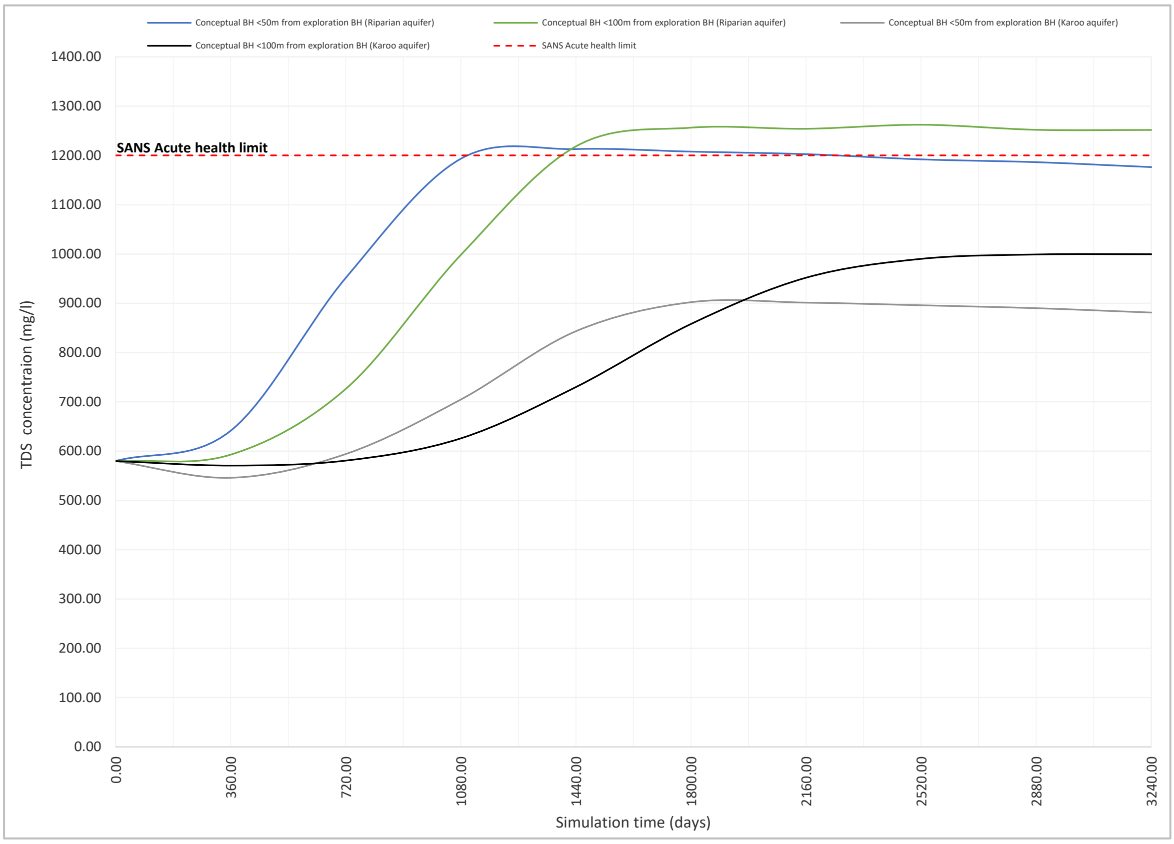


Figure 13-23 **Scenario 02: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Operational phase).**

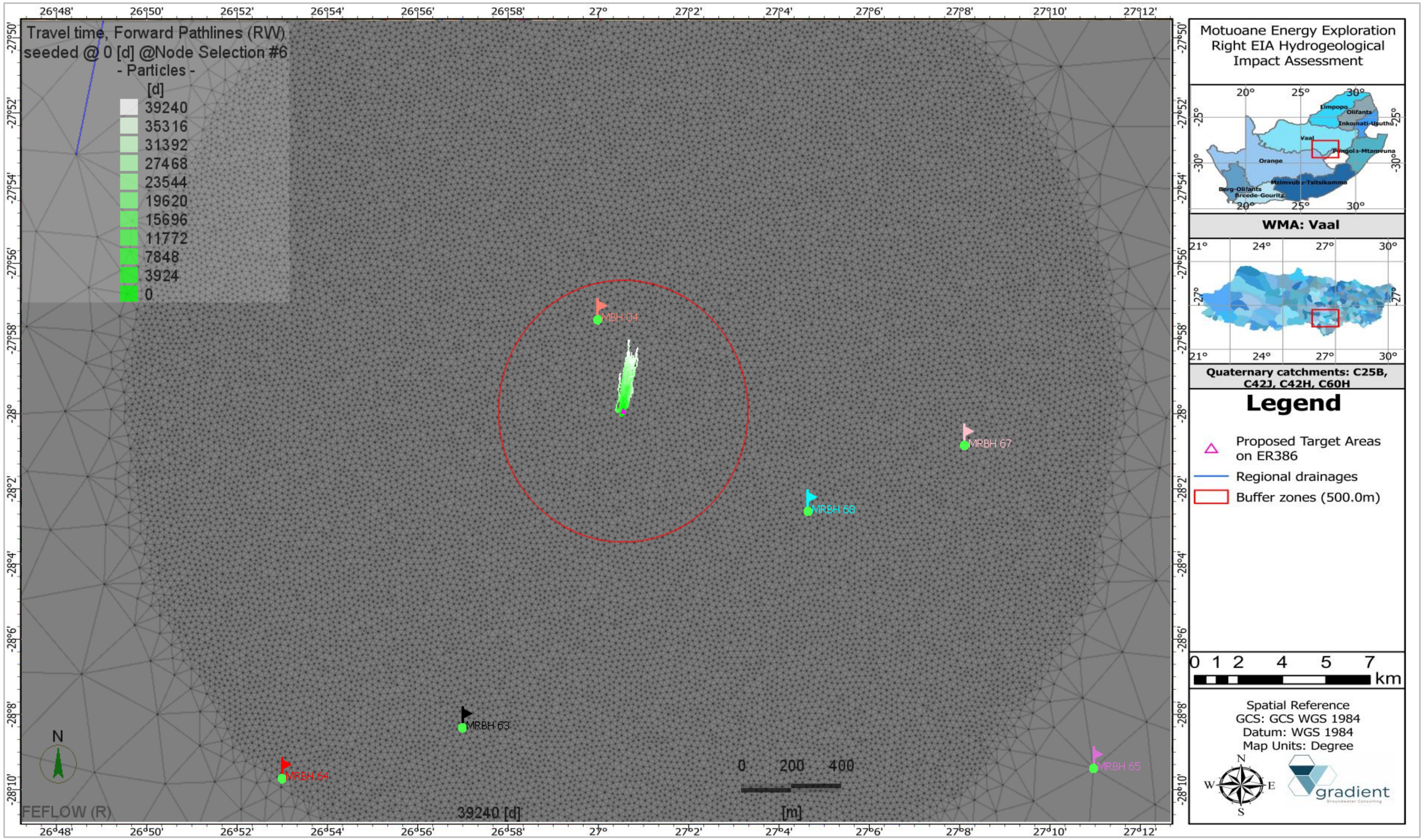


Figure 13-24 **Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the intergranular aquifer in the vicinity of target area 10 (Operational phase).**

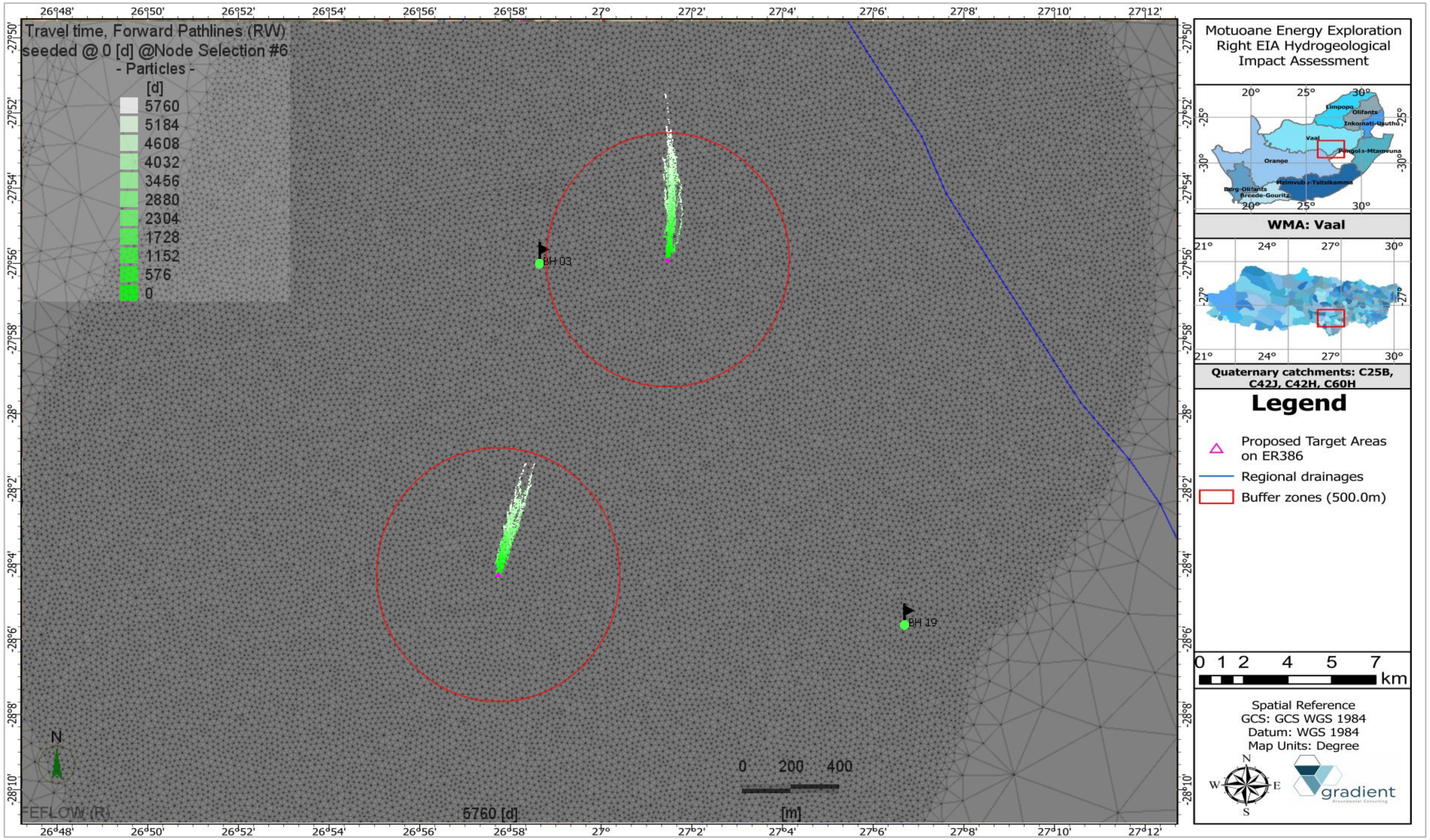


Figure 13-25 **Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating to the riparian zone aquifer in the vicinity of target areas 1 and 2 (Operational phase).**

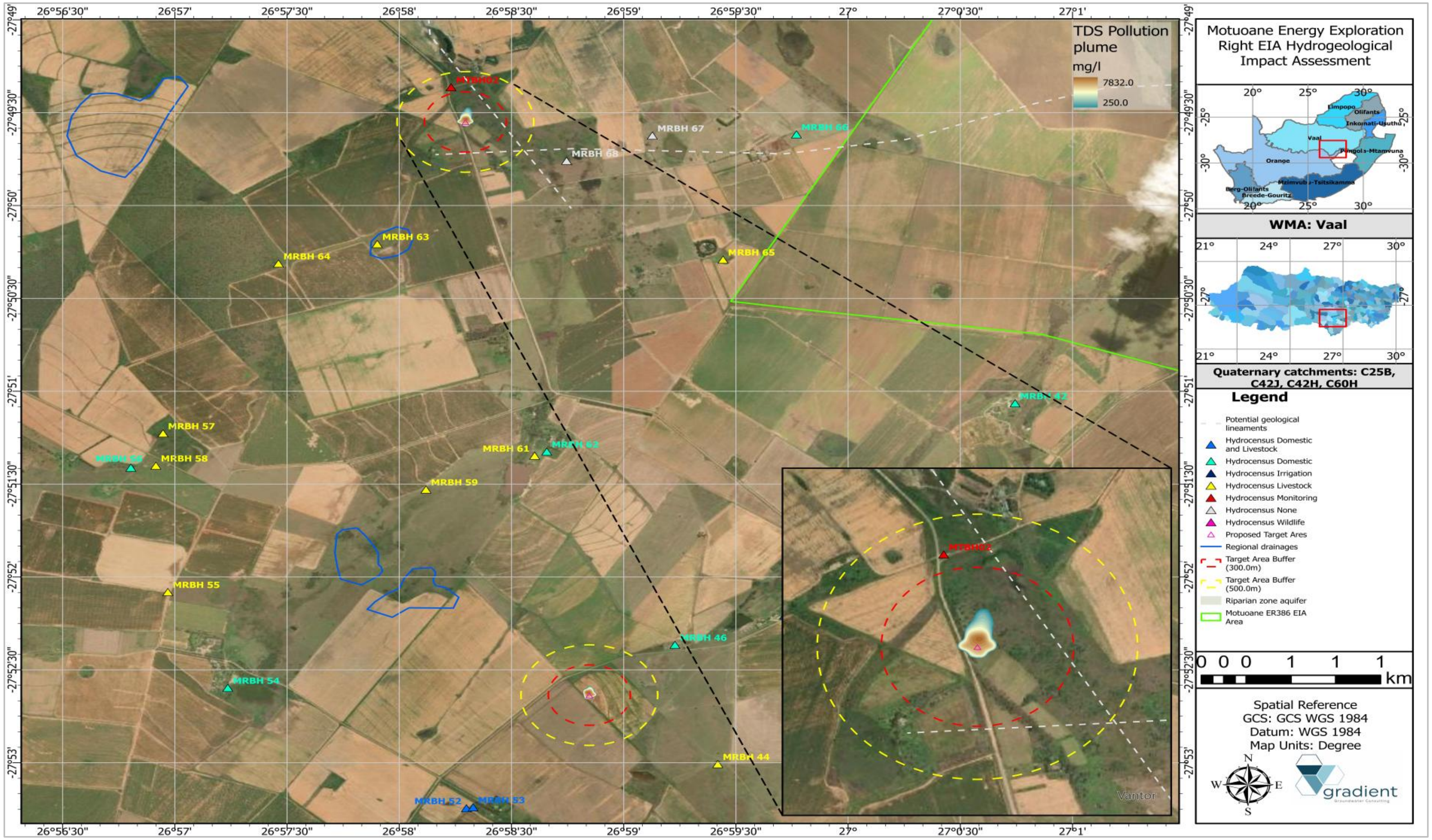


Figure 13-26 **Scenario 02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target areas 10 and 11 (Operational phase).**

Figure 13-27 **ScenarioS 02: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the riparian zone aquifer in the vicinity of target areas 1 and 2 (Operational phase).**

13.7.3. Scenario 03: Migration of stray methane (CH_4) gas emanating from the exploration zone to the overlying, potable aquifer(s) during the operations gas exploration phase

This scenario summarises the simulated point source pollution plume migration of stray methane (CH_4) gas emanating from the exploration zone should the integrity of the gas exploration boreholes be jeopardised after decommissioning.

It should be noted that, due care will be taken to ensure that exploration 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 CH_4 pollution plume will generally mimic topography and will migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system.

It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~90.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~180.0m during the operational exploration 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

Figure 13-28 summarises a time-series graph of the CH_4 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 2.0-3.0mg/l, with the mass load contribution a function of the distance to the source or gas exploration 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 shales.

Figure 13-29 indicates the CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target areas 10 and 11 while Figure 13-30 depicts the CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the riparian zone aquifer in the vicinity of target areas 1 and 2 for the operational phases.

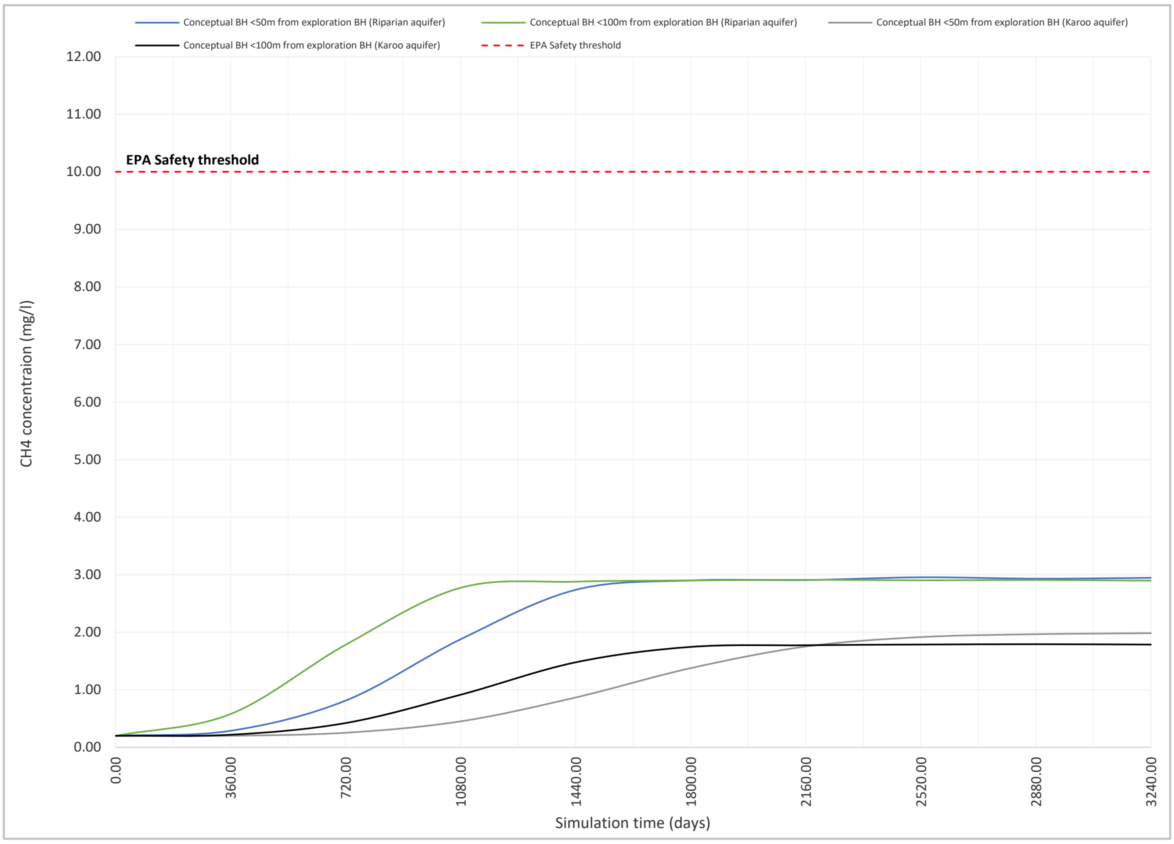


Figure 13-28 **Scenario 03: Time-series graph indicating the CH_4 mass load contribution of the exploration zone on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Operational phase).**

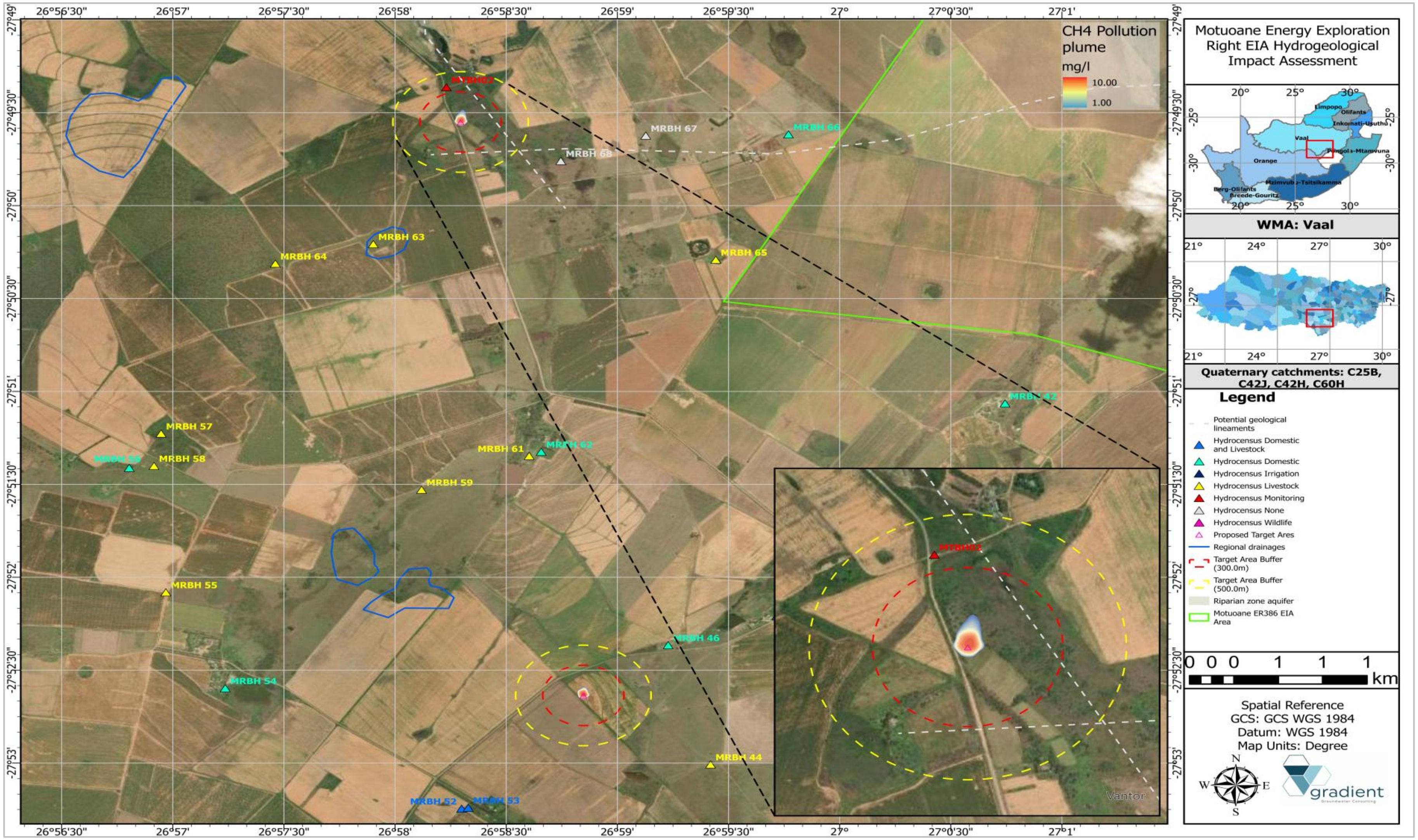


Figure 13-29 **Scenario 03: CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target areas 10 and 11 (Operational phase).**

Figure 13-30 **Scenario 03: CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the riparian zone aquifer in the vicinity of target areas 1 and 2 (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 pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas exploration 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 laying drainage system.

After a simulation period of 100-years, it can be observed that the maximum distance reached is ~450.0m during the post-closure phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation, however salt load contribution to the host aquifer is observed. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

Figure 13-31 depicts a time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targeting the potable shallow, intergranular aquifer for the post-closure phase. It is noted that the TDS load contribution to neighbouring boreholes i.e., BH03, MRBH88, MRBH89 and MRBH90 ranges from ~7.0mg/l to 50.0mg/l.

Figure 13-32 summarises a time-series graph of the TDS mass load contribution to conceptually placed receptors situated in close proximity to simulated gas exploration boreholes (positioned 50m and 100m from the respective boreholes). It can be observed that the TDS mass load contribution remains below the SANS 241:2015 limits ranging between ~950.0mg/l to approximately 600.0mg/l.

Figure 13-33 depicts the TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target area 9 for the post-closure phases.

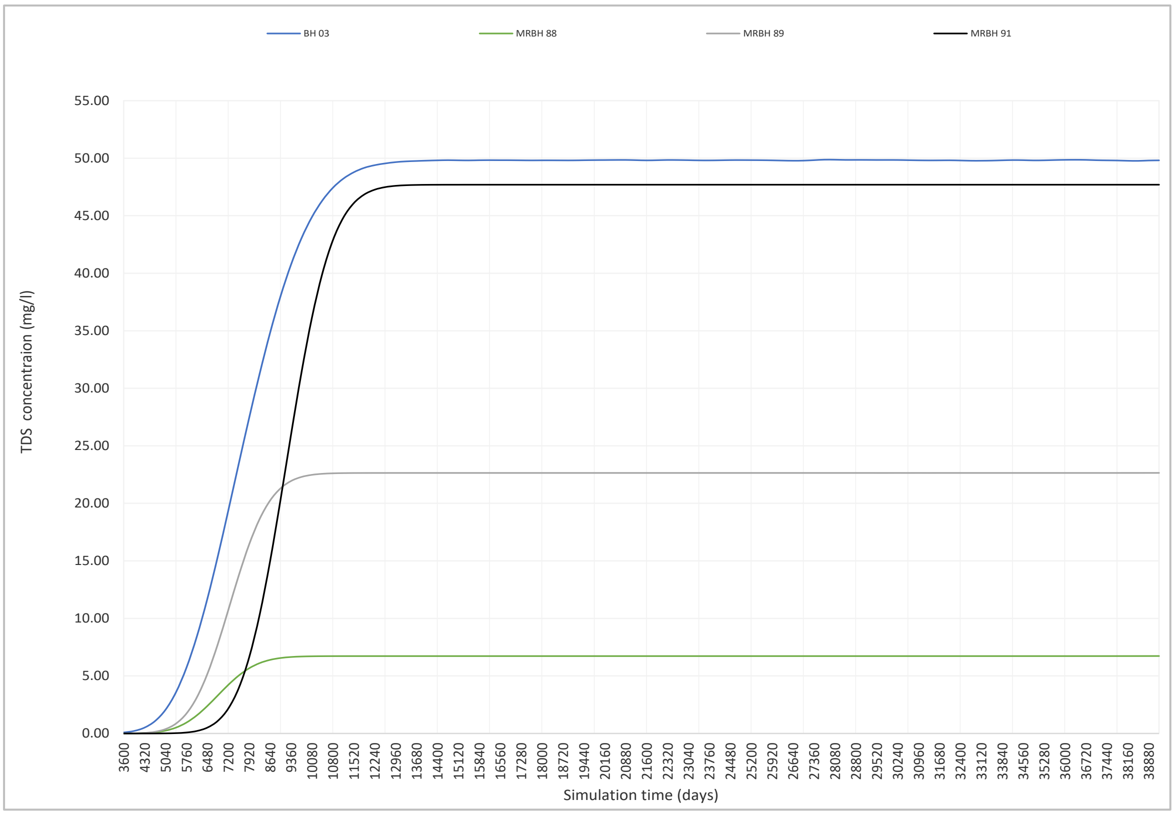


Figure 13-31 **Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targetting the potable shallow, intergranular aquifer (Post-closure phase).**

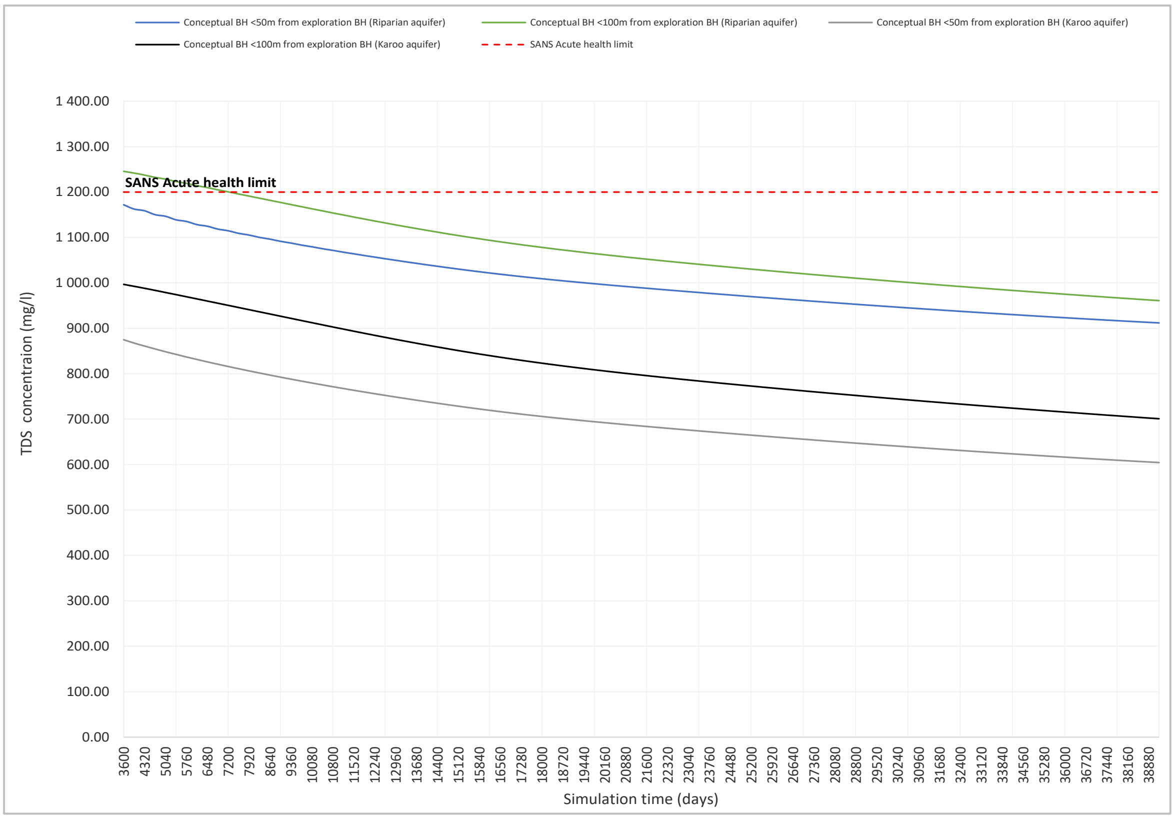


Figure 13-32 **Scenario 04: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).**

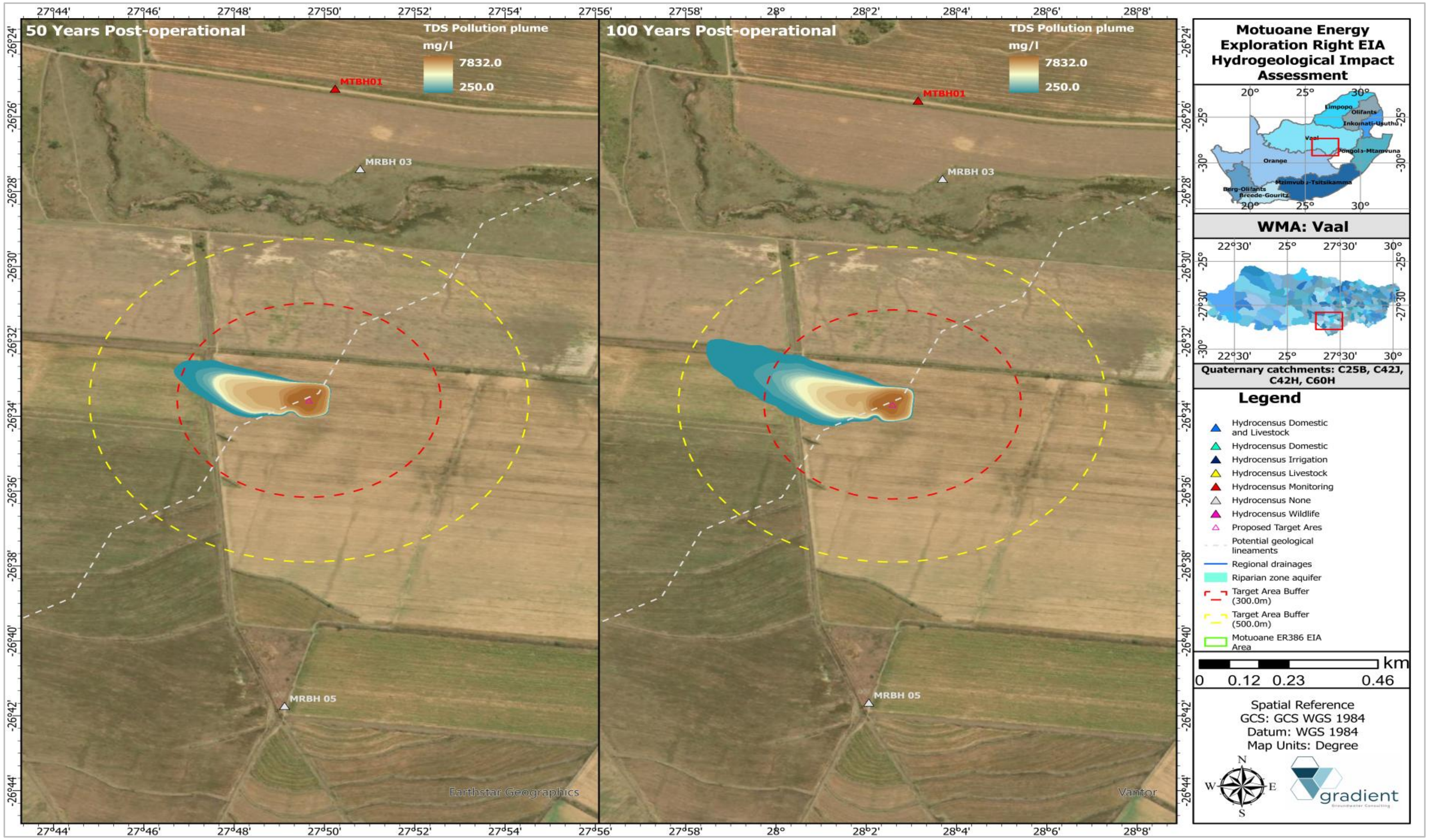


Figure 13-33 **Scenario 04: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target area 9 (Post-closure phase).**

13.7.5. Scenario 05: Migration of stray methane (CH_4) gas emanating from the exploration 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 (CH_4) gas emanating from the exploration zone should the integrity of the decommissioned gas exploration boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated CH_4 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 distance reached is ~350.0m during the post-closure phase. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer. **Figure 13-34** summarises a time-series graph of the CH_4 mass load contribution to conceptually placed receptors targeting the shallow, intergranular as well as riparian zone aquifers for the post-closure phase. It is evident that source term mass load contribution to conceptual receptors remains below the EPA safety threshold (2011) of 10.0mg/l ranging between 1.70-2.80mg/l. **Figure 13-35** depicts the CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through open exploration boreholes to the intergranular aquifer in the vicinity of target area 9 for the post-closure phases.

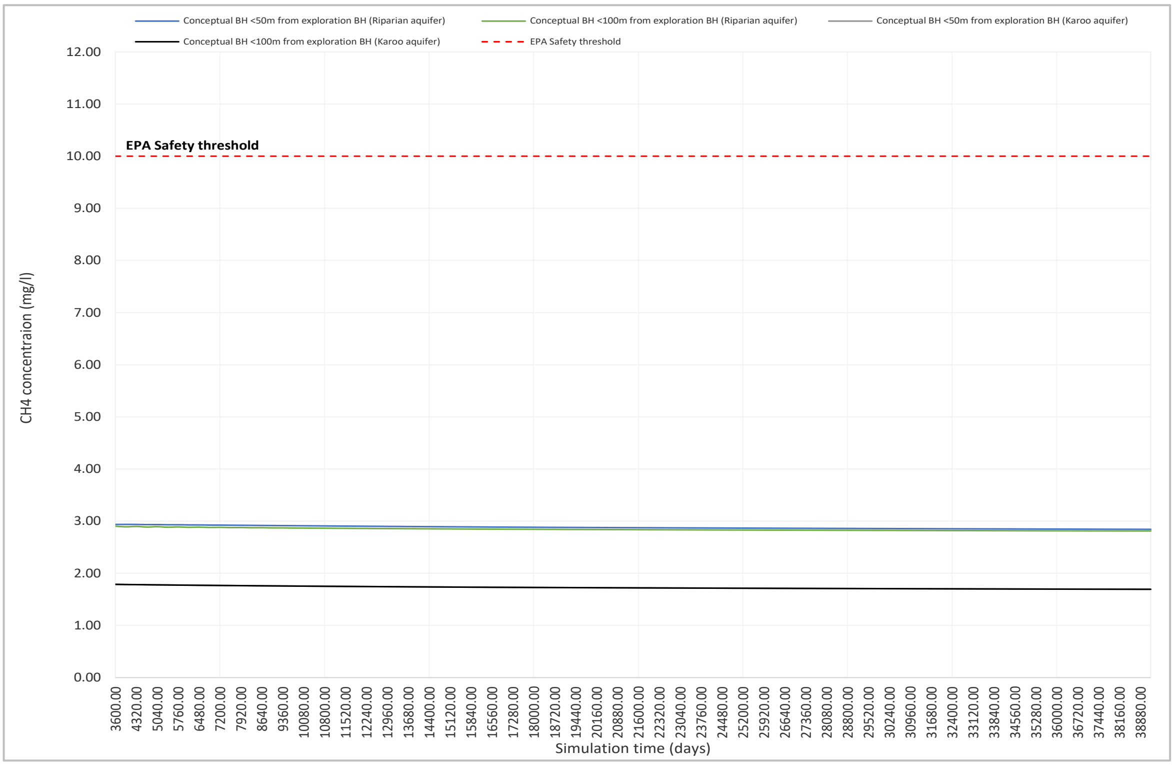


Figure 13-34 **Scenario 05: Time-series graph indicating the CH4 mass load contribution of deeper, fractured aquifer on conceptual receptors targeting the shallow, intergranular as well as riparian zone aquifers (Post-closure phase).**

Figure 13-35 **Scenario 05: CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through the intergranular aquifer in the vicinity of target area 9 (Post-closure 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 is guided by the requirements of the NEMA EIA Regulations 2014 (as amended). The broad approach to the significance rating methodology is to determine the environmental risk (**ER**) by considering the consequence (**C**) of each impact (comprising **N**ature, **E**xtent, **D**uration, **M**agnitude, and **R**eversibility) and relate this to the probability/ likelihood (**P**) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (**PF**) which is applied to the **ER** to determine the overall significance (**S**). The impact assessment will be applied to all identified alternatives. Where possible, mitigation measures will be recommended for impacts identified.

14.2. Determination of Environmental Risk

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

Equation 14-1 Impact Consequence.

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

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

Table 14-2 Probability scoring.

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

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

Equation 14-2 Impact Consequence.

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

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25 as summarised in **Table 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	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5

Table 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 Impact Consequence.

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

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.

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

The significance ratings and additional considerations applied to each impact will be used to provide a quantitative comparative assessment of the alternatives being considered. In addition, professional expertise and opinion of the specialists and the environmental consultants will be applied to provide a qualitative comparison of the alternatives under consideration. This process will identify the best alternative for the proposed project. **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 groundwater quality impacts on down-gradient receptors are rated as **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. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads.

ii. Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.

iii. Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.

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

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

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
1	Groundwater	Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area as well as drilling pads.	Alternative 1	Construction	Normal operations or events	-1	3	2	3	2	-2.5	4	-10	Medium to high -	-1	2	1	2	2	-1.75	3	-5.25	Medium to low -	Medium	2	2	1.25	-6.56	Medium to low -
2	Groundwater	Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.	Alternative 1	Construction	Normal operations or events	-1	2	3	3	3	-2.75	4	-11	Medium to high -	-1	1	1	2	2	-1.5	3	-4.5	Medium to low -	Medium	2	2	1.25	-5.63	Medium to low -
3	Groundwater	Mobilisation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.	Alternative 1	Construction	Normal operations or events	-1	3	4	4	4	-3.75	4	-15	High -	-1	2	2	2	3	-2.25	3	-6.75	Medium to low -	Medium	2	2	1.25	-8.44	Medium to low -
4	Groundwater	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.	Alternative 1	Construction	Normal operations or events	-1	4	3	4	4	-3.75	4	-15	High -	-1	2	2	2	3	-2.25	3	-6.75	Medium to low -	Medium	2	3	1.38	-9.28	Medium to high -

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 groundwater quality impacts on down-gradient receptors are rated as **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures. The main impacts associated with the operational phase activities include the following:

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
iii. Groundwater pollution as a result of wastewater spills and seepage from drilling sumps.
iv. Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.
v. Operation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.
vi. Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.
vii. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
viii. Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.
ix. Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.

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

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
5	Groundwater	Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.	Alternative 1	Operation	Normal operations or events	-1	3	4	4	5	-4	4	-16	High -	-1	2	3	3	4	-3	2	-6	Medium to low -	Medium	2	3	1.38	-8.25	Medium to low -
6	Groundwater	Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.	Alternative 1	Operation	Normal operations or events	-1	3	4	4	5	-4	4	-16	High -	-1	2	3	3	4	-3	2	-6	Medium to low -	Medium	2	3	1.38	-8.25	Medium to low -
7	Groundwater	Groundwater pollution as a result of wastewater spills and seepage from drilling sumps.	Alternative 1	Operation	Normal operations or events	-1	2	3	3	4	-3	4	-12	Medium to high -	-1	1	2	2	3	-2	3	-6	Medium to low -	Medium	2	2	1.25	-7.50	Medium to low -

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
8	Groundwater	Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.	Alternative 1	Operation	Normal operations or events	-1	2	3	3	4	-3	4	-12	Medium to high -	-1	1	2	2	3	-2	3	-6	Medium to low -	Medium	2	2	1.25	-7.50	Medium to low -
9	Groundwater	Operation and maintenance of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.	Alternative 1	Operation	Normal operations or events	-1	2	3	3	4	-3	4	-12	Medium to high -	-1	1	2	2	3	-2	3	-6	Medium to low -	Medium	2	2	1.25	-7.50	Medium to low -
10	Groundwater	Poor storage and management of hazardous chemical substances on-site may cause surface water and groundwater pollution.	Alternative 1	Operation	Normal operations or events	-1	3	3	3	4	-3.25	4	-13	Medium to high -	-1	2	2	2	3	-2.25	3	-6.75	Medium to low -	Medium	2	2	1.25	-8.44	Medium to low -

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
11	Groundwater	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.	Alternative 1	Operation	Normal operations or events	-1	2	3	3	4	-3	4	-12	Medium to high -	-1	1	2	2	3	-2	3	-6	Medium to low -	Medium	2	2	1.25	-7.50	Medium to low -
12	Groundwater	Groundwater pollution as a result of contact with drilling fluids, additives and lubricants.	Alternative 1	Operation	Normal operations or events	-1	2	4	4	5	-3.75	4	-15	High -	-1	1	3	3	4	-2.75	2	-6	Medium to low -	Medium	2	3	1.38	-7.56	Medium to low -
13	Groundwater	Groundwater pollution as a result of unforeseen events such as saline water encountered during well blow-out.	Alternative 1	Operation	Normal operations or events	-1	2	3	3	5	-3.25	4	-13	Medium to high -	-1	1	2	3	4	-2.5	2	-5	Medium to low -	Medium	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 groundwater quality impacts on down-gradient receptors are rated as **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures. The main impacts associated with the decommissioning phase activities include the following:

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.
iii. Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.
iv. De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.

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

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
14	Groundwater	Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.	Alternative 1	Decommissioning	Normal operations or events	-1	3	4	4	5	-4	4	-16	High -	-1	2	3	3	4	-3	2	-6	Medium to low -	Medium	2	3	1.38	-8.25	Medium to low -
15	Groundwater	Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.	Alternative 1	Decommissioning	Normal operations or events	-1	3	4	4	5	-4	4	-16	High -	-1	2	3	3	4	-3	2	-6	Medium to low -	Medium	2	3	1.38	-8.25	Medium to low -
16	Groundwater	Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.	Alternative 1	Decommissioning	Normal operations or events	-1	2	3	1	4	-2.5	4	-10	Medium to high -	-1	1	2	1	3	-1.75	3	-5.25	Medium to low -	Medium	2	2	1.25	-6.56	Medium to low -

Identifier	Discipline	Impact	Alternative	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance Score	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance Score	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
17	Groundwater	De-mobilisation of heavy vehicles, drilling rig as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.	Alternative 1	Decommissioning	Normal operations or events	-1	2	3	1	4	-2.5	4	-10	Medium to high -	-1	1	2	1	3	-1.75	3	-5.25	Medium to low -	Medium	2	2	1.25	-6.56	Medium to low -

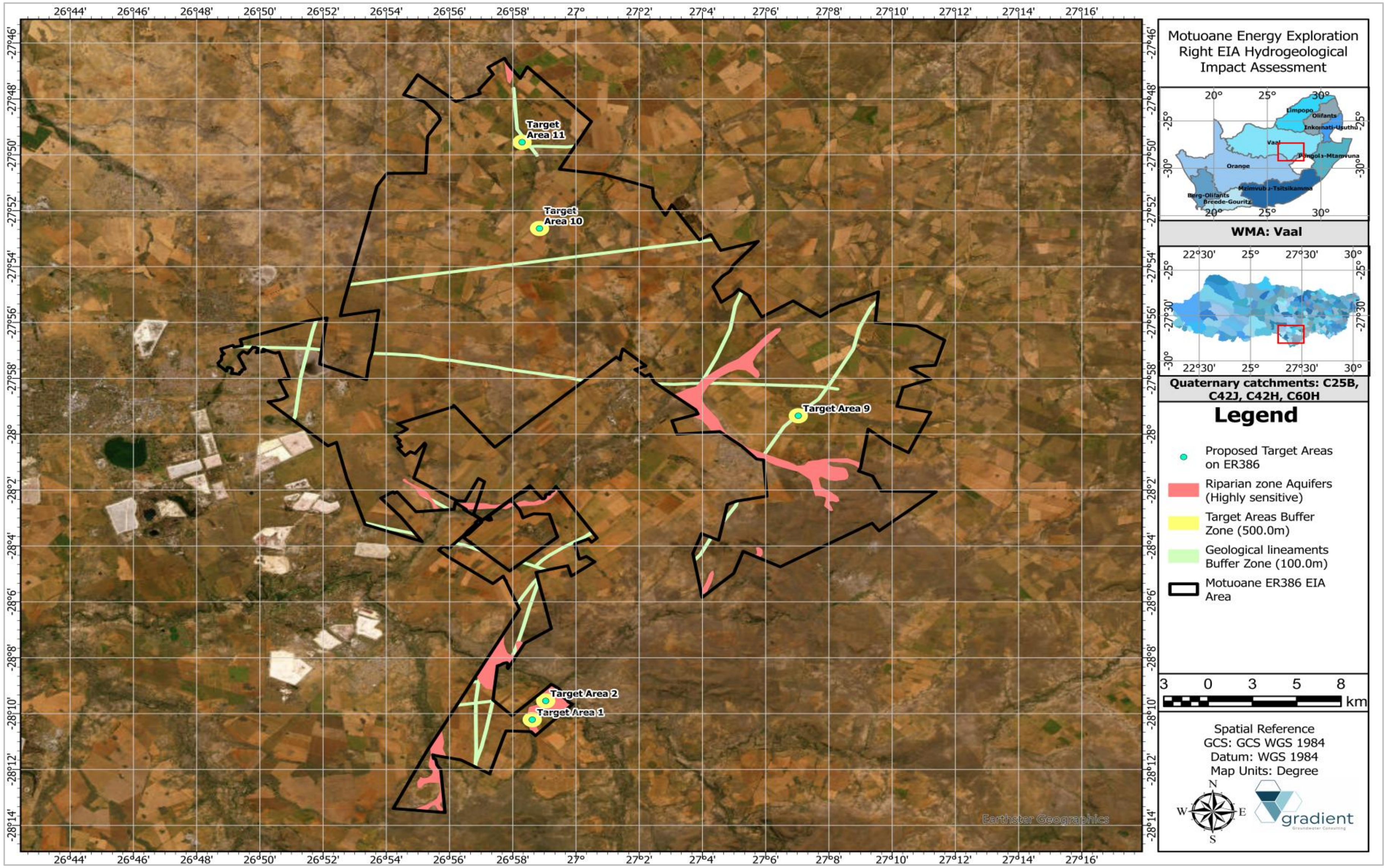


Figure 14-1 Hydrogeological sensitivity map.

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. Contamination of the shallow, intergranular aquifer caused by migration of saline water and/or stray gas from the deep, fractured aquifer. If the decommissioned gas exploration wells are constructed and sealed off to protect the shallow potable Karoo aquifers, the impacts associated with the project can be minimised.

ii. Poor quality leachate may emanate from the workshop and/or drilling pad footprint areas which may have a negative impact on groundwater quality.

iii. Hydrocarbon contamination of groundwater resources caused by heavy vehicles, drilling rigs as well as associated machinery on-site may cause hydrocarbon contamination of groundwater resources.

iv. 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 operational phase.

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 is adjacent to this proposed explorational 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 Motuoane Hennenman exploration area (ER315)). 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. 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)**.

ii. Clean surface water runoff to be diverted around disturbed areas and discharged to the downstream catchment zones.

iii. Develop and implement a stormwater management plan in accordance with GN704 to separate dirty/contact water from clean water circuits.

iv. 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)**.

v. Sites must be located, where possible, on previously disturbed areas and every effort must be made to keep the footprint as small as possible.

vi. Should drilling within the riparian zone and primary porosity aquifer be necessary, alternatives without establishment of a drilling sump should be investigated in order to minimise potential contamination of this sensitive groundwater receptor.

vii. 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)**.

viii. 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)**.

ix. 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)**.

x. 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.

xi. 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)**.

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

xiii. 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)**.

xiv. Workshop areas must be monitored for oil and fuel spills **(This mitigation measure is included in the approved EMPr for exploration area ER315)**.

xv. Spill 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)**.

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

xvii. An appropriate number of spill kits must be available and must be in all areas where activities are being undertaken.

xviii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair.

xix. 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. If significant gas is encountered during explorational 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.

ii. Open exploration 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)**.

iii. Daily inspections of drilling pads must be implemented and operated according to best practise guidelines.

iv. 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)**.

v. 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)**.

vi. 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)**.

vii. 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.

viii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair.

ix. 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)**.

x. 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)**.

xi. 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)**.

xii. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry as well as water levels will serve as early warning mechanism to implement mitigation measures.

xiii. Prior to drilling of the proposed exploration 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.

xiv. 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.

xv. Geological exploration 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 ($\delta^{18}O$, $\delta^{2}H$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.

xvi. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed exploration drilling be recorded along with associated water levels and hydrochemistry and incorporated into an updated groundwater database for future reference.

xvii. The existing conceptual model should be refined with newly gathered geological exploration 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.

xviii. Monitoring results should be evaluated on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation. Based on the water quality results, the monitoring network should be refined and updated every three to five years based on hydrochemical results obtained to ensure optimisation and adequacy of the proposed localities.

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 exploration 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 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:
  - Calliper and CBL logging results;
  - Cement formulations and Material Safety Datasheets of all additives;
  - Cementation methodology and photographs;
  - Recorded pressure test data;
  - Well tagging photographs and coordinates;
  - 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 exploration boreholes should be sealed off and rehabilitated according to best practise guideline.

ix. After exploration coring has been completed, 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)**.

x. 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. DWAF 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.

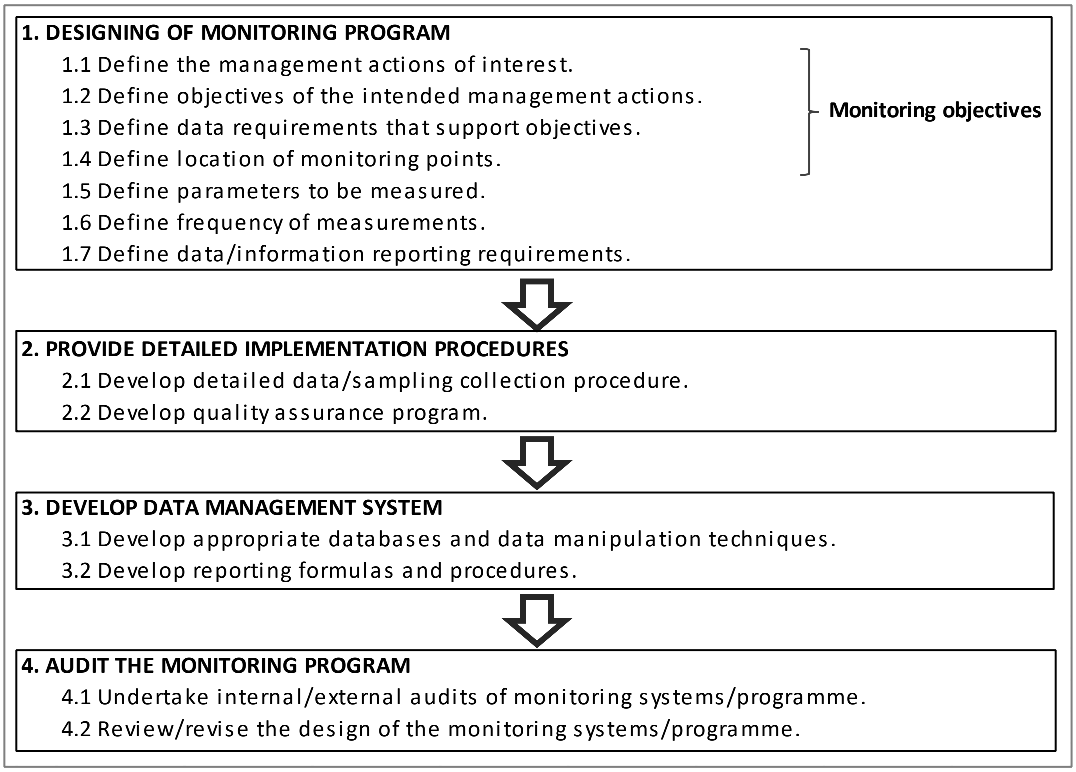


Figure 16-1 Monitoring programme (DWA, 2006).

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 16-1 summarises the proposed monitoring network with relevant information while **Figure 16-2** indicating a spatial distribution map of the monitoring localities in relation to proposed infrastructure and associated activities. It is recommended that additional monitoring boreholes be established in close proximity to proposed target areas in order to create a local groundwater baseline and formulate local background conditions prior to any drilling 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 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. Supplementary guidelines i.e., Water Use Licence (WUL) conditions as well as WMA Resource Quality Objectives (RQO) should also be considered as part of the monitoring protocol. All monitoring localities should be subjected to an initial comprehensive water quality analysis to evaluate hydrochemical composition and identify potentially elevated parameters going forward[14]. 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 (SO_4), Nitrate (NO_3), Chloride (Cl), Fluoride (F), Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na).

iii. ***Micro determinants:*** Aluminium (Al), Iron (Fe), Manganese (Mn), Cadmium (Cd), 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 (CH_4), dissolved Ethane (C_2H_6).

iv. ***Organic determinants:*** Total Oil and Grease, Dissolved Organic Carbon (DOC), Total Organic Carbon (TOC), TPH GRO C6-C10, TPH C28-C40.

[14] 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.

16.4. Water levels

Water levels should be monitored to evaluate the impact of exploration 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 at dedicated monitoring boreholes should be conducted on a quarterly basis whereas water level and water quality monitoring at privately owned boreholes situated within the target areas buffer zone should be conducted on a biennial 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. 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.

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 16-1 Integrated monitoring network and programme.

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
Newly drilled monitoring boreholes						
MTBH01	-27.980284	27.117792	Newly established monitoring borehole in the vicinity of target area 9	Quarterly	Monthly	As in Section 16.3
MTBH02	-27.822672	26.970510	Newly established monitoring borehole in the vicinity of target area 11	Quarterly	Monthly	
MTBH04	-28.210978	26.957666	Newly established monitoring borehole southwest of target areas 1 and 2	Quarterly	Monthly	
MTBH06	-28.224384	26.938921	Newly established monitoring borehole southwest of target areas 1 and 2	Quarterly	Monthly	
Privately owned monitoring boreholes						
BH03	-28.159240	26.978660	Privately owned borehole situated within the target zone buffer area	Quarterly	Monthly	As in Section 16.3
MRBH 03	-27.982520	27.118370	Privately owned borehole situated within the target zone buffer area	Quarterly	Monthly	
MRBH 05	-27.997510	27.116620	Privately owned borehole situated within the target zone buffer area	Quarterly	Monthly	
MRBH 68	-27.829280	26.979090	Privately owned borehole situated within the target zone buffer area	Quarterly	Monthly	
Newly proposed monitoring boreholes						
BH01	-27.873119	26.980699	Down-gradient conceptual borehole situated within the targeted area buffer zone	Quarterly	Monthly	As in Section 16.3
BH02	-27.990050	27.115255	Down-gradient conceptual borehole situated within the targeted area buffer zone	Quarterly	Monthly	
BH03	-28.165226	26.978401	Down-gradient conceptual borehole situated within the targeted area buffer zone	Quarterly	Monthly	
BH04	-28.154909	26.983811	Down-gradient conceptual borehole situated within the targeted area buffer zone	Quarterly	Monthly	

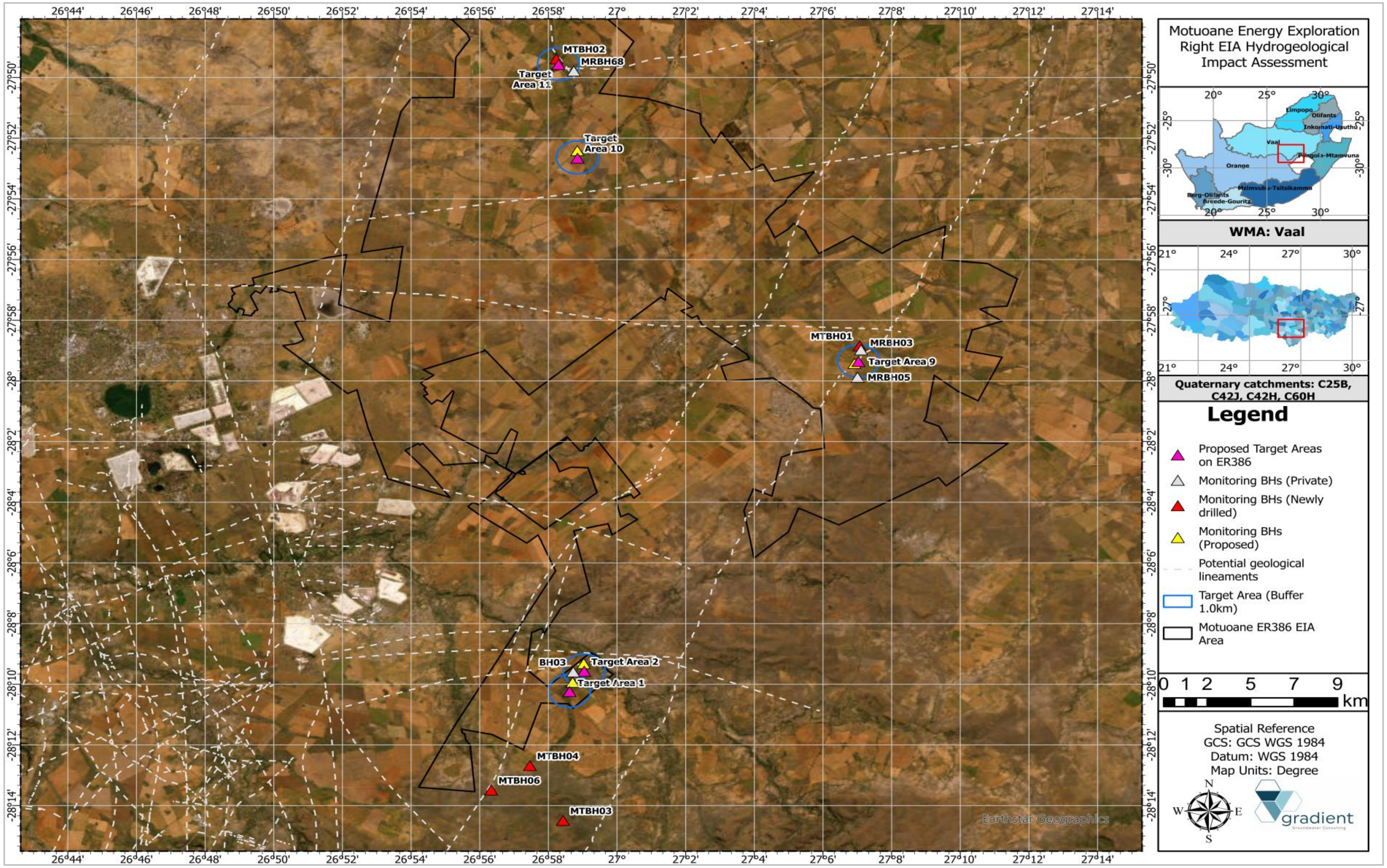


Figure 16-2 **Integrated groundwater monitoring network.**

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 exploration on potential sensitive environmental receptors.

ii. The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. 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 south and east of the study area, thus it can be assumed that, under natural circumstances, surface water and groundwater flow will be in a northwestern direction.

iii. The hydrology of the region is characterised by predominately perennial watercourses with the main rivers draining the greater study area in a general western to northwestern direction. It can be assumed that there will be groundwater contribution to baseflow. Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. Taken this observation into consideration, it can be concluded that the riparian zone will be very vulnerable to groundwater contamination and associated impacts.

iv. The regional geology consists of various lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort and Ecca Groups within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. It can be assumed that hydraulic properties i.e., hydraulic conductivity of saturated quaternary deposits as well as contact zones of dolerite structures will be higher whereas the hydraulic conductivity, hence groundwater flow, of the Beaufort and Ecca Groups will be more sluggish.

v. Structural analysis indicates the presence of faults zones traversing the study area, trending NE as well as SSE. 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.

vi. The study area is predominantly underlain by a Class d2 and d3 intergranular and fractured aquifers consisting primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. 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. The Ecca Group aquifers consist mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, 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.

vii. 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 and fractured aquifer within the Beaufort Group:** 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 the Ecca Group and pre-Karoo rocks:** 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, sandstone, shales 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.

viii. An approximation of recharge for the study area is estimated at ~2.01% of MAP i.e., ~10.67 mm/a which is generally considered as low.

ix. A hydrocensus user survey within the greater study area was conducted and confirmed that the groundwater application throughout the greater study area is for livestock watering and domestic water supply purposes. Thus, although generally low yielding, this aquifer is important to local groundwater users as it forms the sole source of water supply in the region.

x. 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.

xi. 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 >34.0m with a mean thickness of approximately ~6.0m, which is relatively shallow and implies a thin unsaturated zone which deem the host aquifer to be more vulnerable.

xii. Artesian conditions were observed at two of the boreholes surveyed namely MRBH 16 and MRBH 98 which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions.

xiii. Statistical evaluation of the water level data set suggests a dynamic groundwater environment with a potentially pumped aquifer system present.

xiv. 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 >0.97. 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.

xv. The average groundwater gradient (*i*) of the shallow, intergranular aquifer in the vicinity of proposed exploration 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 0.0017 in a general southeast to northwest orientation. The latter implies that the gradient driven groundwater flow and pollution plume propagation will be sluggish.

xvi. Hydrochemical results of the hydrocensus borehole water samples analysed suggest the overall ambient groundwater quality is good and unimpacted on. Isolated sampling localities higher conductivities with main drivers consisting of elevated Calcium (Ca)/Magnesium (Mg)/Sodium (Na)-Chloride (Cl) concentrations which might be indicative of the intermediate, fractured aquifer unit being targeted by the respective borehole(s), sourcing more stagnant groundwater. It is observed that various of the surveyed boreholes indicate elevated Nitrate 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.

xvii. 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 suggest slightly elevated Aluminium (Al) and Iron (Fe) concentration.

xviii. 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.

xix. According to the aquifer classification map of South Africa the project area is underlain by a "**Minor aquifer**", however due to its application it can also be classified as a sole source aquifer.

xx. According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a "**Moderate**" vulnerability rating.

xxi. According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a "**Medium**" susceptibility rating.

xxii. 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.

xxiii. 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.

xxiv. 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.

xxv. A scenario was simulated by assigning a point source pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas exploration boreholes be jeopardised i.e., leaking boreholes for the exploration 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 in a radial pattern from the gas exploration 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 ~100.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~230.0m during the operational exploration phase. It can be observed that the TDS mass load contribution ranges between ~900.0mg/l to approximately 1250.0mg/l, which is slightly above the SANS 241:2015 limits, with the mass load contribution a function of the distance to the source or gas exploration borehole. 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer. 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 shales.

xxvi. A scenario was simulated by assigning a point source pollution plume migration of stray methane (CH_4) gas emanating from the exploration zone should the integrity of the gas exploration boreholes be jeopardised after decommissioning. The simulation indicates that the generated CH_4 pollution plume will generally mimic topography and will migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. It can be observed that the simulated pollution plume migration is more sluggish within the denser Karoo formations, reaching a maximum distance of ~90.0m, whereas movement through the more unconsolidated alluvial deposits of the riparian zone suggest a larger flux reaching a maximum distance of ~180.0m during the operational exploration phase. It is evident that source term mass load contribution to is below the EPA safety threshold (2011) of 10.0mg/l ranging between 2.0-3.0mg/l, with the mass load contribution a function of the distance to the source or gas exploration borehole. 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 exploration right area. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

xxvii. A scenario was simulated by assigning a point source pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the decommissioned gas exploration 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 migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum distance reached is ~450.0m during the post-closure phase. It can be observed that the TDS mass load contribution remains below the SANS 241:2015 limits ranging between ~950.0mg/l to approximately 600.0mg/l. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation, however salt load contribution to the host aquifer is observed. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

xxviii. A scenario was simulated by assigning a point source pollution plume migration from of stray methane (CH_4) gas emanating from the exploration zone should the integrity of the decommissioned gas exploration boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. The simulation indicates that the generated CH_4 pollution plume will also mimic topography during the post-closure phase and will migrate in a radial pattern from the gas exploration borehole(s) towards the lower laying drainage system. After a simulation period of 100-years, it can be observed that the maximum distance reached is ~350.0m during the post-closure phase. It is evident that source term mass load contribution to conceptual receptors remains below the EPA safety threshold (2011) of 10.0mg/l ranging between 1.70-2.80mg/l. The simulation indicates that the potential pollution plumes will not intercept any privately owned, neighbouring boreholes during the duration of the simulation. It should be noted that the pollution plumes originating from exploration boreholes situated within the riparian zone might potentially intersect local drainages i.e., Sandrivier and Rietspruit including the associated riparian zone aquifer.

xxix. 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 groundwater quality impacts on down-gradient receptors are rated as **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures. During the operational phase the environmental significance rating of groundwater quality impacts on down-gradient receptors are rated as **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures. During the decommissioning phase the environmental significance rating of groundwater quality impacts on down-gradient receptors are rated as **medium** to **high** without implementation of remedial measures and **medium** to **low** with implementation of proposed mitigation measures.

18. RECCOMMENDATIONS

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. 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.

iii. 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 within a 500.0m radius of each proposed gas exploration borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas exploration borehole situated within the Karoo formations in order to verify the presence of other sensitive groundwater receptors and/or private boreholes. 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.

iv. 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.

v. 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.

vi. Geological exploration 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 ($\delta^{18}O$, $\delta^{2}H$) and radionuclide analysis in order to determine potential risks as well as validate surface water and groundwater interactions.

vii. Due to limited aquifer characterisation data pertaining to the deep hydrostratigraphical unit, it is recommended that potential water strikes encountered during proposed exploration drilling be recorded along with associated water levels in order to get a better understanding of the deeper aquifer piezometric head and expected behaviour.

viii. 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.

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 groundwater management tool for future scenario predictions.

x. It is recommended that a weather station (i.e., rain gauges) be established 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 exploration 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.

20. REFERENCES

American Society for Testing and Materia ls, 1993. Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem. ASTM. Standard D 5447-93, West Conshohocken, PA.

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

Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hacket, G. 1987. DRASTIC: A standardized system for evaluating groundwater pollution using hydrological settings. Prepared by the National Water Well Association for the US EPA Office of Research and Development, Ada, USA.

Appelo, C.A.J. and Postma, D. (1999) Chemical Analysis of Groundwater, Geochemistry, Groundwater & Pollution.

Barnard, H. C., 2000. An explanation of the 1:500 000 general Hydrogeological Map. Kroonstad 2726.

Bean, J.A., 2003. A critical review of recharge estimation methods used in southern Africa. PhD thesis, (unpubl). University of the Free State, South Africa.

Bear, J. 1979. Hydraulics of Groundwater. Dover Publications, Inc. Mineola, New York. ISBN-13:978-0-486-45355-2.

Botha JF, Verwey JP, Van der Voort I, Vivier JJP, Buys J, Colliston WP and Loock JC, 1998. Karoo Aquifers – Their Geology, Geometry and Physical Properties, WRC Report No 487/1/98, August 1998.

Bredenkamp, D., Botha, L.J., Van Tonder, G.J. and Janse van Rensburg, H., 1995. Manual on qualitative estimation of groundwater recharge and aquifer storativity, based on practical hydro-logical methods. Water Research Commission, TT 73/95. ISBN 1 86845 1763.

Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2727CA, 2727CC, 2726DD, 2826BB, 2826BC, 2826BD, 2827AA[Map]. Edition 9. Scale 1:50,000. Mowbray, South Africa: Chief Directorate of Surveys and Mapping.

Climate Change & Infectious Diseases Group. 2023. World Maps of the Koppen-Geiger Climate Classification. [online]. Available at: World Maps of Köppen-Geiger climate classification. [Accessed: February 2025].

Climate-Data. 2021. Data and Graphs for Weather and Climate in Welkom. [online]. Available at: Welkom climate: Weather Welkom & temperature by month. [Accessed: February 2025].

Council of Geoscience geological map sheet 2726: Kroonstad and 2826: Winburg (1:250 000).

Department of Water Affairs (DWA). 2012. Groundwater Reserve Determination for the Middle Vaal Water Management Area. Department of Water Affairs, Pretoria, RSA.

Department of Water Affairs: Directorate Hydrological Services, 2013. Aquifer classification of South Africa.

Department of Water Affairs: Directorate Hydrological Services, 2013. Aquifer susceptibility of South Africa.

Department of Water Affairs: Directorate Hydrological Services, 2013. Aquifer vulnerability of South Africa.

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.

Department of Water Affairs and Forestry Directorate. 2008. Best Practice Guideline – G3: Water Monitoring Systems. ISBN978-0-9814156-0-4.

Department of Water Affairs and Forestry Directorate. 2008. Best Practice Guideline - G5: Water Management Aspects for Mine Closure. ISBN978-0-9814156-0-4.

Diersch and Kolditz, 1979. Variable density flow and transport in porous media.

Eltschlager, K. K.; Hawkins, J. W.; Ehler, W. C.; Baldassare, F.2001.Technical Measures for the Investigation and Mitigation of Fugitive Methane Hazards in Areas of Coal Mining.

EIA Regulations, 2017. Government Notice (GN) R982.

EIMS, 2025. Notification regarding opportunity to participate in the environmental impact assessment process as part of the Motuoane Exploration Right 386 application, within various farms in Matjhabeng and Moqhaka

Local Municipalities, Lejweleputswa and Fezile Dabi District Municipalities, Free State Province, South Africa.

ESRI basemaps, 2025.

Fetter, C.W. 1994. Applied Hydrogeology. Pearson new international edition. 4th Edition. Pearson Education Limited. ISBN-13: 978-0130882394.

Freeze, R. Allan, and John A. Cherry. 1979. Groundwater. Prentice Hall Inc., New Jersey.

Google Earth, 2025. 6.0.12032 Beta.

Johnson, MR. Anhauser, CR., Thomas, RJ., 2006. The geology of South Africa. Council for Geoscience. ISBN 1-919908-77-3.

Kruseman, G.P, de Ridder, N.A., 1994. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement/lLRI (2000). ISBN 90 70754 207.

Lynch, S.D., Reynders, A.G. and Schulze, R.E., 1994: A DRASTIC approach to groundwater vulnerability mapping in South Africa. SA Jour. Sci., Vol. 93, pp 56 - 60.

Pannell, D., 1997. *Sensitivity analysis of normative economic models: theoretical framework and practical strategies*. Agricultural Economics, 1997, vol. 16, issue 2, 139-152.

Parsons, R, 1995. A South African Aquifer System Management Classification, Water Research Commission, WRC Report No KV 77/95.

Piper, A., 1944. *A graphic procedure in the geochemical interpretation of water-analyses*. Transactions, American Geophysical Union. 25 (6): 914–928.

Plumlee et al., 1999. The environmental geology of mineral deposits.

Pulles W, Banister S and Van Biljon M, 2005. The Development of Appropriate Procedures Towards and After Closure of Underground Gold Mines from a Water Management Perspective, Water Research Commission Report 1215/1/05, dated March 2005.

SANS 241: 2015. South African National Standards: Physical, aesthetic, operational and chemical determinants for drinking water.

Saltelli, 2002. Sensitivity Analysis for Importance Assessment. Risk analysis and international journal.

Schulze, R. 1989. ACRU: Background, Concepts and Theory. Report 35, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa.

Shango, 2016. Development of exploration strategies for gas plays in the Virginia, Kroonstad and Heilbron areas, Report No SS0530/15, prepared by Shango Solutions, dated 20 January 2016.

Spitz, K. and Moreno, J., 1996. A Practical Guide to Groundwater and Solute Transport Modelling. A Wiley-Interscience publication.

Steyl, G, Van Tonder, GJ, and Chevallier, L, 2012. State of the art: Fracking for shale gas exploration in South Africa and the impact on water resources, WRC Report No KV 294/11, dated February 2012.

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

Vegter, JR., DWS and WRC, 1995. Groundwater Resources of the Republic of South Africa.

Vegter, JR., 2006. Hydrogeology of Groundwater Region Northeastern Upper Karoo Region. WRC Report.

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

WR 2016. Rainfall and meteorological data.

Woodford, A.C., and Chevallier, L. 2002. Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs. WRC Report No. TT 179/02. Water Research Commission, Pretoria, RSA.

Yacov Y Haimes, 2012. Systems-based guiding principles for risk modelling, planning, assessment, management, and communication

Younger, P.L., R.S., 2007. Groundwater in the environment: An introduction. Blackwell Publishing.

21. APPENDIX A: RAINFALL DATA (RAINFALL ZONES C2H, C4C AND C6B)

22. APPENDIX B: GEOPHYSICAL SURVEY FIELD MEASUREMENTS AND PROFILES

23. APPENDIX C: BOREHOLE GEOLOGICAL LOGS AND CONSTRUCTION

24. APPENDIX D: AQUIFER TESTING DATASHEETS

25. APPENDIX E: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

26. APPENDIX F MOTUOANE HENNENMAN EXPLORATION AREA (ER315)

27. APPENDIX G: SPECIALIST DECLARATION FORM

28. APPENDIX H: SPECIALIST CURICULUM VITAE