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RENERGEN TETRA 4 CLUSTER 2 GAS PRODUCTION EIA HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

February 2026

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

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

JFW Mostert (Hydrogeologist)

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Executive summary

Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd to conduct a hydrogeological baseline investigation and groundwater impact assessment to be conducted to support an Environmental Impact Assessment (EIA) and Water Use Licence Application (WULA) authorisation process to be followed. The project entails expansion of the existing Tetra 4 natural gas production development and will include a combined helium and liquid natural gas (LNG) plant, gas wells and associated pipelines and compressor infrastructure.

Study objectives

The objective of this investigation is to determine the status quo of the regional groundwater system and aim to quantify and qualify potential impacts of the proposed expansion project on sensitive environmental and groundwater receptors.

Regional setting and site locality

The project area is situated on the farm Mond van Doornrivier 38 which is located between Welkom (16.7km SSW), Virginia (14.4km SWW), and Theunissen (30.0km N). The gas production right and greater study area covers a total area of ~187 000ha and falls within the Free State Province of South Africa.

Topography

The topography of the greater study area is generally flat and can be classified as a central interior plain or plateau. The lowest topographical elevation on-site is recorded as ~1280.0mamsl which is situated towards the western and eastern borders where the Sandrivier enters and exists the gas production right boundary and form part of the on-site drainage system. The highest topographical point recorded on site is approximately 1405.0mamsl and form part of the quaternary catchment boundary and groundwater/ surface water divide to the southern and south-western portion of the study area.

Drainage and catchment

The greater study is situated in primary catchment (C) of the Vaal River drainage system which falls under the Vaal Water Management Area. The project area is situated within quaternary catchments C42K and C42L.

The hydrology of the region is characterised by predominately perennial watercourses with the regional drainage occurring in a general west to north-western direction via the Sandrivier and Doringrivier both of which are traversing the study area from east to west (Sandrivier) and southeast to northwest (Doringrivier). A non-perennial drainage, Bosluisspruit, also traverse the study area and generally drain the catchment in a northern direction.

Climate

The study area's rainfall is strongly seasonal, and the weather pattern reflects a typical summer rainfall region, with > 80.0% of precipitation occurring as convective thunderstorms from October to March. The calculated mean annual precipitation (MAP) for this rainfall zone is 521.0mm/a, with the 5^{th} percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 343.38mm/a while the 95^{th} percentile (representing a 1:20 flood period) is calculated at 752.43mm/a. The mean annual evaporation (s-pan) ranging between 1600mm/a to 1680mm/a, more than threefold the annual precipitation.

Regional geology

The project area's surficial geology comprises of the Adelaide Subgroup (Vpa) consisting of alternating layers of bluish-grey, greenish-grey or greyish-red mudrock and grey, very fine to medium-grained, lithofeldspathic sandstone, the Vryheid Formation (Pv) which consists mainly of fine grained mudstone, carbonaceous shale with alternating and coarse grained, bioturbated immature sandstones respectively as well as the Volksrust Formation (PVo) which consists of grey to black, silty shale with thin, usually bioturbated, siltstone or sandstone lenses and beds, particularly towards its upper and lower boundaries. Furthermore, aeolian sands and quaternary deposits which is mainly associated with the Sand and Doringriver floodplains and constrained by drainage patterns and riparian zones can be observed throughout the project area. Isolated outcrops of the Karoo Supergroup i.e., dolerite dykes and sills are also present. This geological sequence is underlain by rocks of the Ventersdorp Supergroup as well as Witwatersrand Supergroup which host the primary source of gas as well as the shallower Karoo sediments.

Regional hydrogeology

According to the DWS Hydrogeological map the site is predominantly underlain by an intergranular and fractured aquifer system (d2) with the aquifer media consisting mainly of fractured and weathered compact argillaceous strata. According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the North-eastern Pan Belt region.

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

i. **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. These aquifers cover a large portion of the study area and are limited to a zone of variable width and depth. The alluvial aquifer is specifically vulnerable to contamination as it there is a direct connectivity with rivers and streams and associated high permeability.

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

iii. **An intermediate, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults, contact zones as well as fracture zones that occur in the relatively competent Karoo Supergroup host rock. Fractured sandstones, mudstones and shales sequences are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Although generally low yielding, this aquifer is important to local groundwater users as it forms the sole source of water supply in the region (Lea, 2017).

iv. **A deeper, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults and contact zones fracture zones that occur in the relatively competent Ventersdorp and Witwatersrand Supergroups host rock. Volcanic formations of the Ventersdorp lavas can also act as aquicludes, restricting the vertical movement of groundwater. Fractured quartzites of the Witwatersrand Supergroup are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

The water in the deep aquifers is naturally saline due to their marine depositional history. It should be noted that the shallow potable Karoo aquifers are separated from deep aquifer systems associated with the Ventersdorp and Witwatersrand Supergroup formations by the 30.0m thick dolerite sill (which may act as an aquitard) that extends across the study area and by the 65.0m thick Dwyka Tillite sedimentary deposit acting as an aquiclude. It should furthermore be noted that, under natural conditions, there is very limited hydraulic connectivity between the deep, fractured and shallow, intergranular aquifers.

Aquifer hydraulic parameters

The hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. Historical aquifer tests results confirm that the permeability of the shales is very low ($9E^{-4}$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. From historical aquifer tests conducted it is calculated that the average transmissivity for the shallow, weathered aquifer ranges between 0.12 m^2/d to 0.6m^2/d depending on the saturated thickness of the aquifer targeted. The site characterIsation phase indicates that the local transmissivity values range between 0.12m^2/d to 11.0m^2/d with a mean value of 1.04m^2/d.

An approximation of recharge for the study area is estimated at ~4.0% of MAP i.e., ~21.69mm/a, ranging between ~6.0mm for the denser Beaufort formation, ~12.0mm for the Volksrust formation and >37.0mm for loose, unconsolidated sediments of alluvial deposits.

Site investigation

A hydrocensus user survey within the greater study area was conducted during March 2022 as well as in October 2024 where relevant hydrogeological baseline information was gathered. A total of 171 geosites were visited and recorded which include surface water and groundwater receptors, i.e., boreholes, artesian wells, wind pumps as well as surface water features were visited as part of the hydrocensus user survey which are largely applied for livestock watering and domestic water supply purposes. Of the boreholes recorded, the majority are in use (~75.0%) while ~23.0% are not currently being utilized.

Site 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.

A geophysical survey was conducted during October 2024 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 for delineation of sub-surface lineaments and identification of potential preferential groundwater flow pathways to be targeted for monitoring boreholes. Following the geophysical survey, five drilling targets were identified and incorporated as part of the drilling program which was initiated during January 2025. Following the drilling phase, the newly established site characterisation boreholes, including existing monitoring boreholes, were subjected to hydraulic testing i.e., Constant Discharge(CD) pump during March 2025 in order to supplement published aquifer parameter data that was available for the site conditions and setting.

Groundwater flow evaluation

During the wet-season evaluation, artesian conditions were observed at three of the boreholes visited namely HBH31, 21B as well as 8B which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions. The minimum water level was recorded at 0.0mbgl, while the deepest water level was measured at borehole locality Mon-HDR1 (26.71mbgl). During the dry-season evaluation the minimum water level was recorded at 2.20mbgl (HBH161), while the deepest water level was measured at borehole locality HBH136 (42.13mbgl). The average water level is calculated at 7.86mbgl which is much shallower than the regional average water level of ~23.0mbgl.

It is noted that most water levels suggest a decrease in water levels and recovering trend. The latter can be attributed the onset of the wet cycle and above average rainfall events experienced with rainfall recharge replenishing aquifer storage. It can be observed that there is a definite a relatively quick response to rainfall, suggesting that recharge of the shallow, intergranular aquifer takes place without a prolonged lag effect. Statistical analyses of the water level trends furthermore suggest that the local groundwater system is in quasi-steady state conditions.

A groundwater observation borehole situated within the study area have been measured at ~25.0mamsl. This confirms the hypothesis that the deep, fractured aquifer unit have been locally depressurised by years of dewatering from underground mining operations targeting these zones for gold beneficiation.

Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation for both wet-season as well as dry-season contribution (R^2 <0.98). Accordingly, it can be assumed that the regional groundwater flow direction is dictated by topography. Bayesian interpolation was used to interpolate the groundwater levels throughout the study area. The inferred groundwater flow direction will be 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 and Doringrivier, also in the vicinity of the proposed plant expansion footprint, will be in a general northern direction, whereas the groundwater flow direction within the northern catchment of the study area will be mostly in a south to southwestern direction. It is noted that the inferred groundwater flow direction of the deeper, fractured aquifer is in a general northern direction.

The average groundwater gradient (*i*) of the shallow, weathered aquifer in the vicinity of expansion footprints is relatively flat and calculated at a mean of 0.002 – 0.003 for both wet and dry seasons, with a maximum of 0.003 – 0.004 in a south to north orientation and a minimum of 0.001 in a general east to west orientation.

The expected seepage rate from contamination originating at the proposed plant expansion footprint as well as associated infrastructure is estimated at an average of approximately 1.20 to 1.26m/a, with a maximum distance of ~2.86m/a in a southeastern to northwestern direction.

Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater and regional drainages can be generally classified as influent or gaining stream systems. 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.

Hydrochemistry

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

The hydrochemical results of the monitoring boreholes water samples analysed suggest the overall ambient groundwater quality to be moderate with a higher salt load being observed. Groundwater can be described as neutral, saline to very saline and hard to very hard.

The hydrochemical results of the newly established site characterisation boreholes water samples analysed suggest the overall ambient groundwater quality to be good (RTBH08 and RTBH10) to moderate with a higher salt load being observed at boreholes RTBH01 and RTBH04. Groundwater can be described as neutral, saline to very saline (RTBH01 and RTBH04) and hard to very hard.

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. It is noted that borehole localities with elevated NO_3 concentrations are situated within or directly down-gradient of planted crop areas as well as near surface water features.

Surface water quality can be classified as moderate to good with Aluminum (Al) and Iron (Fe) being slightly elevated. It should be noted that there is not a significant change in the downstream water quality compared to the upstream quality with an increase in Aluminum (Al), however all surface water samples analysed suggest elevated heavy metal concentrations i.e., Al and Fe.

Four distinct categories can be observed, Category A: Calcium-Bi-carbonate dominance which suggest a recently recharged and unimpacted groundwater environment (majority of samples), Category B: Calcium-Magnesium-Chloride dominance which indicate a static and disordinate environment as well as Category C: Sodium-Potassium-Bi-carbonate dominance which indicates an area of dynamic groundwater environments as well as Category D: Sodium-Potassium-Bi-carbonate dominance which indicate an area of dynamic groundwater environments.

The surface water samples analysed can be categorized as having Calcium-Magnesium-Chloride dominance which indicates a static and disordinate environment, one would except a more Calcium-Bi-carbonate signature from an unpolluted surface water source, however baseflow discharge present from the saline groundwater resource will have an impact on the salinity of the surface water resources as is evident.

Comparison of different hydrochemical signatures observed suggest on-site boreholes to target a shallow, inter-granular aquifer unit as well as a deeper (possibly intermediate, fractured aquifer unit) being more saline.

The Sodium-Potassium-Chloride dominance of the deep, fractured aquifer groundwater suggests extremely saline conditions as expected.

In order to evaluate the risk of groundwater containing radioactive substances, earmarked boreholes were subjected to analysis of radionuclides (Gross Alpha and Beta Radioactivity). It is noted that the overall ambient groundwater quality with reference to radioactive substances is good with the majority of boreholes analysed falling below the WHO limits for Gross Alpha/Beta activity. It is however observed that borehole 11A suggests elevated Gross Alpha activity i.e., 7.57Bq/l which is above the WHO limit of 0.50Bq/l. It should be noted that this borehole is situated in relatively close proximity to a mine tailings disposal facility, which may potentially hold radioactive material sourced from mining processes.

Geochemistry and waste classification

A geochemical assessment on overburden and drilling waste material was performed in order to determine the chemical nature and character and to evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for acid rock drainage. Due to the low sulphide content, it can be concluded that the material analysed suggest very low potential for acidic drainage with a very low salt load.

Potential waste material collected were submitted for geochemical characterisation to identify the chemical substances present in the material through analysis of the total concentrations (TC) and leachable concentrations (LC) in order to assess the material type and class. Dominant total concentrations above prescribed thresholds include Arsenic (As), Barium (Ba) as well Copper (Cu) whereas Arsenic (As) was observed as the dominant leachate concentration above prescribed thresholds. All samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination.

Operational water and mass load balance

A simplified water and salt balance was developed for the major water balance components of the operations. Major inflows to the evaporation dam include brine water sourced from the LNG production plant (1.30m^3/d) as well as direct precipitation reporting to the facility (2.53m^3/d), while the only major outflow is water loss due to evaporation which accounts to 4.83m^3/d. Due to the high evaporation signature, this component indicates a negative water balance i.e., nett water consumption. Major salt load contribution to this facility includes dissolved salts in the brine reticulated from the LNG production plant (1.13E^{+01}kg/d) as well as dissolved salts in direct precipitation reporting to the facility (5.06E^{-02}kg/d). As salts cannot be removed from the system via evaporation, this component indicates a positive salt balance i.e., nett salt make.

Aquifer classification and groundwater management index

According to the aquifer classification map of South Africa the project area is underlain by a “Minor aquifer”. It should however be noted that the shallow, intergranular aquifer is important to local groundwater users as it forms the sole source of water supply in the region. Furthermore, the primary riparian zone aquifer is classified as a major aquifer system due to its highly permeable nature as well as good water quality.

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 existing/proposed activities and associated infrastructure’s risk to groundwater pollution of the shallow, intergranular aquifer is rated as “Moderate”, Di = 109.

Numerical groundwater flow and pollution plume migration model

A numerical groundwater flow and mass transport migration model was developed and calibrated in steady state based on gathered site characterisation information which was applied as initial hydrogeological conditions for transient simulations.

A scenario was simulated representing point source pollution plume migration of saline groundwater emanating from leaking boreholes targeting the deep, fractured aquifer for the operational phase (20-year period). The TDS pollution plume extend covers a total area of approximately 634.4ha in the Karoo formations, reaching a maximum distance of ~150.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 182.37ha, reaching a maximum distance of ~250.0m propagating in a radial pattern from the gas production borehole(s) after a simulation period of 20-years. The pollution plume footprints reported on seems like a large area, however this is the combined zone of impact which is actually scattered throughout the study area and focussed in close proximity to proposed gas exploration and production boreholes. It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer. It is noted that the pollution plume migration in the denser Karoo formations is sluggish while movement in the unconsolidated alluvial deposits of the riparian zone suggest a larger flux. It can be observed that regional geological lineaments acts as preferred pathways for groundwater flow and contaminant transport mechanisms. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the SANS241:2015 threshold ranging between 400.0-1200.0mg/l, however borehole locality HBH136 suggest an increase in dissolved solids up to a concentration of >5000.0mg/l due to its proximity to the proposed production boreholes. The mass load contribution is a function of the distance to the source or gas production borehole.

A scenario was simulated representing point source pollution plume migration of stray methane (CH_4) gas emanating from leaking boreholes targeting the deep, fractured aquifer for the operational phase (20-year period). The (CH_4) pollution plume extend covers a total area of approximately 848.29ha in the Karoo formations, reaching a maximum distance of ~180.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 246.43ha, reaching a maximum distance of ~300.0m propagating in a radial pattern from the gas production borehole(s) after a simulation period of 20-years. It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes Mon 2057, 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer.

It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the EPA safety threshold (2011) of 10.0mg/l ranging between 0.12-3.90mg/l, however borehole locality HBH136 suggest an increase in the CH_4 concentration of >17.0mg/l due to its proximity to production boreholes. It can be observed that the CH_4 mass load contribution ranges between 2.08mg/l to approximately 7.66mg/l with the mass load contribution a function of the distance to the source or gas production borehole.

A scenario was simulated with a pollution plume migration from the evaporation dam footprint for the operational phase. The TDS pollution plume extend covers a total area of approximately 23.89ha reaching a maximum distance of ~550.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 20-years. The simulation indicates that no neighbouring boreholes or local drainages are expected to be impacted on during the operational phase. Monitoring boreholes which might potentially be intercepted by the pollution plume include BH01 as well as Mon-HDR01. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration of between 1750.0 – 2500.0mg/l, and is a function of the receptor distance from the source. It can be observed that the mass transport of the pollution plume is mostly limited to the shallow, intergranular aquifer, however may also migrate to the deeper, fractured aquifer over time.

A scenario was simulated representing point source pollution plume migration of saline groundwater emanating from leaking boreholes targeting the deep, fractured aquifer for the post-closure phase. After a post-closure simulation period of 50years, the TDS pollution plume extend covers a total area of approximately 1030.26ha in the Karoo formations, reaching a maximum distance of ~180.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 229.56ha, reaching a maximum distance of ~280.0m propagating in a radial pattern from the gas production borehole(s). After a post-closure simulation period of 100years, the TDS pollution plume extend covers a total area of approximately 1326.98ha in the Karoo formations, reaching a maximum distance of ~220.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 266.26ha, reaching a maximum distance of ~300.0m propagating in a radial pattern from the gas production borehole(s). It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the SANS241:2015 threshold ranging between ~400.0-1036.0mg/l, however borehole localities HBH136 and Stoltz L suggest an increase in dissolved solids with concentrations ranging between 1690.0 to up to 5117.0mg/l due to its proximity to production boreholes.

A scenario was simulated representing point source pollution plume migration from of stray methane (CH_4) gas emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase. After a post-closure simulation period of 50years, the CH_4 pollution plume extend covers a total area of approximately 1399.68ha in the Karoo formations, reaching a maximum distance of ~220.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 459.83ha, reaching a maximum distance of ~320.0m propagating in a radial pattern from the gas production borehole(s). After a post-closure simulation period of 100years, the CH_4 pollution plume extend covers a total area of approximately 1755.20ha in the Karoo formations, reaching a maximum distance of ~270.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 571.57ha, reaching a maximum distance of ~350.0m propagating in a radial pattern from the gas production borehole(s). It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes Mon 2057, 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the EPA safety threshold (2011) of 10.0mg/l ranging between 0.35-5.07mg/l, however borehole locality HBH136 suggest an increase in the CH_4 concentration of >17.0mg/l due to its proximity to production boreholes.

This scenario was simulated representing the pollution plume migration from the evaporation dam footprint for the post-closure phase. The TDS pollution plume extend covers a total area of approximately 43.03ha reaching a maximum distance of ~950.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 50-years and covers a total area of approximately 52.90ha reaching a maximum distance of ~1050.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 100-years. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration above the SANS 241:2015 limit of 1200.0mg/l for the post-closure simulation period with the mass load contribution a function of the distance to the source or evaporation dam footprint.

An alternative management and mitigation scenario was simulated to evaluate the remedial options available. A passive management scenario evaluating what the mitigating effect of a liner or barrier system implemented underneath the evaporation dam will have on the pollution plume migration were simulated. It is evident that due to the lower conductivity of the liner or barrier system when implemented, the source of contamination is effectively isolated from the groundwater system in the direct vicinity of the evaporation dam footprint and reduces the simulated pollution plume by >50.0% to ~11.58ha. Accordingly, it is recommended that this remedial alternative should be considered best practise for implementation.

Groundwater impact assessment

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

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. It should be noted that vast areas within the study area have been subjected to historical mining activities and, as such, reflect modified to highly modified present ecological status. A total number of >15 000 historical exploration wells have been drilled throughout the study area, some of which remain uncased and unsealed. The latter may act as preferential pathways and conduits for groundwater flow and contaminant transport mechanisms. Accordingly, this already highly modified zones should form part of the impact significance rating and risk approach.

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

- Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area.
- Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.
- Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
- 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 negative** without implementation of remedial measures and **low** to **medium negative** with implementation of proposed mitigation measures. The main impacts associated with the operational phase activities include the following:

- Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- Migration of stray methane (CH_4) gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.
- Groundwater pollution because of wastewater spills and seepage from the evaporation dams.
- Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.
- Mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of groundwater resources.

- Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.
- Leakage of harmful substances from tanks, pipelines or other equipment may cause groundwater pollution.
- Leachate of contaminants used in the drilling mud sump(s) to the intergranular, potable aquifer(s) during the operational phase.

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

- Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.
- Migration of stray methane (CH_4) gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.
- Groundwater pollution because of wastewater spills and seepage from the evaporation dams.
- Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.
- De-mobilisation of heavy vehicle and machinery as part of the decommissioning phase on-site may cause hydrocarbon contamination of groundwater resources.

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. It can be concluded that, should the prescribed mitigation and management measures, as stipulated in the groundwater management plan, be implemented and honoured, the impacts associated with the project phases can be minimised. It is important that an integrated groundwater monitoring program be developed and applied serving as an early warning and detection mechanism to implement mitigation measures. The calibrated groundwater flow model should be applied as groundwater management tool for future scenario predictions.

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 groundwater management plan 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.

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 a localised hydrocensus user survey be performed within a 500.0m radius of each proposed gas production borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas production borehole situated within the Karoo formations in order to identify the presence of other sensitive groundwater receptors and/or private boreholes. Accordingly, the gas production well design must take the results of the hydrocensus into consideration, specifically with regard to the planning and placement of boreholes as part of future drilling programmes.

iv. Additional monitoring boreholes should be established down-gradient of the existing and proposed plant expansion footprints to evaluate the mass load contribution to sensitive environmental and groundwater receptors. Drilling localities should be determined by means of a geophysical survey to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.

v. It is recommended that the revised monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated 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.

vi. 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.

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

viii. It is noted that the model tends to be sensitive to a variation in porosity ratios assigned and, as such, it is recommended that bulk mass density tests be performed on all newly acquired rock samples in order to verify the effective porosity to be incorporated in the pollution plume migration model update.

ix. It is recommended that a weather station 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.

x. All preferred groundwater flow pathways which are in direct connection with surface topography such as decommissioned gas production boreholes as well as historical mining exploration boreholes should be sealed off and rehabilitated according to best practise guidelines.

List of Abbreviations

ABA	**Acid Base Accounting**
ASLP	**Australian Standard Leaching Procedure**
AP	**Acid Potential**
ARD	**Acid Rock Drainage (also referred to as acid mine drainage (AMD))**
ASTM	**American Society for Testing Materials**
Avg	**Average**
AMD	**Acid Mine Drainage**
BH	**Borehole**
CD	**Constant Discharge**
CMB	**Chloride Mass Balance**
CNG	**Compressed Natural Gas**
CV	**Coefficient of Variation**
b	**Saturated Thickness**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWAF	**Department of Water and Forestry**
DWS	**Department of Water and Sanitation (Formerly DWAF)**
EC	**Electrical Conductivity (mS/m)**
EA	**Environmental Authorisation**
EIA	**Environmental Impact Assessment**
EM	**Electro-magnetic**
EMPr	**Environmental Management Programme**
E.N.	**Electro Neutrality**
EOH	**End of Hole**
EPA	**United States Environmental Protection Agency**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN	**Government Notice**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
IARF	**Infinite Acting Radial Flow**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
IWULA	**Integrated Water Use License Application**
ISP	**Internal Strategic Perspective**
K	**Hydraulic Conductivity (m/d)**
LC	**Leachable Concentration**
LCT	**Leachable Concentration Threshold**
LNG	**Liquid Natural Gas**
l/s	**Litre per second**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute**
MRS	**Magnetic Resonance Sounding**
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	**Mineral and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
NAG	**Net-Acid Generation**
NAWL	**No Access to the Water Level**
NEMA	**National Environmental Management Act (Act 107 of 1998)**
NEMWA	**National Environmental Management: Waste Act (Act 59 of 2008)**
NGA	**National Groundwater Archive**
NGDB	**National Groundwater Database**
NMR	**Nuclear Magnetic Resonance**
NP	**Neutralisation Potential**
NPR	**Neutralisation Potential Ratio**
NRMSD	**Normalised Root Mean Square Deviation**
NWA	**National Water Act (Act 36 of 1998)**
REV	**Representative Elementary Value**
RMSE	**Root Mean Square Error**
S	**Storage coefficient**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
Sc	**Specific Storage**
SoW	**Scope of Work**
SWL	**Static Water Level**
T	**Transmissivity (m^2/d)**
TC	**Total Concentration**
TCLP	**Toxicity characteristic leaching procedure**
TCT	**Total Concentration Threshold**
TDS	**Total Dissolved Solids**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
USGS	**United States Geological Survey**
VSD	**Variable Speed Drive**
WGS	**World Geodetic System**
WHO	**World Health Organisation**
WMA	**Water Management Area**
WM	**With Mitigation**
WOM	**Without Mitigation**
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 to be conducted to support an Environmental Impact Assessment (EIA) and Water Use Licence Application (WULA) authorisation process to be followed.

The project entails the Tetra 4 natural gas production development which operates under an existing production right (PASA Ref. 12/4/1/07/2/2) as well as environmental authorisation and associated water use licence for their current gas production activities (referred to as Cluster 1).

The Tetra 4 Cluster 2 natural gas production project entails the expansion of the existing natural gas production and will include a combined helium and liquid natural gas (LNG) plant, gas wells and the associated pipelines and compressor infrastructure. A follow-up hydrogeological assessment evaluating the potential impact and risks associated with the expansion activities was conducted and submitted in 2022 with the application approved by the DMRE and issued with environmental authorization (IEA) on 13 July 2023. On 08 August 2023, two separate appeals against the decision of the DMRE to grant the IEA were lodged. The grounds of appeal submitted were based on the following gaps identified:

i. Groundwater baseline conditions need to be expanded focusing more on ambient groundwater quality, with elaboration of radioactivity and associated risks, of non-project boreholes as well as abstraction volumes.

ii. Gather more site-specific geological and hydrogeological information. Additional site work, i.e., drilling and testing of site characterisation boreholes to determine site-specific hydraulic parameters and to inform the conceptual model.

iii. The conceptual groundwater model should be refined and updated with newly gathered site-specific information.

iv. Potential source terms should be clearly defined, i.e., what is the risk of contamination of potential waste material.

v. Water flow and water qualities between various flow components should be defined more clearly.

vi. Additional information is required on the mitigation measures of contact water storage facilities i.e., will facilities be lined, where is water sourced from and what will the water quality be.

vii. Details of the construction of the gas wells should be addressed.

viii. Details of the stratigraphy and hydrogeology of the gas wells are required. More focus should be given to the water quality and piezometric head of the deeper, confined aquifer.

ix. Incorporate all newly gathered site characterisation information as well as newly formulated conceptual model into the numerical groundwater flow and pollution plume migration model.

This report focuses on the status quo of the regional groundwater system as well addressing the expert critique received and aims to incorporate the updated data and information into this study to aid in quantifying and qualifying the potential impacts of the proposed expansion project on sensitive environmental and groundwater receptors.

1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors.

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

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

iv. Source term determination via geochemical characterisation of drilling sludge to be disposed of in the form of acid generating potential and risk to produce any acidic conditions.

v. Development of an operational salt and mass load balance summarising respective flow components as well as evaluating the potential mass load contribution to environmental receptors.

vi. Development of a conceptual groundwater flow model.

vii. Development of a numerical groundwater flow and mass transport model to quantify and qualify the potential impact of the gas extraction as well as simulate potential saline water migration towards the shallow aquifer.

viii. Hydrogeological impact assessment and risk matrix.

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

x. 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-21-055-V1, submitted in September 2021 as well as proposal ref.no. HG-P-24-027-V4, submitted in August 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 (BPG4 – Impact Prediction) as published by the former Department of Water Affairs and Sanitation (DWS, 2008).

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 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, radionuclides (Gross Alpha and Beta Radioactivity) 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 5x site characterisation boreholes i.e. targeting various lithologies and aquifer units. Borehole diameter = 165 mm (6.5"), UPVC casing = 4 mm wall; 155mm ID steel with slotted intervals at major water strikes/seepage zones. 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. Four (4) to eight (8) hour constant rate and recovery measurements on newly drilled boreholes as well as existing 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: Geochemical characterisation, waste assessment and source term determination

Phase D will entail the following activities:

i. Laboratory analysis and geochemical assessment of composite waste samples of strategically placed sampling localities (Acid Base Accounting (ABA) to determine AMD generation, NAG Potential and sulphide speciation).

ii. Processing of geochemical data.

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

iv. Formulation of a geochemical conceptual model.

v. Waste assessment accordance with Regulation GNR 635 and GNR 636 of the National Waste Act (Act 59 of 2008).

1.3.5. Phase E: Development of an operational salt and mass balance

Phase E will entail the following activities:

i. Evaluation of the existing water balance flow reticulation diagram which will form the basis of the salt and mass load balance.

ii. Development of an operational salt and mass balance incorporating salt load per facility to include all aspects as listed in the DWA Best Practise Guidelines (BPG-G2).

1.3.6. Phase F: Numerical groundwater flow and contamination transport model update

Phase F 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.

  f. Water management alternatives and best practice mitigation measures.

1.3.7. Phase G: Hydrogeological impact assessment update and reporting

Phase G will include the following activities:

i. Compilation of a detailed hydrogeological specialist investigation update 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

Ferdinand Mostert is a consulting hydrogeologist and specializes in providing hydrogeological advisory and supporting services. He holds a M.Sc. in Hydrogeological from the Institute of Groundwater Studies (IGS) at the University of the Free State and is a registered Professional Scientist in the Water Resource Sciences field. His experience of 17 years includes environmental impact and risk assessments, hydrogeological baseline assessments, aquifer sustainability studies contamination risk assessments, numerical groundwater flow and mass transport modeling, mine dewatering designs, groundwater due diligence studies, groundwater resource development, integrated groundwater and surface water management as well as practical implementation and decision-making approaches. He also has thorough knowledge and understanding of the National Water Act (Act 36 of 1998) and has extensive experience in compliance auditing focusing mainly on external water use licence audits. He has worked in all provinces throughout South Africa as well as sub-Saharan Africa countries, and his experience includes commodities such as iron ore, gold, coal and platinum. 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	17
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. GRA II DWS dataset. 2005.

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

iv. Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2826BA, 2826BB, 2826BC, 2826BD [Map]. Edition 9. Scale 1:50,000. Mowbray, South Africa: Chief Directorate of Surveys and Mapping.

v. Council of Geoscience geological map sheet 2826: Winburg (1:250 000).

vi. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer classification of South Africa.

vii. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer susceptibility of South Africa.

viii. Department of Water Affairs: Directorate Hydrological Services, 2012. Aquifer vulnerability of South Africa.

ix. 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.

x. EIMS, 2022. Tetra4 Virginia Production Drilling Waste: Waste Assessment and Classification Report. Report Ref.No.: 1445.

xi. ESRI basemaps, 2022.

xii. Google Earth, 2022. 6.0.12032 Beta.

xiii. i.lEH. 2017. *Tetra 4 Cluster 1 Production Right EIA Hydrogeological Specialist Report.* Report No iLEH-EIMS MOL-1 05-15.

xiv. 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.

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

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

iii. Tetra 4, 2025. Monthly Groundwater Monitoring Data.

iv. UIS Organic Laboratory, 2022. Tetra4 Waste Stream SANS 10234:2008 Classification Report.

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

vi. 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, Aquiworx, GRAII As well as WR2005 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 monitoring 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. The model basement 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.
x. Model calibration was achieved by assigning a ratio of 1:1 for Hydraulic Conductivity (K) in x and y directions, with a ratio of 1:10 in the z direction i.e., anisotropic aquifer (except for alluvial deposits which were assigned at a 1:1 ratio).
xi. Perennial rivers within the model domain have been treated as gaining type streams. As such groundwater is lost from the system via baseflow to local drainages.
xii. Groundwater divides have been assumed to align with surface water divides and it is assumed that groundwater cannot flow across this type of boundaries.
xiii. The numerical groundwater flow model was developed considering site specific information. It should be stated that influences from neighbouring mining developments were not taken into consideration as part of this investigation.
xiv. Prior to development, the system is in equilibrium and therefore in steady state.
xv. 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, development 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

A hydrocensus user survey was conducted in March 2022 (representative of wet-season contribution and conditions) as well as in October 2024 (representative of dry-season contribution and conditions) in which high-risk environmental receptors have been identified. The hydrocensus user survey will 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 existing gas production operations.

2.3. Hydrochemical analysis

Water samples collected were submitted at a SANAS accredited laboratory to determine the macro and micro inorganic chemistry, analysis of radionuclides (Gross Alpha and Beta Radioactivity) and potential hydraulic connections present. SANS 241:2015 Drinking Water Standards as well as World Health Organization (WHO) limits were applied and used a guideline for all water quality analysis.

2.4. Hydrogeological baseline description

Based on the gathered 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.

2.5. 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.

2.5.1. 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.

2.5.2. 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.

2.5.3. Aquifer testing

Production 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.

2.6. Development of a water and mass load balance

An operational water balance was developed based on the existing reticulation infrastructure and current flow meter volumes. Each component's hydrochemical composition was evaluated and an operation salt and mass load balance will be developed in accordance with BPG Series G: Water and Salt Balances (Munnik and Pulles, 2009) which will be based on the existing water balance.

2.7. Geochemical assessment and waste classification

The potential risk of waste material to generate acid i.e. acid rock drainage (ARD) was evaluated by acid base accounting testing. The latter involves a combined measurement of sulphur contents (total sulphur, sulphuric acid, sulphur, and organic sulphur), neutralisation capacity (NP), paste pH and the calculation of acid potential (AP), net neutralisation potential (NNP) and NP/AP ratio (NPR). Furthermore, waste classification of waste was undertaken in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010) [2]. The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations (LC) of samples taken.

2.8. Development of a conceptual hydrogeological model

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

2.9. 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.

2.10. 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 to render the significance of impacts identified.

[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 risk based approach.

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) as amended

The Mineral and Petroleum Resources Development Act 28 of 2002 intends to

i. to make provision for equitable access to and sustainable development of the nation's mineral and petroleum resources; and

ii. to provide for matters connected therewith.

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

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

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

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

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

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

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

The project area is situated on the farm Mond van Doornrivier 38 which is located between Welkom (16.7km SSW), Virginia (14.4km SWW), and Theunissen (30.0km N). The gas production right and greater study area covers a total area of ~187 000ha and falls within the Free State Province of South Africa. The site is accessible via the R30 secondary route from the north as well as the southeast. 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 4-2 with the project boundary and topo-cadastral map depicted in Figure 4-3.

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

Latitude	-28.129°
Longitude	26.718°

4.2. Project description and proposed infrastructure

The Tetra 4 Gas Production Project entails a natural gas production facility within an existing Production Right (PASA Ref. 12/4/1/07/2/2). The resource is not considered to be conventional. The gas will be extracted from deep-seated fracture zones and not from conventional confined reservoirs (*i*LEH, 2017). The extracted gas is compressed and reticulated via pipelines to further infield compressors. From here the gas is piped to a combined helium and liquid natural gas (LNG) plant for processing. The final products (helium and LNG) will be stored temporarily in tankers on site and then trucked away for sale to the end users (EIMS, 2016a). The current development includes a combined helium and LNG plant, gas wells as well as associated pipelines and compressor infrastructure. Refer to Figure 4-4 for an infrastructure and layout map indicating the proposed drilling priorities as well expansion footprints. The planned expansions will include the following:

i. Expansions to the current liquid natural gas (LNG) and Helium production plant located on the Farm Mond van Doorn River. The planned expansions will be to increase the helium and LNG production capacities significantly (~30fold increase) and increase the footprint of the existing approved plant by approximately 10ha.

ii. The drilling of new gas wells ~300 wells spread over a total study area (referred to as Cluster 2) of approximately 27 500ha.

4.3. Gas exploration and production well construction

The proposed gas-producing wells will be drilled using percussions methods. The initial well diameter will be 10 – 12” to a depth of 70m, as illustrated in Figure 4-1. A 9 – 10” wellbore casing (conductor casing) will be installed in this section of the well to stabilise the unconsolidated Aeolian sands. The diameter of the well will be decreased to 7 – 8” at depths of 300 - 450m in the Karoo Formation sediments. The depth of this diameter casing will be determined by the depth of the contact between the Karoo and Ventersdorp or Witwatersrand Supergroups. A 6” casing will be installed in this section of the well. The annulus between the well and the casing will be sealed with cement to the depth of this contact. The well will be continued to a depth of 500 – 700m, depending on the presence and depth of gas-bearing fractures intersected. The diameter of the well at this depth will be 4 – 5”. This section of the well will be left uncased. Horizontal drilling may be considered in the Ventersdorp/Witwatersrand Supergroup sediments to increase the flow of gas into the well (*i*LEH, 2017).

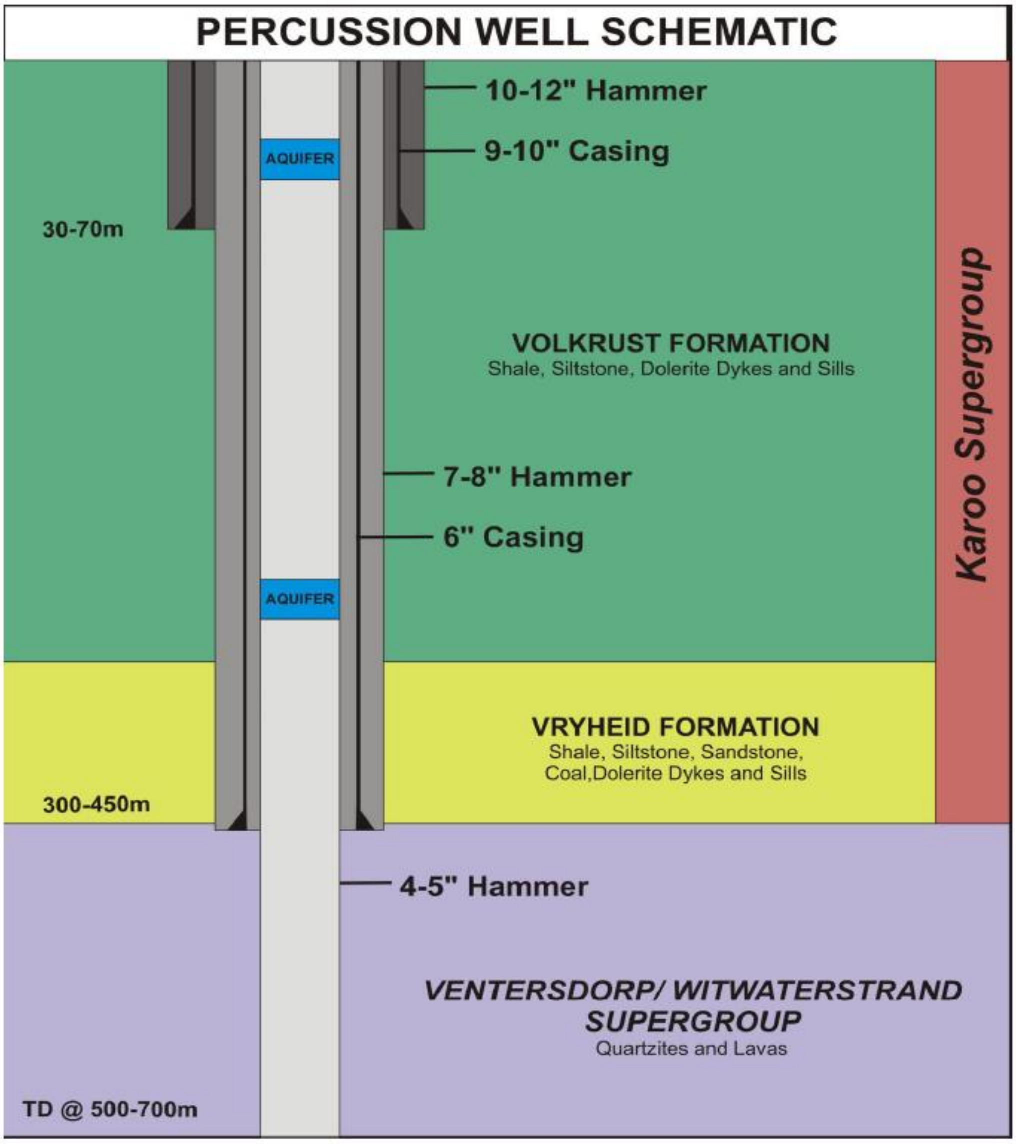


Figure 4-1 Schematic section indicating a typical well construction (after *i*LEH, 2017).

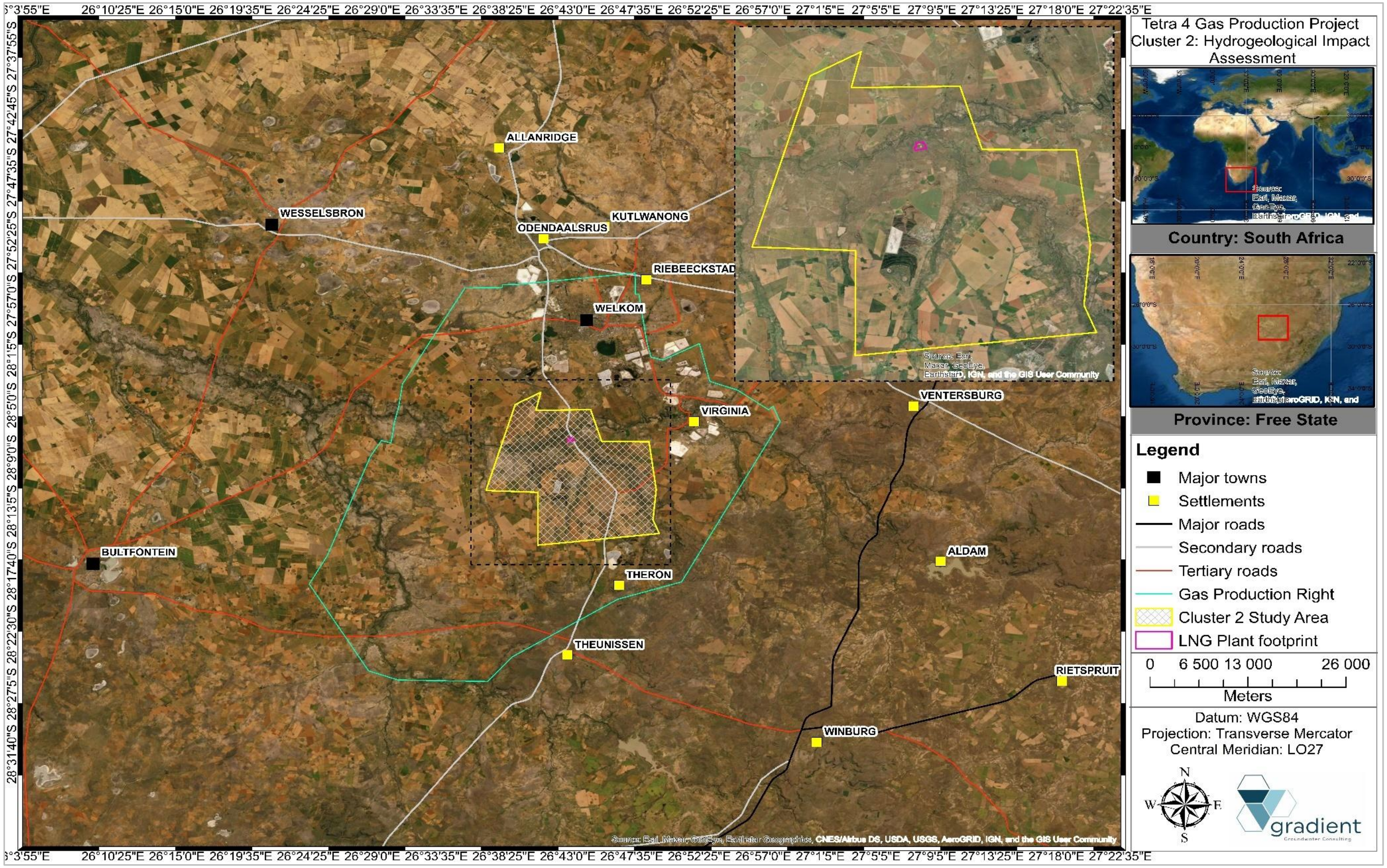


Figure 4-2 **Aerial extent and greater study area.**

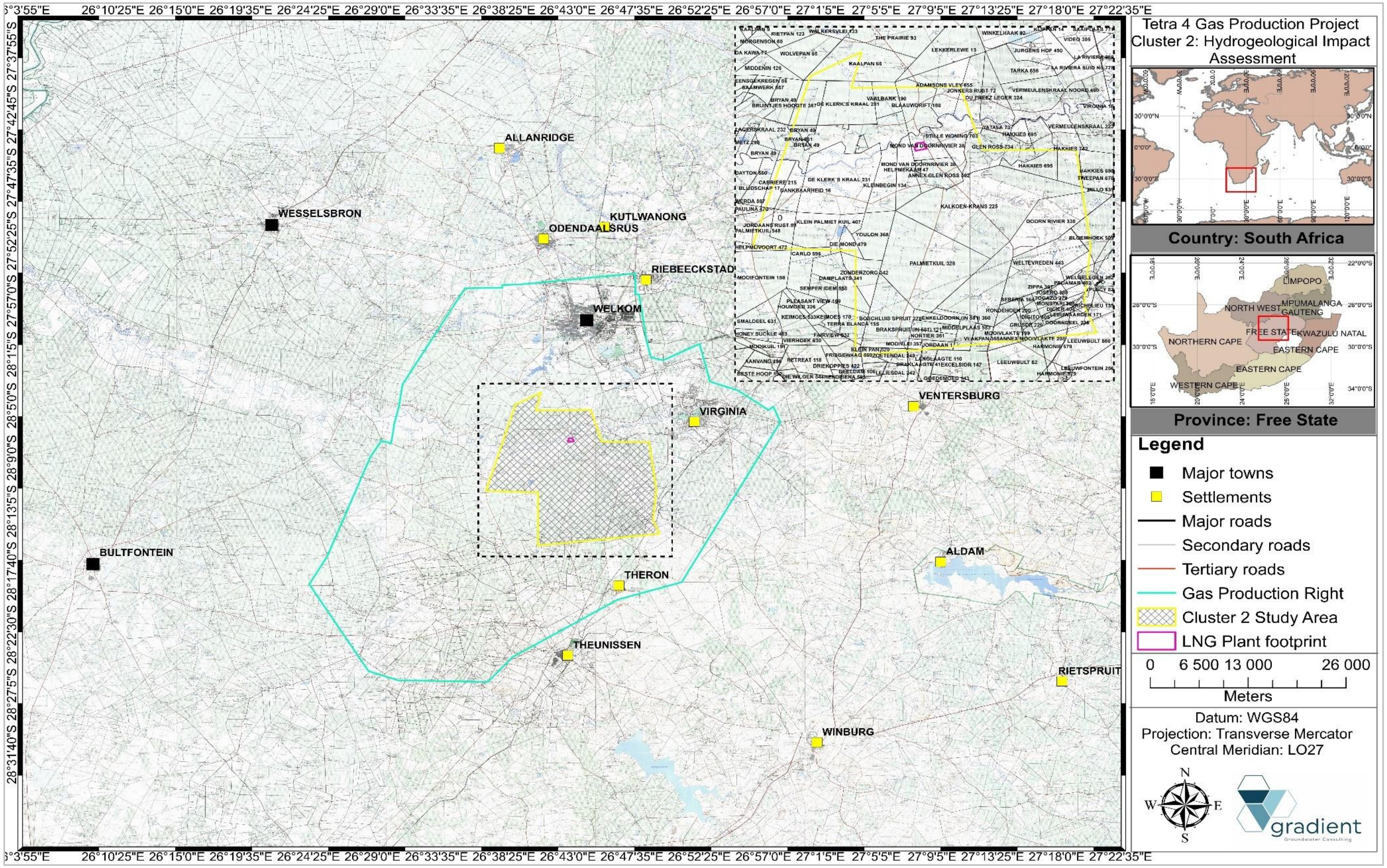


Figure 4-3 **Greater study area (1:50 000 topographical mapsheet 2826BA).**

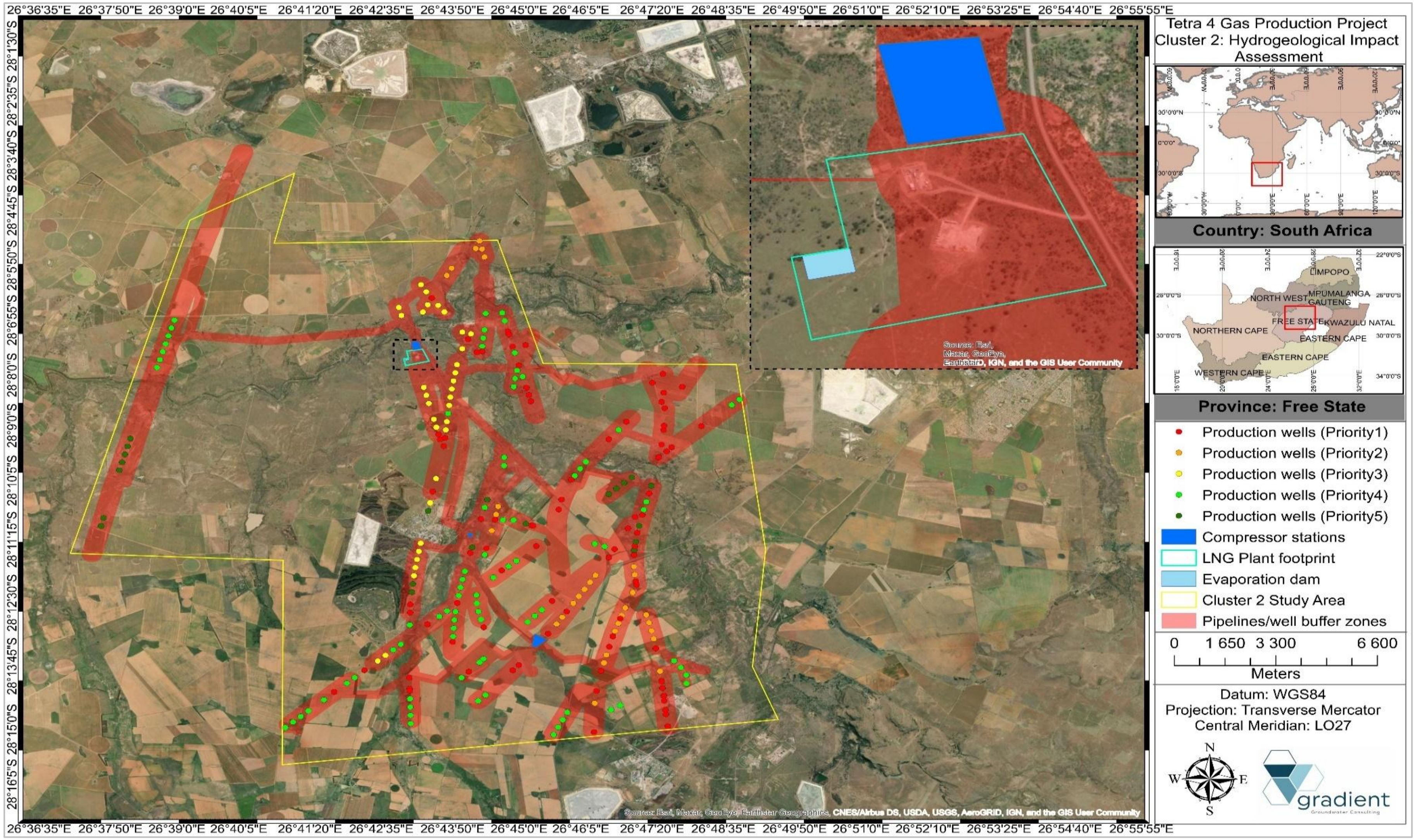


Figure 4-4 **Layout and infrastructrure map.**[4]

[4] It should be note that the indicated production borehole localities is based on a high level of uncertainty and is subject to change. Borehole positions will however not fall outside of the proposed buffer zone(s).

5. PHYSIOGRAPHY

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

5.1. Topography

The topography of the greater study area is generally flat 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. The landscape gradually flattens out towards the lower laying drainage system in the north-west (approximate elevation low of 1250.0mamsl), while the southern and south-eastern perimeters are shaped by scattered outcrops with a regional topographical high point recorded as 1540.0mamsl.

The lowest topographical elevation on-site is recorded as ~1280.0mamsl which is situated towards the western and eastern borders where the Sandrivier enters and exists the gas production right boundary and form part of the on-site drainage system. The highest topographical point recorded on site is approximately 1405.0mamsl and form part of the quaternary catchment boundary and groundwater/ surface water divide to the southern and south-western portion of the study area. On-site gradients are variable, but generally gentle with the average slope calculated at ~0.80% and an elevation loss of 130.0 m over a lateral distance of 16.0km in a north-south orientation whereas an average slope of ~0.40% and elevation loss of 70.0m over a lateral distance of 17.50km is calculated in an east- west orientation. Figure 5-1 depicts a topographical cross-section (south-western aspect) of the greater study area while Figure 5-2 shows the regional topographical contours and setting.

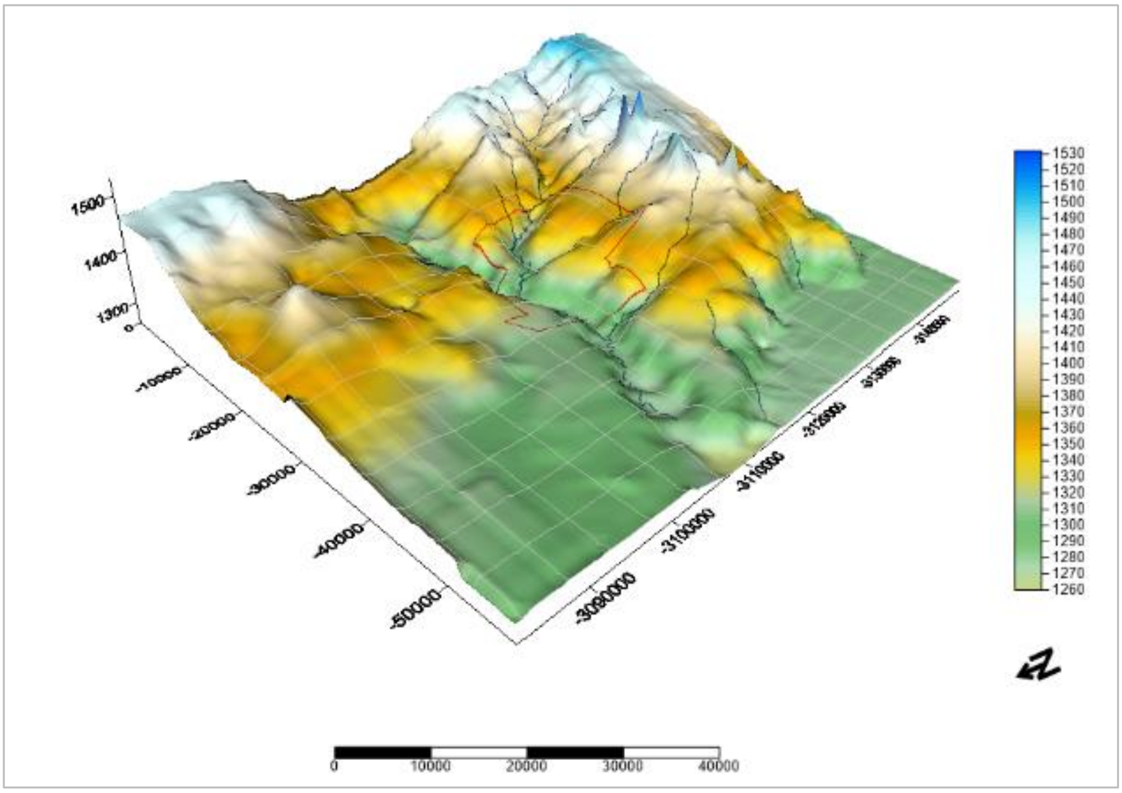


Figure 5-1 **Topographical cross-sections of the greater project area.**

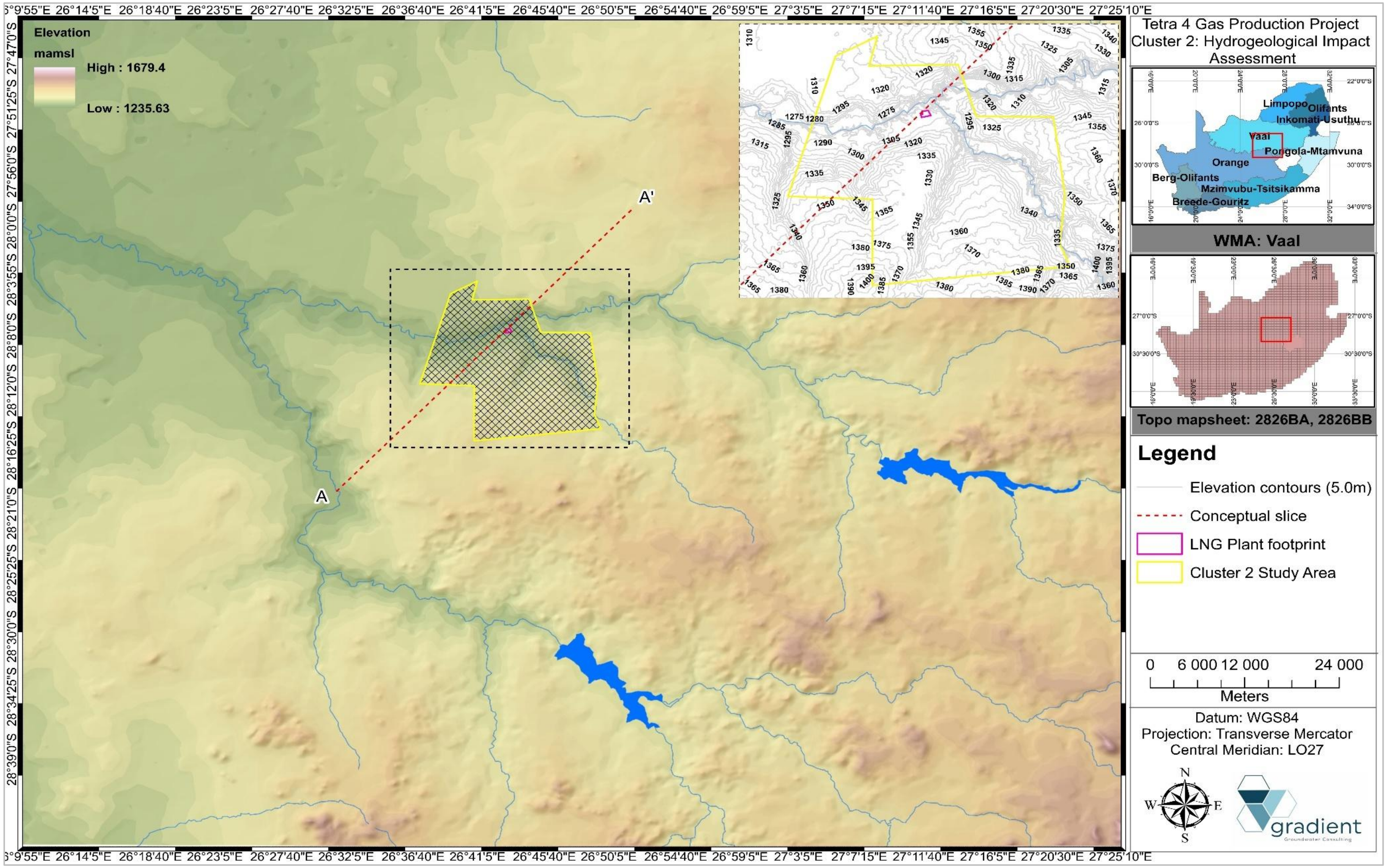


Figure 5-2 Regional topography and conceptual slice (Refer to Figure 14-2).

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 246 674.5km^2. The resource management falls under the Vaal Water Management Area (WMA5) which spans portions of the North West Province, northern Free State as well northern sections of the Northern Cape.

The project area is situated within quaternary catchments C42K (nett surface area of 668.0km^2) and C42L (nett surface area of 510.8km^2), falls within hydrological zone E and has an estimated mean annual runoff (MAR) of between 10.0 to 13.0mcm (million cubic metres) (WR 2012).

The hydrology of the region is characterised by predominately perennial watercourses with the regional drainage occurring in a general west to north-western direction via the Sandrivier and Doringrivier both of which are traversing the study area from east to west (Sandrivier) and southeast to northwest (Doringrivier). A non-perennial drainage, Bosluisspruit, also traverse the study area and generally drain the catchment in a northern direction. The Doringrivier convergences with the Sandrivier approximately 1.30km to the northeast of the study area from where it flows in a general westerly direction before joining the Vetrivier roughly ~ 30.0km downstream of the project area. Major surface water features being fed by the drainage system(s) of this quaternary catchment include the Bloemhof Dam situated <100.0 km to the northwest. Table 5-1 provides a summary of relevant climatological and hydrogeological information for the relevant quaternary catchments.

Table 5-1 Quaternary catchment information.

Attribute	C42K	C42L
Water Management Area (WMA)	Vaal	Vaal
Primary catchment	C	C
Secondary catchment	C4	C4
Tertiary catchment	C42	C42
Quaternary catchment	C42K	C42L
Major rivers	Sandrivier, Vetrivier and Doringrivier	Sandrivier, Vetrivier and Doringrivier
Hydro-zone	E	E
Rainfall zone	C4C	C4D
Area (km^2)	668.0	510.8
Mean annual rainfall (mm)	521.2	505.9
Mean annual evaporation (mm)	1600.0	1680.0
Mean annual runoff (mm)	23.8	22.7
Baseflow	2.9	2.5
Total groundwater use (l/s)	27.9	22.7
Present Eco Status Category	Category C	Category C
Recharge (mm)	15 - 25	15 - 25
Average water level (mbgl)	39.3	23.0
Soil type	SaClLm-SaCl	SaClLm-SaCl
Groundwater General Authorization	75m^3/ha/a	75m^3/ha/a

Note: Catchment based information sourced from Aquiworx 2014

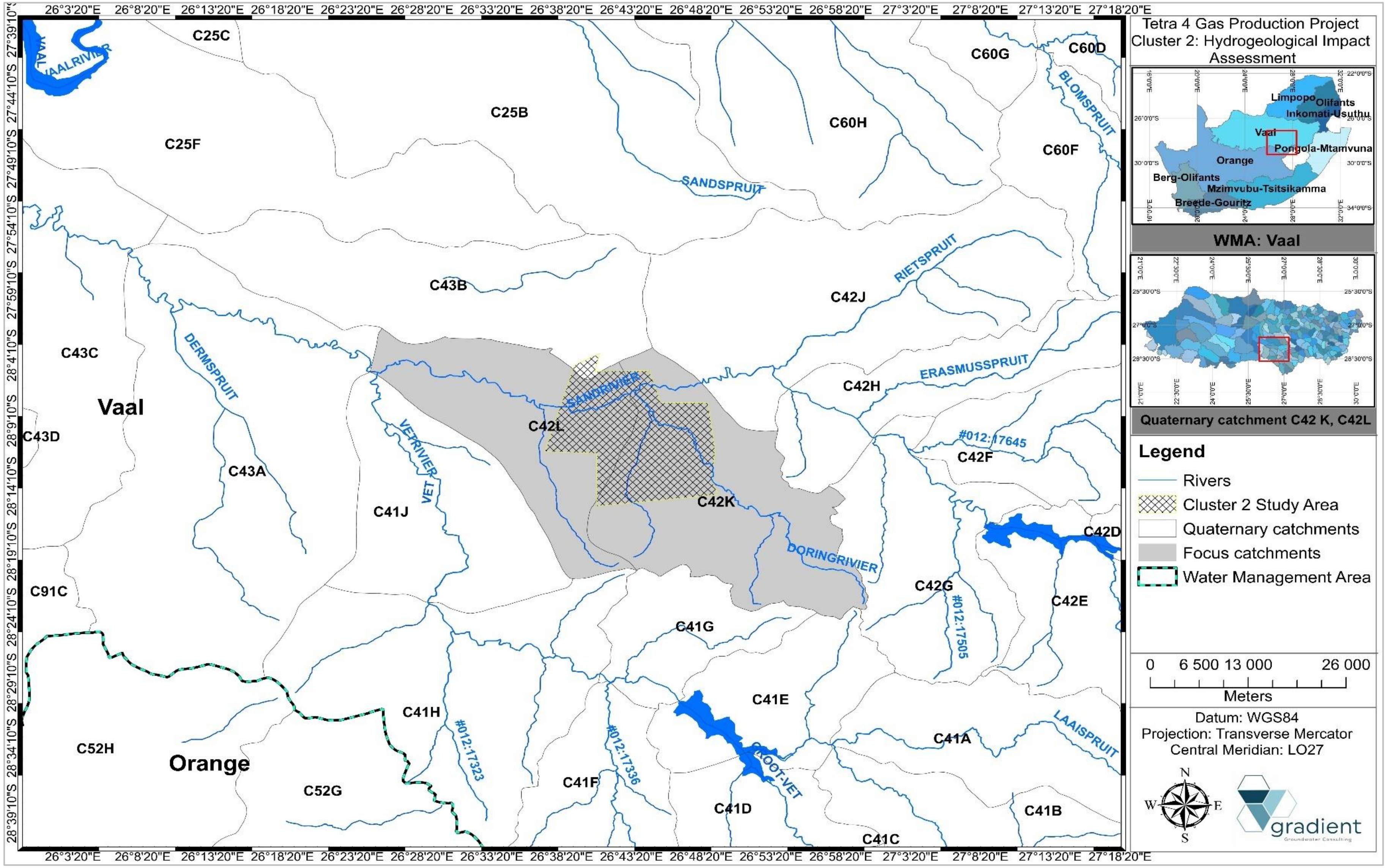


Figure 5-3 **Quaternary catchments and water management area.**

5.3. Climate

The study area's rainfall is strongly seasonal, and the weather pattern reflects a typical summer rainfall region, with > 80.0% of precipitation occurring as convective thunderstorms from October to March. Patched rainfall and evaporation data were sourced from the WR2012 database (Rainfall zone 4C4) and span a period of some 90 years (1920 – 2009). Refer to Appendix A for time-series rainfall data tables.

The calculated mean annual precipitation (MAP) for this rainfall zone is 521.0mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 343.38mm/a while the 95th percentile (representing a 1:20 flood period) is calculated at 752.43mm/a. The highest MAP for the 90 years of rainfall data was recorded as 860.30mm (1942) while the lowest MAP of 264.0mm was recorded during 2006.

Both catchment areas are categorised under evaporation zone 19C which have a mean annual evaporation (s-pan) ranging between 1600.0mm/a to 1680.0mm/a. The highest evaporation is usually experienced in December (215.0mm) while the lowest evaporation is in June (61.0mm). Figure 5-4 depicts a bar chart of the yearly rainfall distributions with Figure 5-5indicating monthly rainfall patterns. It is evident that the peak rainfall months are December and January. Figure 5-6 compares monthly precipitation volumes with monthly evaporation volumes. It is noted that the annual evaporation volumes are more than threefold the annual precipitation.

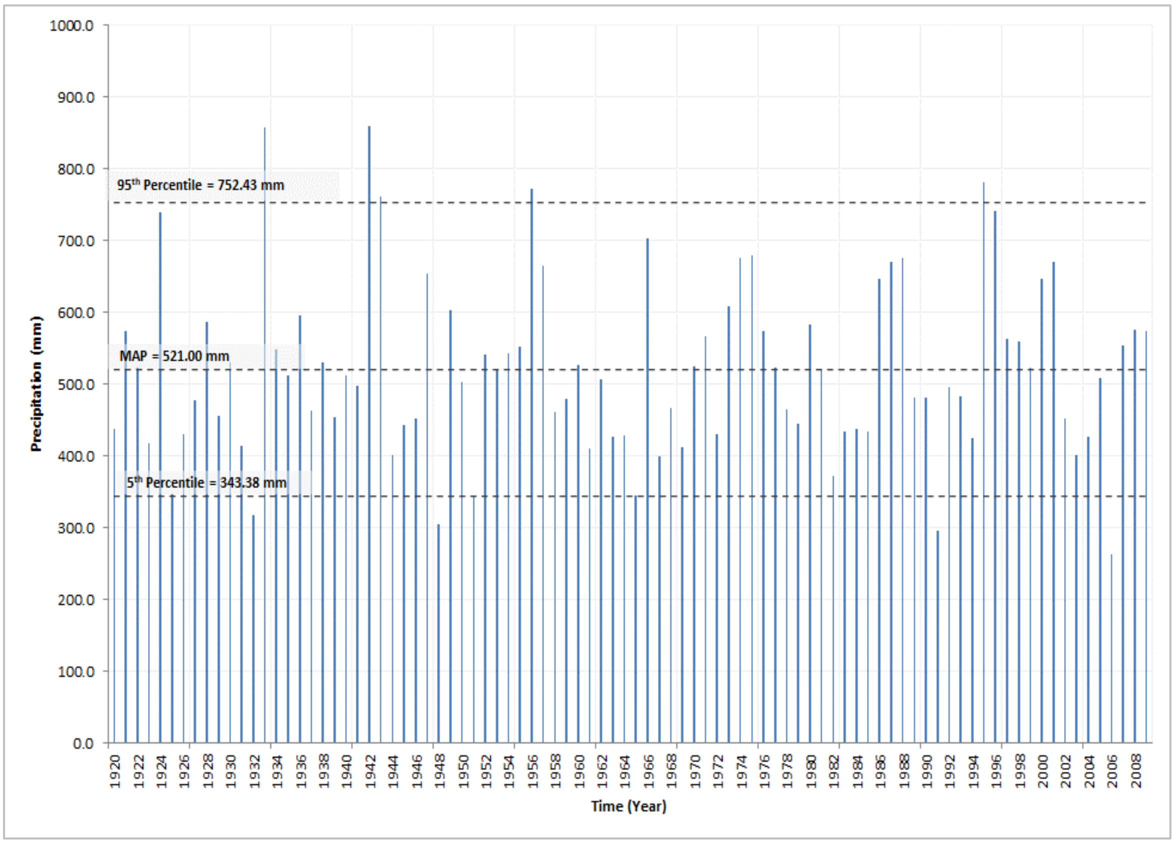


Figure 5-4 Bar chart indicating yearly rainfall distribution for rainfall zone V3B (WR2012).

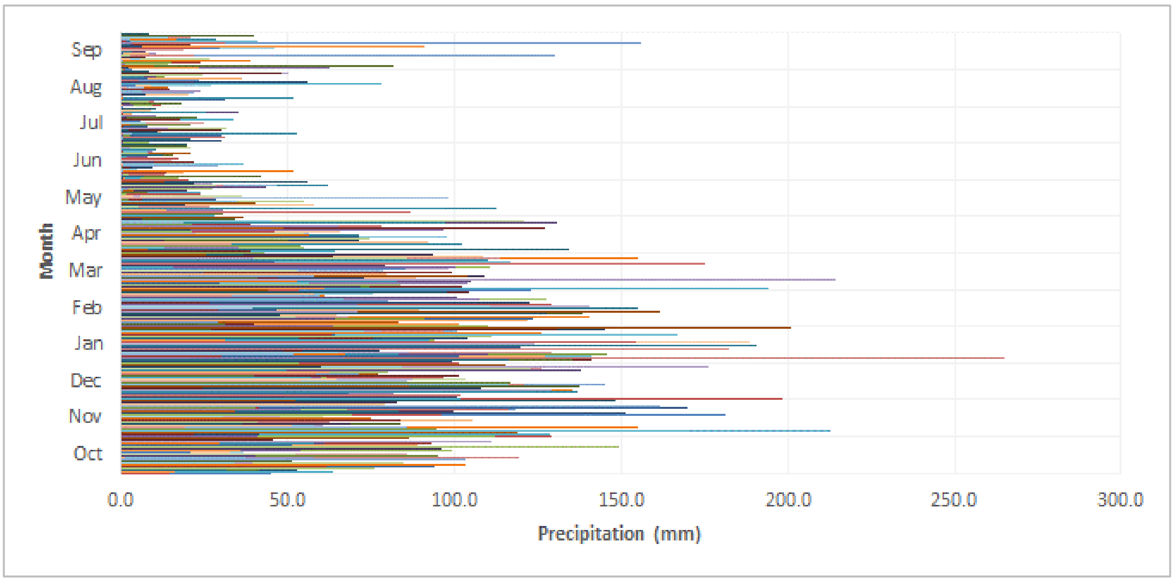


Figure 5-5 **Bar chart indicating monthly rainfall distribution for rainfall zone 4C4 (WR2012).**

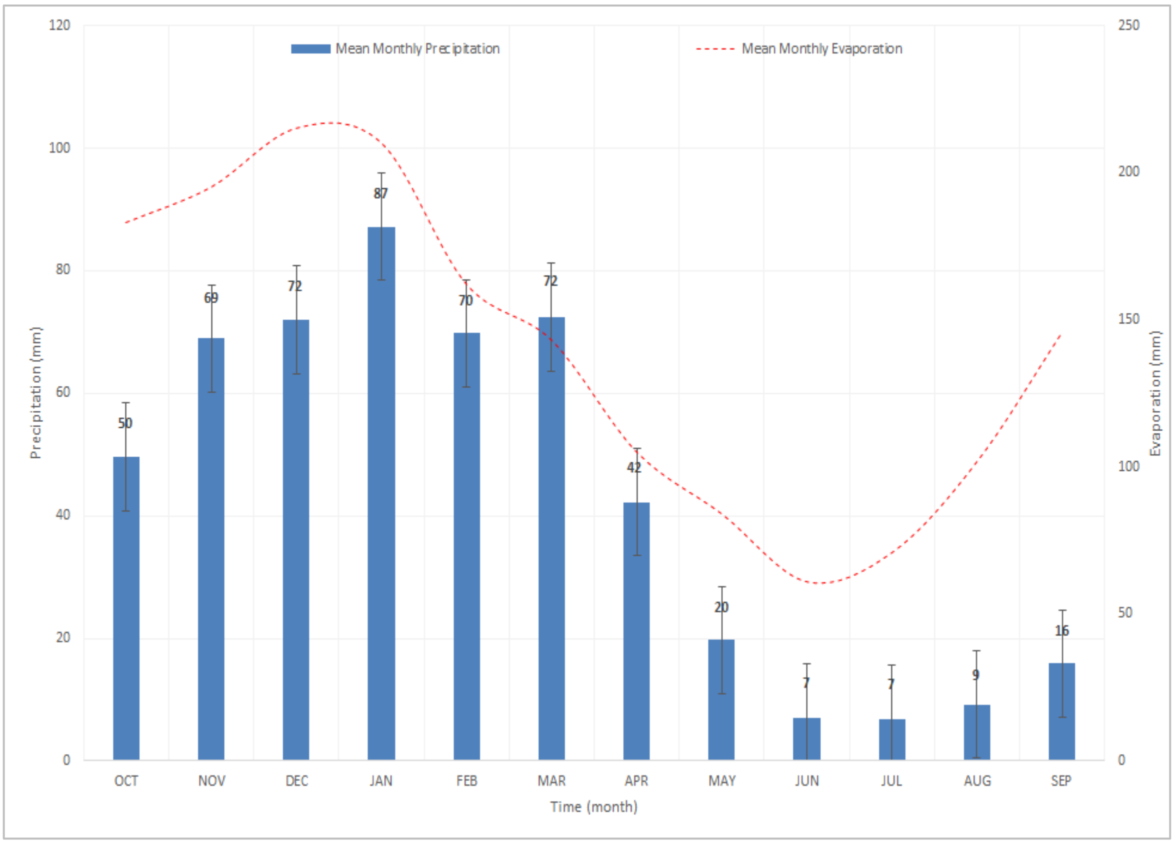


Figure 5-6 **Bar chart and curve comparing monthly rainfall and evaporation distribution for rainfall zone 4C4 (WR2012).**

5.4. Geological setting

The following sections summarises the regional and local geology.

5.4.1. Regional geology

Although the project area's surficial geology comprises mostly aeolian sands, quaternary deposits and isolated outcrops of the Karoo Supergroup i.e., dolerite and sandstone/ shales, the greater study area is generally also underlain by rocks of the Witwatersrand Supergroup as well as the Ventersdorp Supergroup. The primary source of gas originates from the Witwatersrand Supergroup as well as the shallower Karoo sediments (Lea, 2017). Figure 5-7 represents a regional geological cross section (Shango, 2016). It can be inferred from exploration borehole geological logs that the estimated depth of the unconsolidated material on-site is approximately 11.0m (Lea, 2017).

The Witwatersrand Supergroup is a sedimentary deposition across the stable granite-gneiss basement which commenced around 3 billion years ago. In stratigraphic terms the Witwatersrand sequence is divided into two divisions, the lower dominantly marine, slate rich West Rand Group and the upper dominantly alluvial sandstone rich Central Rand Group (Johnson, 2006). The Witwatersrand Supergroup depth within the study area was inferred from exploration borehole geological logs and is estimated at an average depth of >1600.0mbgl (Lea, 2017).

The Ventersdorp Supergroup uncomformably overlies the Witwatersrand Supergroup. This Group is very thick, more than 4500.0m. The lower Kliprivierberg Group is mafic lava and tuff while the upper Platberg Group is conglomerates and breccia on top of Kliprivierberg, with intermediate and felsic lava higher, with quartzite, shale and siltstone layers in between (Johnson, MR. Anhauser, CR., Thomas, RJ., 2006). The Ventersdorp Supergroup depth within the study area was inferred from exploration borehole geological logs and is estimated at an average depth of >1120.0mbgl. Gas will be extracted from deep-seated fracture zones associated with the Ventersdorp lavas and Witwatersrand quartzites (Lea, 2017).

The Karoo Super Group is the largest stratigraphic unit in Southern Africa covering almost two thirds of the land surface. The supergroup consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic, a period of about 120 million years. The Karoo Supergroup consist of argillaceous rocks of the Beaufort Group i.e. lower Adelaide Subgroup (Late Permian) and an upper Tarkastad Subgroup, the Permian Ecca Group which consist largely of shales and sandstones as well as the Dwyka Group (Late Carboniferous to Early Permian) which consists mainly of diamictite (tillite). The Ecca Group underlies the Beaufort Group in all known outcrops and exposures and follows conformably after the Dwyka Group in certain sections, however in some localities overlies unconformably over older basement rocks (Schlüter and Thomas, 2008). The Karoo Supergroup (which include the Beaufort as well as Ecca Groups) depth within the study area was inferred from exploration borehole geological logs and is estimated at an average depth of 300.0mbgl. Refer to Table 5-2 for a summary of the regional stratigraphical sequence.

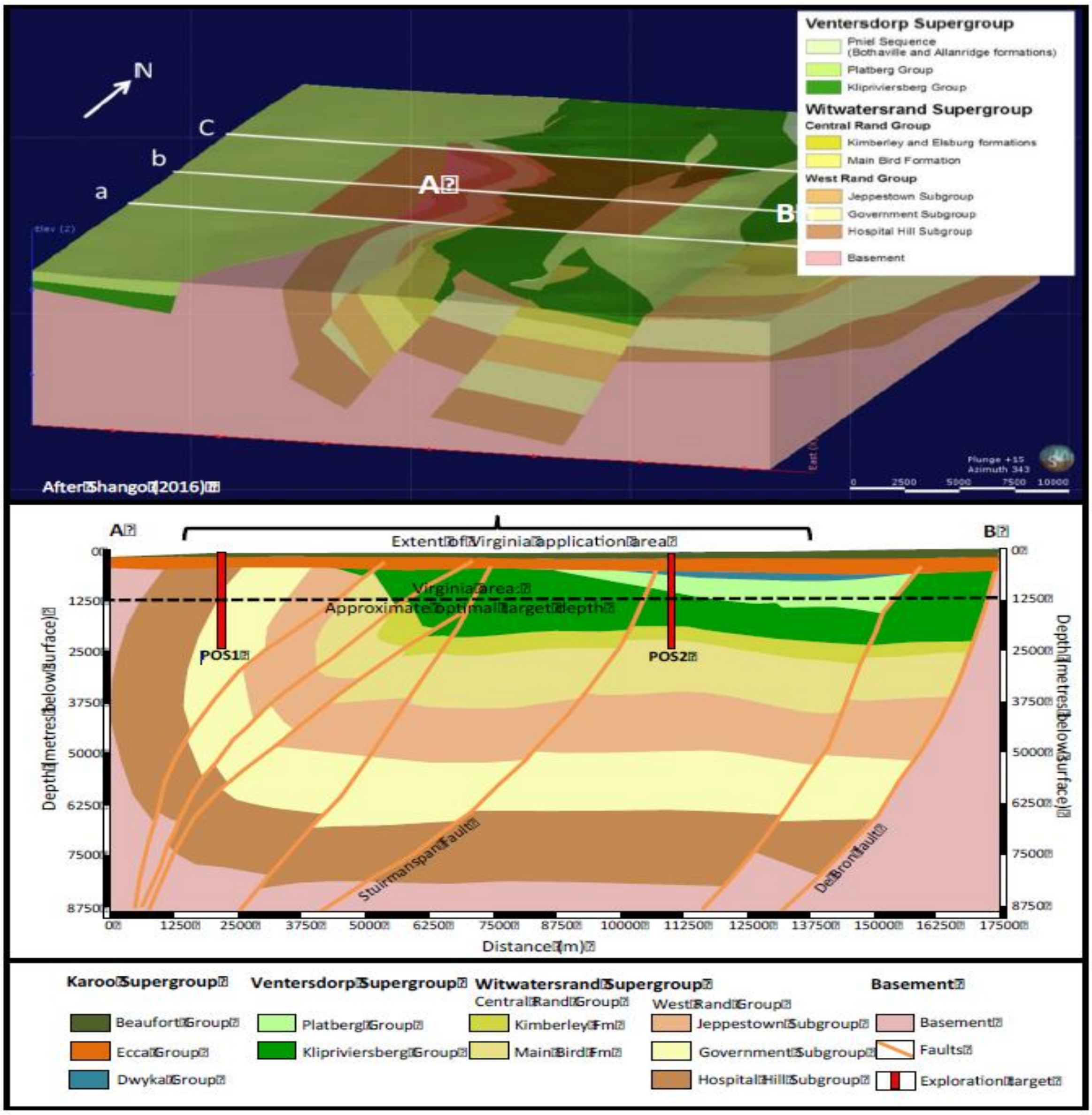


Figure 5-7 Cross section of the regional geology (after Shango, 2016).

Table 5-2 Regional stratigraphical sequence based on exploration borehole data evaluated (Figure 5-9).

Lithology	Average depth (m)	Description
Aeolian sand and alluvium	8	Quaternary unconsolidated surficial calcrete, pebbles, gravel, sand and clay
Karoo Supergroup - Ecca and Beaufort Group shales and sandstones	301	Blue-grey mudstone and shale interbedded with very fine to coarse-grained sandstone. Subordinate conglomerate may be present
Dolerite (Sill)	335	Karoo-age dolerite sills and dykes
Karoo Supergroup – Ecca and Dwyka Tillite in places	437	Glaciated bedrock including tillite, diamictite, sandstone, mudstone and conglomerates.
Ventersdorp Supergroup Lava	805	Volcanic and sedimentary deposits, unconformibly overlain on the Witwatersrand Supergroup. The Klipriviersberg Group comprises lava and tuff, while the Platberg Group consists of clastic and chemical sediments.
Witwatersrand Supergroup Quartzite	1130	Quartzite, conglomerate and subordinate shale that hosts gold-bearing reefs. Central Rand Group quartzites are prevalent in the project area.

Notes: Lithology descriptions after *i*LEH (2017)

5.4.2. Local geology

According to the 1:250 000 geological maps (2826: Winburg), a large portion of the study area's surficial geology comprises aeolian sands and quaternary deposits as shown in Figure 5-8. Isolated patches within the study area are also covered by alluvial sand deposits which is mainly associated with the Sand and Doringriver floodplains and constrained by drainage patterns and riparian zones. The site is underlain by the Adelaide Subgroup (Vpa) consisting of alternating layers of bluish-grey, greenish-grey or greyish-red mudrock and grey, very fine to medium-grained, lithofeldspathic sandstone, the Vryheid Formation (Pv) which consists mainly of fine grained mudstone, carbonaceous shale with alternating and coarse grained, bioturbated immature sandstones respectively as well as the Volksrust Formation (PVo) which consists of grey to black, silty shale with thin, usually bioturbated, siltstone or sandstone lenses and beds, particularly towards its upper and lower boundaries. The Dwyka Group consists mainly of diamictite (tillite) which is generally massive with little jointing, but it may be stratified in places. Various historical and recently drilled exploration boreholes were utilised in order to gather site specific geological data (refer to Figure 5-9). The geological database, summarising the local stratigraphical sequence, was applied to incorporate site specific geological information into the conceptual and numerical groundwater model development as shown in Figure 5-10, Figure 5-11 and Figure 5-12.

5.4.3. Structural geology

Large dolerite intrusions in the form of dykes and sills are observed throughout the study area as depicted in Figure 8-1. 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. On a regional scale various dykes can be observed which may have an impact on the local hydrogeological regime as it can serve as potential preferred pathways for groundwater flow and contaminant transport. Deep fault zones that will be targeted for gas production are associated with the Central Rand Group and Ventersdorp lavas.

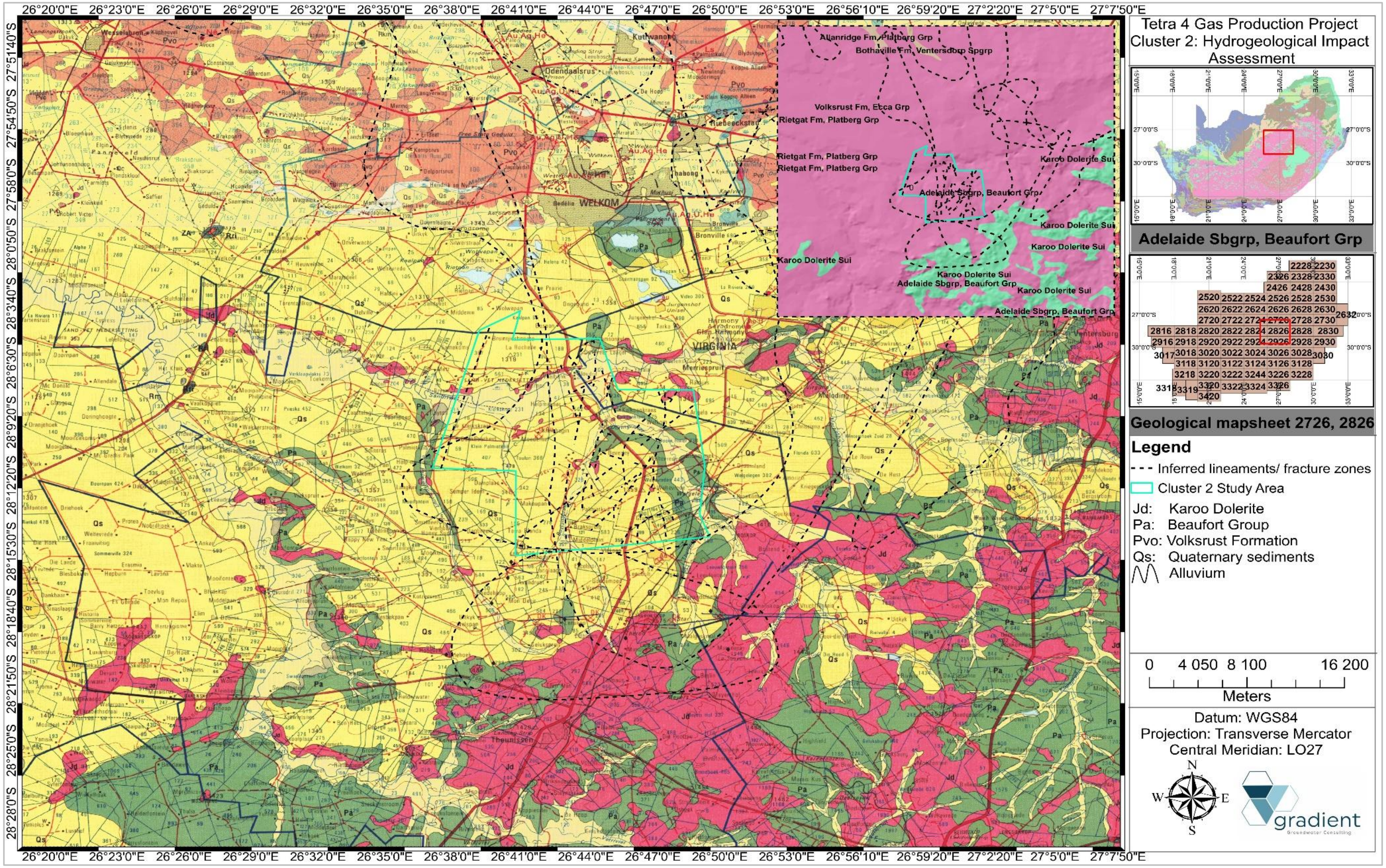


Figure 5-8 **Regional geology and stratigraphy (Geological map sheet 2826: Winburg).**

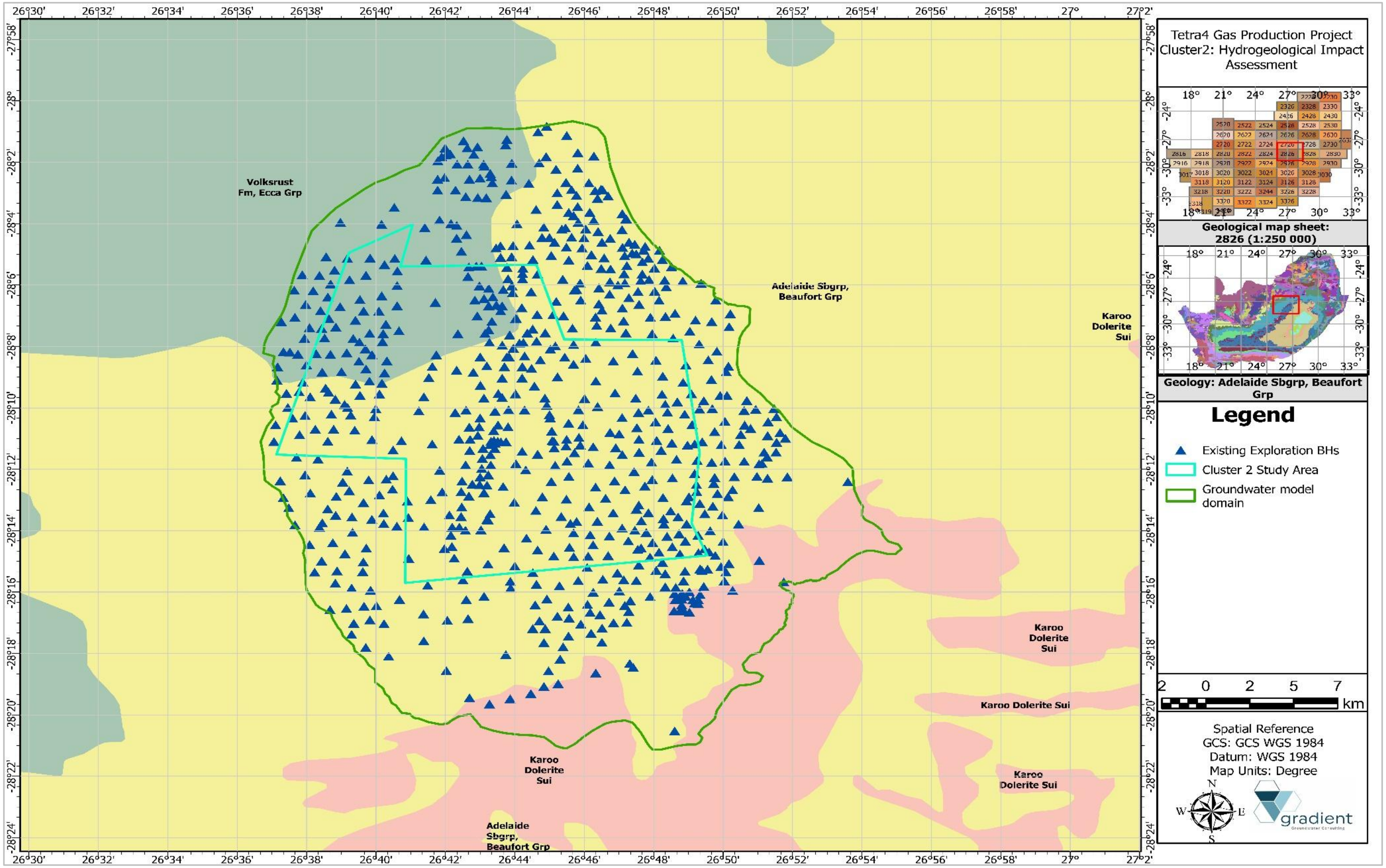


Figure 5-9 **Spatial distribution map of regional geological exploration boreholes.**

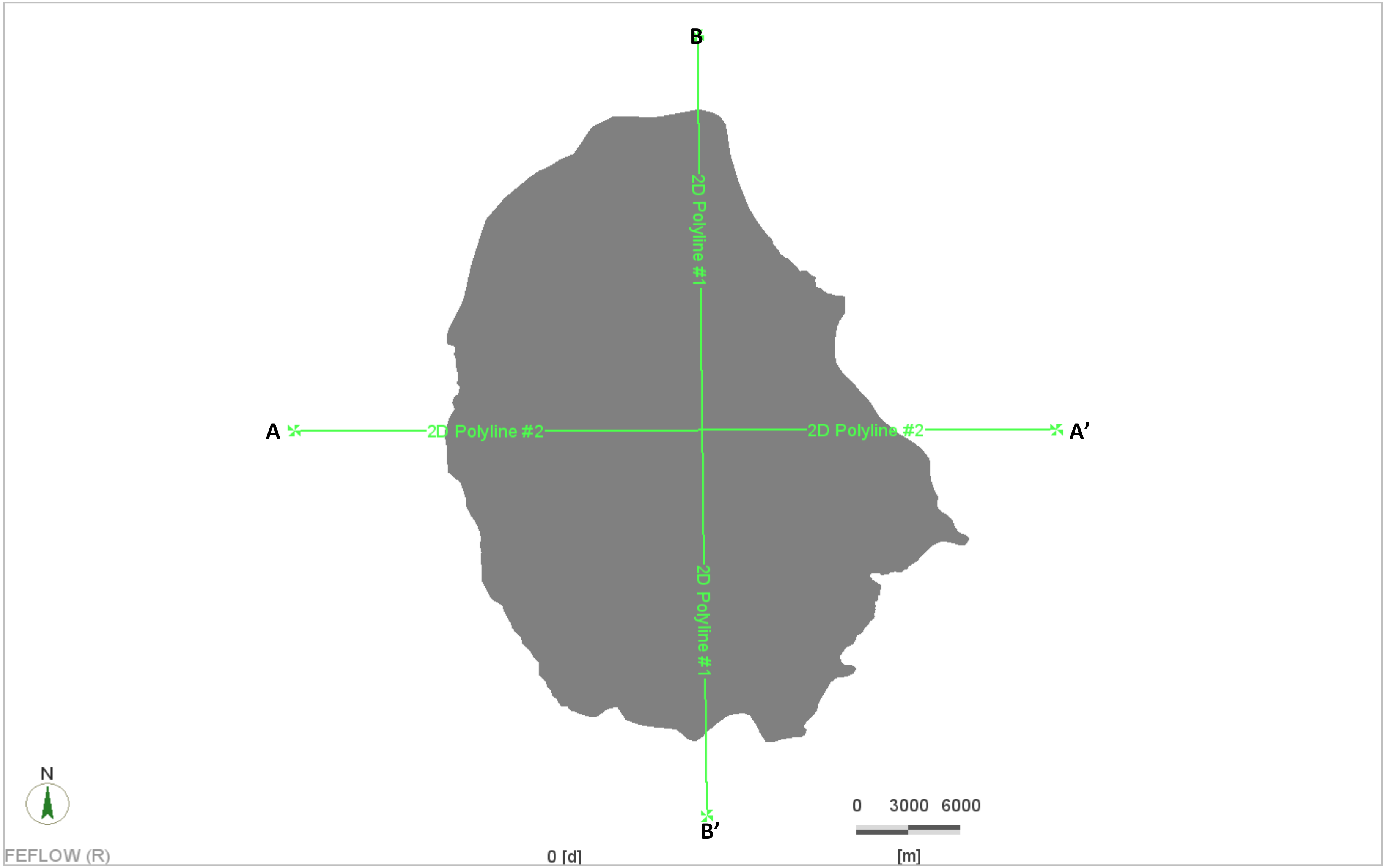


Figure 5-10 **Plan view of the modelled domain with relevant geological cross sections.**

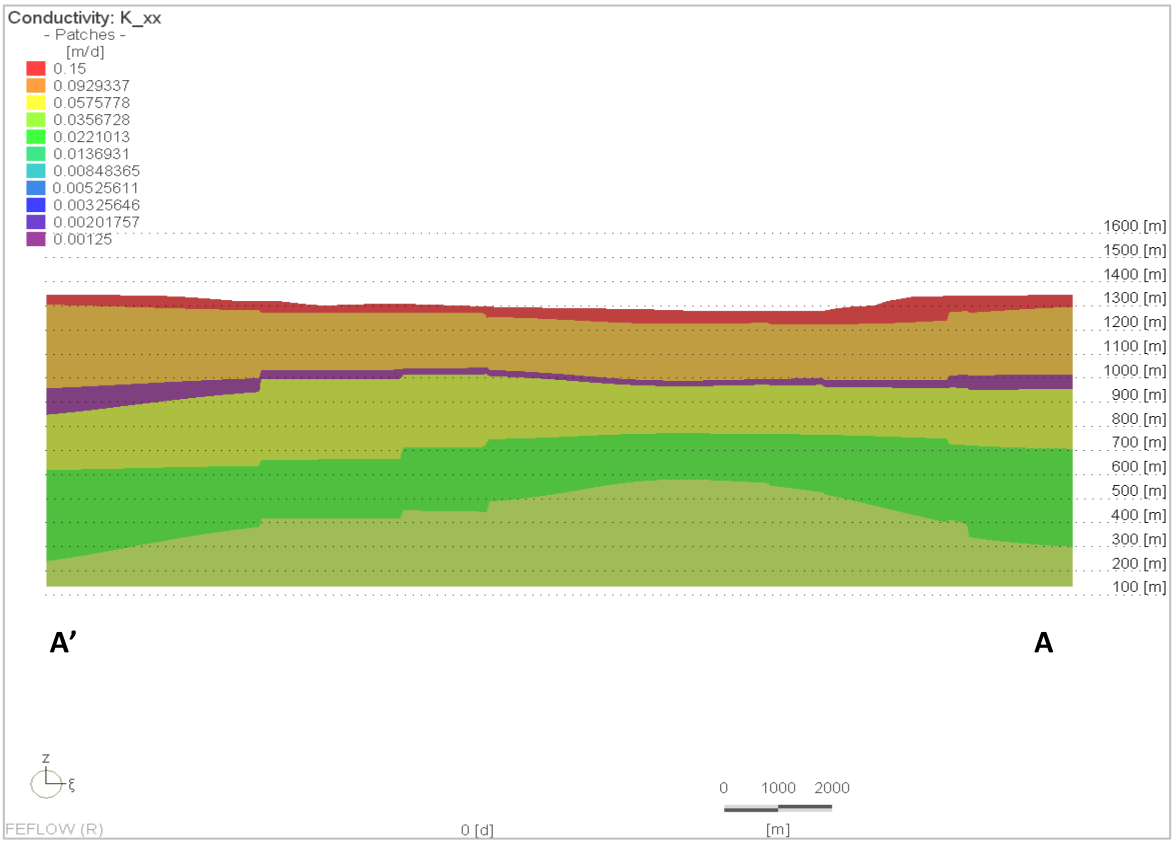


Figure 5-11 **Model cross section A-A' depicting stratigraphical sequence (refer to Figure 5-10).**

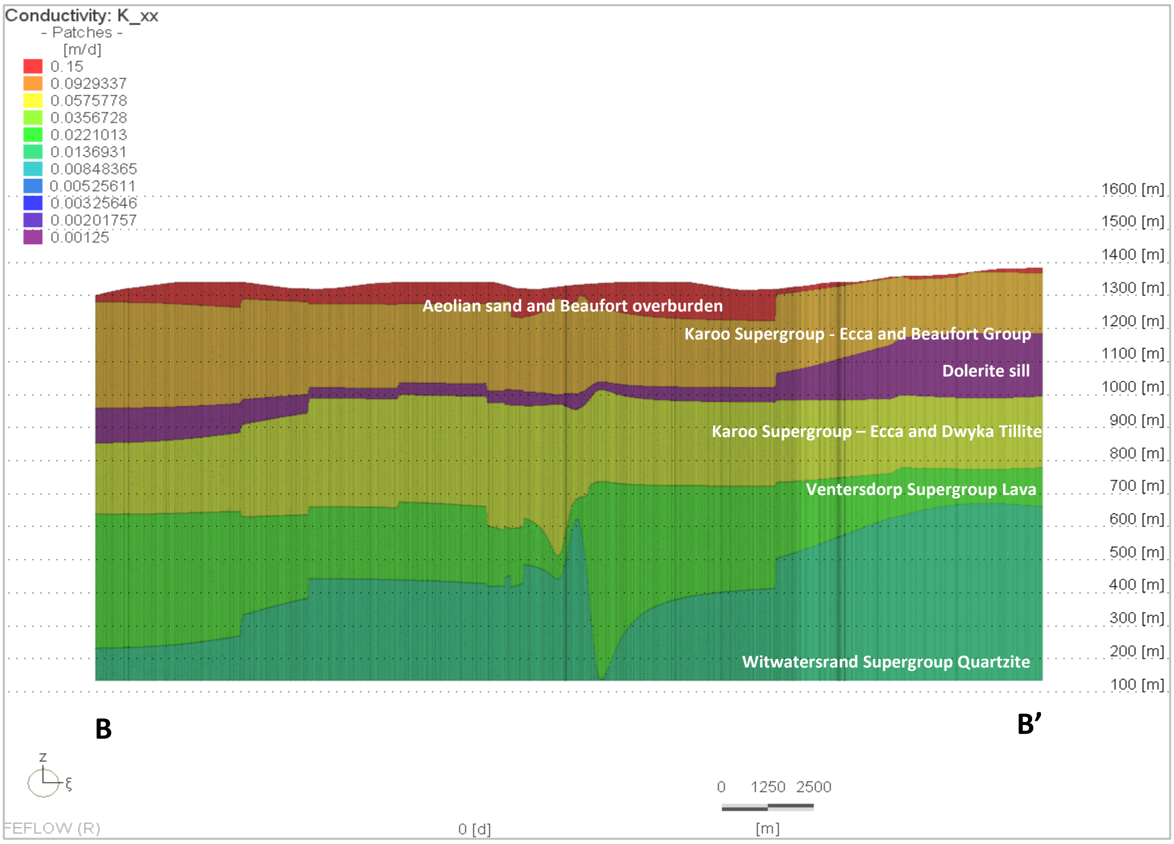


Figure 5-12 **Model cross section B-B' depicting stratigraphical sequence (refer to Figure 5-10).**

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 site is predominantly underlain by an intergranular and fractured aquifer system (d2) (refer to Figure 6-1) with the aquifer media consisting mainly of fractured and weathered compact argillaceous strata (refer to Figure 6-2). According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the North-eastern Pan Belt region. Most hard-rock aquifers are secondary in nature with groundwater associated with fracturing, fault zones as well as contact zones of the dolerite intrusions.

The geometry of argillaceous rock aquifers is complicated by the lateral migration of meandering streams over a floodplain. Aquifers in the Beaufort Group will thus 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 consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. The aquifer has a low development potential (Botha *et al*., 1998) with borehole yields ranging from 0.1 – 0.5l/s, however higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. (Barnard, 2000). The maximum aquifer thickness (i.e., shallow, intergranular aquifer system) is 20m with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level. It should be noted that the hydrogeological desktop assessment has been confirmed by means of a site-specific aquifer characterisation phase performed as discussed under Section 8 of this report.

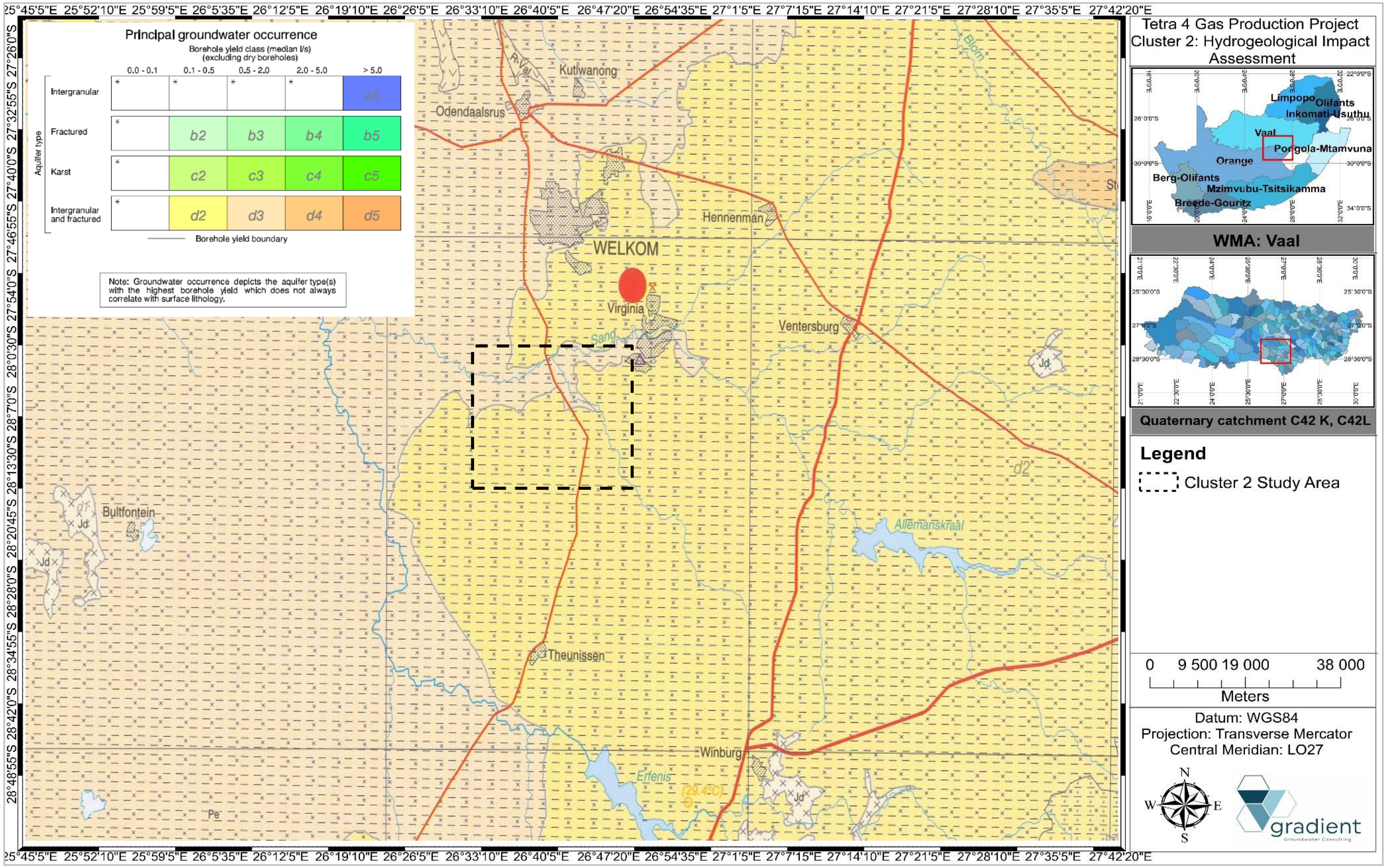


Figure 6-1 **Hydrogeological map illustrating the typical groundwater occurrence for the study area (2726 Kroonstad).**

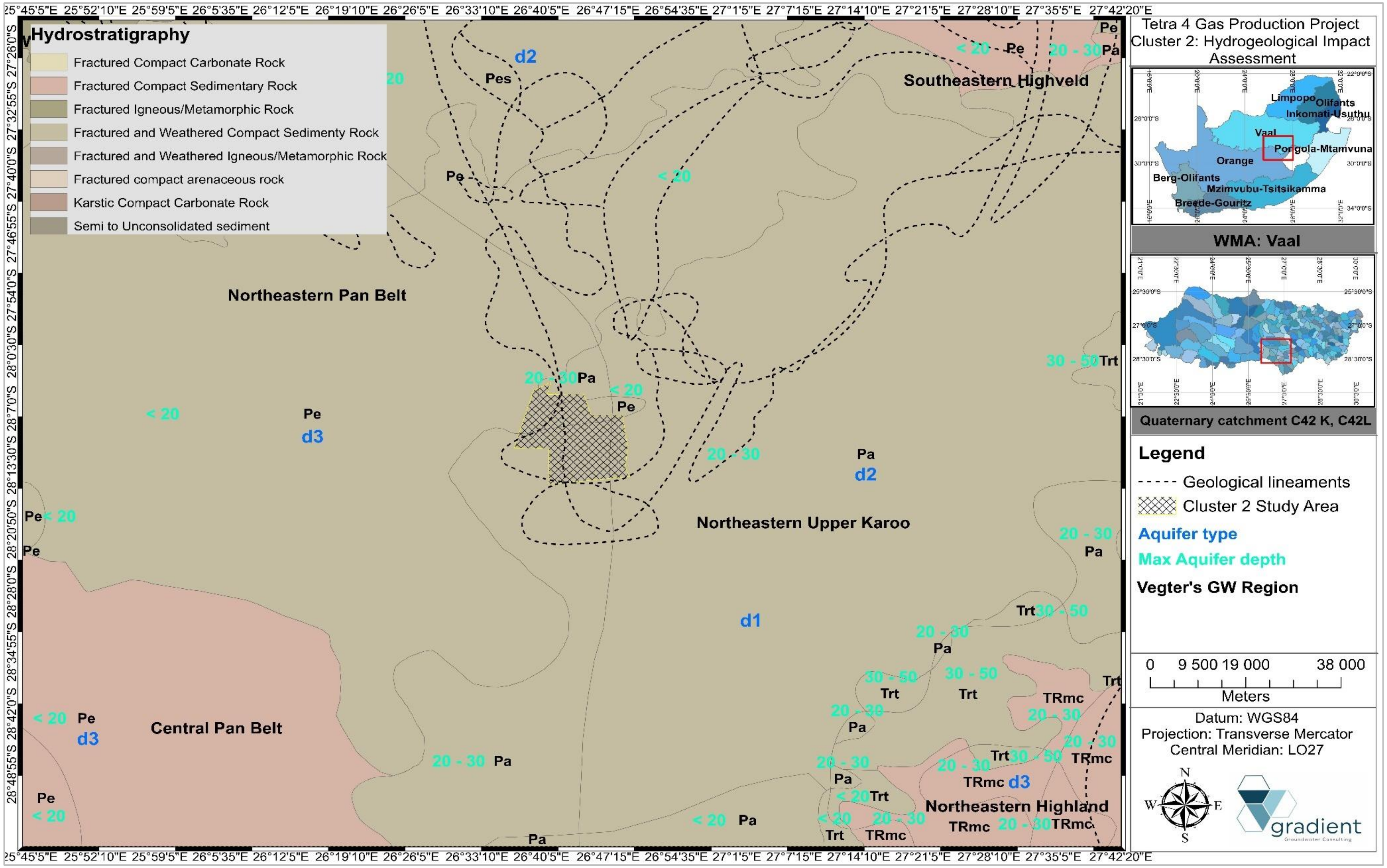


Figure 6-2 **Hydrogeological map illustrating the typical groundwater occurrence for the study region (2726 Kroonstad).**

6.2. Local hydrostratigraphic units

For the purposes of this investigation, four main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone (also refer to Table 6-1 for a typical section of the local hydrogeological sequence(Tetra4, 2017)):

i. **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. These aquifers cover a large portion of the study area and are limited to a zone of variable width and depth. The alluvial aquifer is specifically vulnerable to contamination as it there is a direct connectivity with rivers and streams and associated high permeability.

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

iii. **An intermediate, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults, contact zones as well as fracture zones that occur in the relatively competent Karoo Supergroup host rock. Fractured sandstones, mudstones and shales sequences are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Although generally low yielding, this aquifer is important to local groundwater users as it forms the sole source of water supply in the region (Lea, 2017).

iv. **A deeper, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults and contact zones fracture zones that occur in the relatively competent Ventersdorp and Witwatersrand Supergroups host rock. Volcanic formations of the Ventersdorp lavas can also act as aquicludes, restricting the vertical movement of groundwater. Fractured quartzites of the Witwatersrand Supergroup are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. The water in the deep aquifers is naturally saline due to their marine depositional history. Below a depth of 300.0m, groundwater quality deteriorates, and the permeability of the water-bearing formations decreases by orders of magnitude and consequently these aquifers are not used for water supply or private water use (Steyl et al, 2012). It should be noted that the shallow potable Karoo aquifers are separated from deep aquifer systems associated with the Ventersdorp and Witwatersrand Supergroup formations by the 30.0m thick dolerite sill (which may act as an aquitard) that extends across the study area and by the 65.0m thick Dwyka Tillite sedimentary deposit acting as an aquiclude (Lea, 2017). It should furthermore be noted that, under natural conditions, there is very limited hydraulic connectivity between the deep, fractured and shallow, intergranular aquifers (Steyl et al, 2012).

Table 6-1 **Typical hydrogeological section (after Tetra4, 2017).**

Average depth (m)	Lithology	Target zone	Depositional Environment/Lithology
11	Alluvium	Not a target zone. Will be cased and cemented off in gas wells.	**Lithological description:** Alluvial sand/gravel interbedded with lenses of clay material situated along riparian zones. **Aquifer system:** Primary aquifer. High porosities and permeabilities are associated with the alluvium. The aquifer is recharged during periods of high stream flows. It is unconfined and typically has a high specific yield. Groundwater levels are commonly shallow (<3m). Alluvial aquifers play an important role in groundwater-surface water interaction, as they are directly connected to the rivers/streams. Due to the unconfined nature, shallow groundwater table and high permeability of the aquifer, it is vulnerable to surface sources of contamination.
11	Quaternary Aeolian Sands		**Lithological description:** Calcrete, ferricrete and red Aeolian sand layers. **Aquifer system:** Intergranular aquifer. High porosities, permeabilities and rates of recharge of rainwater are associated with the unconsolidated sands, which makes this aquifer vulnerable to surface sources of contamination. Regional groundwater level measurements suggest that the quaternary sediments may carry groundwater. The aquifer, where present, is unconfined, typically has a high specific yield and form an important recharge mechanism to the underlying fractured and intergranular aquifers.
400	Karoo Supergroup: Ecca and Beaufort Groups		**Lithological description:** Shales, siltstone, sandstone & coal. **Aquifer system:** Low-yielding anisotropic fractured aquifer. Groundwater is associated with fractures, jointing and bedding planes within the shales. Lithological contact zones and the transition from weathered to fresh rock could also be associated with increased groundwater yield. Increased groundwater yields are further associated with the contact zones of dolerite intrusions. These represent thin linear zones of higher permeability, acting as conduits to groundwater flow. Borehole yields associated with dykes are highly variable due to the variability of the aquifer parameters along the strike of dykes. The dykes can also act as semi-impermeable barriers to groundwater flow. Local farmers target the Karoo aquifer for water supply. Although the aquifer is low yielding, it plays an important role in terms of local water supply.
330	Karoo age: Dolerite sill		**Lithological description:** Dolerite dyke and sill intrusions. **Aquifer system:** Heterogenous anisotropic confined fractured aquifer. Contact zones between the intrusion and the host rock typically form a thin linear zone of increase permeability, which act as preferential conduits to groundwater flow. The intrusive, however, normally has a very low permeability and act as an aquitard or even a barrier to groundwater flow. Aquifer potential associated with dykes and sills are highly variable as a result of the variable aquifer parameters along the strike of the intrusion.
400	Karoo Supergroup: Dwyka Group		**Lithological description:** Predominantly tillite and diamictite. **Aquifer system:** Heterogenous anisotropic confined fractured aquifer. These formations tend to form aquitards, rather than aquifers. Since the Dwyka sediments were deposited mainly under marine conditions, the water in these formations is saline.
1120	Ventersdorp Supergroup	Target Zone	**Lithological description:** Quartzites and lavas **Aquifer System:** Intergranular and fractured aquifer system. The volcanic and sedimentary rocks generally have low porosities and permeabilities. The aquifers are typically confined. The volcanic formations can act as aquicludes, restricting the vertical movement of groundwater. The sedimentary rocks are typically higher yielding aquifers.
Greater than 1600	Witwatersrand Supergroup		**Lithological description:** Quartzites, conglomerates, gold-bearing reefs and shales **Aquifer System:** Fractured aquifer. Groundwater is associated with secondary fractures, which in turn are associated with shear zones and intrusive rock formations. Faults zones and weathered rock formations in deep gold mines result in large volumes of groundwater inflow into mines. This aquifer is isolated from the shallow potable Karoo aquifers by Ventersdorp volcanics as well as Karoo shales and the dolerite sill.

6.3. Hydraulic parameters

To follow is a brief overview of aquifer hydraulic parameters based on published literature for similar hydrogeological conditions as. Refer to Section 8 of this report for a detailed discussion on the interpretation of site representative hydraulic parameters.

6.3.1. Hydraulic conductivity and Transmissivity

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

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

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

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)

According to literature, the hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. Historical aquifer tests results confirm that the permeability of the shales is very low ($9E^{-4}$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 as depicted in Figure 6-3 (Freeze and Cherry, 1979).

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

Equation 6-2 Transmissivity.

$$T = Kb$$

where:

T = Transmissivity (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

From historical aquifer tests conducted it is calculated that the average transmissivity for the shallow, weathered aquifer ranges between 0.12 m^2/d to 0.6m^2/d depending on the saturated thickness of the aquifer targeted. The site characterisation phase indicates that the local transmissivity values range between 0.12m^2/d to 11.0m^2/d with a mean value of 1.04m^2/d.

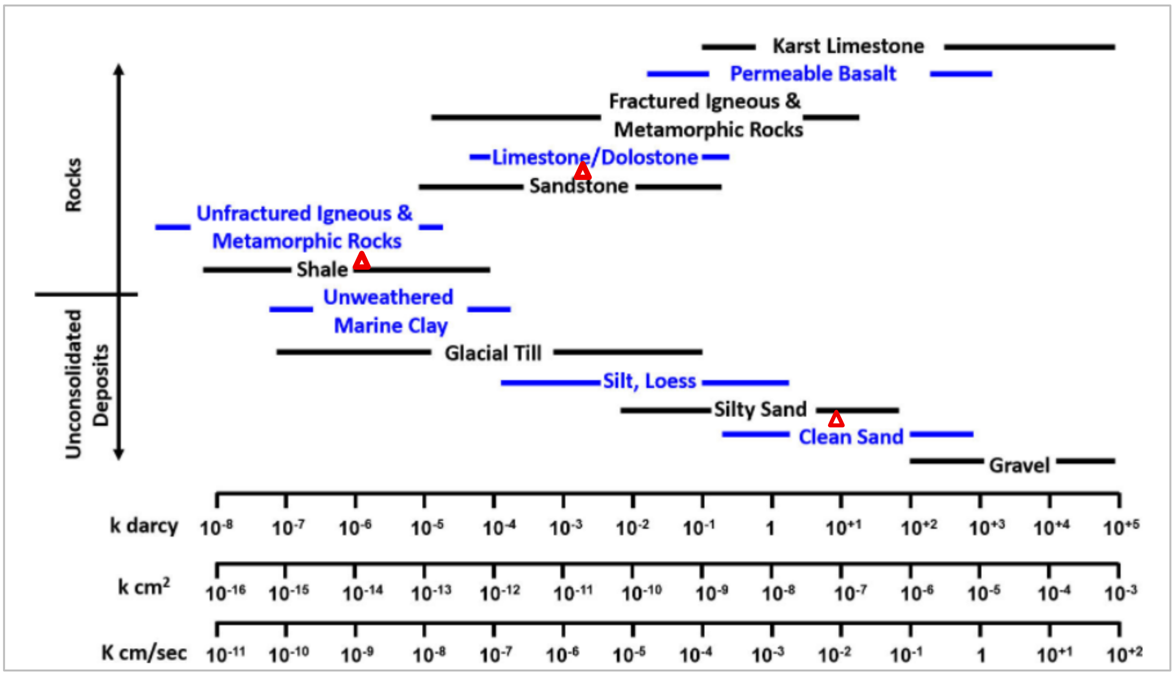


Figure 6-3 **Typical hydraulic conductivity values for on-site hydrostratigraphical units.**

6.3.2. Storativity

Storativity refers to the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. Typical storativity values for 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., $10E^{-2}$.

6.3.3. Porosity

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).

6.3.4. Recharge

An approximation of recharge for the study area is estimated at ~4.0% of MAP i.e., ~21.69 mm/a as summarised in Table 6-2. Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using a qualified opinion as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride (Cl) method (Figure 6-4) (ii) Geology (iii) Vegter Groundwater Recharge Map (Figure 6-7) (iv) Harvest Potential (Figure 6-8) (v) Baseflow as a minimum of recharge (vi) Qualified opinion and, (vii) Literature review. Figure 6-4 to Figure 6-6 summarises the recharge calculations (CMB methodology) based on the specific geological formation targeted.

Table 6-2 Recharge estimation (after van Tonder and Xu, 2000).

Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Chloride	15.40	2.96	4.00
Geology	21.60	4.15	2.00
Vegter	32.00	6.14	3.00
Harvest Potential	25.00	4.80	2.00
Baseflow	25.00	4.80	2.00
Qualified Opinion	18.24	3.50	4.00
Literature	14.58	2.80	3.00
Weighted average	**21.69**	**4.01**	**20.00**

Notes: Recharge per annum were calculated using a MAP of 521.0 mm/a.

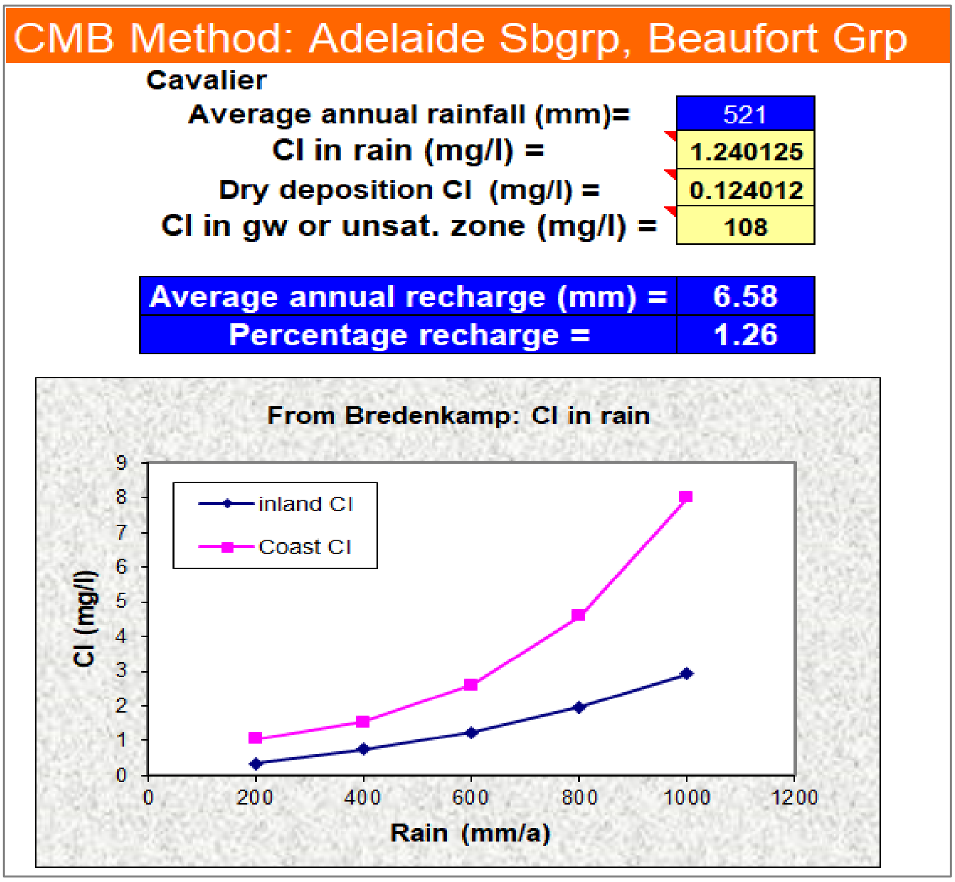


Figure 6-4 Chloride Mass Balance (CMB) method recharge summary: Adelaide Sbgrp, Beaufort Grp Aquifer.

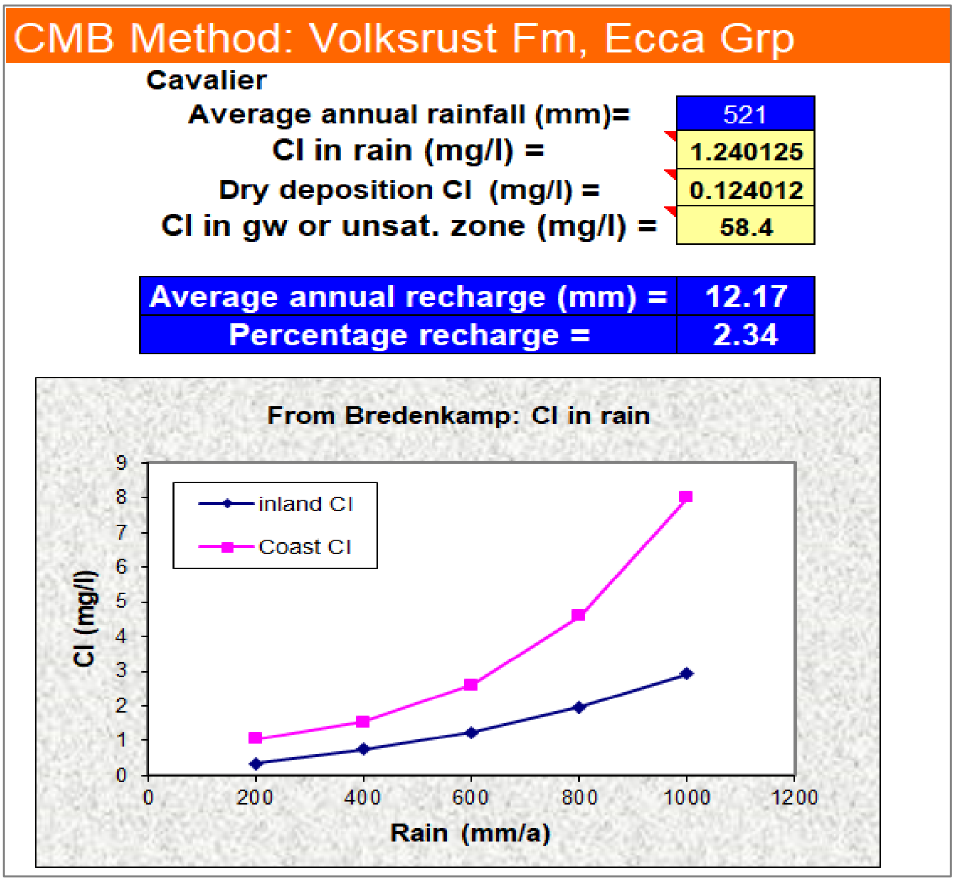


Figure 6-5 Chloride Mass Balance (CMB) method recharge summary: Volksrust Fm, Ecca Grp.

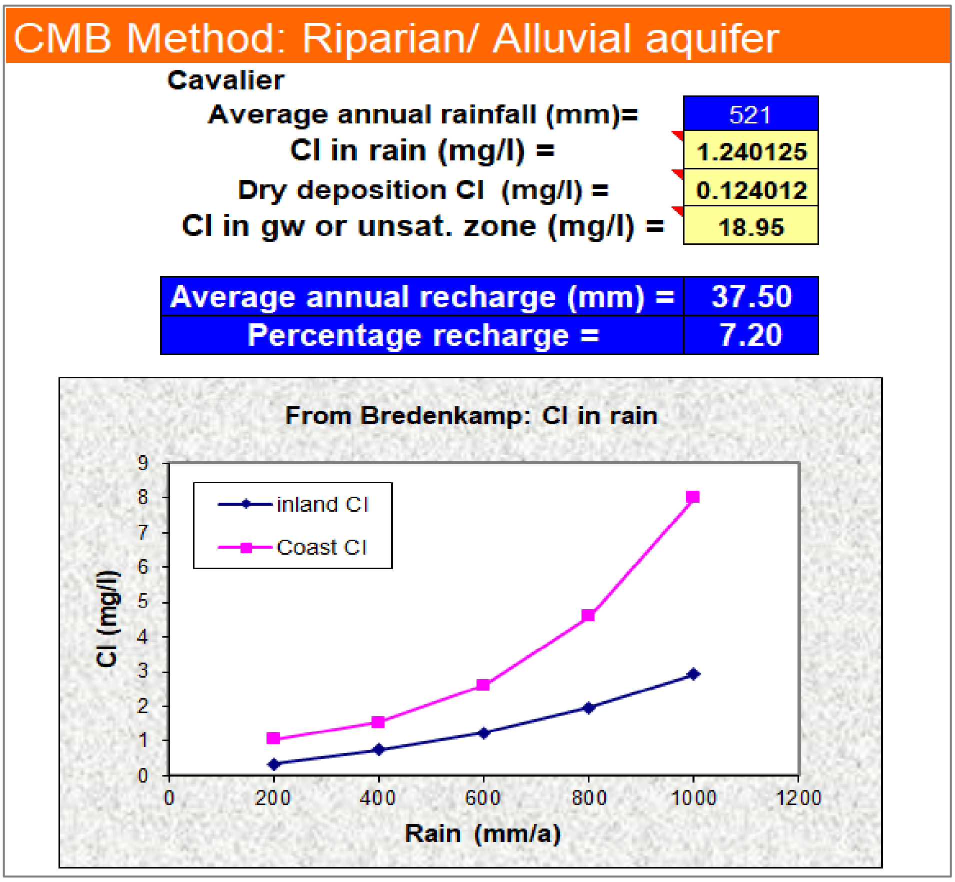


Figure 6-6 Chloride Mass Balance (CMB) method recharge summary: Riparian zonw/ Alluvial Aquifer.

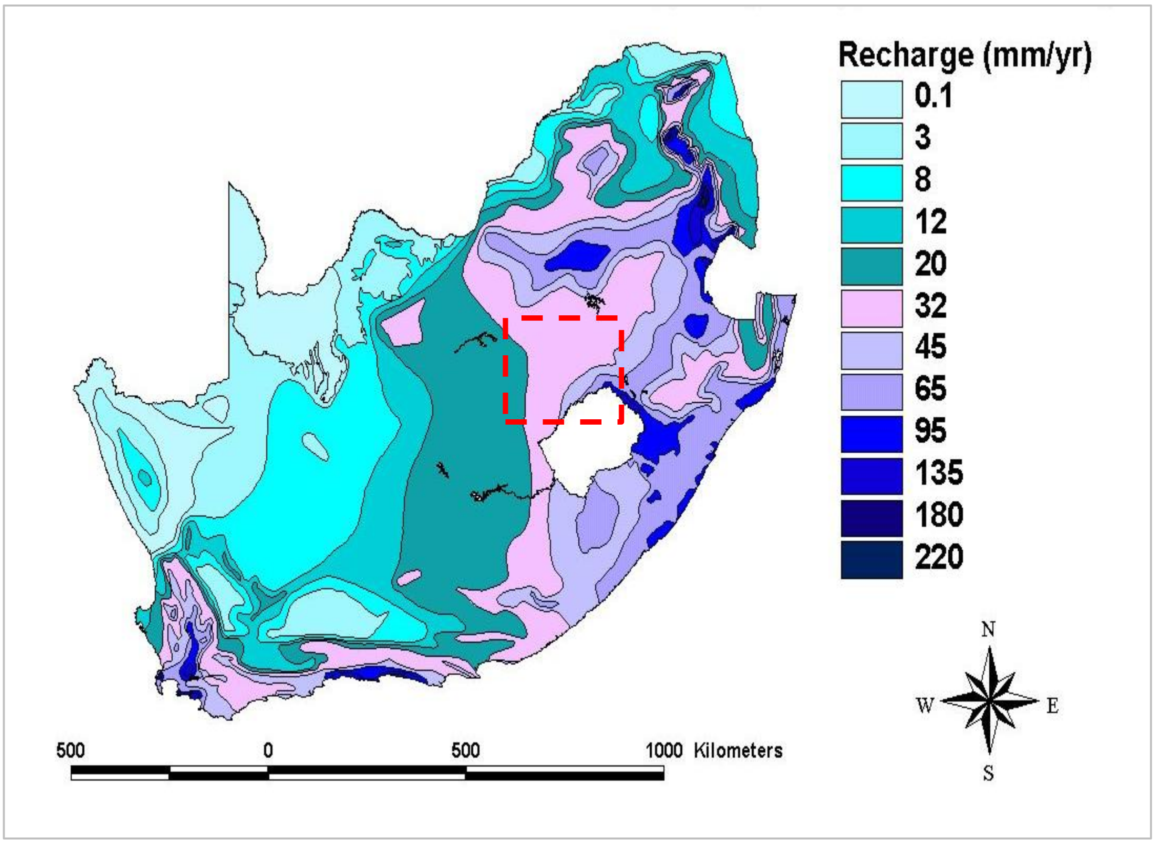


Figure 6-7 **Groundwater recharge distribution in South Africa (After Vegter, 1995).**

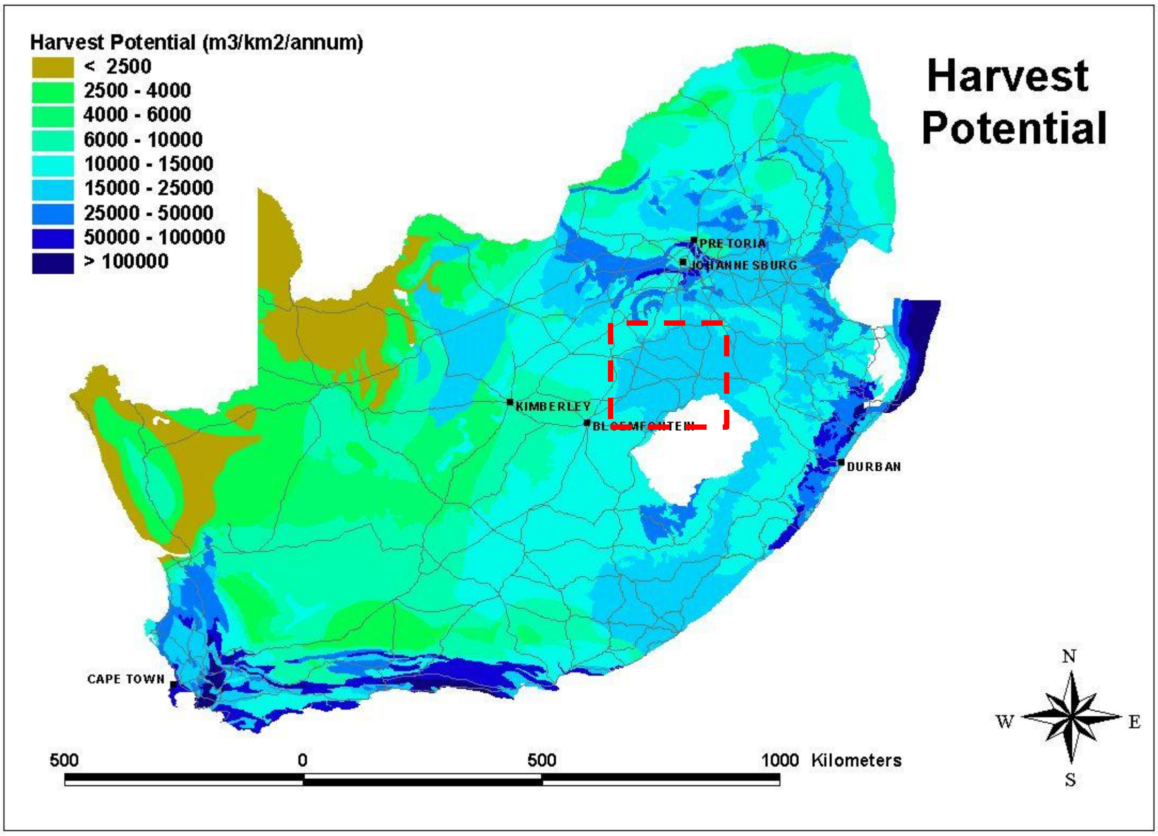


Figure 6-8 **Harvest potential distribution in South Africa (DWS, 2013).**

7. SITE INVESTIGATION

7.1. Hydrocensus user survey

A hydrocensus user survey within the greater study area was conducted during March 2022[5] as well as in October 2024[6] 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 gas production operations. A total of 171 geosites were visited and recorded which include surface water and groundwater receptors (refer to Figure 7-1) i.e., boreholes, artesian wells, wind pumps as well as surface water features were visited as part of the hydrocensus user survey which are largely applied for livestock watering and domestic water supply purposes. Relevant hydrocensus information is summarised in Table 7-1 (2022 hydrocensus user survey) and Table 7-2 (2024 hydrocenus user survey). Figure 7-5 depicts the spatial distribution of geosites visited as part of the hydrocensus user surveys while Figure 7-6 indicate the various groundwater status and applications.

7.1.1. Groundwater status

Of the boreholes recorded, the majority are in use (~75.0%) while ~23.0% are not currently being utilized. Approximately 2.0% of boreholes allocated could not be visited due to access challenges. 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 and domestic water supply purposes (~35.0%) while domestic and household purposes which are combined with either irrigation or livestock purposes account for >16.0%. A small number of boreholes are also being applied for either monitoring or industrial purposes (~5.0%) while ~27.0% of boreholes do not have an application and are not currently being utilized. 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 54.0%, while 18.0% of boreholes were fitted either with a wind pump, mono pump (2.0%), handpump (1.0%) or solar pump (1.0%). An average of 22.0% 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.
[6] It should be noted that relevant site information gathered will be representative of dry season contribution and conditions.

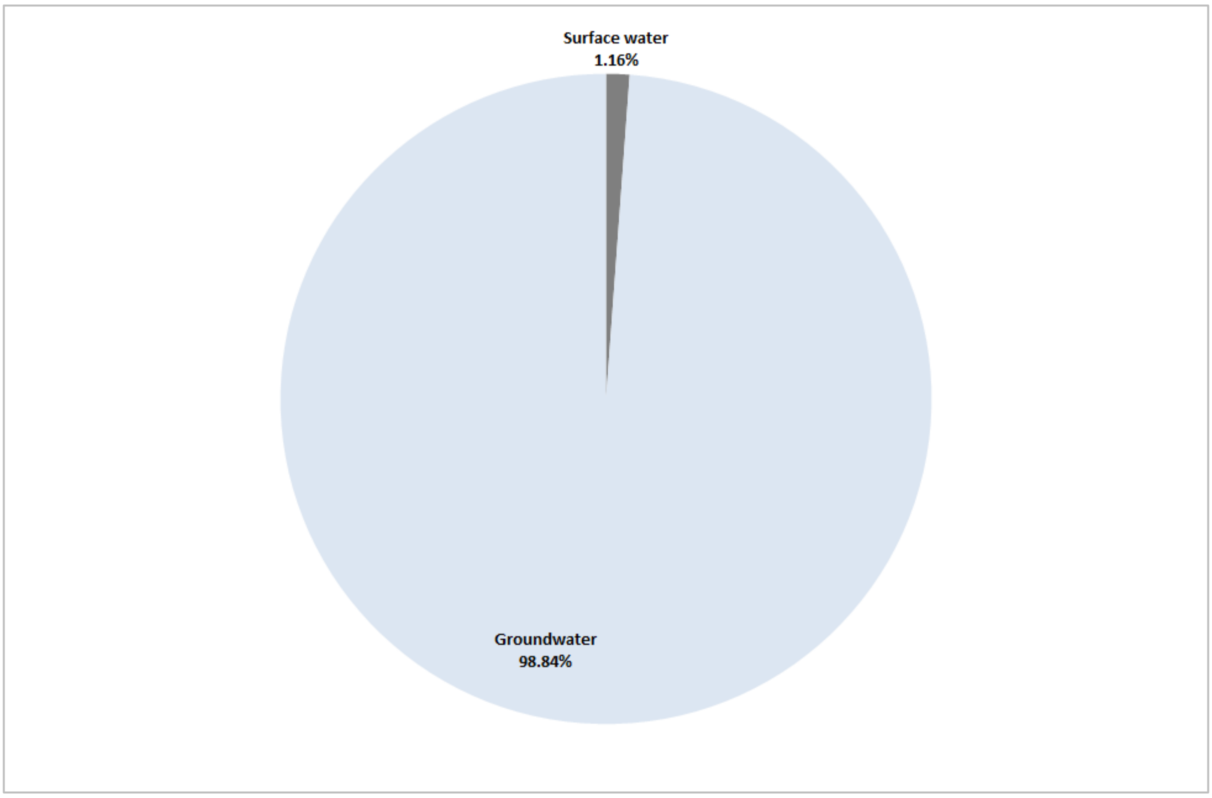


Figure 7-1 Hydrocensus user survey: Geosite type.

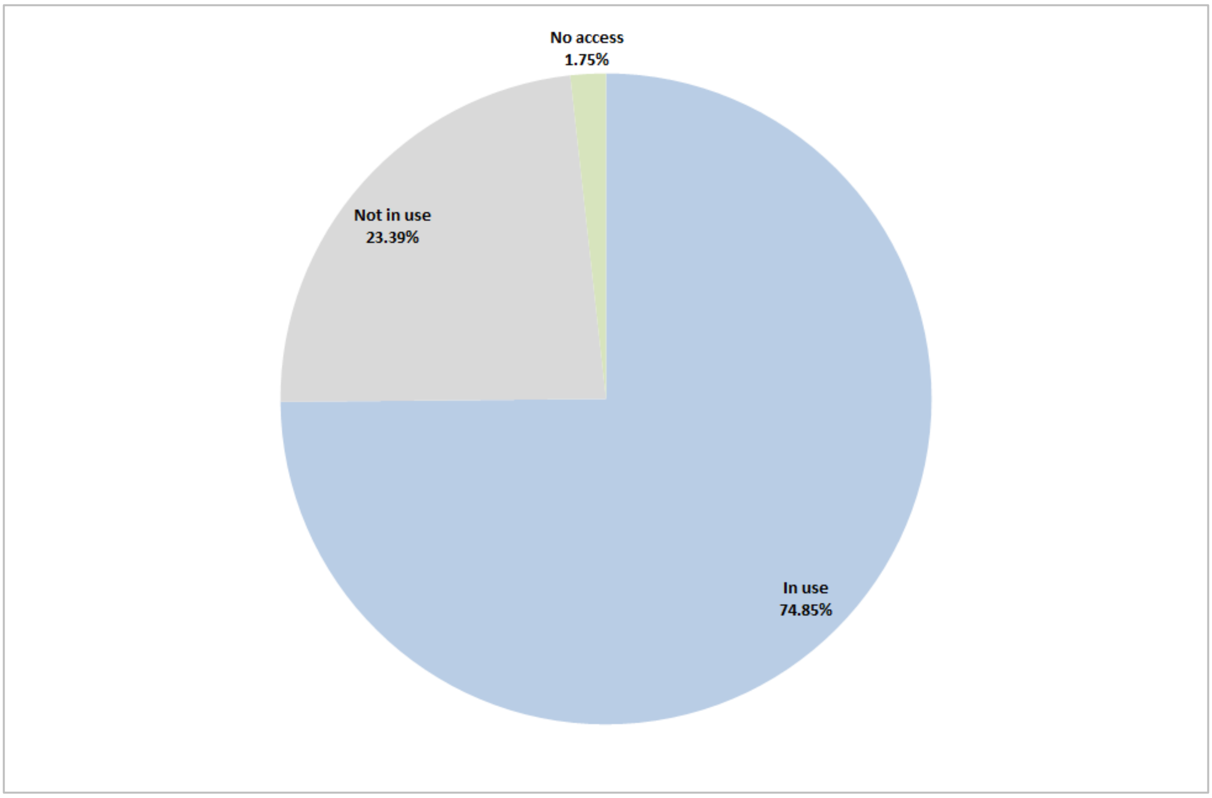


Figure 7-2 Hydrocensus user survey: Groundwater status.

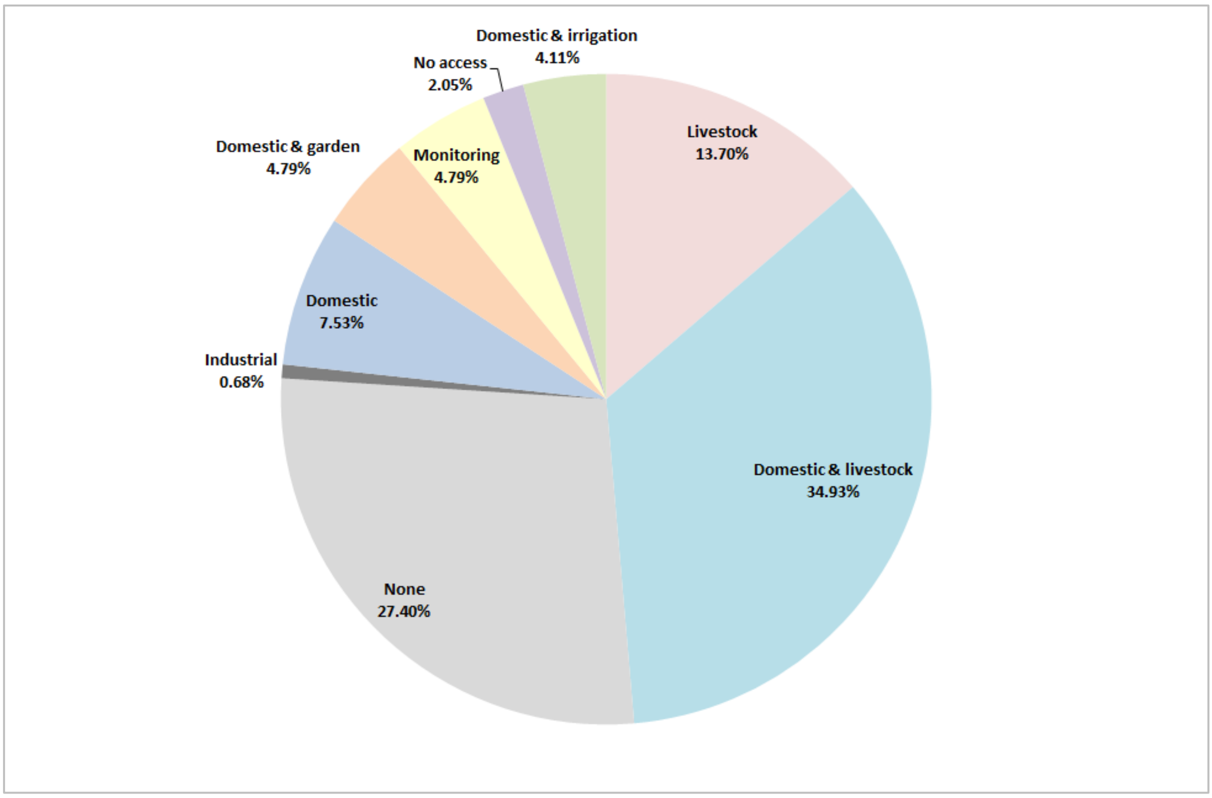


Figure 7-3 **Hydrocensus user survey: Groundwater application.**

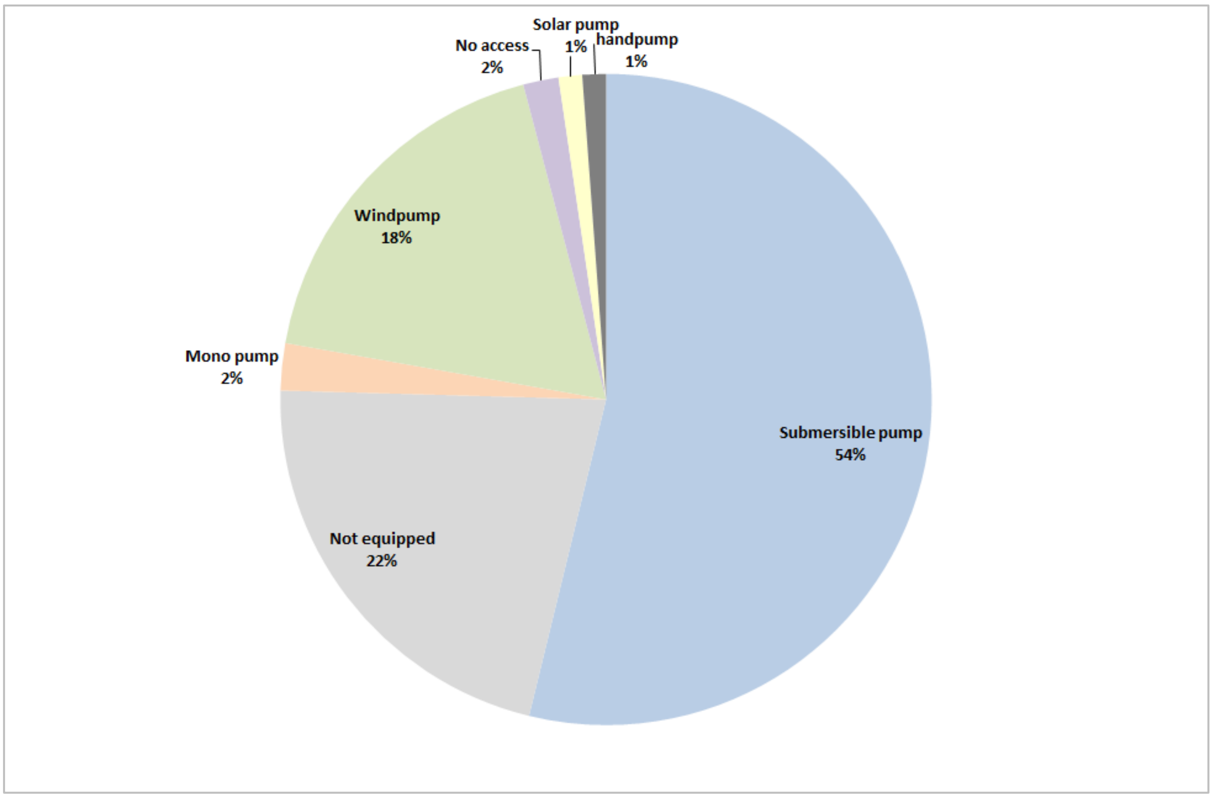


Figure 7-4 **Hydrocensus user survey: Equipment type.**

Table 7-1 Hydrocensus user survey: relevant information for geosites visited as part of the 2022 survey.

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH1	-28.14362	26.80863	NAWL		Borehole	In use	Submersible pump		Livestock	Flooded Area
HBH2	-28.12872	26.80516	NAWL		Borehole	In use	Windpump		Domestic & livestock	
HBH3	-28.12768	26.80522	NAWL		Borehole	In use	Submersible pump		Domestic & livestock	ROCLA
HBH4	-28.12407	26.80630	NAWL		Borehole	In use	Submersible pump		Domestic & livestock	ROCLA
HBH5	-28.11982	26.80036	NAWL		Borehole	In use	Submersible pump		Domestic & livestock	ROCLA
HBH6	-28.12005	26.79521	1.52	30	Borehole	In use	Submersible pump		Domestic & garden	
HBH7	-28.12940	26.77388	NAWL		Borehole	Not in use	No access		None	Blocked
HBH8	-28.15651	26.79403	NAWL		Borehole	In use	Submersible pump		Livestock	
HBH9	-28.15477	26.78428	10.87	30	Borehole	In use	Submersible pump		Livestock	
HBH10	-28.11906	26.81375	NAWL		Borehole	In use	Submersible pump		Industrial	ROCLA
HBH11	-28.11540	26.81199	NAWL		Borehole	In use	Submersible pump		Domestic	
HBH12	-28.13337	26.76153	13.65	30	Borehole	In use	Submersible pump		Domestic & livestock	
HBH13	-28.13200	26.76094	12.35	70	Borehole	In use	Submersible pump		Domestic & livestock	
HBH14	-28.12823	26.75381	16.65		Borehole	In use	Submersible pump		Domestic & livestock	
HBH15	-28.12852	26.75373	17.74		Borehole	In use	Submersible pump		Domestic & livestock	
HBH16	-28.13105	26.75641	25.40	45	Borehole	In use	Submersible pump		Domestic & livestock	
HBH17	-28.12700	26.75455	11.55	40	Borehole	In use	Submersible pump		Domestic & livestock	
HBH18	-28.13405	26.75741	16.47	40	Borehole	Not in use	Not equipped		None	Open
HBH19	-28.13356	26.75760	NAWL		Borehole	In use	Submersible pump		Domestic & livestock	
HBH20	-28.08584	26.75406	1.10	70	Borehole	In use	Submersible pump		Domestic & livestock	
HBH21	-28.09424	26.73133	2.67		Borehole	Not in use	Not equipped		None	Open
HBH22	-28.11837	26.71244	NAWL		Borehole	Not in use	Not equipped		None	Closed
HBH23	-28.10725	26.70513	3.16	18	Borehole	Not in use	Not equipped		None	Open
HBH24	-28.11683	26.70197	8.50		Borehole	In use	Submersible pump		Domestic & livestock	
HBH25	-28.11792	26.68013	24.20		Borehole	In use	Submersible pump		Domestic & livestock	
HBH26	-28.12714	26.65699	NAWL		Borehole	Not in use	Not equipped		None	Closed
HBH27	-28.12845	26.65437	1.40		Borehole	In use	Submersible pump		Domestic & livestock	
HBH28	-28.06977	26.66653	5.02	40	Borehole	In use	Submersible pump		Domestic	
HBH29	-28.07050	26.66551	NAWL		Borehole	In use	Mono pump		Livestock	
HBH30	-28.07475	26.67059	NAWL		Borehole	In use	Submersible pump		Livestock	
HBH31	-28.10189	26.64343	0.00		Borehole	In use	Not equipped		Domestic & garden	Artesian
HBH32	-28.09055	26.65710	NAWL		Borehole	In use	Mono pump		Domestic & garden	
HBH33	-28.11279	26.63522	15.70		Borehole	In use	Submersible pump		Domestic & garden	

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH34	-28.12682	26.69912	26.04	60	Borehole	In use	Submersible pump		Domestic & livestock	
HBH35	-28.11991	26.69965	3.70	20	Borehole	In use	Submersible pump		Domestic & garden	
HBH36	-28.06441	26.66184	2.66	18	Borehole	In use	Submersible pump		Domestic & garden	
HBH37	-28.06606	26.66227	3.18	20	Borehole	In use	Submersible pump		Domestic & garden	
HBH38	-28.18060	26.64045	2.94	50	Borehole	In use	Submersible pump		Livestock	
HBH39	-28.16963	26.63504	8.26	40	Borehole	In use	Submersible pump		Domestic & livestock	
HBH40	-28.16964	26.63456	8.75	16	Borehole	Not in use	Not equipped		None	Open
HBH41	-28.14747	26.72413	NAWL	80	Borehole	In use	Submersible pump		Domestic & irrigation	
HBH42	-28.14750	26.72416	NAWL	80	Borehole	In use	Submersible pump		Domestic & irrigation	
HBH43	-28.15102	26.72540	NAWL		Borehole	Not in use	Not equipped		None	No access
HBH44	-28.15038	26.72384	8.46	50	Borehole	In use	Submersible pump		Domestic & livestock	
HBH45	-28.15055	26.72382	8.40	50	Borehole	In use	Submersible pump		Domestic & livestock	
HBH46	-28.14817	26.72182	14.50		Borehole	In use	Submersible pump		Domestic & livestock	
HBH47	-28.14472	26.73037	NAWL		Borehole	In use	Solar pump		Domestic & livestock	
HBH48	-28.17827	26.74558	11.03		Borehole	In use	Submersible pump		Domestic & livestock	
HBH49	-28.17886	26.74621	7.12		Borehole	In use	Submersible pump		Domestic & livestock	
HBH50	-28.18372	26.74679	NAWL		Borehole	In use	No access		Domestic & livestock	No access
HBH51	-28.19216	26.72884	NAWL		Borehole	In use	No access		Monitoring	No access
HBH52	-28.18767	26.73012	1.08	10	Borehole	In use	Not equipped		Monitoring	Open
HBH53	-28.18655	26.73110	2.80	5	Borehole	In use	Not equipped		Monitoring	Open
HBH54	-28.24539	26.71029	7.98		Borehole	In use	Submersible pump		Domestic & livestock	
HBH55	-28.24598	26.71291	NAWL		Borehole	In use	Submersible pump		Domestic & livestock	
HBH56	-28.21266	26.69929	1.79	30	Borehole	Not in use	Not equipped		None	Open
HBH57	-28.25142	26.74366	NAWL		Borehole	Not in use	Not equipped		None	Blocked
HBH58	-28.25125	26.74377	7.95		Borehole	In use	Submersible pump		Domestic & livestock	
HBH59	-28.25111	26.74382	8.35		Borehole	In use	Submersible pump		Domestic & irrigation	
HBH60	-28.24983	26.74353	12.90		Borehole	In use	Submersible pump		Domestic & irrigation	
HBH61	-28.24970	26.74315	12.55		Borehole	In use	Submersible pump		Domestic & irrigation	
HBH62	-28.22459	26.80767	12.70	30	Borehole	In use	Windpump		Livestock	
HBH63	-28.20166	26.78398	NAWL		Borehole	In use	Windpump		Livestock	
HBH64	-28.21076	26.78479	NAWL		Borehole	No access	Windpump		No access	
HBH65	-28.21203	26.79141	NAWL		Borehole	No access	Windpump		No access	
HBH66	-28.21220	26.78951	NAWL		Borehole	No access	Windpump		No access	
HBH67	-28.21859	26.75478	NAWL		Borehole	Not in use	Not equipped		None	Open. Bees.
HBH68	-28.22435	26.75422	NAWL		Borehole	In use	Windpump		Domestic & livestock	

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH69	-28.22273	26.75010	1.67		Borehole	In use	Submersible pump		Domestic & livestock	
HBH70	-28.22878	26.74097	3.10		Borehole	In use	Windpump		Domestic & livestock	
HBH71	-28.19508	26.74163	NAWL		Borehole	In use	Windpump		Domestic & livestock	
HBH72	-28.19312	26.73970	1.75		Borehole	Not in use	Not equipped		None	Open
HBH73	-28.19301	26.73964	1.63		Borehole	In use	Mono pump		Domestic & livestock	
HBH74	-28.22959	26.80025	NAWL		Borehole	In use	Windpump		Domestic & livestock	
HBH75	-28.23077	26.80533	NAWL		Borehole	In use	Windpump		Domestic & livestock	
HBH76	-28.09771	26.73687	NAWL		Borehole	Not in use	Handpump		None	
SRD	-28.12263	26.70925	N/A		Surface water	N/A	N/A		N/A	Sandrivier downstream point
SRU	-28.10651	26.73623	N/A		Surface water	N/A	N/A		N/A	Sandrivier upstream point

Notes:

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)**

Table 7-2 Hydrocensus user survey: relevant information for geosites visited as part of the 2024 survey.

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH 161	-28.08858	26.73558	2.20		Borehole	In Use	Mono pump		Domestic	
HBH 159	-28.08745	26.73073	8.04		Borehole	In Use	Windpump		Domestic & livestock	
HBH 190	-28.07487	26.67060	3.36		Borehole	In Use	Submersible pump		Domestic	Automatic Float Switch / Pump 24/7 during planting season - Pivot
HBH 191	-28.07050	26.66555	4.11		Borehole	In Use	Submersible pump		Domestic	Pump 1 x pd for 7-5 h
HBH 186	-28.07994	26.66407	6.20		Borehole	In Use	Submersible pump		Irrigation	Automatic Float Switch / Pump 24/7 during planting season - Pivot
HBH 188	-28.07389	26.69870	3.69		Borehole	Not in Use	Not Equipped		None	Possible Collapsed
HBH 187	-28.07589	26.71036	NAWL	5.85	Borehole	Not in Use	Submersible pump		None	
HBH 192	-28.07726	26.71039	6.19		Borehole	In Use	Windpump		Domestic	
HBH 185	-28.07550	26.71388	8.10	30	Borehole	In Use	Solar pump		Domestic	Solar pump.
HBH 193	-28.07540	26.71435	8.61	80	Borehole	Not in Use	Not Equipped		None	
HBH 199	-28.12519	26.64163	6.44		Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1x pd for 3h - 25000 to 30000 L pd
HBH 180	-28.12453	26.64343	10.00	32.53	Borehole	Not in Use	Not Equipped		None	
HBH 181	-28.12470	26.64352	10.78	23.83	Borehole	Not in Use	Not Equipped		None	
BH 3 DDK	-28.16213	26.66035	32.61		Borehole	In Use	Windpump		Domestic & livestock	
HBH 194	-28.16296	26.65305	11.74		Borehole	In Use	Windpump		Livestock	
BH 1 DDK	-28.16716	26.66031	16.66		Borehole	In Use	Windpump		Livestock	
BH 2 KLPK	-28.17369	26.68213	5.51		Borehole	Not in Use	Not Equipped		None	
HBH 195	-28.17092	26.67996	3.86	38.15	Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1x pd for 8h
HBH 196	-28.24546	26.71033	13.15	13.85	Borehole	Not in Use	Not Equipped		None	
HBH 197	-28.24557	26.71066	14.15	18	Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1x pd for 3h
BH 2 BOS 278 0	-28.24598	26.71292	11.73	26	Borehole	In Use	Submersible pump		Domestic & irrigation	Current: Pump 1x pd for 8h Planting Season: Pump 24/7
BH 2 BOS 278 2	-28.22336	26.70576	5.22		Borehole	Not in Use	Windpump		None	Sibanye mine supply water to farmer
HBH 135	-28.22730	26.72159	42.13		Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1x pd for 3h

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH 137	-28.22991	26.73038	NAWL		Borehole	In Use	Windpump		Livestock	
HBH 136	-28.21125	26.73142	7.19		Borehole	In Use	Windpump		Livestock	
BH MOV	-28.24672	26.76825	6.78	37.3	Borehole	Not in Use	Not Equipped		None	
HBH 149	-28.24129	26.77019	3.08	52.76	Borehole	Not in Use	Not Equipped		None	
BH 3 MVL	-28.24176	26.77052	6.78	31.8	Borehole	Not in Use	Not Equipped		None	
HBH 198	-28.11798	26.68012	19.40	49.18	Borehole	Not in Use	Not Equipped		None	
HBH 163	-28.20290	26.64291	12.21		Borehole	In Use	Submersible pump		Domestic & livestock	Current: Pump every 2nd day for livestock for 3h Planting Season: Pump 3 months per year 24/7 when planting - Pivot
HBH 200	-28.20139	26.65805	4.34		Borehole	In Use	Submersible pump		Irrigation	Current: Pump every 2nd day for livestock for 3h Planting Season: Pump 3 months per year 24/7 when planting - Pivot
HBH 1645	-28.22122	26.67334	6.84		Borehole	In Use	Submersible pump		Irrigation	Current: Pump every 2nd day for livestock for 3h Planting Season: Pump 3 months per year 24/7 when planting - Pivot
HBH 201	-28.16963	26.63507	8.96	30	Borehole	In Use	Submersible pump		Domestic & livestock	
HBH 178	-28.17027	26.60951	4.41		Borehole	In Use	Submersible pump		Domestic & livestock	
HBH 166	-28.18181	26.76878	4.53	21.52	Borehole	Not in Use	Not Equipped		None	
BH 2 DDR	-28.18179	26.78140	5.39	34.1	Borehole	Not in Use	Not Equipped		None	
BH 2 DRR	-28.18186	26.78145	5.01	11.4	Borehole	Not in Use	Not Equipped		None	
BH 3 DRR	-28.18549	26.78080	5.52		Borehole	In Use	Windpump		Livestock	
BH 1 DRR	-28.19014	26.78088	8.20		Borehole	Not in Use	Windpump		None	
HBH 202	-28.18104	26.78060	13.31	44.39	Borehole	Not in Use	Not Equipped		None	
HBH 203	-28.27801	26.71489	18.13	60	Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1X pd for 5h
HBH 204	-28.27730	26.71795	8.41		Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1X pd for 5h
HBH 205	-28.31111	26.74324	NAWL		Borehole	In Use	Submersible pump		Livestock	
HBH 114	-28.30193	26.74312	NAWL		Borehole	Not in Use	Windpump		None	
HBH 125	-28.26804	26.67350	5.15		Borehole	In Use	Windpump		Livestock	
HBH 123	-28.27317	26.69540	4.69	38	Borehole	In Use	Submersible pump		Irrigation	Planting Season: Pump 1X pd for 12h - Have 2 pump in

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
HBH 124	-28.27297	26.69471	4.60	35	Borehole	Not in Use	Submersible pump		None	
HBH 130	-28.27903	26.69258	5.89		Borehole	In Use	Submersible pump		Irrigation	Planting Season: Pump 1X pd for 12h - Use as back up pump
HBH 129	-28.27726	26.68714	5.56	18.28	Borehole	In Use	Submersible pump		Irrigation	Planting Season: Pump 1X pd for 12H
HBH 128	-28.26253	26.69294	5.50		Borehole	In Use	Windpump		Irrigation	
HBH 127	-28.25532	26.67986	7.34		Borehole	Not in Use	Windpump		None	
HBH 119	-28.26786	26.70028	5.14		Borehole	In Use	Windpump		Livestock	
HBH 120	-28.26775	26.70218	13.85		Borehole	In Use	Submersible pump		Domestic	
HBH 118	-28.26952	26.70053	5.37		Borehole	In Use	Windpump		Livestock	
HBH 122	-28.26731	26.70009	6.06		Borehole	In Use	Submersible pump		Domestic & livestock	
HBH 116	-28.23821	26.71827	4.70		Borehole	Not in Use	Windpump		None	
HBH 117	-28.24192	26.73159	3.21		Borehole	In Use	Windpump		Livestock	
HBH 151	-28.25538	26.75884	6.98	44.25	Borehole	Not in Use	Not Equipped		None	
BH GLR	-28.13207	26.77029	11.58	30	Borehole	In Use	Submersible pump		Domestic	Pump 1X per week for 5H
BH 1 GLR	-28.13375	26.79048	6.55		Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1X pd for 8H
HBH 168	-28.13460	26.77929	4.95	48	Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1X pd for 4H
HBH 206	-28.13106	26.75650	15.20		Borehole	In Use	Submersible pump		Domestic & livestock	Pump 1X pd for 6H
HBH 207	-28.12670	26.75457	25.20		Borehole	In Use	Submersible pump		Domestic	Automatic Float Switch
HBH 208	-28.13339	26.76155	14.93	24.28	Borehole	Not in Use	Not Equipped		None	
HBH 209	-28.13201	26.76096	11.65	35	Borehole	In Use	Submersible pump		Domestic & livestock	
HBH 210	-28.13407	26.75744	15.89	20.99	Borehole	Not in Use	Not Equipped		None	
HBH 211	-28.13360	26.75759	15.87	45	Borehole	In Use	Submersible pump		Domestic & livestock	Pump 3X per week for 4H
HBH 212	-28.12873	26.80519	9.46		Borehole	In Use	Windpump		Livestock	
BH 2 HAK	-28.13681	26.80747	6.45	24.25	Borehole	Not in Use	Not Equipped		None	
HBH 138	-28.15011	26.76916	8.86		Borehole	In Use	Windpump		Livestock	
HBH 167	-28.12028	26.80224	24.33		Borehole	Not in Use	Submersible pump		None	
HBH 213	-28.21268	26.69928	3.87	30.03	Borehole	Not in Use	Not Equipped		None	
HBH 214	-28.21028	26.60866	9.54	30	Borehole	In Use	Submersible pump		Domestic	Pump every second day for 2H

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
12A	-28.27250	26.74197	9.89		Borehole	In use	Equipped		Domestic & livestock	Robert have previous sample data
BH04	-28.11950	26.72231			Borehole	In use	Equipped		Domestic & livestock	Borehole also utilised for monitoring purposes
BH17C	-28.14753	26.71414	12.24	60	Borehole	In use	Equipped		Livestock	Borehole also utilised for monitoring purposes
AVO1	-28.09539	26.73217			Borehole	In use	Equipped		Domestic	This site was drilled by Tetra4 for use by the local community. Borehole also utilised for monitoring purposes.
BR26B	-28.10730	26.70517			Borehole	In use	Not Equipped		Monitoring	
7A	-28.15336	26.71242			Borehole	In use	Equipped		Domestic	Water is used for domestic purposes by the nearby community. Borehole also utilised for monitoring purposes
7B	-28.14756	26.72417	12.12		Borehole	In use	Equipped		Domestic	Borehole also utilised for monitoring purposes
11A	-28.19314	26.73970			Borehole	In use	Equipped		Livestock	Borehole also utilised for monitoring purposes
11B	-28.19206	26.74042			Borehole	In use	Equipped		Domestic	Borehole also utilised for monitoring purposes
OB	-28.22934	26.75741			Borehole	In use	Not Equipped		Monitoring	
15D	-28.27739	26.64169	5.71		Borehole	In use	Equipped		Livestock	Borehole also utilised for monitoring purposes
15C	-28.27614	26.64281			Borehole	In use	Equipped		Domestic	Water is used by the nearby community for domestic purposes. Borehole also utilised for monitoring purposes
15A	-28.27368	26.64421			Borehole	In use	Equipped		Domestic	Borehole also utilised for monitoring purposes
25A	-28.28703	26.74206			Borehole	In use	Equipped		Domestic & livestock	Borehole also utilised for monitoring purposes
Kal2_1	-28.17840	26.74535	7.70		Borehole	In use	Equipped		Domestic & livestock	Borehole also utilised for monitoring purposes
BH01	-28.12723	26.71919			Borehole	In use	Not Equipped		Monitoring	Borehole also utilised for monitoring purposes
MON MVDRE1	-28.12801	26.72016			Borehole	In use	Not Equipped		Monitoring	

Site ID	Latitude	Longitude	Water level (mbgl)	Borehole depth (mbgl)	Site type	Site status	Equipment	Property Owner**	Water application	Field notes
16B	-28.14819	26.72186	13.89		Borehole	In use	Equipped		Irrigation	Borehole also utilised for monitoring purposes
24A	-28.15353	26.73250	8.00		Borehole	In use	Equipped		Domestic	Borehole also utilised for monitoring purposes
24B	-28.15169	26.73694			Borehole	In use	Equipped		Livestock	Borehole also utilised for monitoring purposes
8A			7.45		Borehole	In use	Equipped		Livestock	Borehole also utilised for monitoring purposes
BH8	-28.11837	26.72098			Borehole	In use	Equipped		Domestic	Borehole also utilised for monitoring purposes

Notes:

N/A: Not applicable

NAWL: No access to water level

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

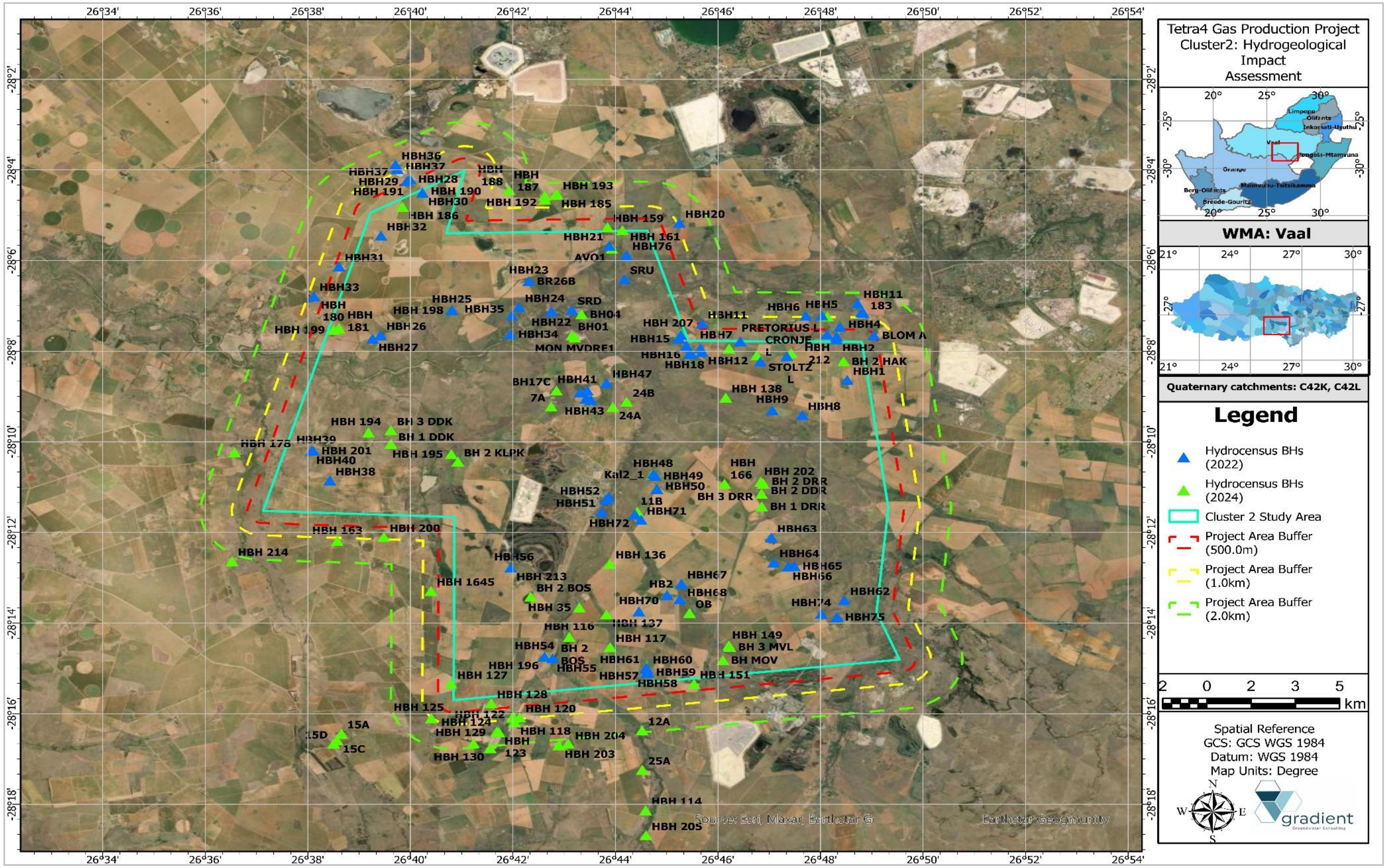


Figure 7-5 **Spatial distribution map of the geosites visited as part of the 2022 and 2024 hydrocensus user surveys.**

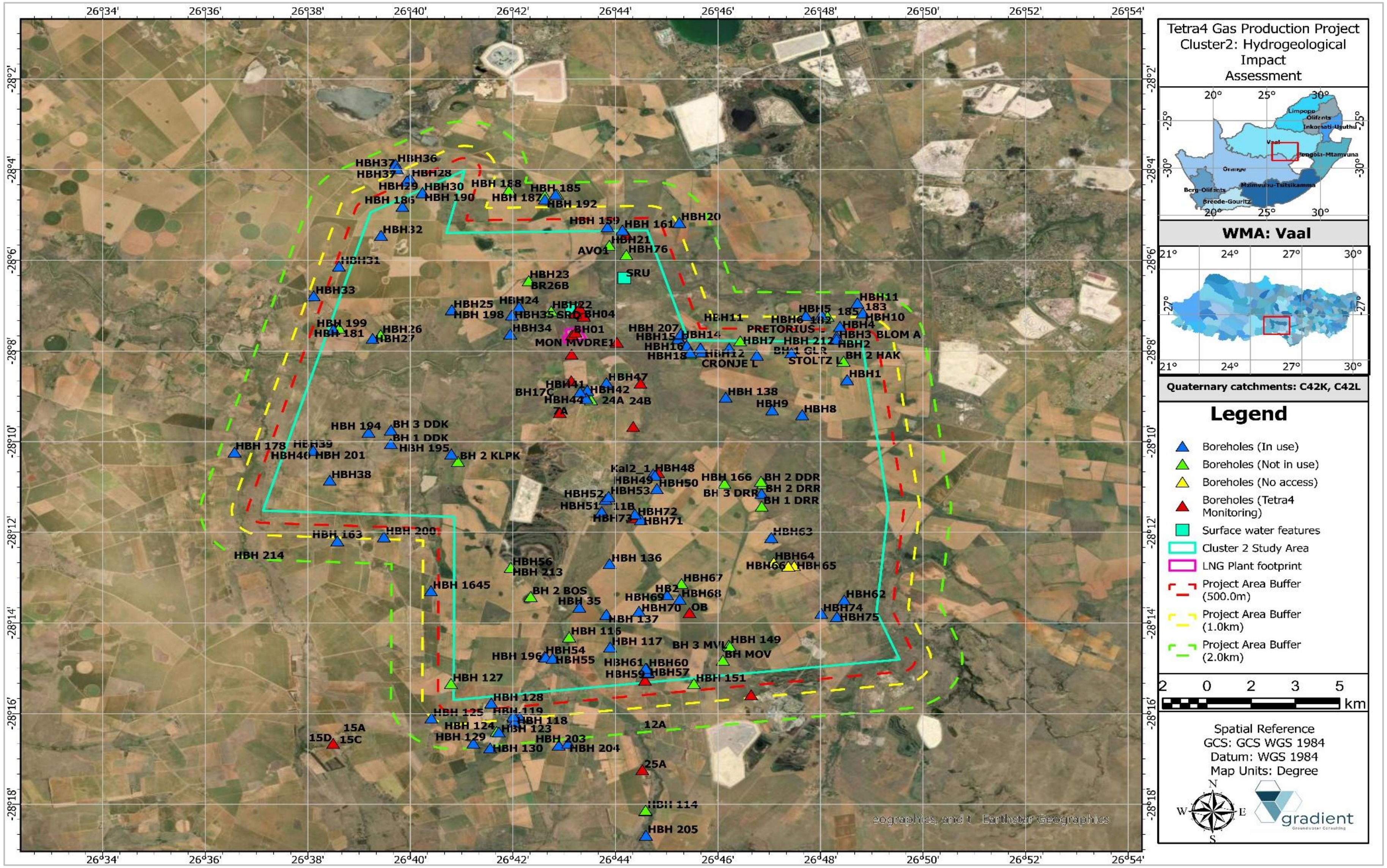


Figure 7-6 **Spatial distribution map of of the groundwater status and application.**

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. Areas requiring additional site characterisation data or zone(s) lacking monitoring boreholes were identified based on the distribution of existing boreholes and geosites as well as density of geological lineaments i.e., fault zones and dyke structures serving as potential preferred pathways and mechanisms for pollution plume migration (refer to Figure 8-2). 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 October 2024 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 monitoring boreholes. Figure 8-1 shows a Total Magnetic Intensity (TMI) map of the greater study area with geological lineaments transecting the project site clearly delineated. 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)	Potential anomalies	Drilling target	Approximate orientation
	Latitude	Longitude						
Traverse T4L01	-28.210299	26.718890	400.00	SW-NE striking lineament	10.00	290m	RTBH01	N-S
Traverse T4L02	-28.220152	26.715513	600.00	SW-NE striking lineament	10.00	70m, 350m	n/a	NE-SW
Traverse T4L03	-28.227395	26.712563	600.00	SW-NE striking lineament	10.00	500m	n/a	SW-NE
Traverse T4L04	-28.114075	26.651247	300.00	N-S striking lineament	10.00	200m	n/a	E-W
Traverse T4L05	-28.121882	26.648155	300.00	N-S striking lineament	10.00	180.00	RTBH04	SE-NW
Traverse T4L06	-28.167441	26.631815	300.00	N-S striking lineament	10.00	190m	RTBH05	E-W
Traverse T4L07	-28.166528	26.624882	400.00	N-S striking lineament	10.00	280m	n/a	E-W
Traverse T4L08	-28.168632	26.623755	300.00	W-E striking lineament	10.00	None	n/a	E-W
Traverse T4L09	-28.207595	26.781354	200.00	N-S striking lineament	10.00	90m, 170m	RTBH08	NW-SE
Traverse T4L10	-26.782248	-28.207770	100.00	SW-NE striking lineament	10.00	None	n/a	W-E
Traverse T4L11	-28.166306	26.768910	200.00	NW-SE striking lineament	10.00	140m	n/a	SW=NE
Traverse T4L12	-28.164963	26.769849	350.00	NW-SE striking lineament	10.00	60m, 190m	n/a	NW-SE
Traverse T4L13	-28.168011	26.779978	400.00	NW-SE striking lineament	10.00	120m	n/a	NW-SE
Traverse T4L14	-28.168910	26.787345	400.00	NW-SE striking lineament	10.00	130m	n/a	NW-SE

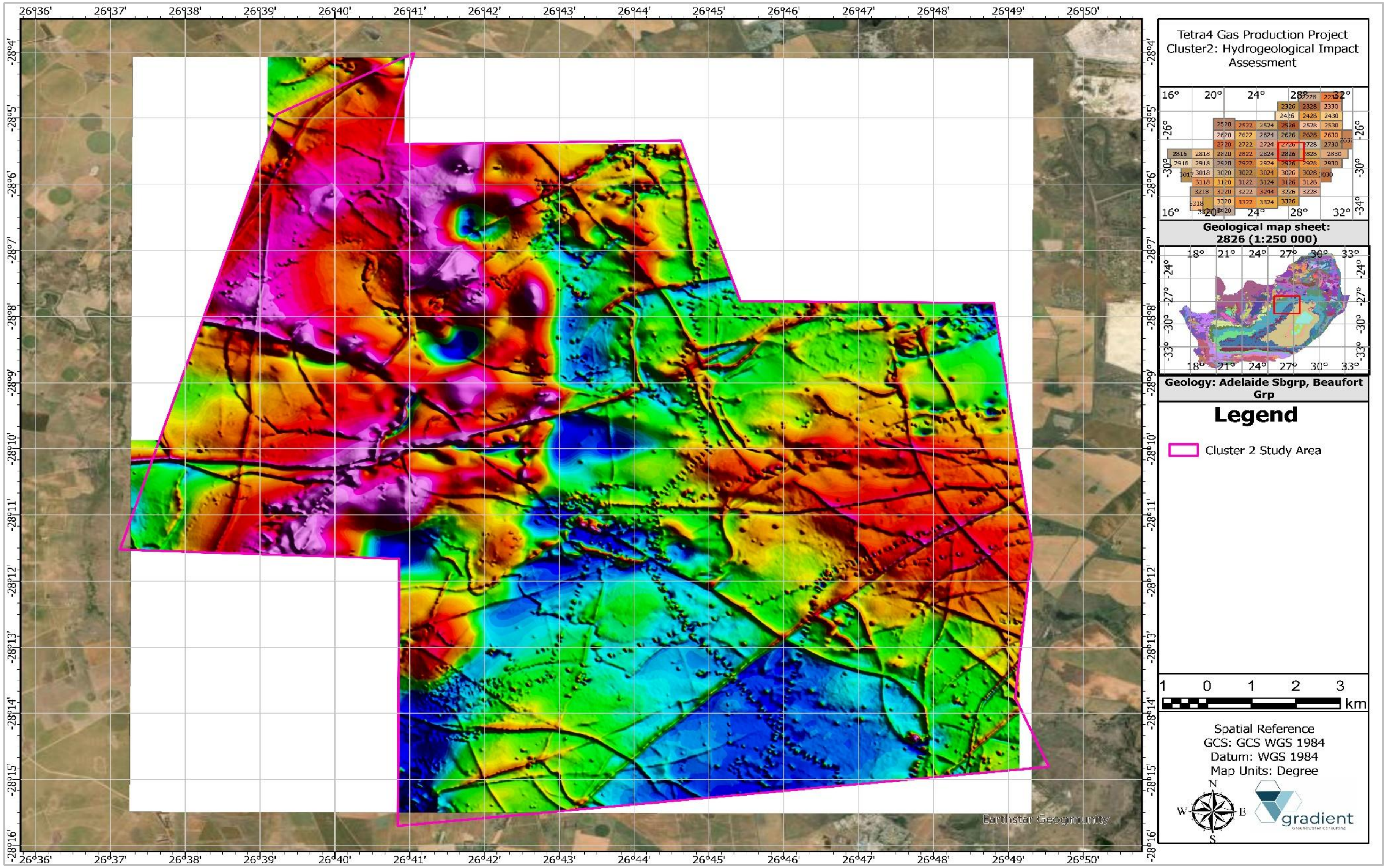


Figure 8-1 **Total Magnetic Intensity (TMI) map of the greater study area indicating regional structural activity.**

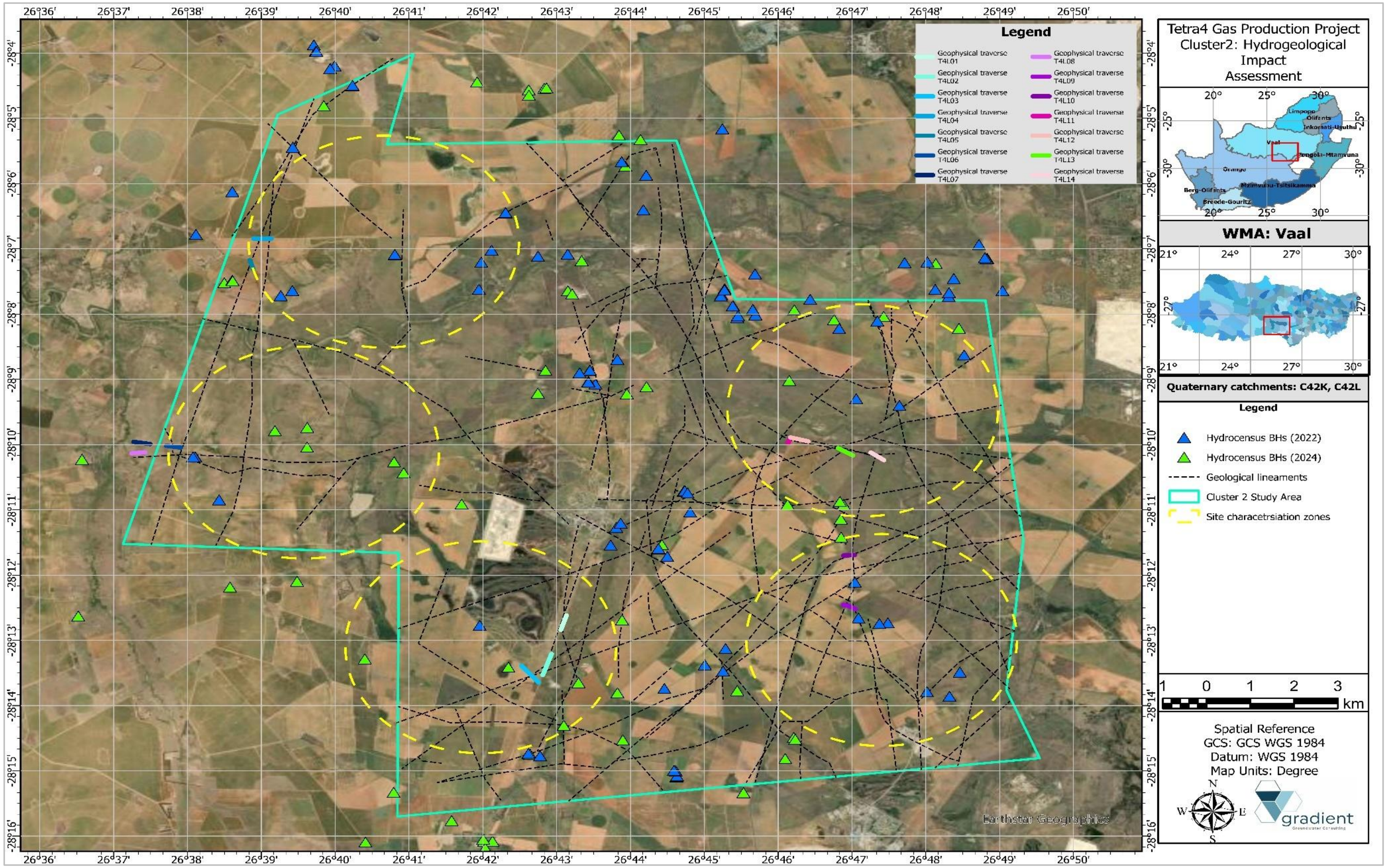


Figure 8-2 **Geophysical traverse array in relation to geosites recorded as well as gap zones delineated.**

8.1.1. Traverse T4L01

Traverse T4L01 was surveyed over a lateral distance of 400.0m (10 m-electrode spacing) and was conducted in an approximate north-south orientation targeting a southwest-northeast striking geological lineament. A prominent magnetic low zone can be observed between stations 10.0-40.0m and again at stations 280.0 – 290.0m. The second magnetic anomaly is also associated with an increase in the electro-magnetic field on its perimeter. Accordingly, station 290.0m was identified as drilling position RTBH01, targeting a potential 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 T4L05

Traverse T4L05 was surveyed over a lateral distance of 300.0m (10 m-electrode spacing) and was conducted in an approximate southeast-northwest orientation targeting a north-south striking geological lineament. A prominent increase in the measured magnetic field can be observed at station 180.0m. The latter can be inferred as a potential contact zone between the Vryheid host and a possible dolerite sill and outcrop with a magnetic signature. The electro-magnetic profiles suggest a slight decrease in the vertical dipole reading associated with a slight increase in the horizontal dipole reading. Accordingly, station 180.0m was identified as drilling position RTBH04, targeting a potential geological contact which may act as contaminant transport mechanism. Refer to Figure 8-4 for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.3. Traverse T4L06

Traverse T4L06 was surveyed over a lateral distance of 300.0m (10 m-electrode spacing) and was conducted in an approximate east-west orientation targeting a north-south striking geological lineament. A steep dip in the magnetic reading followed by a sharp increase above the regional average can be observed between stations 180.0-210.0m. This anomaly is generally associated with a dyke structure and is inferred as such. The electro-magnetic profiles indicate a decrease in the vertical dipole reading with an increase in the horizontal dipole reading also associated with this anomaly. Accordingly, station 190.0m was identified as drilling position RTBH05, 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 8-5 for the magnetic curve and electro-magnetic profile summarising relevant information.

8.1.4. Traverse T4L09

Traverse T4L09 was surveyed over a lateral distance of 200.0m (10 m-electrode spacing) and was conducted in an approximate northwest-southeast orientation targeting a north-south striking geological lineament. Although the initial magnetic readings along the first segment of the traverse are quite erratic, a magnetic low can be observed between station 90.0-130.0m. The electro-magnetic profiles indicate a decrease in the vertical dipole reading with an increase in the horizontal dipole reading also associated with this anomaly. Accordingly, station 190.0m was identified as drilling position RTBH05, 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 8-5 for the magnetic curve and electro-magnetic profile summarising relevant information

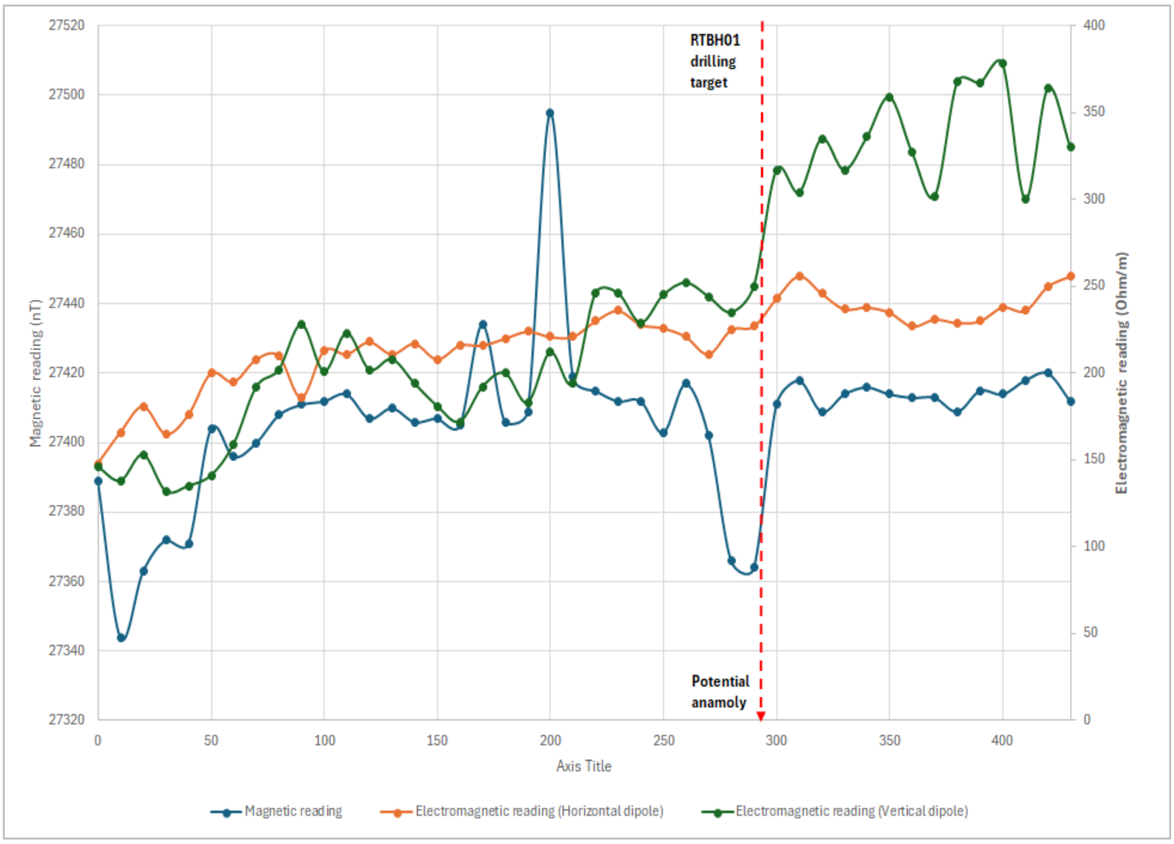


Figure 8-3 **Geophysical traverse T4L01: Magnetic curve as well as electro-magnetic profile with relevant information.**

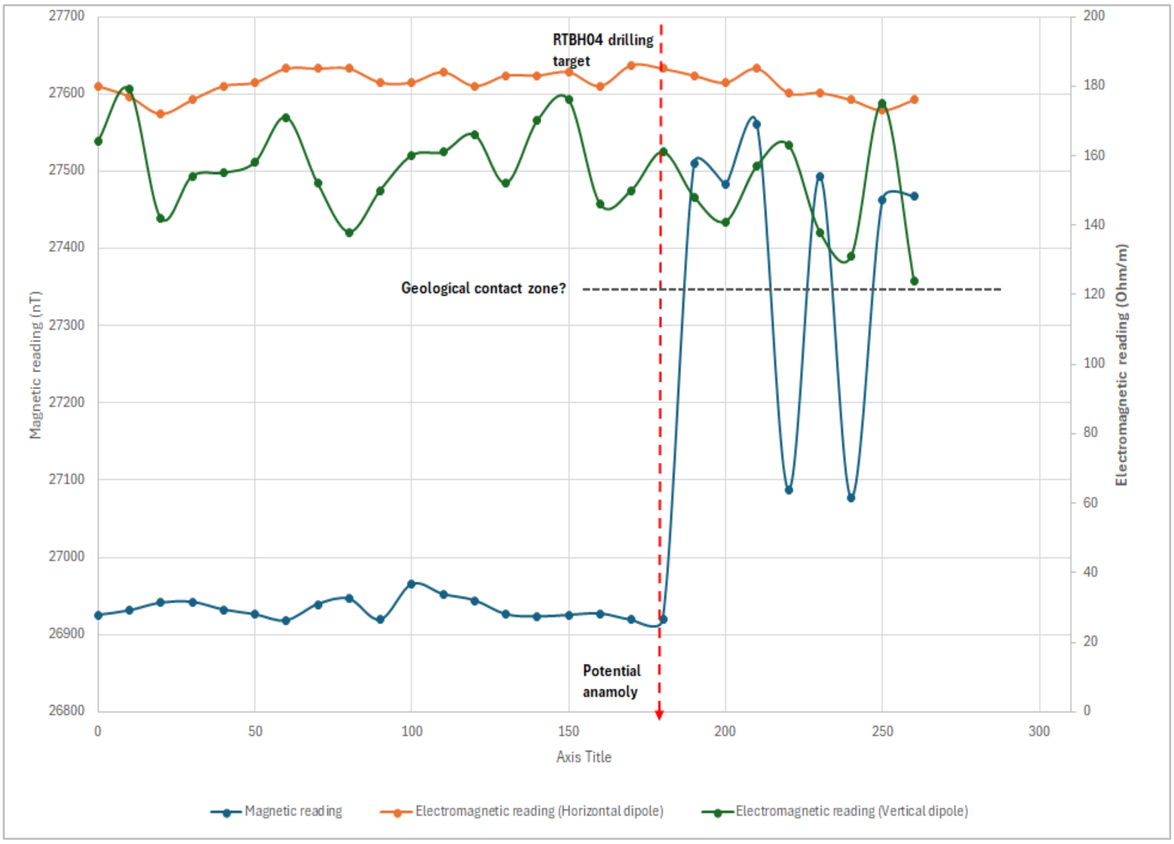


Figure 8-4 **Geophysical traverse T4L05: Magnetic curve as well as electro-magnetic profile with relevant information.**

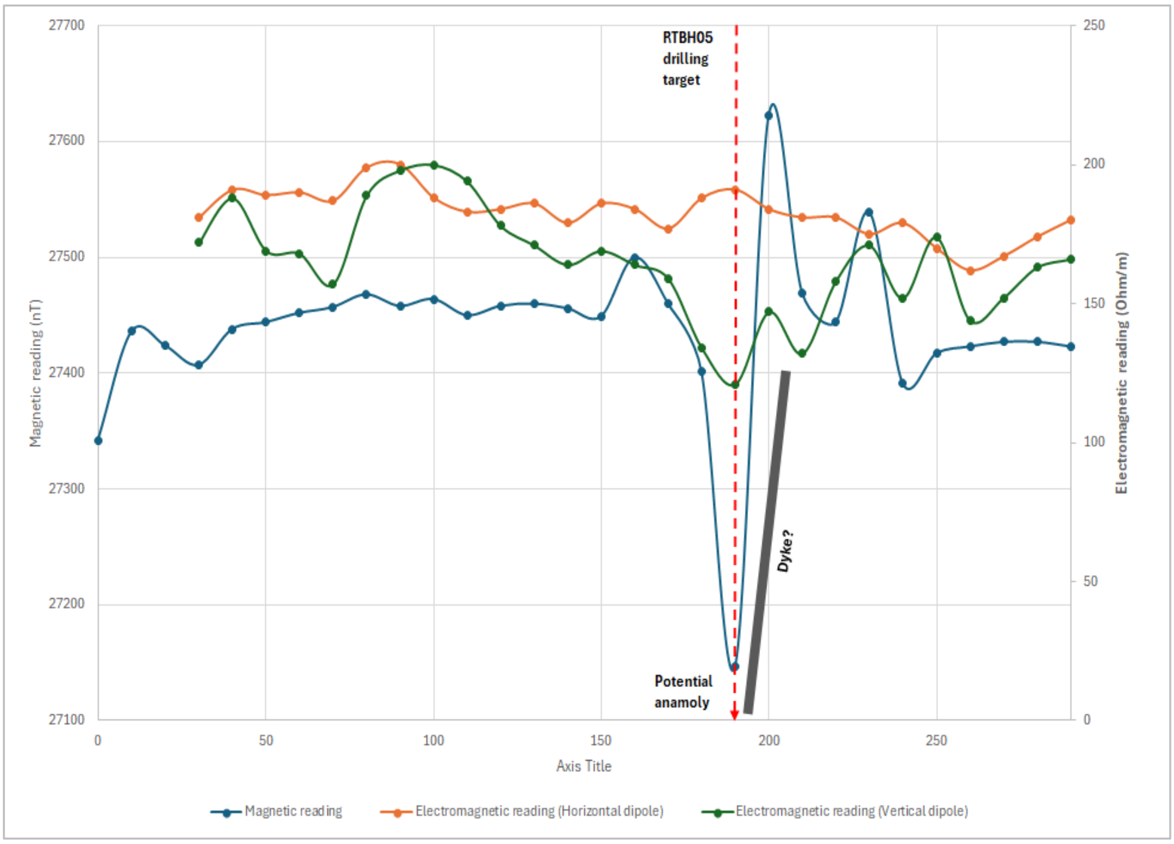


Figure 8-5 Geophysical traverse T4L06: Magnetic curve as well as electro-magnetic profile with relevant information.

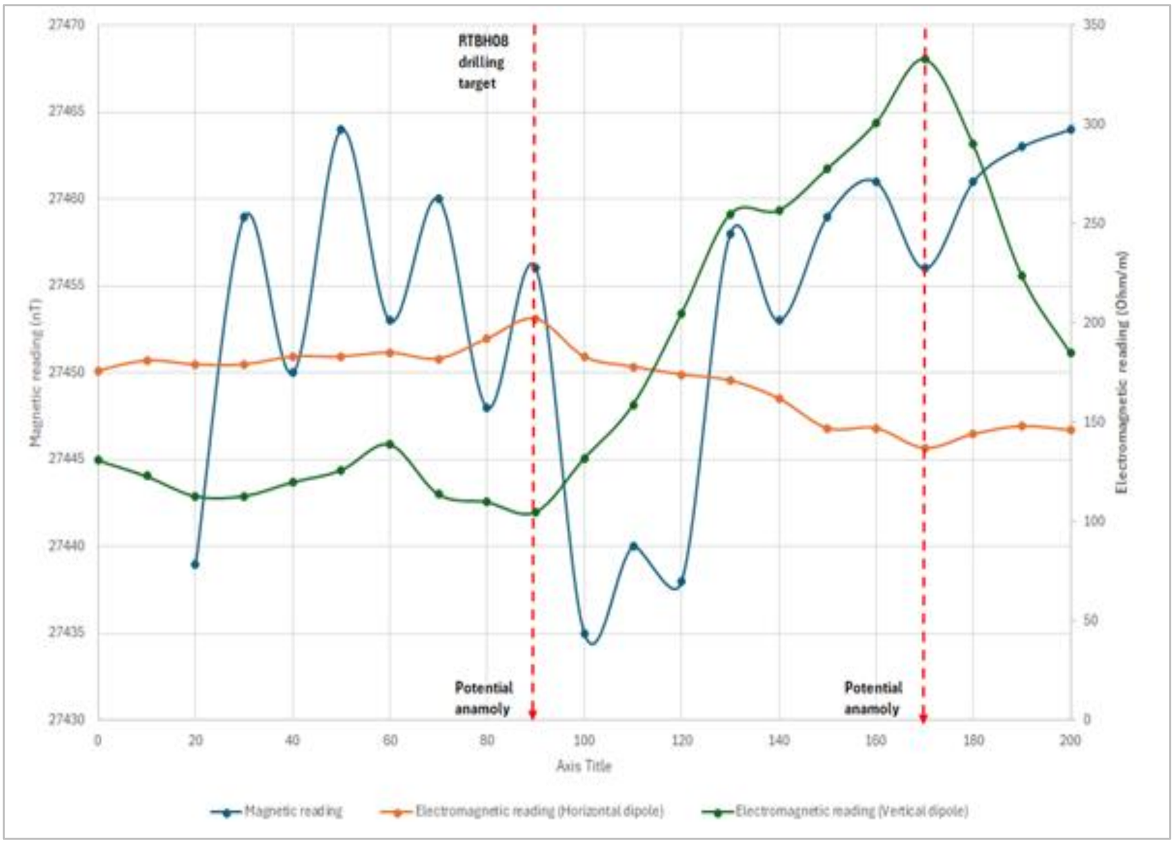


Figure 8-6 Geophysical traverse T4L09: Magnetic curve as well as electro-magnetic profile with relevant information.

8.2. Drilling

Following the geophysical survey, five drilling targets were identified and incorporated as part of the drilling program which was initiated during January 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 8-8 shows the newly drilled borehole positions in relation to existing geosites 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
RTBH 01	-28.212736	26.718075	Fractured aquifer (confined)	Site characterisation and monitoring
RTBH 04	-28.120242	26.647642	Fractured aquifer (confined)	Site characterisation and monitoring
RTBH 05	-28.167142	26.629660	Fractured aquifer (confined)	Site characterisation and monitoring
RTBH 08	-28.207812	26.782083	Fractured aquifer (confined)	Site characterisation and monitoring
RTBH 10	-28.177746	26.764675	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)
RTBH 01	88.00	8.57	215.0mm(0-24m); 165.0mm (24m-EOH)	Steel	177 (0-24m)	100.00	26/27	0.13
RTBH 04	100.00	7.00	215.0mm(0-24m); 165.0mm (24m-EOH)	Steel	177 (0-24m)	100.00	Seepage (13/14)	None
RTBH 05	100.00	8.93	215.0mm(0-24m); 165.0mm (24m-EOH)	Steel	177 (0-24m)	100.00	91/92	0.55
RTBH 08	100.00	4.29	215.0mm(0-24m); 165.0mm (24m-EOH)	Steel	177 (0-24m)	100.00	Seepage (17/18)	n/a
RTBH 10	100.00	5.52	215.0mm(0-24m); 165.0mm (24m-EOH)	Steel	177 (0-24m)	100.00	39/40	1.38

Notes: EOH = End of Hole.

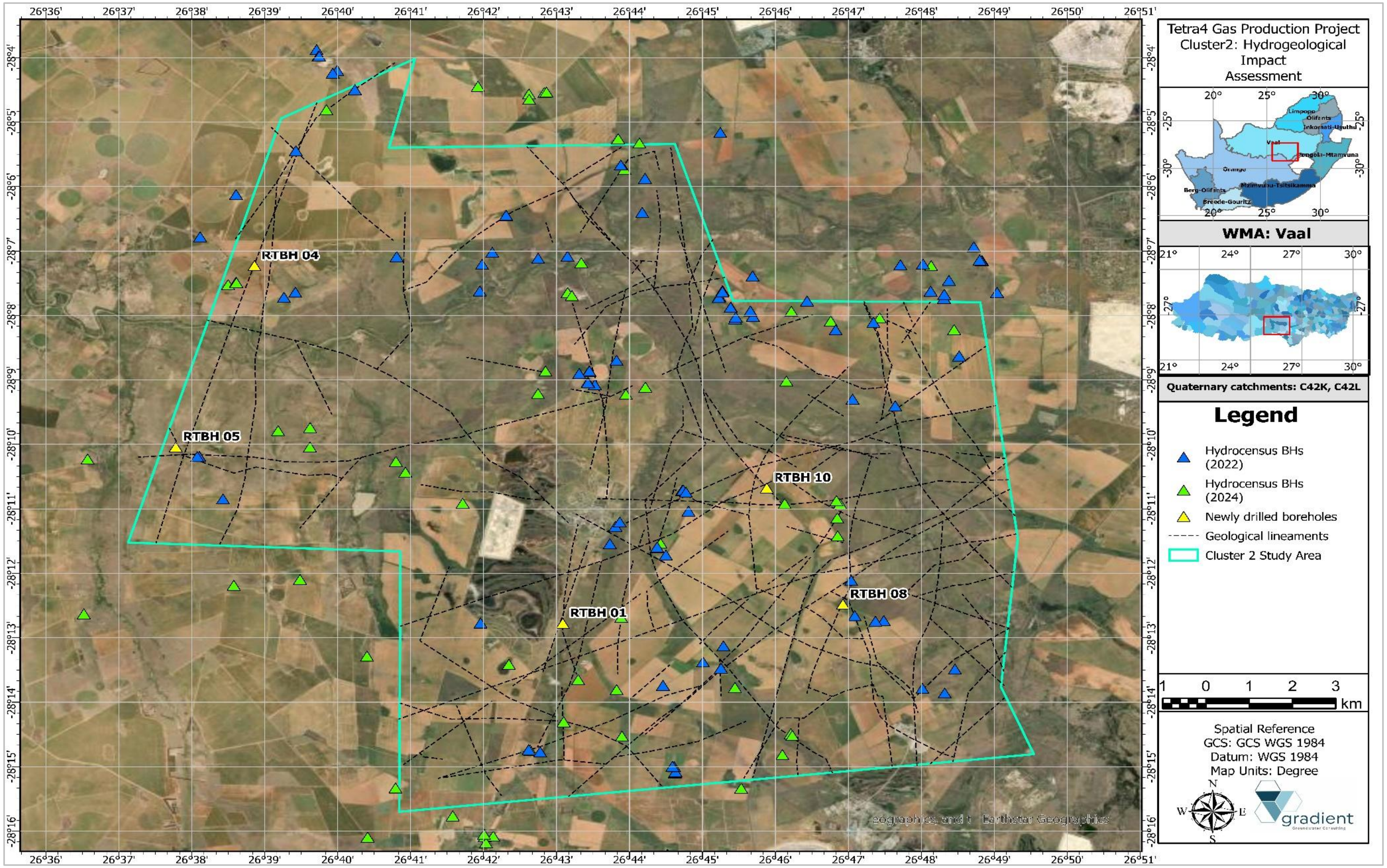


Figure 8-7 **Map depicting new drilled site characterisation borehole positions in relation to geosites recorded.**

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

8.2.1. Drilling locality RTBH01

Borehole locality RTBH01 was drilled at a 165.0mm (6.50”) diameter to a depth of 88.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 215.0mm (8.50”) and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 24.0mbgl. 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 thin (1.0-3.0m) topsoil and hill wash layer followed by highly weathered Beaufort Group formations up to a depth of 16.0mbgl which is followed by more competent Volksrust formations to the end of the hole (EOH). A seepage zone was encountered at a depth of between 16.0 – 17.0m and a major water strike (blow yield = 0.13l/s) was encountered at approximately 27.0mbgl. After borehole development, the static water level was recorded at 8.57mbgl.

8.2.2. Drilling locality RTBH04

Borehole locality RTBH04 was drilled at a 165.0mm (6.50”) diameter to a depth of 100.0mbgl. The borehole was reamed to a diameter of 215.0mm (8.50”) and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 24.0mbgl. 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 thin (1.0-4.0m) topsoil and hill wash layer followed by highly weathered Beaufort Group formations up to a depth of 18.0mbgl which is followed by more competent Volksrust formations to a depth of approximately 92.0mbgl after which a dolerite intrusion was encountered to the end of the hole. A seepage zone was encountered at a depth of between 13.0 – 14.0m, however the water ingress was not enough to perform a blow yield measurement. After borehole development, the static water level was recorded at 7.0mbgl.

8.2.3. Drilling locality RTBH05

Borehole locality RTBH05 was drilled at a 165.0mm (6.50”) diameter to a depth of 100.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 215.0mm (8.50”) and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 24.0mbgl. A 3.0mm silica gravel-pack was used to fill the borehole annulus surrounding the saturated sediments. Drilling chips collected confirmed the presence of highly weathered Beaufort Group formations up to a depth of 11.0mbgl which is followed by more competent Volksrust formations to a depth of approximately 90.0mbgl after which a dolerite intrusion was encountered to the end of the hole. A seepage zone was encountered at a depth of between 15.0 – 16.0m and a major water strike (blow yield = 0.56l/s) was encountered at approximately 92.0mbgl. After borehole development, the static water level was recorded at 8.93mbgl.

8.2.4. Drilling locality RTBH08

Borehole locality RTBH08 was drilled at a 165.0mm (6.50”) diameter to a depth of 100.0mbgl. The borehole was reamed to a diameter of 215.0mm (8.50”) and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 24.0mbgl. 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 thin (1.0-3.0m) topsoil and hill wash layer followed by highly weathered Beaufort Group formations up to a depth of 18.0mbgl which is followed by more competent Volksrust formations to the end of the hole. A seepage zone was encountered at a depth of between 45.0 – 46.0m, however the water ingress was not enough to perform a blow yield measurement. After borehole development, the static water level was recorded at 4.29mbgl.

8.2.5. Drilling locality RTBH10

Borehole locality RTBH10 was drilled at a 165.0mm (6.50”) diameter to a depth of 100.0 meters below ground level (mbgl). The borehole was reamed to a diameter of 215.0mm (8.50”) and the unsaturated, vadose zone was cased using a steel casing (177.0mm) up to a depth of 24.0mbgl. 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 thin (1.0-4.0m) topsoil and hill wash layer followed by highly weathered Beaufort Group formations up to a depth of 34.0mbgl which is followed by more competent Volksrust formations to the end of the hole. A major water strike (blow yield = 1.38l/s) was encountered at approximately 39.0mbgl. After borehole development, the static water level was recorded at 5.52mbgl.

8.3. Aquifer testing

Following the drilling phase, the newly established site characterisation boreholes, including existing monitoring boreholes, were subjected to hydraulic testing i.e., Constant Discharge(CD) pump during March 2025 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. Figure 8-8 shows the boreholes subjected to hydraulic testing in relation to existing geosites identified. Borehole specific drawdown and recovery data are included in Appendix D.

Table 8-4 Constant discahrge aquifer tests summary.

Basic Information								
BH ID	Borehole depth (mbgl)	Tested yield (ℓ/s)	Constant discharge duration (min.)	Water level (mbgl)	Pump depth inlet	Available Drawdown (m)	Drawdown reached (m)	% Drawdown used
7B	40.00	1.76	240.00	12.12	30.00	17.88	16.46	92.06
16B	30.00	1.44	120.00	13.89	20.00	6.11	5.99	98.04
17C	60.00	2.22	150.00	12.24	55.00	42.76	13.71	32.06
24A	45.00	0.92	90.00	8.00	40.00	32.00	33.91	97.58
Kal2_1	40.00	0.20	240.00	7.70	30.00	22.30	19.49	87.40
RTBH 01	88.00	0.26	480.00	8.57	75.00	66.43	29.59	44.54
RTBH 05	100.00	0.26	480.00	8.93	75.00	66.07	17.03	25.78
RTBH 08	100.00	0.26	120.00	2.05	75.00	72.95	72.95	100.00
RTBH 10	100.00	0.56	480.00	5.52	75.00	69.48	6.63	9.54

Table 8-5 Aquifer tests: Hydraulic parameter estimation.

BH ID	Potential hydrostratigraphical unit targeted	HYDROSOLV analysis		FC analysis	Results	
		Constant discharge Transmissivity (m^2/d)	Recovery Transmissivity (m^2/d)	Constant discharge Transmissivity (m^2/d)	Average Transmissivity (m^2/d)	Hydraulic conductivity (m/d)
7B	Beaufort Group formation	1.67	1.86	1.75	1.76	0.117
16B	Quaternary sediments, alluvial deposit	12.18	9.59	9.45	11.00	0.550
17C	Geological lineament	10.60	9.02	8.50	9.37	0.375
24A	Karoo formation matrix	0.16	0.29	0.60	0.35	0.017
Kal2_1	Karoo formation matrix	0.18	0.19	0.50	0.29	0.014
RTBH 01	Karoo formation matrix	0.20	0.19	0.35	0.25	0.012
RTBH 05	Dolerite intrusion	0.80	0.66	0.90	0.79	0.039
RTBH 08	Dolerite intrusion in close proximity	0.03	0.03	0.30	0.12	0.006
RTBH 10	Volksrust formation	2.04	5.36	2.00	3.13	0.157
Minimum		**0.03**	**0.03**	**0.30**	**0.12**	**0.006**
Maximum		**12.18**	**9.59**	**9.45**	**11.00**	**0.55**
Geometric mean		**0.74**	**0.84**	**1.26**	**1.04**	**0.05**
Harmonic mean		**0.18**	**0.19**	**0.73**	**0.43**	**0.02**
Standard deviation		**4.50**	**3.71**	**3.41**	**3.96**	**0.18**

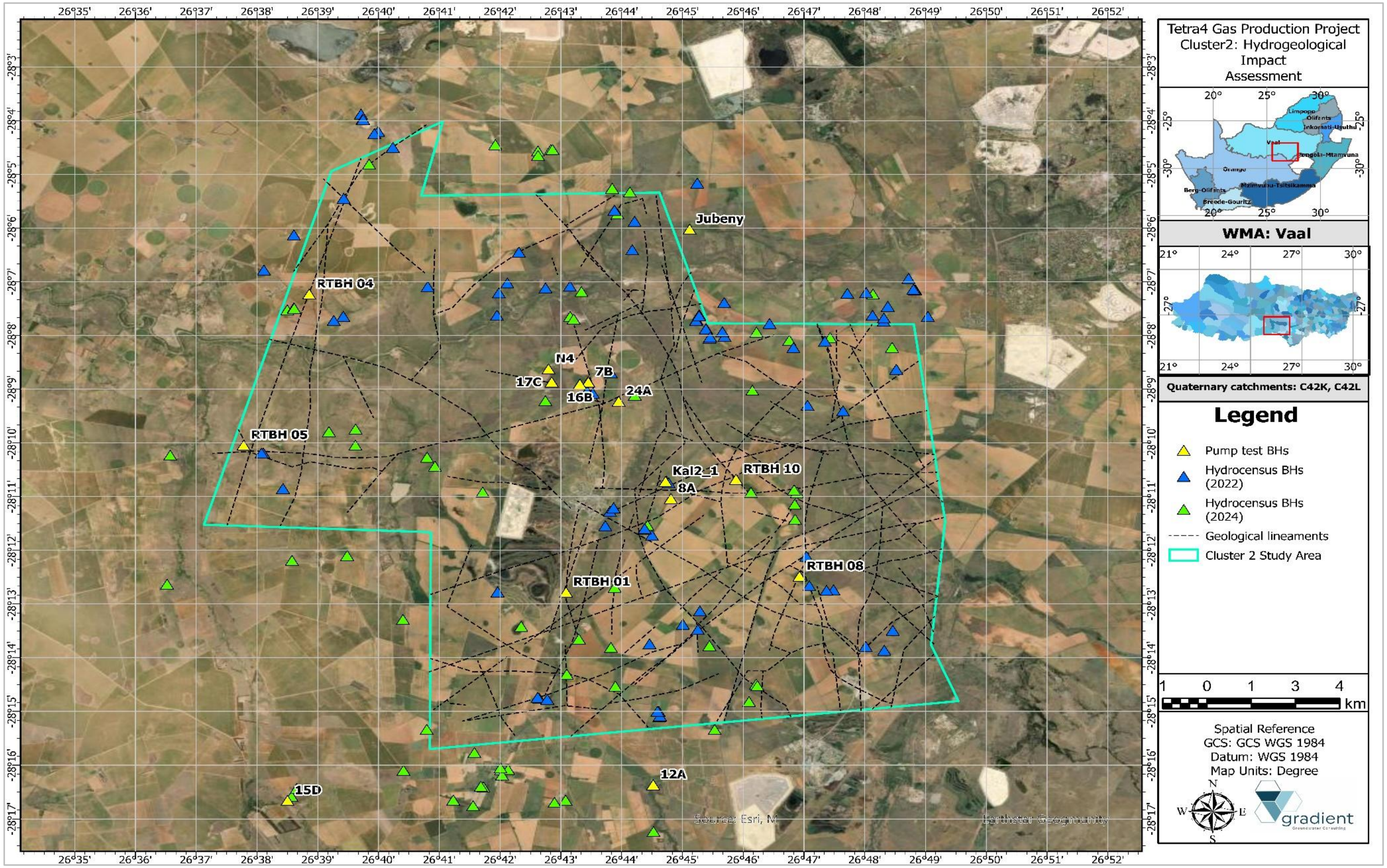


Figure 8-8 **Map indicating boreholes subjected to constant discharge aquifer tests in relation to existing hydrocensus geosites.**

To determine the appropriate analytical methods, diagnostic plots (log-log and semi-log) of drawdown versus time were compared to the theoretical plots provided by Kruseman and De Ridder (2000) as summarised in Figure 8-10 below.

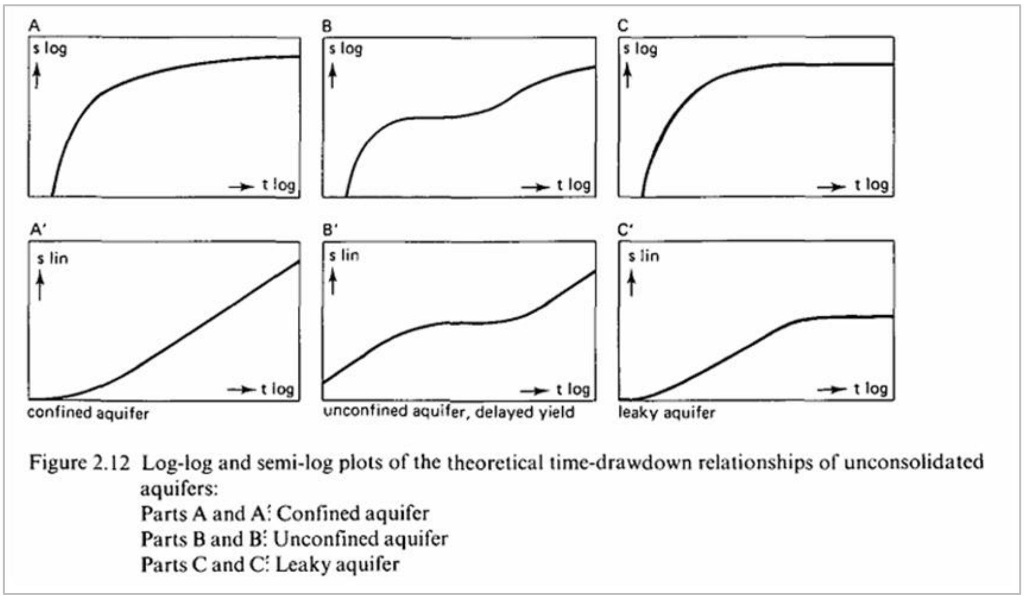


Figure 8-9 Log-log and semi-log plots of the theorectical time-drawdown relationships of unconsolidated aquifers (Kruseman and De Ridder (2000).

Furthermore, the respective names of the selected analytical methods are according to the method names of Kruseman and De Ridder (2000). The data were analysed using AQTESOLV and MATLAB scripts. The Theis Recovery method was used for all the aquifer parameter tests to double-check and confirm the determined aquifer parameter results based on the selected methods. According to Kruseman and De Ridder (2000), recovery data is not affected by changes in discharge rates, since recovery occurs at a constant rate and, therefore, the recovery data is considered more reliable.

The aquifer parameters were determined by fitting curves to the period of infinite acting radial flow (IARF). The IARF periods were identified by constructing drawdown derivative plots according to the Bourdet derivative (Bourdet, 1989). In cases where a definite period of IARF could not be identified, the aquifer parameters were determined by fitting curves to the straight-line segment of the late-time semi-log drawdown data, which is indicative of pseudo-radial flow (Kruseman and De Ridder, 2000; Van Tonder *et al.*, 2001).

To follow is a brief description of the constant discharge 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 RTBH01

A static water level of 8.57mbgl was measured at testing locality RTBH01. Four calibration step tests of 0.18l/s, 0.26l/s, 0.37l/s and 0.50l/s were conducted, followed by a constant discharge test at a rate of 0.26l/s. A maximum drawdown depth of 29.59 meter below datum level (mbsl) was reached after a pump duration of 8-hours, representing ~45.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole RTBH01 is characteristic of a confined aquifer considering the non-linear relationship between drawdown versus time at early time and the linear drawdown versus time relationship at late time. Therefore, Jacob's and Theis's methods were selected to determine the aquifer parameters. Refer to Table 8-6 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-10 depicts the Theiss method displacement time curve fitment while Figure 8-11 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 0.25m^2/d with the hydraulic conductivity calculated as 0.012m/d. Gathered site characterisation information suggest that this borehole is targeting the Karoo matrix formation, hence the sluggish seepage volumes observed.

Table 8-6 Aquifer tests summary: borehole RTBH01.

Method	T (m^2/day)	S
Jacob	0.20	0.0014
Theis	0.18	0.001773
Recovery	0.1918	-

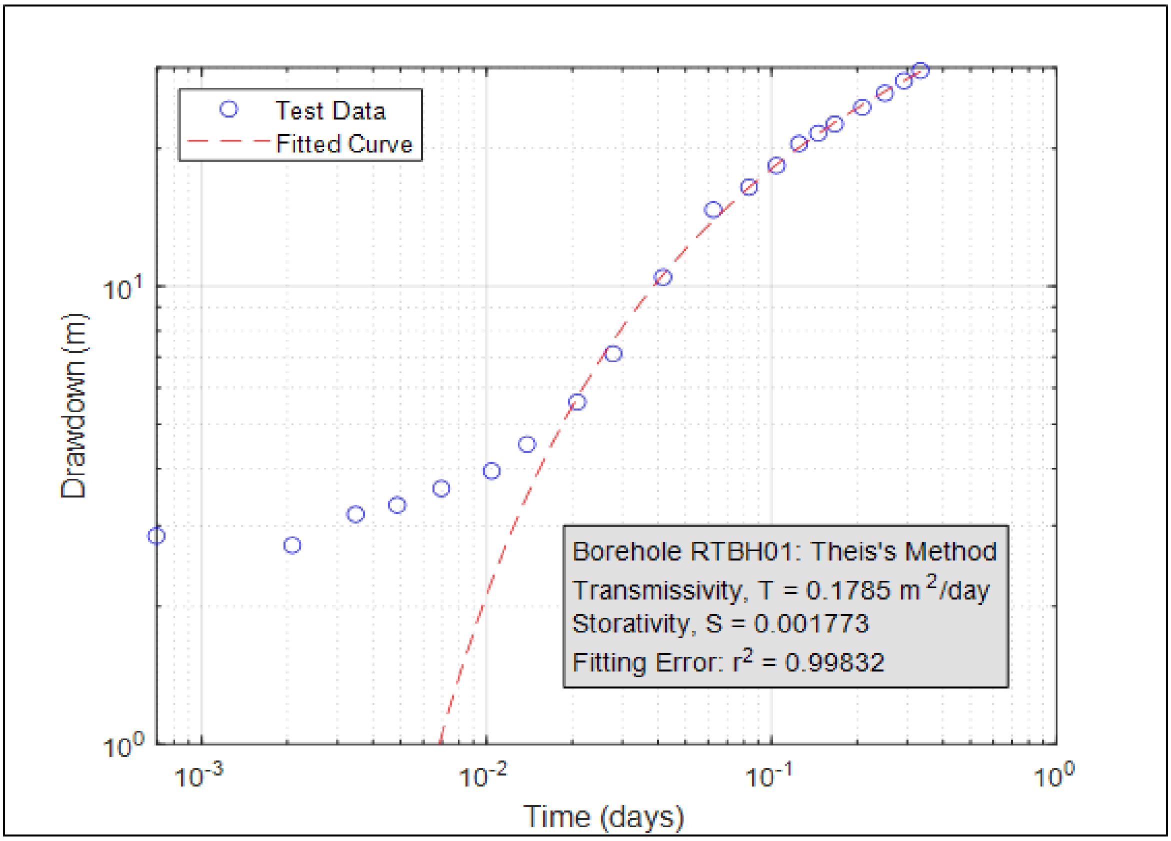


Figure 8-10 Aquifer tests: Theiss method displacement time curve for borehole RTBH01.

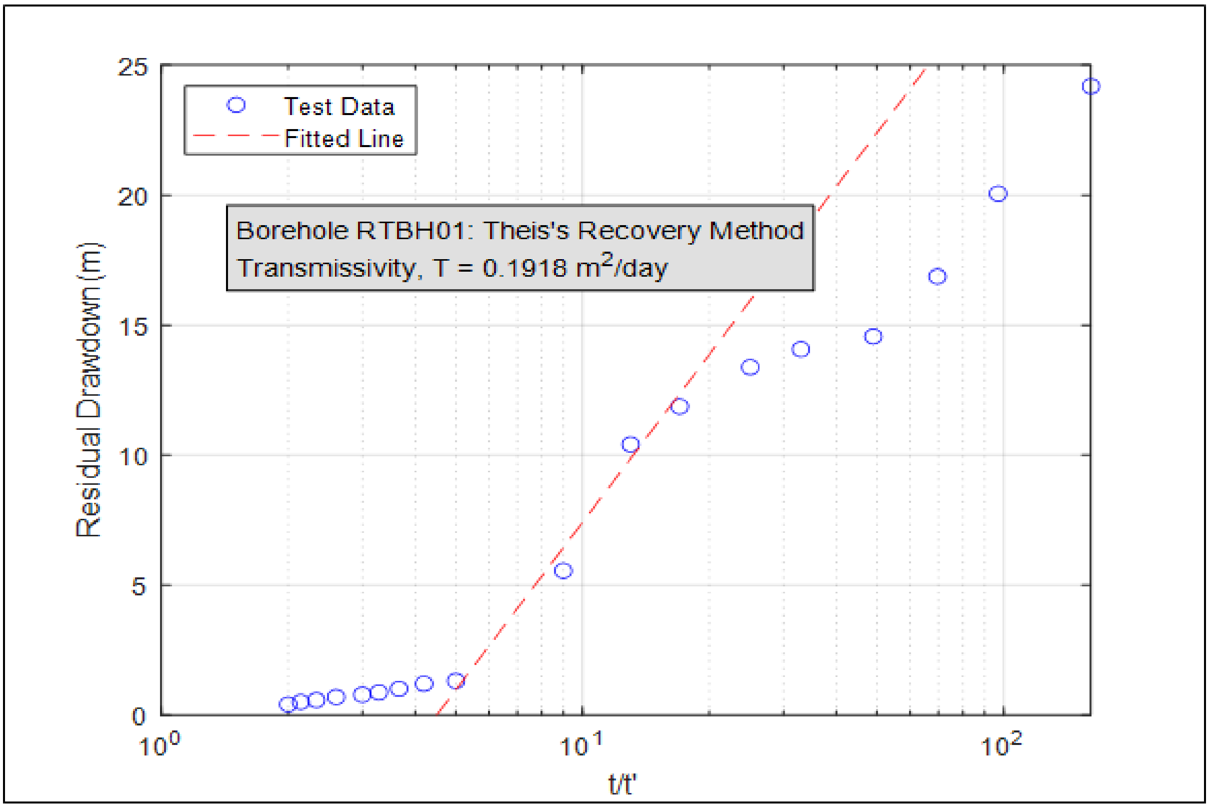


Figure 8-11 Aquifer tests: Theiss method recovery curve for borehole RTBH01.

8.3.2. Constant Rate Test borehole RTBH04

A static water level of 7.00mbgl was measured at testing locality RTBH04. Due to the low yield of the borehole, only one step test could be conducted, while no constant discharge test was initiated. The latter can be attributed to only seepage encountered during the drilling phase with no major water strike targeted.

8.3.3. Constant Rate Test borehole RTBH05

A static water level of 8.93mbgl was measured at testing locality RTBH05. Four calibration step tests of 0.18l/s, 0.22l/s, 0.30l/s and 0.75l/s were conducted, followed by a constant discharge test at a rate of 0.26l/s. A maximum drawdown depth of 17.03mbsl was reached after a pump duration of 8-hours, representing >20.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole RTBH05 do not exactly conform to the theoretical plots shown above. However, the semi-log plot of drawdown versus time shows a straight-line segment at late-time, possibly indicating pseudo-radial flow, while the log-log plot of drawdown versus time indicates a possible confined aquifer. Therefore, Jacob's method, Theis's method, and the Theis Recovery method were selected to estimate the aquifer parameters. However, since both Jacob's and Theis's methods assume a confined aquifer, the results from the Thies Recovery method are assumed to be the most representative of the aquifer parameters. Refer to Table 8-7 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-12 depicts the Theiss method displacement time curve fitment while Figure 8-13 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 0.79m^2/d with the hydraulic conductivity calculated as 0.04m/d.

Gathered site characterisation information suggest that this borehole is targeting a dolerite intrusion encountered deeper.

Table 8-7 Aquifer tests summary: borehole RTBH05.

Method	T (m²/day)	S
Jacob	0.80	0.00001
Theis	0.64	0.000032
Recovery	0.6625	-

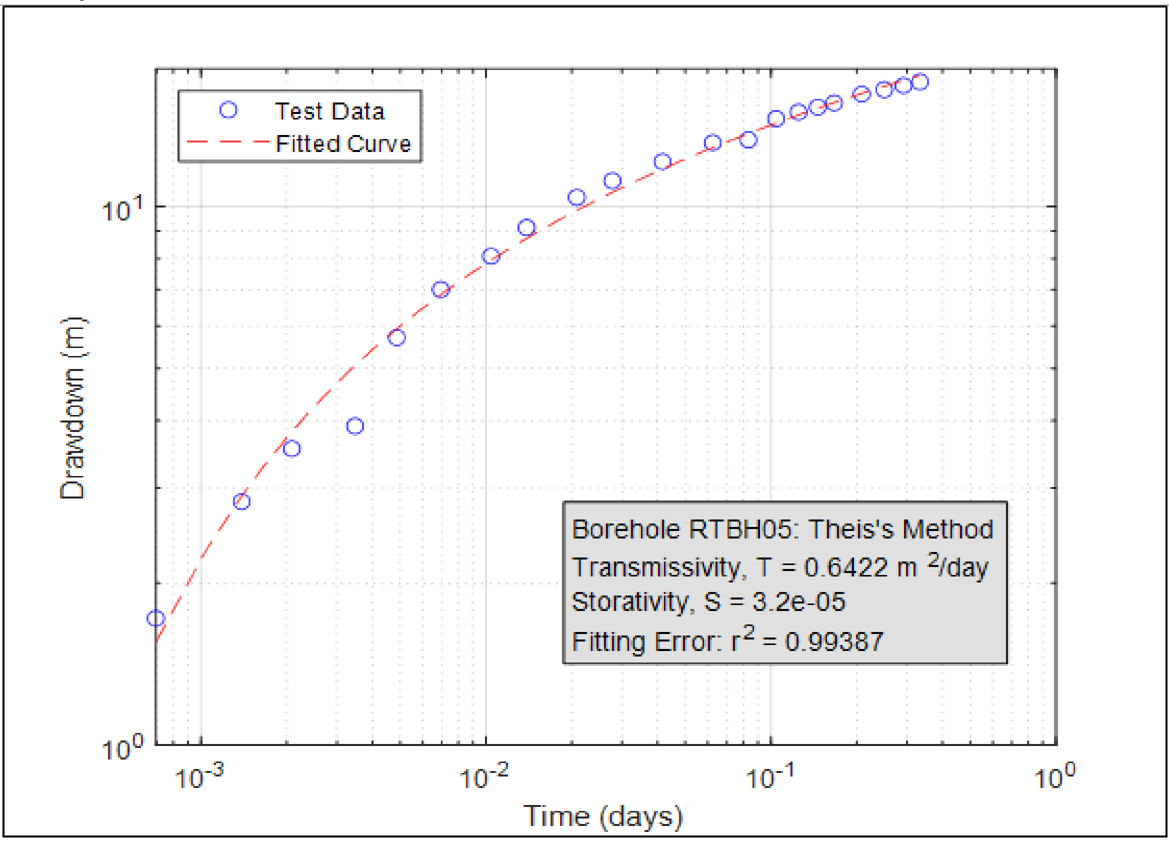


Figure 8-12 Aquifer tests: Theiss method displacement time curve for borehole RTBH05.

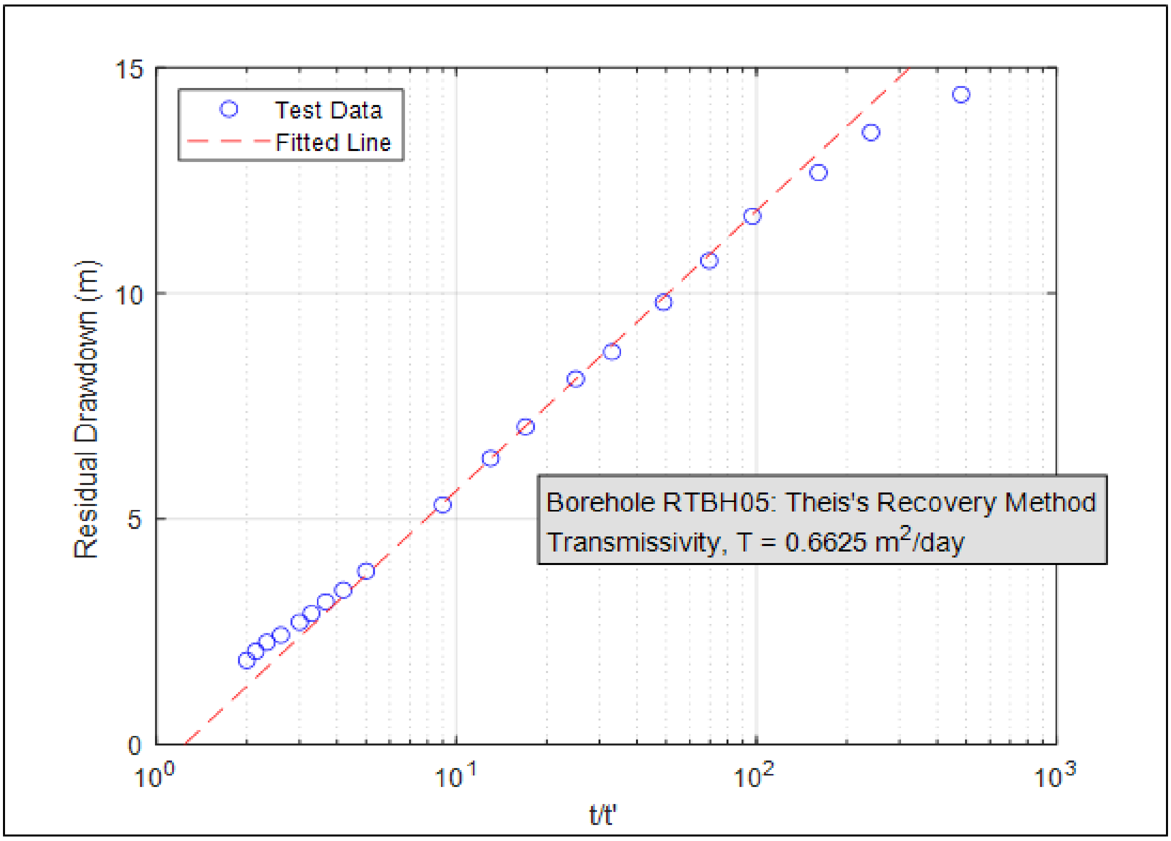


Figure 8-13 **Aquifer tests: Theiss method recovery curve for borehole RTBH05.**

8.3.4. Constant Rate Test borehole RTBH08

A static water level of 4.29mbgl was measured at testing locality RTBH08. Due to the low yield of the borehole, no calibration step tests could be conducted and the test directly went into a constant discharge phase (0.26l/s). A maximum drawdown depth of 75.25mbsl was reached after a pump duration of 2.5-hours, representing >90.0% of available drawdown utilised. The drawdown versus time data for the aquifer test conducted on Borehole RTBH08 do not conform to the theoretical plots shown above. However, the semi-log plot of drawdown versus time shows a straight-line segment at late-time, possibly indicating pseudo-radial flow. Therefore, Jacob's and Theis's methods were selected to estimate the aquifer parameters. However, since both Jacob's and Theis's methods assume a confined aquifer, the results from the Thies Recovery method are assumed to be the most representative of the aquifer parameters. Refer to Table 8-8 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-14 depicts the Theiss method displacement time curve fitment while Figure 8-15shows the Jacob's method displacement curve fitment. The average transmissivity was calculated as 0.12m^2/d with the hydraulic conductivity calculated as 0.006m/d. Gathered site characterisation information suggest that this borehole is targeting the Karoo matrix formation, hence the sluggish seepage volumes observed.

Table 8-8 Aquifer tests summary: borehole RTBH08.

Method	T (m^2/day)	S
Jacob	0.03	0.0001
Theis	0.03	0.000069

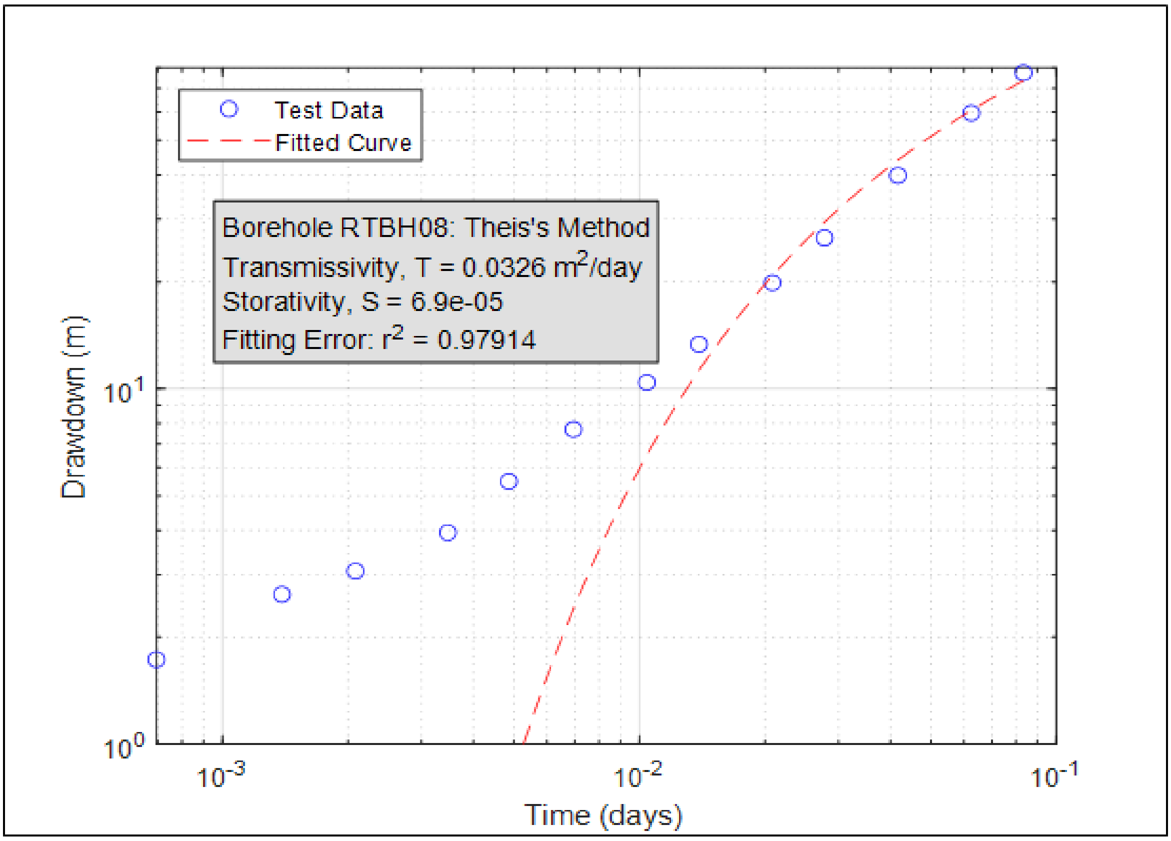


Figure 8-14 Aquifer tests: Theiss method displacement time curve for borehole RTBH08.

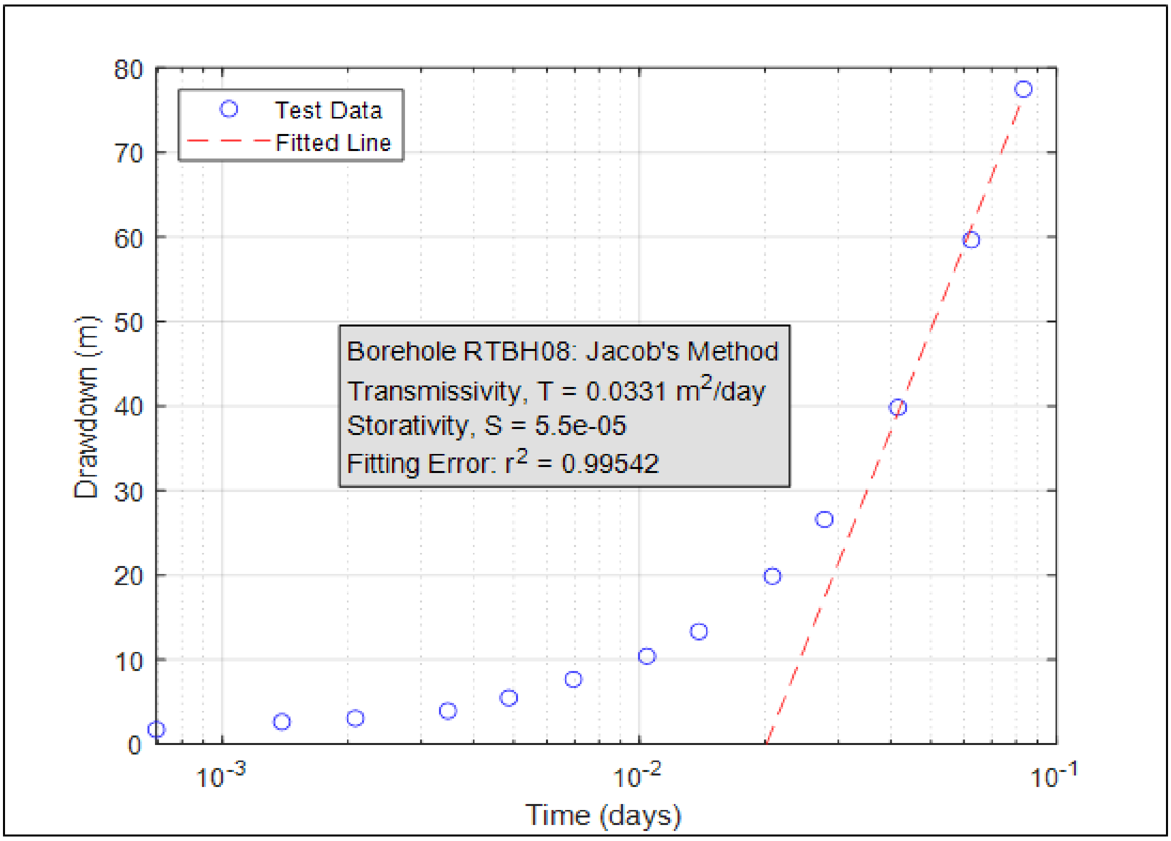


Figure 8-15 **Aquifer tests: Jacob's method displacement curve for borehole RTBH08.**

8.3.5. Constant Rate Test borehole RTBH10

A static water level of 5.52mbgl was measured at testing locality RTBH10. Four calibration step tests of 0.28l/s, 0.50l/s, 0.75l/s and 1.30l/s were conducted, followed by a constant discharge test at a rate of 0.56l/s. It should be noted that the pump testing equipment could not be lowered past ~27.0mbgl due to an obstruction in the borehole. A maximum drawdown depth of 6.63mbsl was reached after a pump duration of 8-hours, representing >25.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole RTBH10 is characteristic of an unconfined aquifer considering the stabilisation of drawdown at intermediate times, and the two parallel straight-lines of the early-time and late-time drawdown data. Therefore, Neuman's method was selected to determine the aquifer parameters. Refer to Table 8-9 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-16 depicts the Neuman method displacement time curve fitment while Figure 8-17 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 3.13m^2/d with the hydraulic conductivity calculated as 0.15m/d. Gathered site characterisation information suggest that this borehole is targeting the Volksrust formation aquifer.

Table 8-9 **Aquifer tests summary: borehole RTBH10.**

Method	T (m^2/day)	S	Sy	β
Neuman	2.04	0.0001	0.001938	0.02
Recovery	5.36	-	-	-

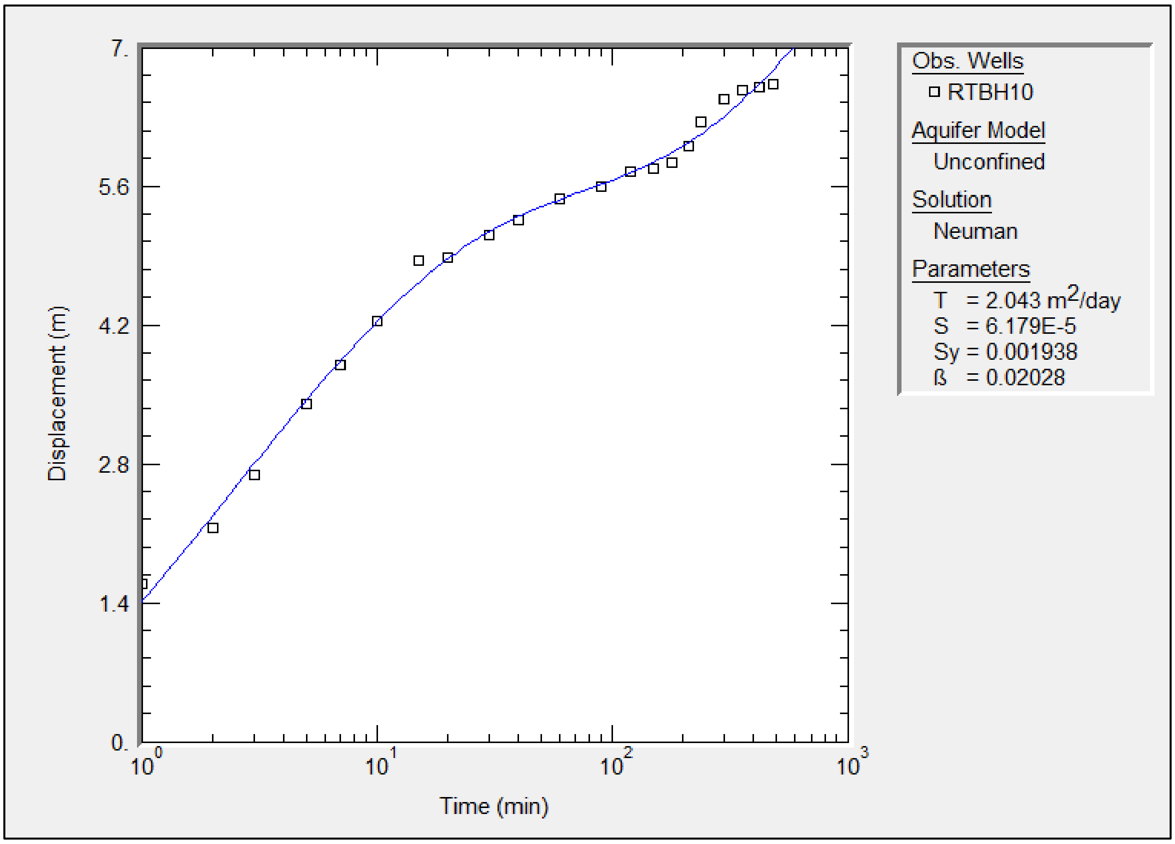


Figure 8-16 **Aquifer tests: Neuman method displacement time curve for borehole RTBH10.**

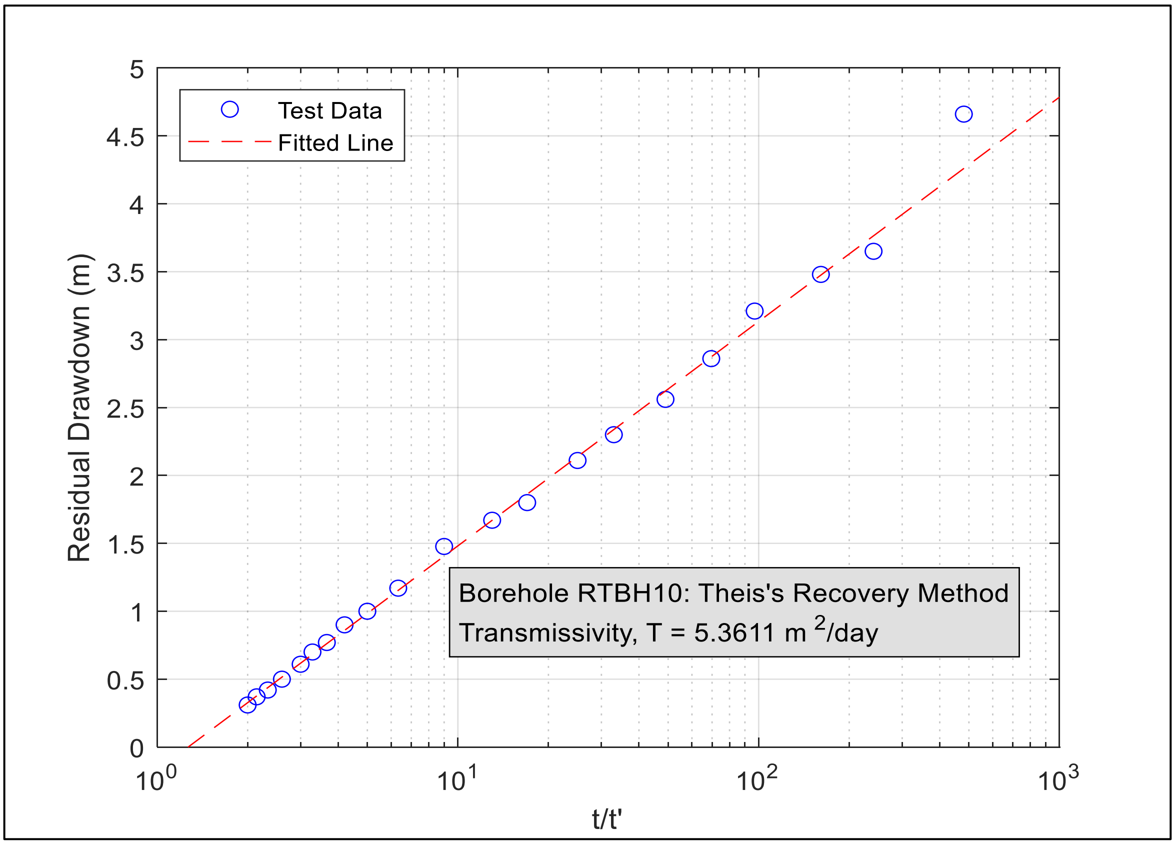


Figure 8-17 **Aquifer tests: Theiss method recovery curve for borehole RTBH10.**

To follow is a brief description of the constant discharge tests performed on existing monitoring boreholes along with analysis and interpretation of the water level drawdown and recovery curves. It should be noted that the majority of boreholes tested are privately owned and currently applied for domestic and/or livestock purposes. Thus, due to logistical constraints the constant discharge pump test was performed with existing equipment and fitment of a variable speed drive (VSD) to maintain a constant discharge rate, no calibration step tests could be performed.

8.3.6. Constant Rate Test borehole 7B

A static water level of 12.12mbgl was measured at testing locality 7B. A constant discharge test was performed at a rate of approximately 1.76l/s for a duration of 4 hours. A maximum drawdown depth of 16.46mbsl was reached during the pump test duration representing >90.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole 7B is characteristic of a leaky aquifer considering the stabilisation of drawdown at late time. Therefore, Walton's method was selected to determine the aquifer parameters. Refer to Table 8-10 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-18 depicts the Walton’s method displacement time curve fitment while Figure 8-19 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 1.76m^2/d with the hydraulic conductivity calculated as 0.11m/d. Gathered site characterisation information suggest that this borehole is targeting the Beaufort formation aquifer.

Table 8-10 Aquifer tests summary: borehole 7B.

Method	T (m^2/day)	S	r/L	L (m)	c (days)	K' (m/day)
Walton	1.67	0.0012	0.38	5.26	16.57	0.60
Recovery	1.86	-	-	-	-	-

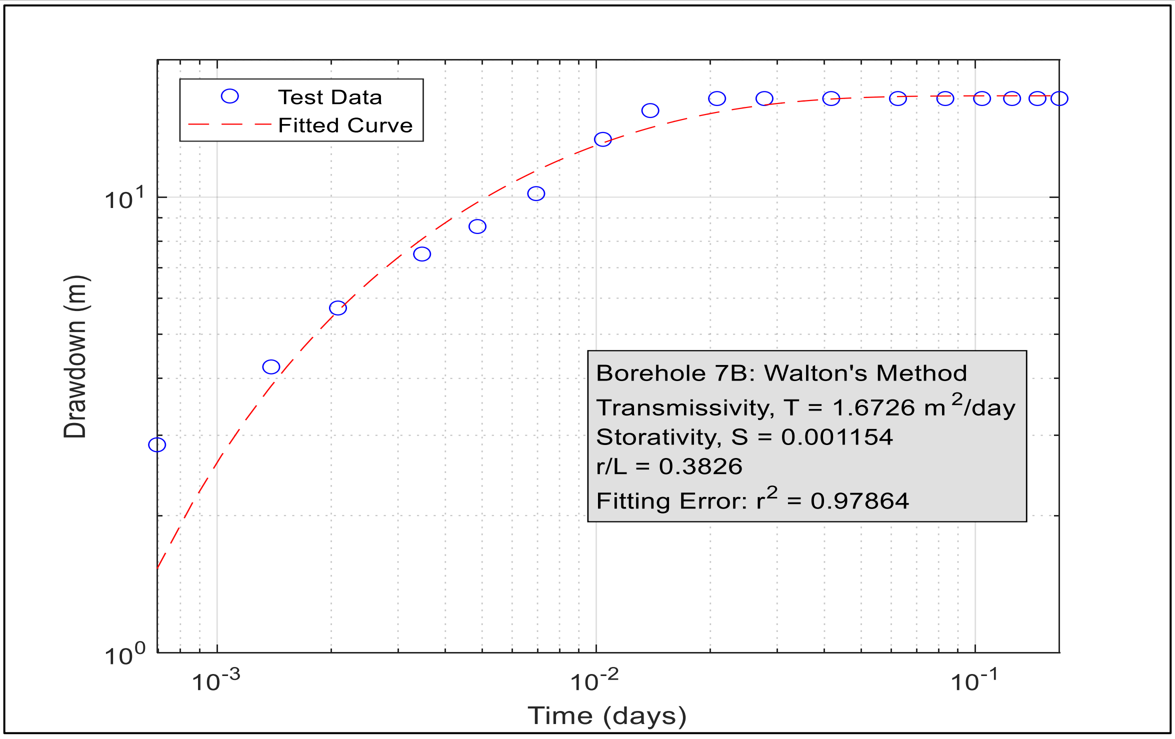


Figure 8-18 Aquifer tests: Walton’s method displacement time curve for borehole 7B.

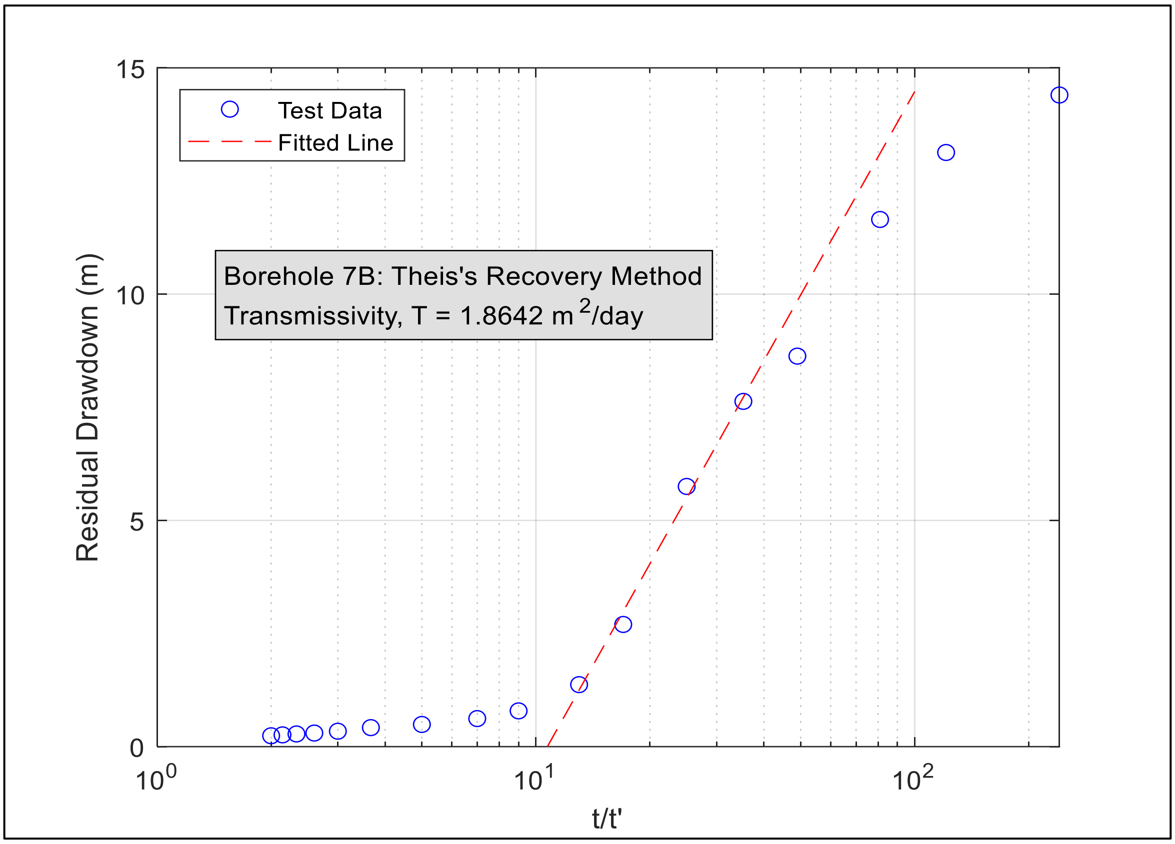


Figure 8-19 **Aquifer tests: Theiss method recovery curve for borehole 7B.**

8.3.7. Constant Rate Test borehole 17C

A static water level of 12.24mbgl was measured at testing locality 17C. A constant discharge test was performed at a rate of approximately 2.22l/s for a duration of 2.5 hours, after which the test was interrupted by a power failure. A maximum drawdown depth of 13.71mbsl was reached during the pump test duration representing >30.0% of available drawdown utilised. Borehole recovery observed was not so good with a 65% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole 17C does not conform to the theoretical plots shown above. However, the semi-log plot of drawdown versus time shows a straight-line segment at late-time, possibly indicating pseudo-radial flow. Therefore, Jacob's method, Theis's method, and the Theis Recovery method were selected to estimate the aquifer parameters. However, since both Jacob's and Theis's methods assume a confined aquifer, the results from the Thies Recovery method are assumed to be the most representative of the aquifer parameters. Refer to Table 8-11 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-20 depicts the Theiss method displacement time curve fitment while Figure 8-21 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 9.37m^2/d with the hydraulic conductivity calculated as 0.375m/d. Gathered site characterisation information suggest that this borehole is targeting a regional geological lineament.

Table 8-11 Aquifer tests summary: borehole 17C.

Method	T (m^2/day)	S
Jacob	10.60	0.0178
Theis	10.61	0.01779
Recovery	9.023	-

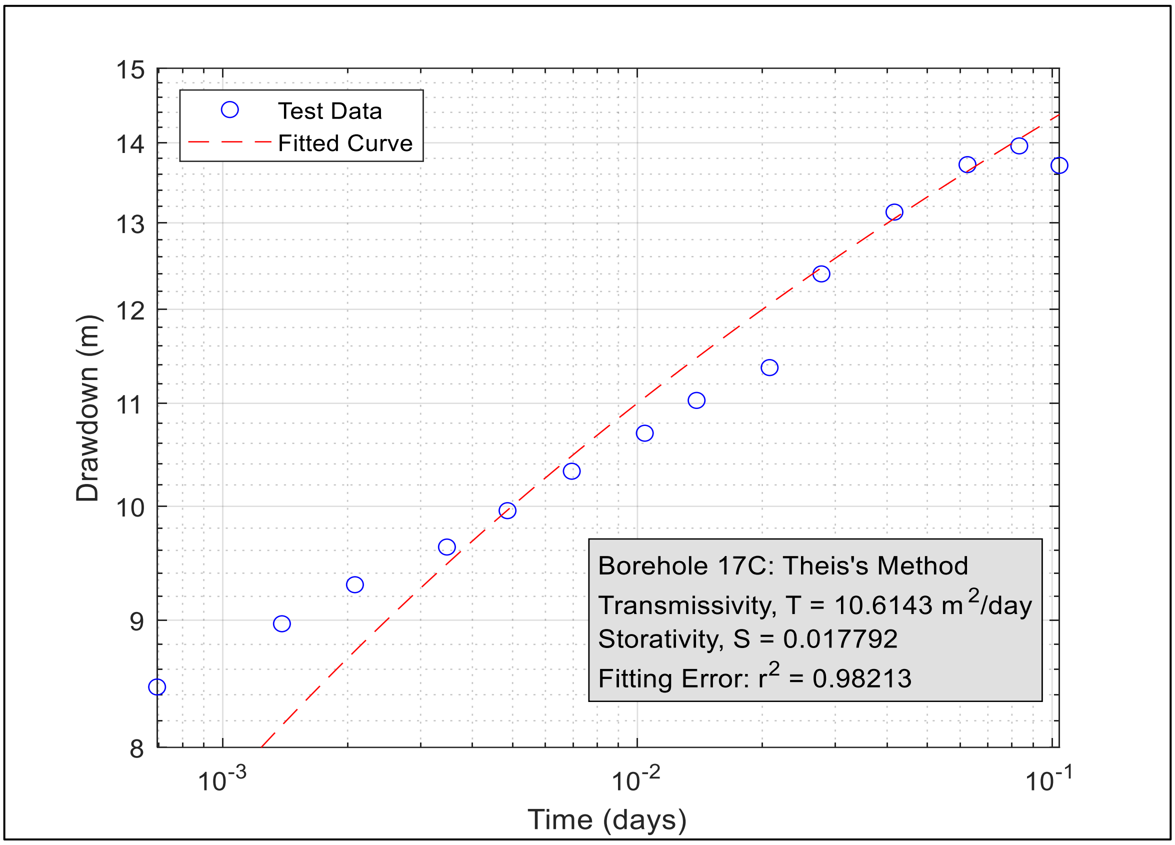


Figure 8-20 Aquifer tests: Theiss method displacement time curve for borehole 17C.

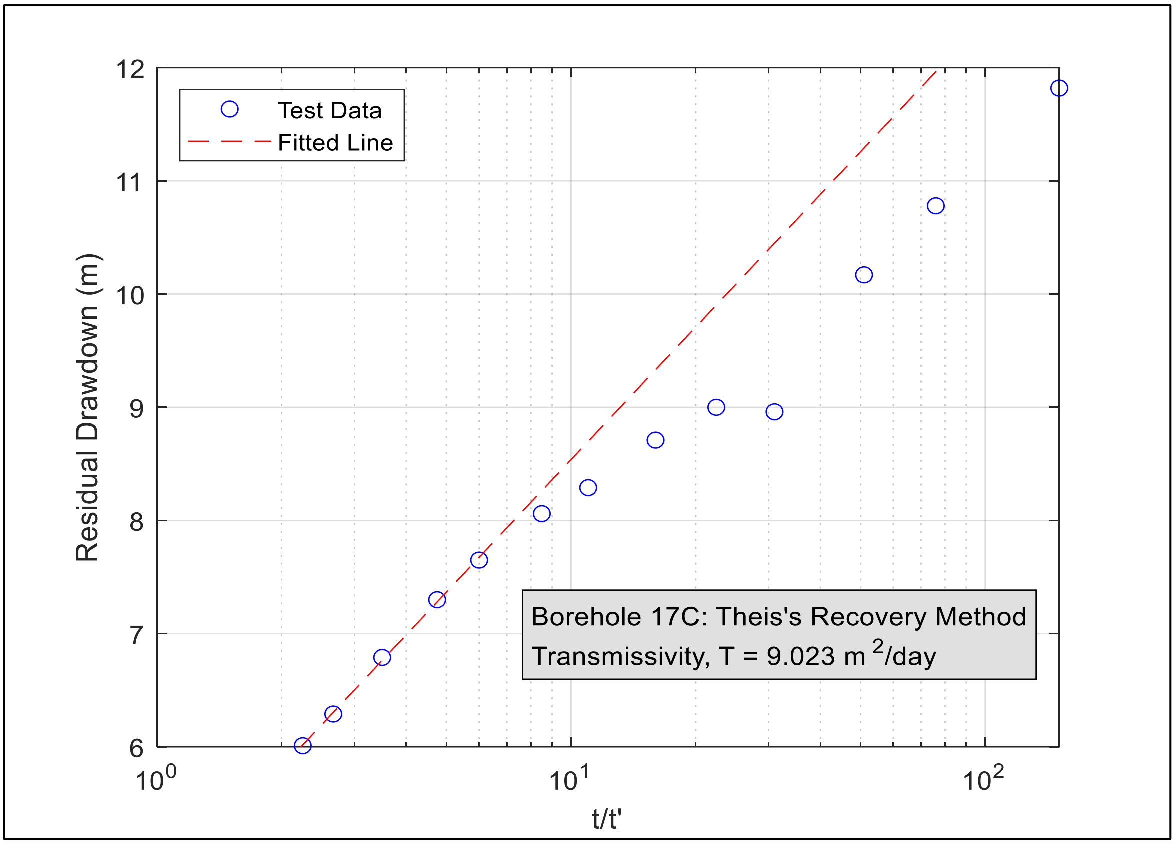


Figure 8-21 **Aquifer tests: Theiss method recovery curve for borehole 17C.**

8.3.8. Constant Rate Test borehole 24A

A static water level of 8.0mbgl was measured at testing locality 24A. A constant discharge test was performed at a rate of 0.92l/s for a duration of an hour. A maximum drawdown depth of 33.91mbsl was reached during the pump test duration, representing >95.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole 24A is characteristic of a leaky aquifer considering the stabilisation of drawdown at late time. Therefore, Walton's method was selected to determine the aquifer parameters. Refer to Table 8-12 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-22 depicts the Walton’s method displacement time curve fitment while Figure 8-23 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 0.35m^2/d with the hydraulic conductivity calculated as 0.017m/d. Gathered site characterisation information suggest that this borehole is targeting the Karoo matrix formation, hence the sluggish seepage volumes observed.

Table 8-12 **Aquifer tests summary: borehole 24A.**

Method	T (m^2/day)	S	r/L	L (m)	c (days)	K' (m/day)
Walton	0.16	0.0001	0.9836	4.26	117.2694	0.085273766
Recovery	0.29	-	-	-	-	-

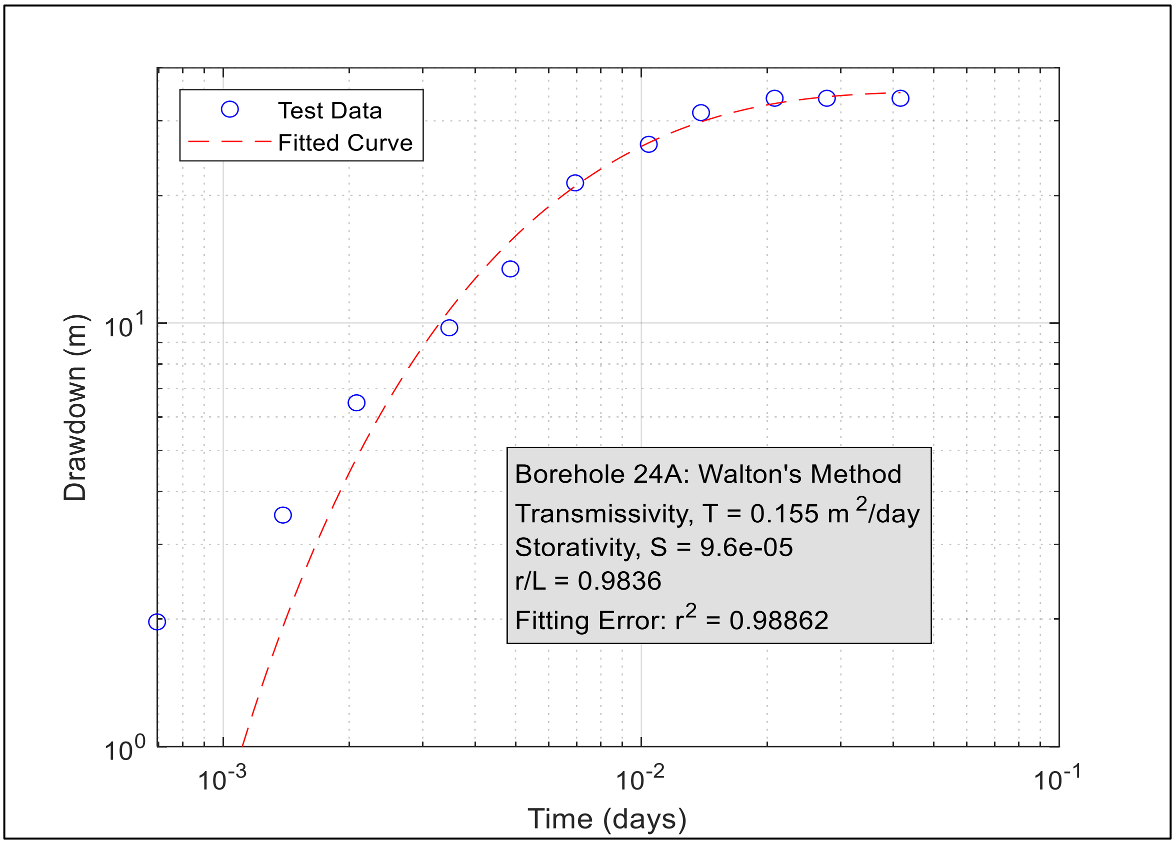


Figure 8-22 **Aquifer tests: Walton's method displacement time curve for borehole 24A.**

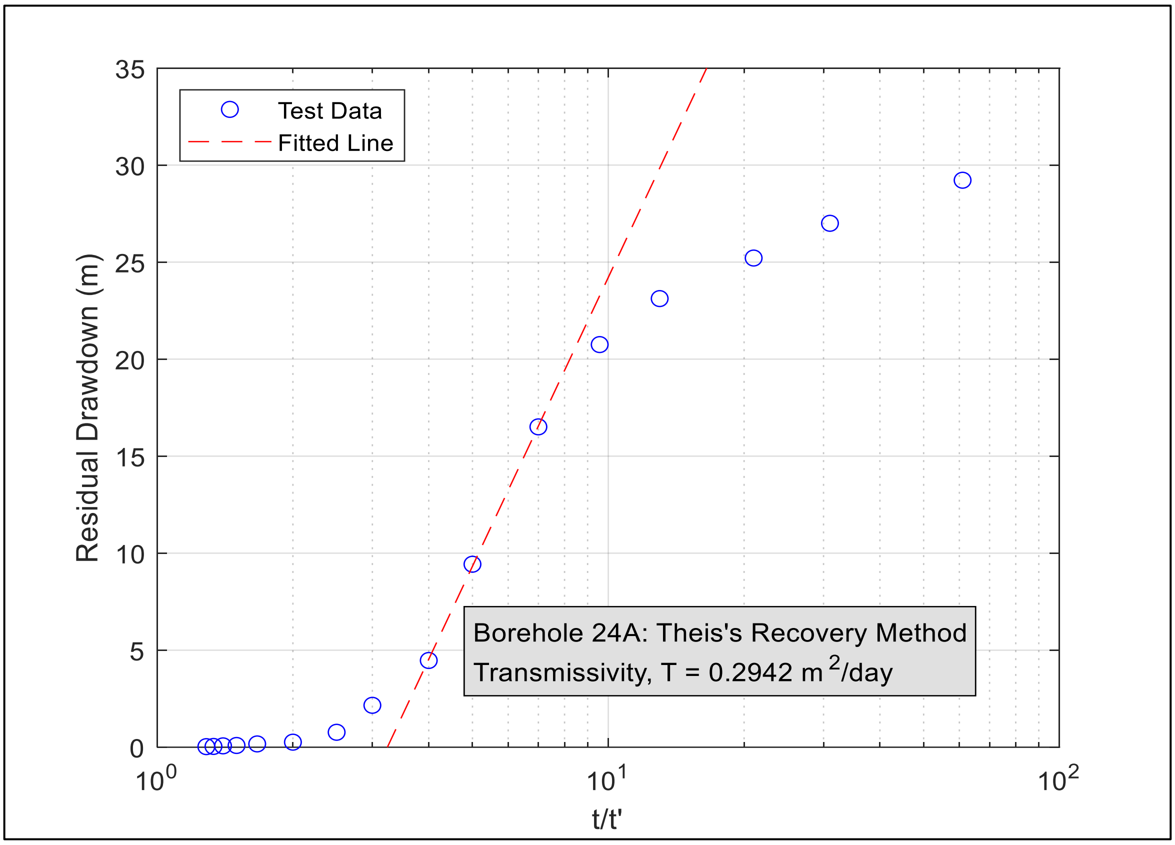


Figure 8-23 **Aquifer tests: Theiss method recovery curve for borehole 24A.**

8.3.9. Constant Rate Test borehole Kal 2.1

A static water level of 7.70mbgl was measured at testing locality Kal2.1. Three calibration step tests of 0.20l/s, 0.30l/s, 0.40l/s and 0.75l/s were conducted, followed by a constant discharge test at a rate of 0.20l/s. A maximum drawdown depth of 19.49mbsl was reached after a pump duration of 4-hours representing >85.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole KAL 2.1 does not conform to the theoretical plots shown above. However, the semi-log plot of drawdown versus time shows a straight-line segment at late-time, possibly indicating pseudo-radial flow. Therefore, Jacob's method, Theis's method, and the Theis Recovery method were selected to estimate the aquifer parameters. However, since both Jacob's and Theis's methods assume a confined aquifer, the results from the Thies Recovery method are assumed to be the most representative of the aquifer parameters.

Refer to Table 8-13 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-24 depicts the Theiss method displacement time curve fitment while Figure 8-25 shows the Theiss method recovery curve fitment. The average transmissivity was calculated as 0.29m^2/d with the hydraulic conductivity calculated as 0.014m/d. Gathered site characterisation information suggest that this borehole is targeting the Karoo matrix formation, hence the sluggish seepage volumes observed.

Table 8-13 Aquifer tests summary: borehole Kal2.1.

Method	T (m^2/day)	S
Jacob	0.09	0.00001
Theis	0.18	0.000017
Recovery	0.1896	-

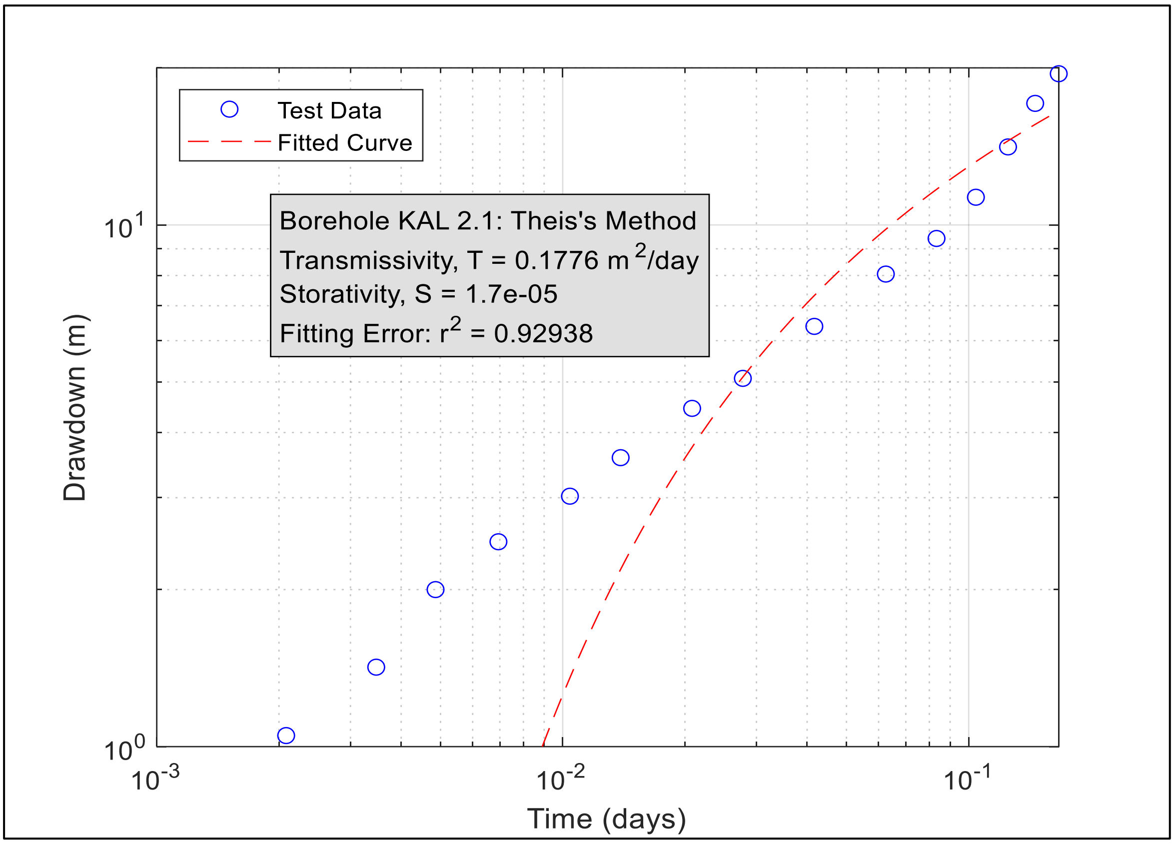


Figure 8-24 **Aquifer tests: Theiss method displacement time curve for borehole Kal 2-1.**

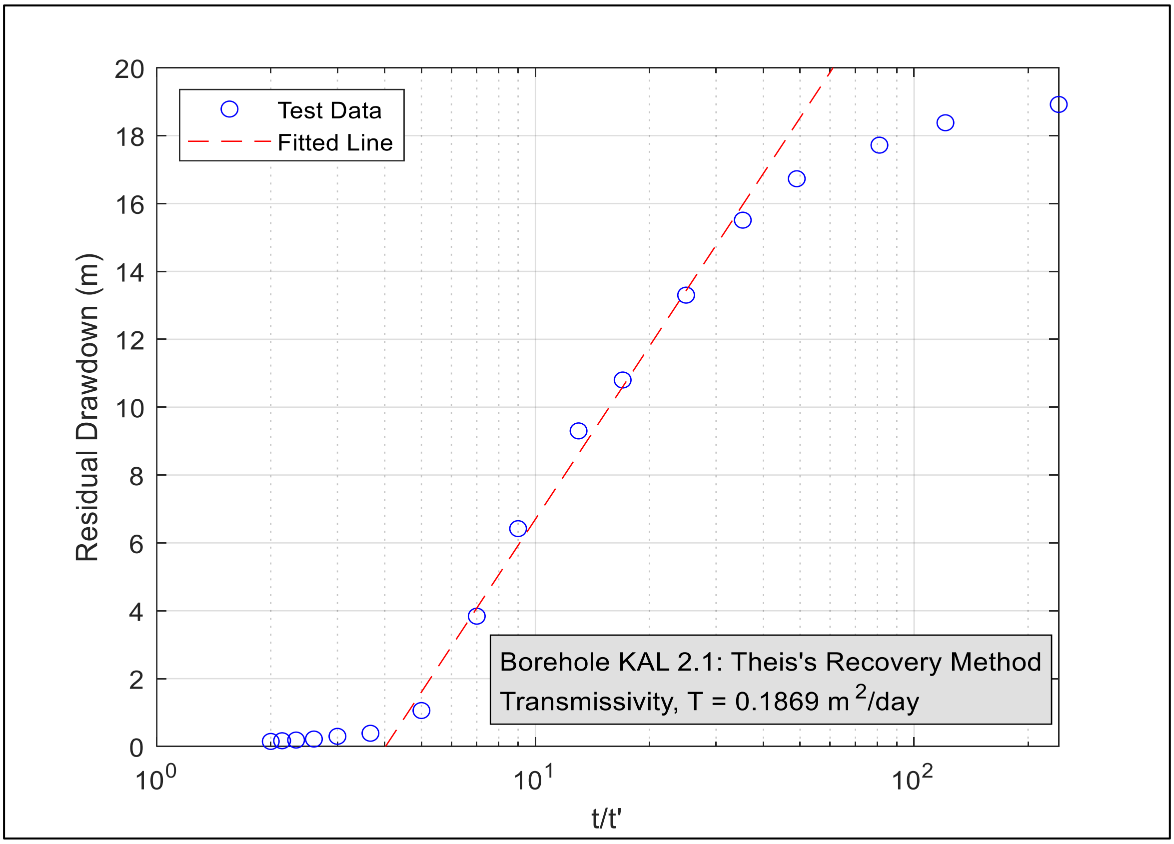


Figure 8-25 **Aquifer tests: Theiss method recovery curve for borehole Kal 2-1.**

8.3.10. Constant Rate Test borehole 16B

A static water level of 13.89mbgl was measured at testing locality 16B. A constant discharge test was performed at a rate of 1.44l/s for a duration of two hours. A maximum drawdown depth of 5.99mbsl was reached during the pump test duration, representing >95.0% of available drawdown utilised representing >95.0% of available drawdown utilised. Borehole recovery observed was good with a 90% recovery of pre-testing water levels obtained within the pumping duration. The drawdown versus time data for the aquifer test conducted on Borehole 16B does not exactly conform to the theoretical plots shown above. However, the semi-log plot of drawdown versus time shows a straight-line segment at late-time, possibly indicating pseudo-radial flow, while the log-log plot of drawdown versus time indicates a possible confined aquifer. Therefore, Jacob's method, Theis's method, and the Theis Recovery method were selected to estimate the aquifer parameters. However, since both Jacob's and Theis's methods assume a confined aquifer, the results from the Thies Recovery method are assumed to be the most representative of the aquifer parameters. Refer to Table 8-14 for a summary of hydraulic parameters inferred from the constant discharge pump test. Figure 8-26 depicts the Theiss method displacement time curve fitment while Figure 8-27 shows the Theiss method recovery curve fitment. This borehole indicate the highest transmissivity calculated from all testing localities with an average transmissivity value calculated at 11.0m^2/d and the hydraulic conductivity calculated at 0.55m/d. Gathered site characterisation information suggest that this borehole is targeting the shallow quaternary sediments and alluvial deposit aquifer unit.

Table 8-14 Aquifer tests summary: borehole 16B.

Method	T (m^2/day)	S
Jacob	14.53	0.00001
Theis	12.18	0.000033
Recovery	9.5857	-

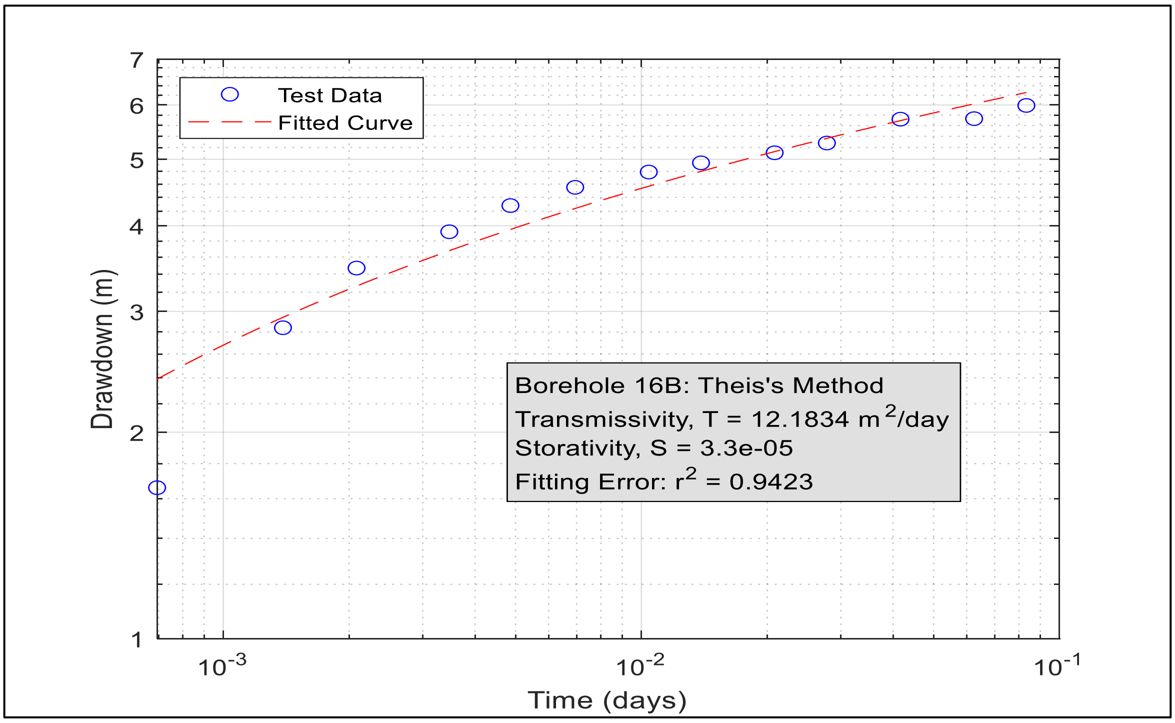


Figure 8-26 Aquifer tests: Theiss method displacement time curve for borehole 16B.

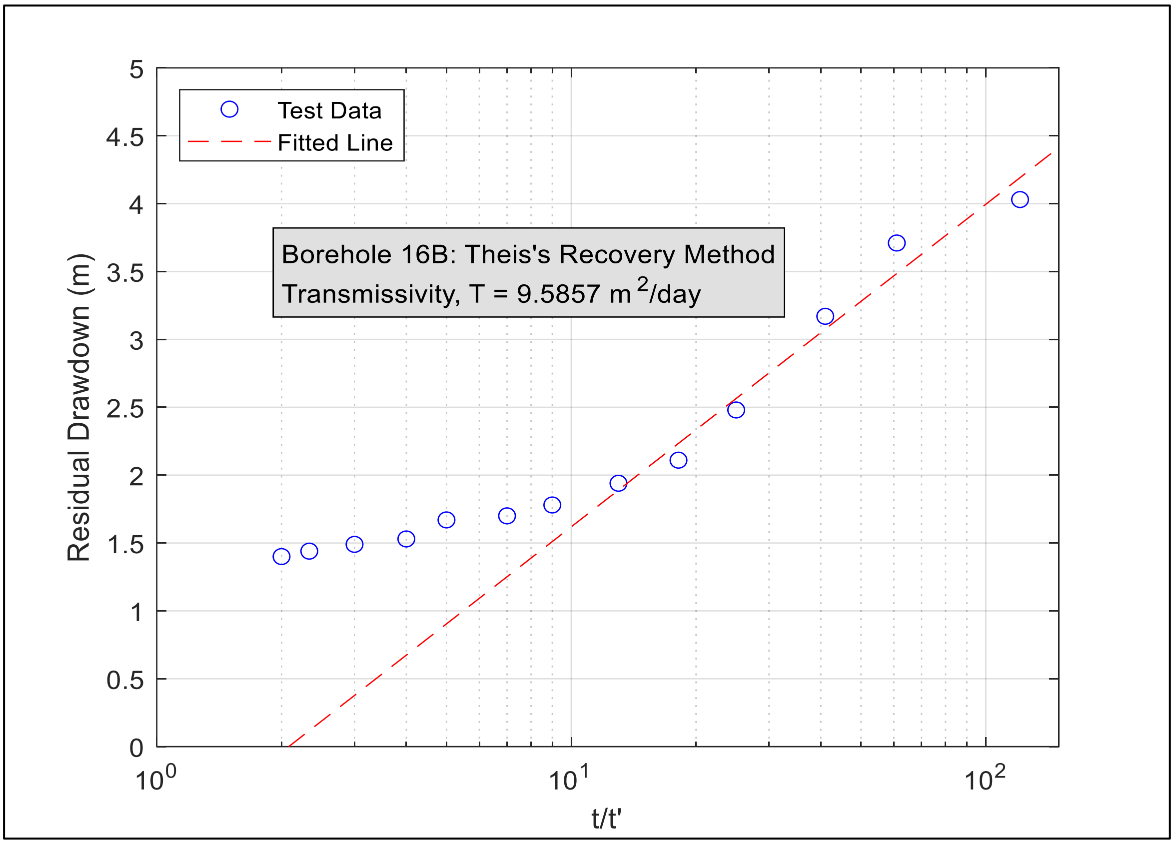


Figure 8-27 Aquifer tests: Theiss method recovery curve for borehole 16B.

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). During the wet-season evaluation the unsaturated zone within the study area were in the order of 0 (fully saturated to surface) to >21.0m with a mean thickness of approximately ~8.91m. During the dry-season evaluation the unsaturated zone within the study area were in the order of 2.20 to 19.40.0m with a mean thickness of approximately ~7.17m. The variation in the vadose zone thickness and extent observed, can potentially be attributed to the variations in rainfall hence recharge experienced within these periods. 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 as well as monitoring borehole water levels measured were considered and used to interpolate local groundwater elevation and hydraulic head contours as summarised in Table 9-1 and Figure 9-1 (wet-season) as well as Table 9-2 and Figure 9-2 (dry-season).

During the wet-season evaluation, artesian conditions were observed at three of the boreholes visited namely HBH31, 21B as well as 8B which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions. The minimum water level was recorded at 0.0mbgl, while the deepest water level was measured at borehole locality Mon-HDR1 (26.71mbgl)[7]. The average water level is calculated at 8.91mbgl which is much shallower than the regional average water level of ~23.0mbgl (Aquiworx, 2014).

During the dry-season evaluation the minimum water level was recorded at 2.20mbgl (HBH161), while the deepest water level was measured at borehole locality HBH136 (42.13mbgl)[8]. The average water level is calculated at 7.86mbgl which is much shallower than the regional average water level of ~23.0mbgl (Aquiworx, 2014).

A groundwater observation borehole situated within the study area have been measured at ~25.0mamsl. This confirms the hypothesis that the deep, fractured aquifer unit have been locally depressurised by years of dewatering from underground mining operations targeting these zones for gold beneficiation.

Table 9-1 Regional water level summary (Wet-season).

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
HBH6	1308.35	1.52	1306.83
HBH9	1314.33	10.87	1303.46
HBH12	1317.12	13.65	1303.47
HBH13	1317.12	12.35	1304.77
HBH14	1306.16	16.65	1289.51
HBH15	1306.16	17.74	1288.42
HBH16	1311.92	25.40	1286.52
HBH17	1306.16	11.55	1294.61
HBH18	1312.93	16.47	1296.46
HBH20	1341.47	1.10	1340.37
HBH21	1316.68	2.67	1314.01
HBH23	1313.61	3.16	1310.45
HBH24	1296.78	8.50	1288.28
HBH25	1306.46	24.20	1282.26
HBH27	1300.84	1.40	1299.44
HBH28	1312.85	5.02	1307.83
HBH31	1308.76	0.00	1308.76
HBH33	1303.06	15.70	1287.36
HBH34	1282.46	26.04	1256.42
HBH35	1293.51	3.70	1289.81
HBH36	1311.04	2.66	1308.38
HBH37	1311.33	3.18	1308.15

[7] 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.

[8] It should be noted that due to this borehole currently being applied for domestic and livestock watering supply purposes, it can be assumed that this water level represents a dynamic water level.

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
HBH38	1338.24	2.94	1335.30
HBH39	1312.52	8.26	1304.26
HBH40	1312.52	8.75	1303.77
HBH44	1318.93	8.46	1310.47
HBH45	1318.93	8.40	1310.53
HBH46	1314.70	14.50	1300.20
HBH48	1325.03	11.03	1314.00
HBH49	1325.03	7.12	1317.91
HBH52	1323.97	1.08	1322.89
HBH53	1323.97	2.80	1321.17
HBH54	1363.06	7.98	1355.08
HBH56	1358.94	1.79	1357.15
HBH58	1373.57	7.95	1365.62
HBH59	1373.57	8.35	1365.22
HBH60	1371.99	12.90	1359.09
HBH61	1371.99	12.55	1359.44
HBH62	1337.84	12.70	1325.14
HBH69	1358.14	1.67	1356.47
HBH70	1360.24	3.10	1357.14
HBH72	1332.90	1.75	1331.15
HBH73	1332.90	1.63	1331.27
15E	1380.01	2.20	1377.81
21A (BH05)	1281.21	12.48	1268.74
21B	1281.21	0.00	1281.21
21D	1280.00	16.09	1263.91
22A	1282.95	10.64	1272.31
22D (BH09)	1281.21	8.33	1272.89
23C	1373.57	5.42	1368.16
25B	1404.66	9.39	1395.27
8B	1325.03	0.00	1325.03
BD52	1381.39	0.73	1380.66
BH01	1283.95	23.33	1260.63
BH02	1308.60	10.07	1298.53
BH07	1281.69	16.97	1264.73
Mon-2057	1320.23	3.09	1317.14
Mon-F1	1290.60	21.46	1269.14
Mon-F3	1304.74	7.74	1297.00
Mon-F4	1319.62	7.69	1311.93
Mon-HDR1	1283.95	26.71	1257.24
OB	1364.24	0.70	1363.54
Geometric Mean	**1321.87**	**8.91**	**1312.88**
Minimum	**1280.00**	**0.00**	**1256.42**
Maximum	**1404.66**	**26.71**	**1395.27**
Standard deviation	**30.02**	**7.17**	**33.46**
Correlation		**0.98**	

Notes: Boreholes highlighted in green represent the current Tetra 4 monitoring localities.

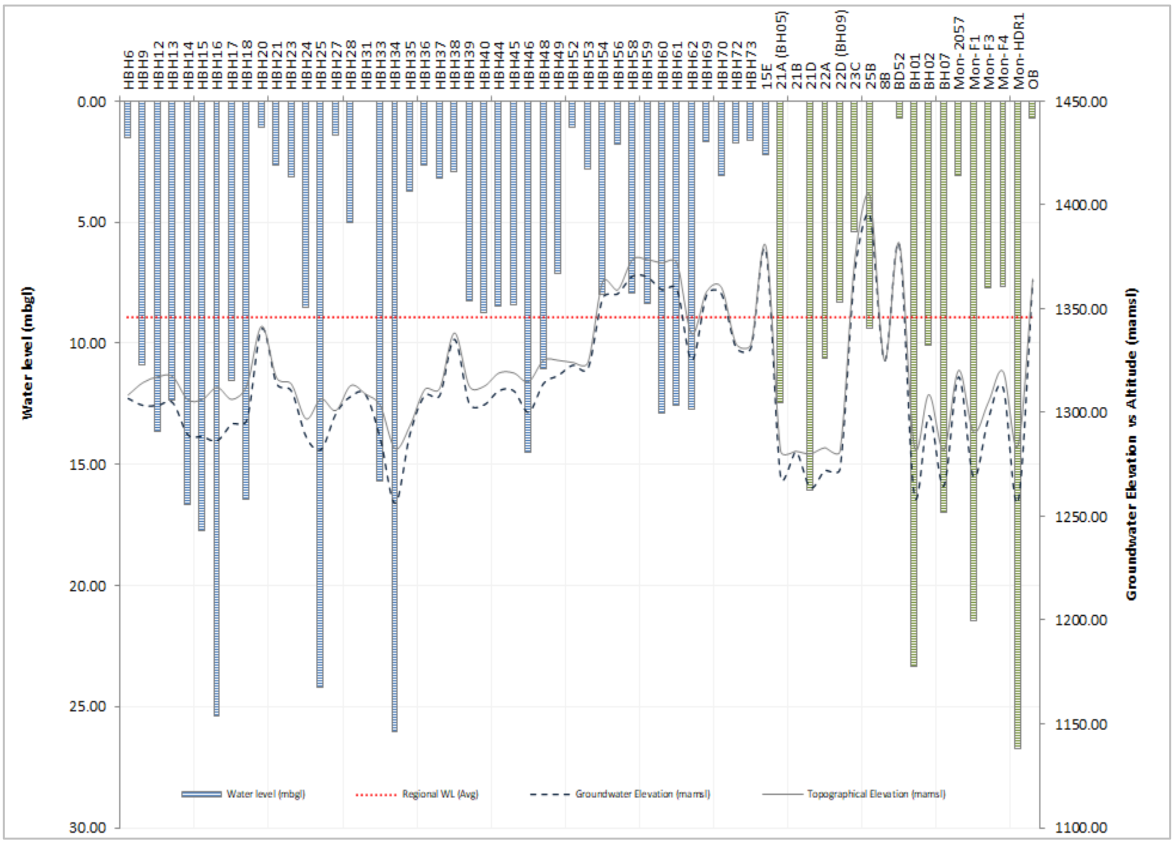


Figure 9-1 **Bar chart indicating regional water level summary (wet-season).**

Table 9-2 **Regional water level summary (Dry-season).**

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
HBH 161	1320.07	2.20	1317.87
HBH 159	1326.36	8.04	1318.32
HBH 190	1315.61	3.36	1312.25
HBH 191	1313.35	4.11	1309.24
HBH 186	1314.19	6.20	1307.99
HBH 188	1328.55	3.69	1324.86
HBH 192	1337.04	6.19	1330.85
HBH 185	1340.00	8.10	1331.90
HBH 193	1340.00	8.61	1331.39
HBH 199	1303.75	6.44	1297.31
HBH 180	1305.31	10.00	1295.31
HBH 181	1305.24	10.78	1294.46
BH 3 DDK	1305.05	32.61	1272.44
HBH 194	1301.79	11.74	1290.05
BH 1 DDK	1301.72	16.66	1285.06
BH 2 KLPK	1318.92	5.51	1313.41
HBH 195	1312.24	3.86	1308.38
HBH 196	1360.68	13.15	1347.53
HBH 197	1360.40	14.15	1346.25
BH 2 BOS 0	1360.00	11.73	1348.27
BH 2 BOS 2	1361.19	5.22	1355.97
HBH 135	1360.07	42.13	1317.94
HBH 136	1342.58	7.19	1335.39
BH MOV	1376.42	6.78	1369.64

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
HBH 149	1372.93	3.08	1369.85
BH 3 MVL	1373.20	6.78	1366.42
HBH 198	1307.48	19.40	1288.08
HBH 163	1346.62	12.21	1334.41
HBH 200	1345.18	4.34	1340.84
HBH 1645	1362.89	6.84	1356.05
HBH 201	1312.87	8.96	1303.91
HBH 178	1323.00	4.41	1318.59
HBH 166	1342.11	4.53	1337.58
BH 2 DDR	1329.49	5.39	1324.10
BH 2 DRR	1329.47	5.01	1324.46
BH 3 DRR	1334.02	5.52	1328.50
BH 1 DRR	1339.76	8.20	1331.56
HBH 202	1329.76	13.31	1316.45
HBH 203	1385.45	18.13	1367.32
HBH 204	1385.57	8.41	1377.16
HBH 125	1399.70	5.15	1394.55
HBH 123	1380.32	4.69	1375.63
HBH 124	1380.11	4.60	1375.51
HBH 130	1387.81	5.89	1381.92
HBH 129	1390.03	5.56	1384.47
HBH 128	1383.07	5.50	1377.57
HBH 127	1399.84	7.34	1392.50
HBH 119	1379.76	5.14	1374.62
HBH 120	1379.05	13.85	1365.20
HBH 118	1379.96	5.37	1374.59
HBH 122	1379.75	6.06	1373.69
HBH 116	1360.00	4.70	1355.30
HBH 117	1365.56	3.21	1362.35
HBH 151	1380.00	6.98	1373.02
BH GLR	1314.28	11.58	1302.70
BH 1 GLR	1320.63	6.55	1314.08
HBH 168	1318.19	4.95	1313.24
HBH 206	1313.91	15.20	1298.71
HBH 207	1308.09	25.20	1282.89
HBH 208	1318.94	14.93	1304.01
HBH 209	1317.23	11.65	1305.58
HBH 210	1316.30	15.89	1300.41
HBH 211	1316.46	15.87	1300.59
HBH 212	1328.07	9.46	1318.61
BH 2 HAK	1340.00	6.45	1333.55
HBH 138	1313.54	8.86	1304.68
HBH 167	1311.02	24.33	1286.69
HBH 213	1359.10	3.87	1355.23
HBH 214	1340.00	9.54	1330.46
12A	1380.97	9.89	1371.08
BH17C	1309.35	12.24	1297.11
7B	1313.74	12.12	1301.62
15D	1379.68	5.71	1373.97
Kal2_1	1324.49	7.70	1316.79
16B	1316.16	13.89	1302.27
24A	1317.56	8.00	1309.56
8A	1332.75	7.45	1325.30
RTBH 01	1341.13	8.57	1332.56
RTBH 04	1309.66	7.00	1302.66
RTBH 05	1307.45	8.93	1298.52

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
RTBH 08	1350.17	4.29	1345.88
RTBH 10	1342.94	5.52	1337.42
Geometric Mean	**1340.40**	**7.86**	**1331.05**
Minimum	**1301.72**	**2.20**	**1272.44**
Maximum	**1399.84**	**42.13**	**1394.55**
Standard deviation	**28.41**	**6.43**	**30.58**
Correlation		**0.98**	

Cells highlighted in red representative of dynamic water levels

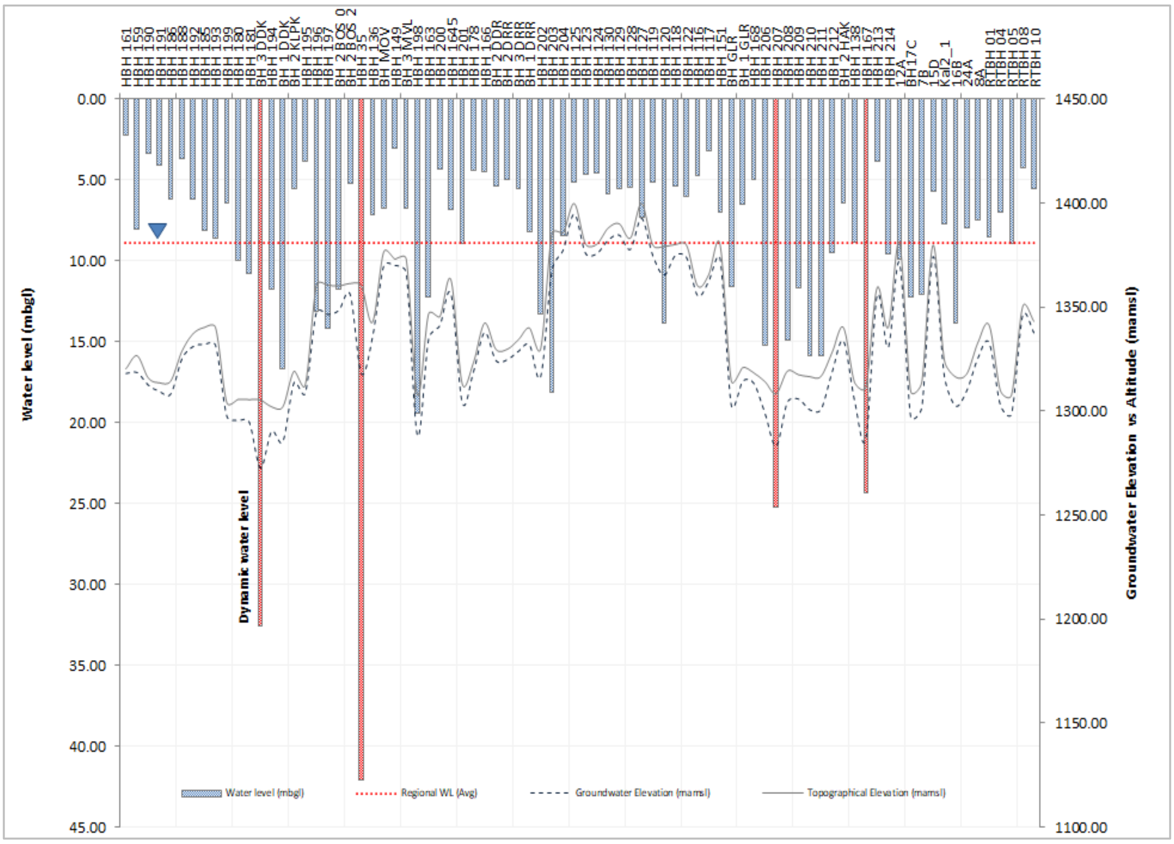


Figure 9-2 **Bar chart indicating regional water level summary (Dry-season).**

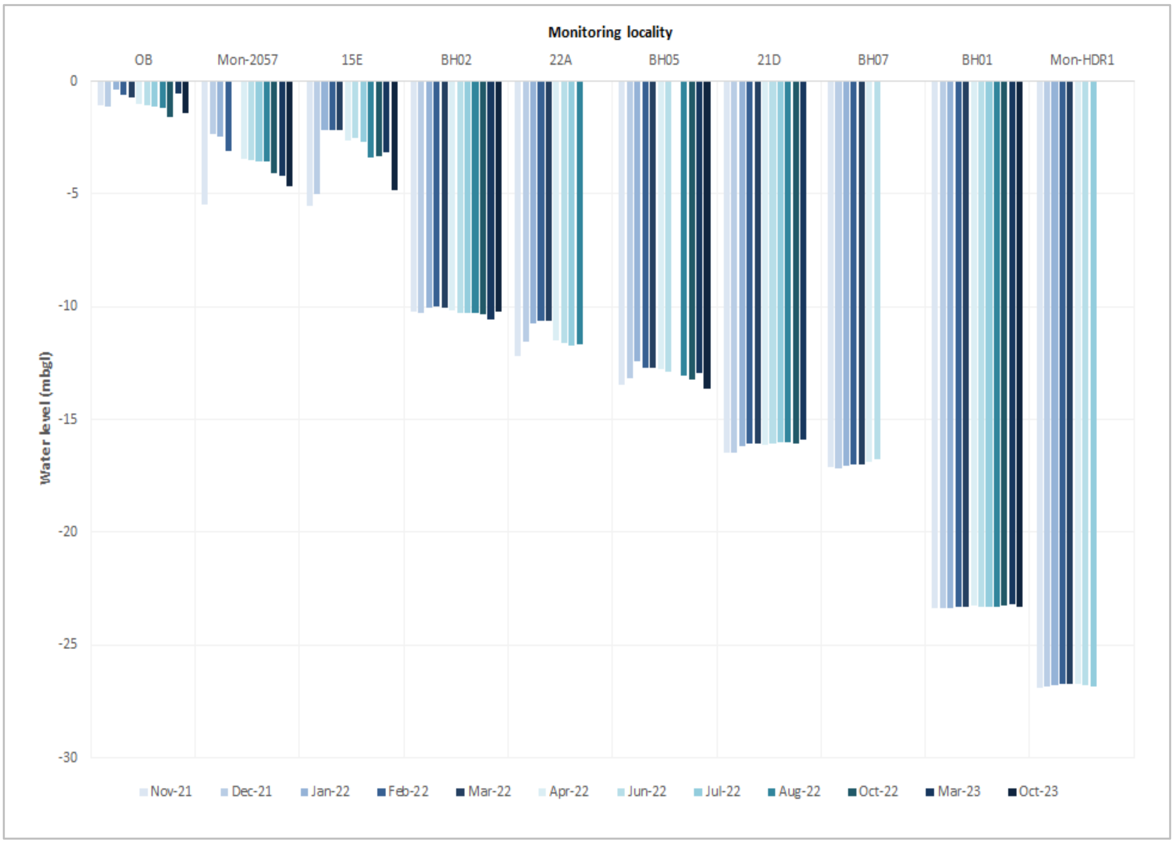


Figure 9-3 **Bar chart indicating time-series water level comparison of the Tetra 4 monitoring boreholes (2021-2024).**

Table 9-3 summarises time-series water levels within the existing Tetra 4 monitoring boreholes by comparing water levels representative of the dry-cycle contribution vs water levels representative of the wet cycle contribution. It is noted that most water levels suggest a decrease in water levels and a recovering trend. The latter can be attributed to the onset of the wet cycle and above average rainfall events experienced with rainfall recharge replenishing aquifer storage. It can be observed that there is a definite relatively quick response to rainfall, suggesting that recharge of the shallow, intergranular aquifer takes place without a prolonged lag effect. The average change in most water levels is <5.0%, which accounts to less than 0.5m, while the relatively low Coefficient of Variation (CV) values derived from statistical analyses suggest that the local groundwater system is in quasi-steady state conditions.

Table 9-3 Water level statistical summary.

BH ID	Geometric Mean	5th Percentile	95th Percentile	Standard Deviation	Coefficient of Variation (CV)
OB	0.99	0.49	1.49	0.35	0.357
Mon-2057	3.66	2.39	5.06	0.91	0.249
15E	3.30	2.20	5.23	1.18	0.357
BH02	10.22	10.03	10.43	0.15	0.014
22A	11.36	10.64	12.01	0.56	0.050
BH05	13.00	12.57	13.55	0.36	0.028
21D	16.13	15.95	16.47	0.18	0.011
BH07	16.99	16.81	17.14	0.13	0.008
BH01	23.30	23.22	23.36	0.05	0.002
Mon-HDR1	26.79	26.71	26.89	0.07	0.003

9.3. Groundwater flow direction and hydraulic gradients

Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation for both wet-season as well as dry-season contribution as indicated in Figure 9-4 (R^2 <0.98) and Figure 9-5 (R^2 <0.98) respectively. Accordingly, it can be assumed that the regional groundwater flow direction is dictated by topography. Bayesian interpolation was used to interpolate the groundwater levels throughout the study area. The inferred groundwater flow direction will be 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 and Doringrivier, also in the vicinity of the proposed plant expansion footprint, will be in a general northern direction, whereas the groundwater flow direction within the northern catchment of the study area will be mostly in a south to southwestern direction as depicted in Figure 9-6 and Figure 9-7. Figure 9-8 indicates the inferred piezometric surface of the fractured aquifer and it is noted that the groundwater flow direction is in a general northern direction[9].

[9] Observation borehole piezometric head applied as part of this assessment was based on hydrochemical signature and the target aquifer should be confirmed.

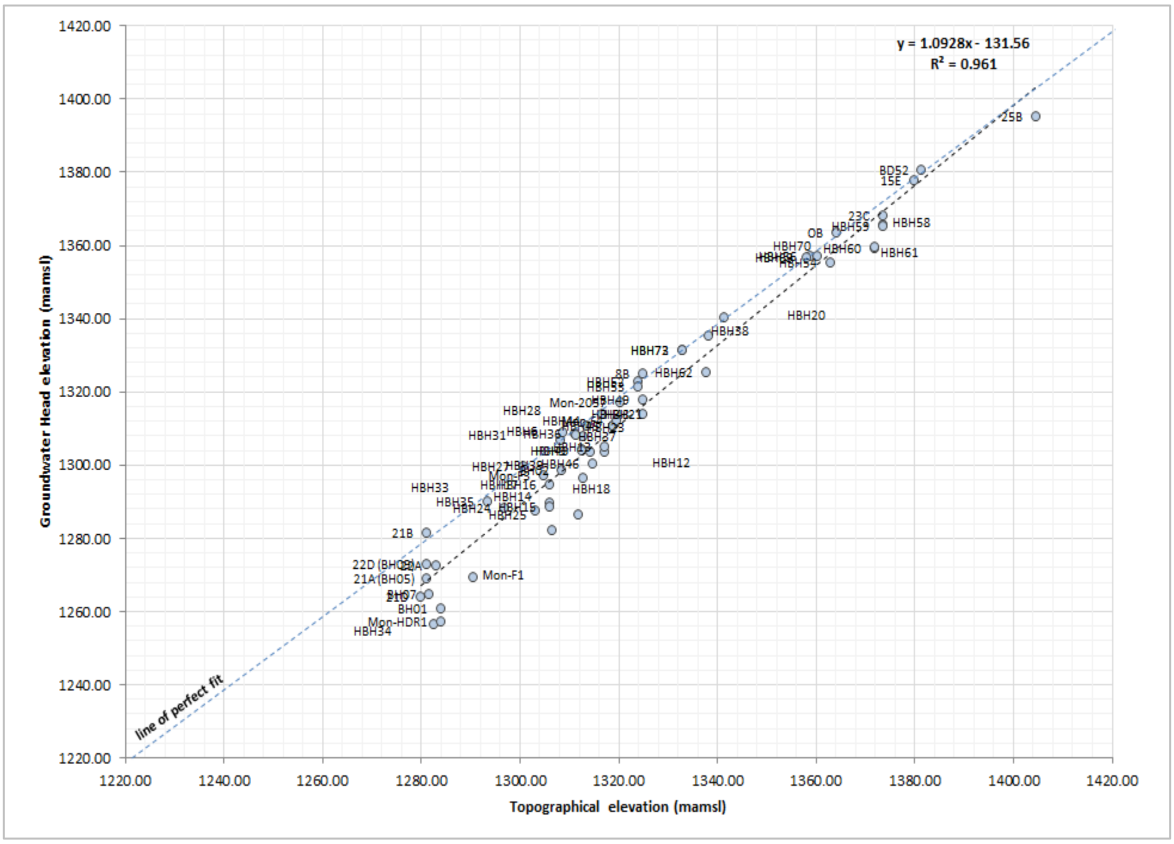


Figure 9-4 **Topographical elevation vs. groundwater elevation correlation graph (Wet season).**

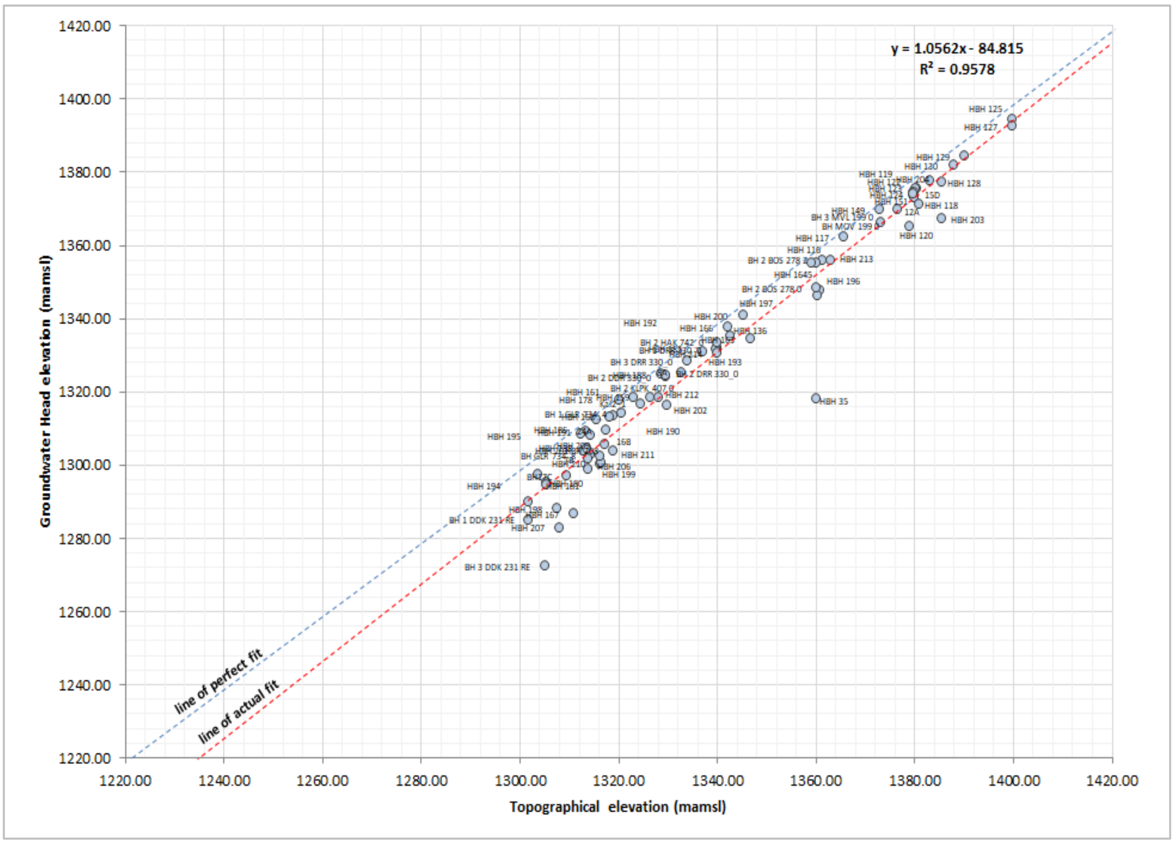


Figure 9-5 **Topographical elevation vs. groundwater elevation correlation graph (Dry season).**

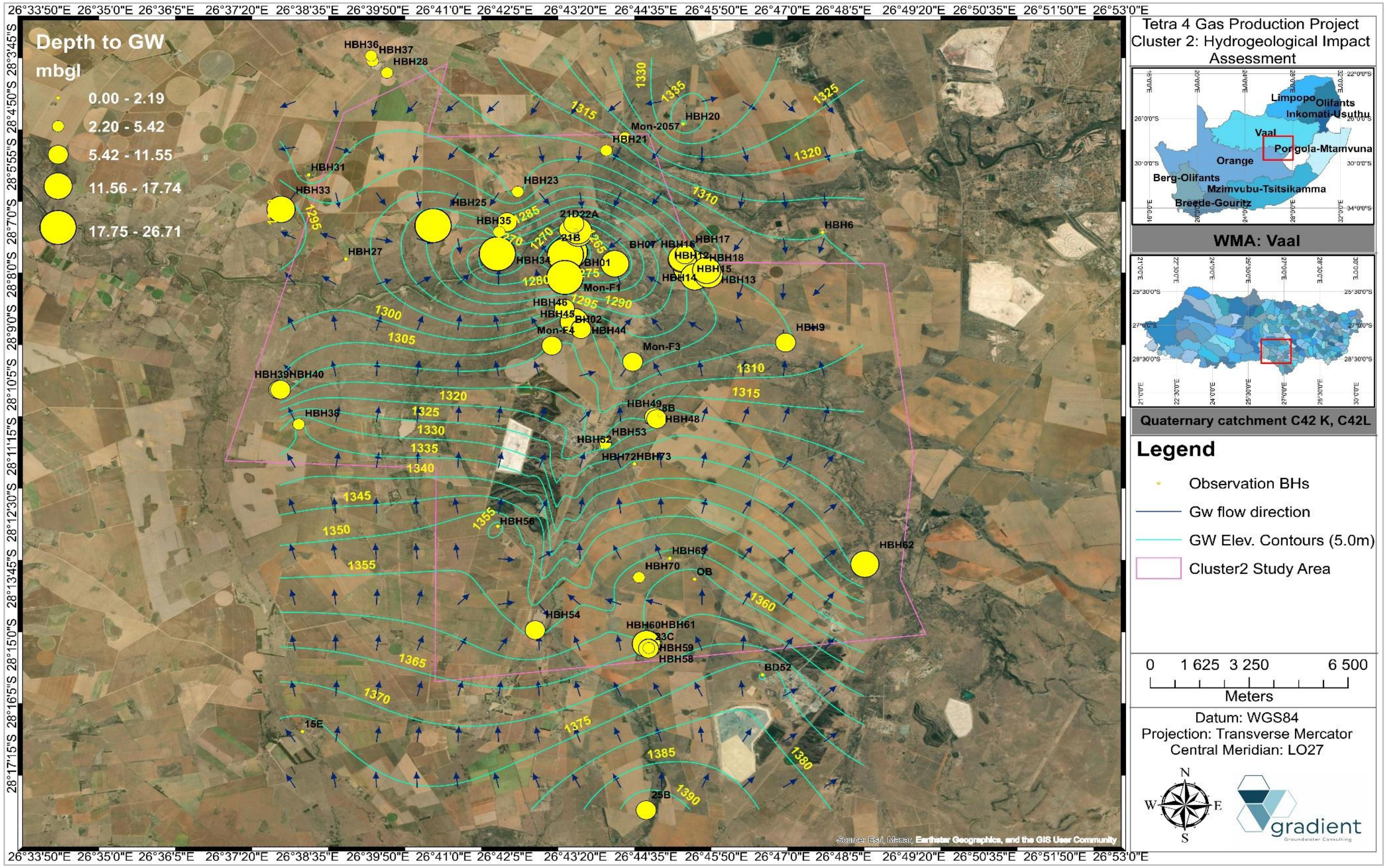


Figure 9-6 **Regional groundwater flow direction and depth to groundwater during the wet season.**

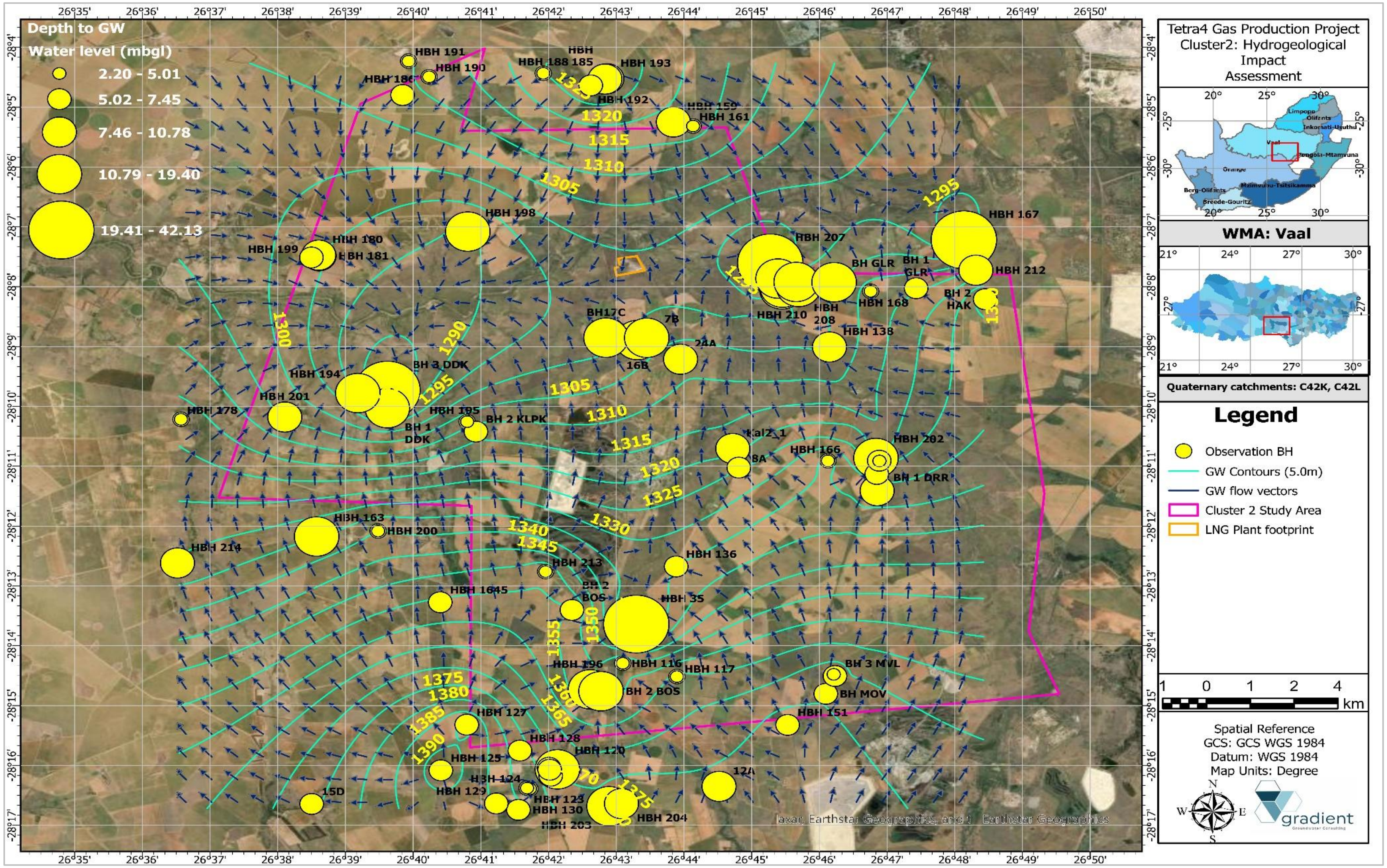


Figure 9-7 **Regional groundwater flow direction and depth to groundwater during the dry season.**

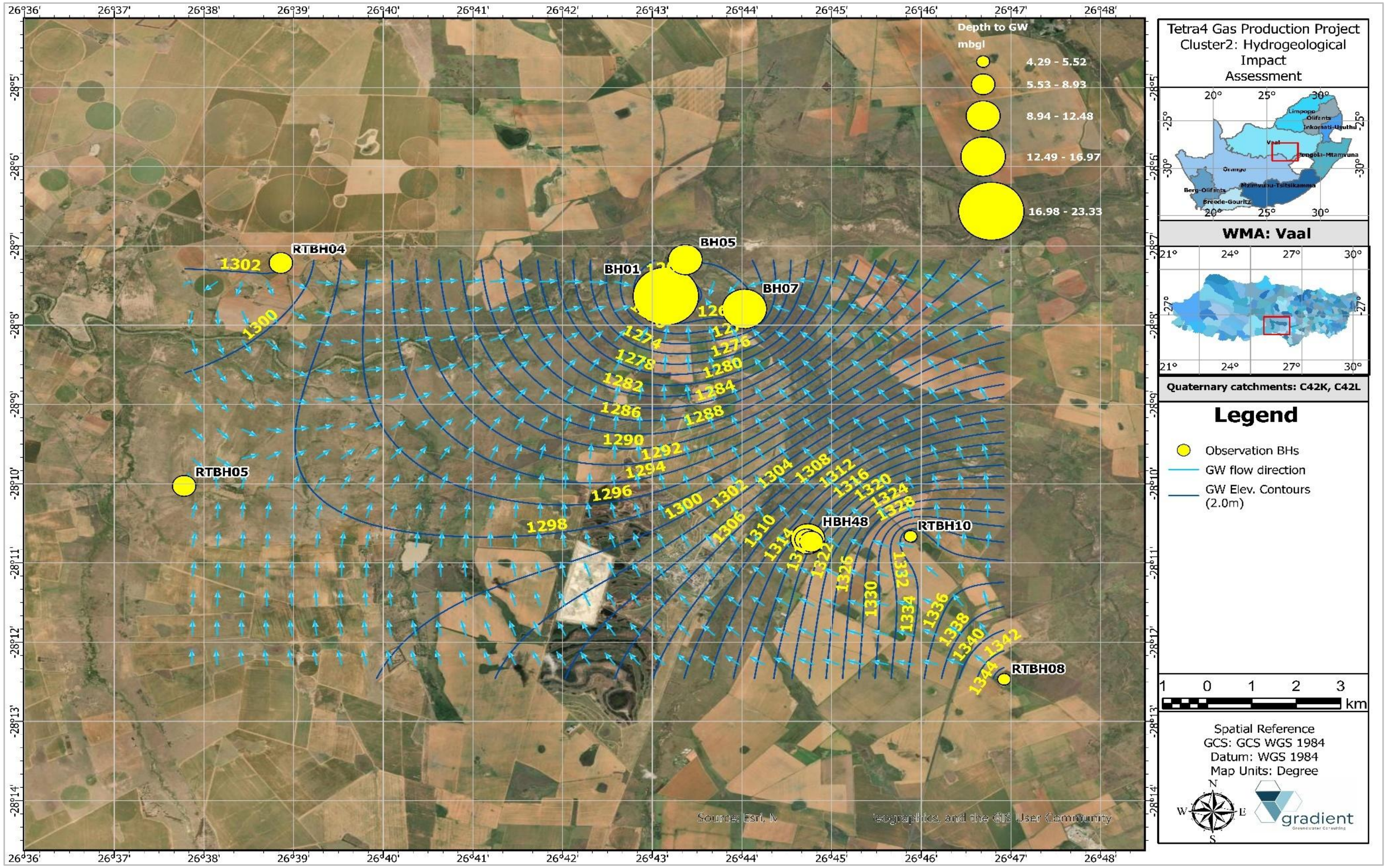


Figure 9-8 **Map depicting the piezometric surface of the deeper, fractured aquifer.**

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

Equation 9-1 Hydraulic gradient.

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

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points...

The average groundwater gradient (*i*) of the shallow, weathered aquifer in the vicinity of expansion footprints is relatively flat and calculated at a mean of 0.002 – 0.003 for both wet and dry seasons, with a maximum of 0.003 – 0.004 in a south to north orientation and a minimum of 0.001 in a general east to west orientation as summarised in Table 9-4 and Table 9-5 below.

Table 9-4 Inferred groundwater gradient and seepage direction (Wet season).

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

Table 9-5 Inferred groundwater gradient and seepage direction (Dry season).

Inferred seepage direction	Hydraulic gradient (i)
S to N	0.004
E to W	0.001
SW to NE	0.002
SE to NW	0.004
Minimum	**0.001**
Maximum	**0.004**
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[10] (Equation 9-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

Equation 9-2 Darcy flux.

$$v = Ki$$

Equation 9-3 Seepage velocity.

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

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

The expected seepage rate from contamination originating at the proposed plant expansion footprint as well as associated infrastructure is estimated at an average of approximately 1.20 to 1.26m/a, with a maximum distance of ~2.86m/a in a southeastern to northwestern direction as summarised in Table 9-6 and Table 9-7 below.

Table 9-6 Darcy flux and seepage rates (Wet season)[11].

Shallow, intergranular aquifer	Hydraulic gradient (i)	Hydraulic conductivity (K)	Darcy flux (m/d)	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
S to N	0.003	0.188	0.00060	0.100	0.006	2.202
E to W	0.001	0.188	0.00023	0.100	0.002	0.825
SW to NE	0.001	0.188	0.00025	0.100	0.002	0.908
SE to NW	0.002	0.188	0.00035	0.100	0.003	1.264
Minimum	**0.001**	**0.188**	**0.0002**	**0.100**	**0.002**	**0.825**
Maximum	**0.003**	**0.188**	**0.0006**	**0.100**	**0.006**	**2.202**
Standard deviation	**0.001**	**0.000**	**0.0001**	**0.000**	**0.001**	**0.546**
Geometric Mean	**0.002**	**0.188**	**0.0003**	**0.100**	**0.003**	**1.202**

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

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

Table 9-7 Darcy flux and seepage rates (Dry season).

Shallow, intergranular aquifer	Hydraulic gradient (i)	Hydraulic conductivity (K)	Darcy flux (m/d)	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
S to N	0.004	0.188	0.00075	0.100	0.008	2.738
E to W	0.001	0.188	0.00020	0.100	0.002	0.724
SW to NE	0.002	0.188	0.00039	0.100	0.004	1.425
SE to NW	0.004	0.188	0.00079	0.100	0.008	2.866
Minimum	**0.001**	**0.188**	**0.0002**	**0.100**	**0.002**	**0.724**
Maximum	**0.004**	**0.188**	**0.0008**	**0.100**	**0.008**	**2.866**
Standard deviation	**0.001**	**0.000**	**0.0002**	**0.000**	**0.002**	**0.900**
Geometric Mean	**0.002**	**0.188**	**0.0005**	**0.100**	**0.005**	**1.687**

9.5. Groundwater-surface water interaction

Groundwater and surface water interaction is an essential component of the hydrological cycle. The hyporheic zone (stream bed) is the zone of most interaction (Adams et. al.,2012). According to records documented by Van Tonder and Dennis (2003), under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. The two regimes are therefore well-linked and should be integrated to manage any water-related issues in these catchments. Regional drainages can be generally classified as influent or gaining stream systems 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 (Lea, 2017).

10. HYDROCHEMISTRY

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

10.1. Water quality analysis

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

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.

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

Table 10-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
HBH 2	10.059	10.210	-0.75%
HBH 9	7.701	8.017	-2.01%
HBH 12	9.023	9.401	-2.05%
HBH 15	7.072	7.356	-1.97%
HBH 16	9.304	9.647	-1.81%
HBH 19	11.087	11.471	-1.70%
HBH 21	12.503	12.595	-0.37%
HBH 23	3.118	3.238	-1.89%
HBH 24	8.057	8.363	-1.86%
HBH 25	13.868	13.865	0.01%
HBH 27	12.578	12.225	1.42%
HBH 31	6.659	6.955	-2.18%
HBH 32	8.917	9.245	-1.81%
HBH 34	11.112	11.473	-1.60%
HBH 35	9.681	9.871	-0.97%
HBH 38	6.811	7.078	-1.93%
HBH 42	8.578	8.858	-1.61%
HBH 44	15.226	15.754	-1.70%
HBH 46	10.424	10.775	-1.66%
HBH 48	26.369	26.526	-0.30%
HBH 49	13.933	14.434	-1.77%
HBH 55	7.981	8.271	-1.79%
HBH 56	5.985	6.212	-1.86%
HBH 63	9.392	9.699	-1.61%
HBH 68	9.863	9.480	1.98%
HBH 69	12.426	12.921	-1.95%
HBH 70	11.028	11.473	-1.98%
HBH 73	11.682	12.043	-1.52%
HBH 74	19.709	20.530	-2.04%
HBH 75	21.617	22.267	-1.48%
HBH 76	16.525	17.199	-2.00%
SRD	8.764	9.039	-1.55%
SRU	10.504	10.822	-1.49%
RT BH 01	54.234	54.234	-2.37%
RT BH 04	26.838	26.838	-1.56%
RT BH 05	8.404	8.404	-2.97%
RT BH 08	6.734	6.734	-2.65%
RT BH 10	9.010	9.010	-1.57%
BH 04	25.336	25.336	-2.63%
Jubery	11.435	11.435	-2.93%
12:00 AM	11.598	11.598	-2.81%
N4	4.670	4.670	-2.30%
7B	11.288	11.288	-1.86%
8A	15.336	15.336	-2.59%
15 D	14.367	14.367	-1.44%
16 B	9.273	9.273	-1.80%
17 C	17.933	17.933	-1.52%
24 A	11.828	11.828	-1.23%
Kal 2-1	24.057	24.057	0.53%

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

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

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

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

Table 10-5 Hydrochemical classification according to salinity.

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

Table 10-6 Hydrochemical classification according to hardness.

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

10.3. Water quality

The hydrochemical results of the hydrocensus boreholes water samples analysed suggest the overall ambient groundwater quality is good with most macro and micro determinants falling within or below the SANS 241:2015 limits. Groundwater can be described as neutral, saline to very saline and hard to very hard. The groundwater quality is impacted by the geological formations, which were deposited in shallow marine environments and are therefore naturally saline (Lea, 2017).

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. It should be noted that elevated nitrate concentrations were also recorded in most of the hydrocensus boreholes identified during the initial groundwater study of 2017. It is noted that the TDS concentration increases towards the northern section of the study area as well as near the drainages present. This can most likely be attributed to the geology within these sections, however, should be confirmed. Refer to Figure 10-5 for a spatial distribution map of nitrate concentrations per borehole locality analysed. It is noted that borehole localities with elevated NO_3 concentrations are generally situated within or directly down-gradient of planted crop areas as well as near surface water features.

Isolated sampling localities also suggest elevated Calcium (Ca)/Magnesium (Mg)/Sodium (Na)-Chloride (Cl) concentrations which may be indicative of the intermediate, fractured aquifer unit being targeted by the respective borehole(s), sourcing more stagnant groundwater. The latter may also be indicative of over-abstraction of the respective boreholes which result in more saline matrix water being sourced due to turbulent flow conditions instead of water being sourced from fractures via laminar flow conditions.

Surface water samples include an upstream (SRU) and down-stream (SRD) water sample which were collected from the Sandrivier passing down-gradient of the existing and proposed plant expansion footprint area. The surface water quality can be classified as moderate to good with Aluminum (Al) and Iron (Fe) being slightly elevated. It should be noted that there is not a significant change in the downstream water quality compared to the upstream quality with an increase in Aluminum (Al), however all surface water samples analysed suggest elevated heavy metal concentrations i.e., Al and Fe.

The hydrochemical results of the monitoring boreholes water samples analysed suggest the overall ambient groundwater quality to be moderate with a higher salt load being observed. Groundwater can be described as neutral, saline to very saline and hard to very hard. Most samples analysed suggest elevated Calcium/Magnesium-Chloride concentrations with isolated boreholes (BH04 and BH05) indicating elevated concentrations of Manganese (Mn).

The hydrochemical results of the newly established site characterisation boreholes water samples analysed suggest the overall ambient groundwater quality to be good (RTBH08 and RTBH10) to moderate with a higher salt load being observed at boreholes RTBH01 and RTBH04. Groundwater can be described as neutral, saline to very saline (RTBH01 and RTBH04) and hard to very hard. The latter samples analysed suggest elevated Calcium/Magnesium-Chloride concentrations with isolated boreholes (RTBH01) indicating elevated concentrations of Barium (Ba) while RTBH04 suggest elevated Sulphate (SO_4), Aluminum (Al) and Iron (Fe) concentrations.

Table 10-7, Table 10-8 and Table 10-9 summarises water quality analysis for the 2022 hydrocensus samples analysed whereas Table 10-10 and Table 10-11 summarises water quality analysis for the 2024 hydrocensus samples analysed. Table 10-12 tabulates the monitoring borehole water samples analysed. Figure 10-1 (hydrocensus boreholes 2022), Figure 10-2 (hydrocensus boreholes 2024) and Figure 10-3 (monitoring boreholes) depicts a bar-chart of the major anion and cation composition while Figure 10-4 indicate a spatial distribution map of hydrochemical composition per sampling locality. It is evident that borehole localities HBH44, HBH48, HBH74, HBH75, BH01, BH04, BH05, BH08, Kal 2-1, RTBH01 and RTBH04 indicate a higher salt load compared to the other sampling localities which may be indicative of a different, potentially deeper, aquifer unit being targeted, however this should be confirmed be evaluation of borehole drilling logs and construction. Refer to Appendix E for water quality analysis laboratory certificates. Below is a short summary of water quality per sampling locality.

10.3.1. Borehole locality HBH2

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

- pH of 7.60.
- TDS of 537.38mg/l.
- Total Hardness ($CaCO_3$/l) of 375.86mg/l.

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

10.3.2. Borehole locality HBH9

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

- pH of 7.51.
- TDS of 449.27mg/l.
- Total Hardness ($CaCO_3$/l) of 236.78mg/l.

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

- NO_3 of 16.03mg/l.

10.3.3. Borehole locality HBH12

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

- pH of 7.33.
- TDS of 511.56mg/l.
- Total Hardness ($CaCO_3$/l) of 361.56mg/l.

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

- NO_3 of 12.80 mg/l.

10.3.4. Borehole locality HBH15

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

- pH of 7.55.
- TDS of 420.78mg/l.
- Total Hardness ($CaCO_3$/l) of 219.26mg/l.

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

- NO_3 of 18.80mg/l.

10.3.5. Borehole locality HBH16

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

- pH of 7.48.
- TDS of 539.41mg/l.
- Total Hardness ($CaCO_3$/l) of 323.10mg/l.

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

- NO_3 of 16.90mg/l.

10.3.6. Borehole locality HBH19

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

- pH of 7.44.
- TDS of 646.73mg/l.
- Total Hardness ($CaCO_3$/l) of 417.83mg/l.

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

- NO_3 of 21.70mg/l.

10.3.7. Borehole locality HBH21

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

- pH of 7.24.
- TDS of 686.31mg/l.
- Total Hardness ($CaCO_3$/l) of 430.64mg/l.

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

10.3.8. Borehole locality HBH23

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

- pH of 8.32.
- TDS of 174.51mg/l.
- Total Hardness ($CaCO_3$/l) of 70.0mg/l.

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

10.3.9. Borehole locality HBH24

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

- pH of 7.52.
- TDS of 462.11mg/l.
- Total Hardness ($CaCO_3$/l) of 258.30mg/l.

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

- NO_3 of 14.30mg/l.

10.3.10. Borehole locality HBH25

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

- pH of 7.40.
- TDS of 747.67mg/l.
- Total Hardness ($CaCO_3$/l) of 360.76mg/l.

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

- NH_3 of 3.89mg/l.

10.3.11. Borehole locality HBH27

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

- pH of 7.47.
- TDS of 671.76mg/l.
- Total Hardness ($CaCO_3$/l) of 390.20mg/l.

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

10.3.12. Borehole locality HBH31

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

- pH of 7.47.
- TDS of 410.94mg/l.
- Total Hardness ($CaCO_3$/l) of 189.05mg/l.

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

- NO_3 of 26.20mg/l.

10.3.13. Borehole locality HBH32

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

- pH of 7.52.
- TDS of 528.42mg/l.
- Total Hardness ($CaCO_3$/l) of 249.77mg/l.

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

- NO_3 of 24.60mg/l.

10.3.14. Borehole locality HBH34

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

- pH of 8.17.
- TDS of 635.87mg/l.
- Total Hardness ($CaCO_3$/l) of 7.48mg/l.

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

10.3.15. Borehole locality HBH35

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

- pH of 7.37.
- TDS of 546.79mg/l.
- Total Hardness ($CaCO_3$/l) of 281.13mg/l.

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

- NO_3 of 14.50mg/l.

10.3.16. Borehole locality HBH38

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

- pH of 7.12.
- TDS of 417.21mg/l.
- Total Hardness ($CaCO_3$/l) of 205.38mg/l.

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

10.3.17. Borehole locality HBH42

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

- pH of 7.23.
- TDS of 478.99mg/l.
- Total Hardness ($CaCO_3$/l) of 291.82mg/l.

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

10.3.18. Borehole locality HBH44

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

- pH of 7.40.
- TDS of 848.64mg/l.
- Total Hardness ($CaCO_3$/l) of 491.49mg/l.

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

10.3.19. Borehole locality HBH46

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

- pH of 7.62.
- TDS of 613.93mg/l.
- Total Hardness ($CaCO_3$/l) of 333.20mg/l.

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

- NO_3 of 21.10mg/l.

10.3.20. Borehole locality HBH48

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

- pH of 7.05.
- TDS of 1558.04mg/l.
- Total Hardness ($CaCO_3$/l) of 946.03mg/l.

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

- TDS of 1558.04mg/l.
- Electrical Conductivity 255.0mS/m.
- Cl of 523.0mg/l.
- NO_3 of 53.5mg/l.
- Ca of 272.0mg/l.

10.3.21. Borehole locality HBH49

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

- pH of 7.72.
- TDS of 806.77mg/l.
- Total Hardness ($CaCO_3$/l) of 444.52mg/l.

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

- NO_3 of 19.70mg/l.

10.3.22. Borehole locality HBH55

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

- pH of 7.91.
- TDS of 462.33mg/l.
- Total Hardness ($CaCO_3$/l) of 178.29mg/l.

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

- NO_3 of 12.80mg/l.

10.3.23. Borehole locality HBH56

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

- pH of 8.47.
- TDS of 354.36mg/l.
- Total Hardness ($CaCO_3$/l) of 208.12mg/l.

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

- NO_3 of 14.80mg/l.

10.3.24. Borehole locality HBH63

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

- pH of 7.78.
- TDS of 530.94mg/l.
- Total Hardness ($CaCO_3$/l) of 288.56mg/l.

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

- NO_3 of 13.0mg/l.

10.3.25. Borehole locality HBH68

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

- pH of 7.58.
- TDS of 527.78mg/l.
- Total Hardness ($CaCO_3$/l) of 310.88mg/l.

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

- NO_3 of 13.80mg/l.

10.3.26. Borehole locality HBH69

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

- pH of 7.40.
- TDS of 698.14mg/l.
- Total Hardness ($CaCO_3$/l) of 387.80mg/l.

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

- NO_3 of 15.70mg/l.

10.3.27. Borehole locality HBH70

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

- pH of 8.17.
- TDS of 630.74mg/l.
- Total Hardness ($CaCO_3$/l) of 323.66mg/l.

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

- NO_3 of 19.90mg/l.

10.3.28. Borehole locality HBH73

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

- pH of 7.83.
- TDS of 664.41mg/l.
- Total Hardness ($CaCO_3$/l) of 351.60mg/l.

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

- NO_3 of 14.90mg/l.

10.3.29. Borehole locality HBH74

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

- pH of 7.56.
- TDS of 1132.04mg/l.
- Total Hardness ($CaCO_3$/l) of 782.31mg/l.

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

- Electrical Conductivity 189.0mS/m.
- Cl of 477.0mg/l.
- NO_3 of 26.30mg/l.
- Ca of 216.0mg/l.

10.3.30. Borehole locality HBH75

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

- pH of 7.83.
- TDS of 1230.35mg/l.
- Total Hardness ($CaCO_3$/l) of 479.80mg/l.

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

- Electrical Conductivity 208.0mS/m.
- TDS of 1230.35mg/l.
- Cl of 598.0mg/l.

10.3.31. Borehole locality HBH76

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

- pH of 7.49.
- TDS of 942.94mg/l.
- Total Hardness ($CaCO_3$/l) of 669.22mg/l.

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

- NO_3 of 30.20mg/l.

10.3.32. Surface water locality SRU

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

- pH of 7.38.
- TDS of 613.94mg/l.
- Total Hardness ($CaCO_3$/l) of 290.92mg/l.

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

- Fe of 1.05mg/l.

10.3.33. Surface water locality SRD

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

- pH of 7.42.
- TDS of 506.36mg/l.
- Total Hardness ($CaCO_3$/l) of 235.90mg/l.

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

- Al of 1.18mg/l.
- Fe of 0.94mg/l.

10.3.34. Borehole locality BH04

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

- pH of 7.77.
- TDS of 1337.58mg/l.
- Total Hardness ($CaCO_3$/l) of 643.39mg/l.

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

- Electrical Conductivity 254.0mS/m.
- TDS of 1337.58mg/l.
- Cl of 640.0mg/l.
- Na of 252.0mg/l.
- Ca of 132.0mg/l.
- Mg of 76.20mg/l.
- Ba of 0.72mg/l.

10.3.35. Borehole locality Jubery

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

- pH of 7.85.
- TDS of 616.77mg/l.
- Total Hardness ($CaCO_3$/l) of 387.06mg/l.

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

10.3.36. Borehole locality 12A

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

- pH of 7.63.
- TDS of 611.13mg/l.
- Total Hardness ($CaCO_3$/l) of 367.65mg/l.

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

10.3.37. Borehole locality N4

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

- pH of 7.83.
- TDS of 236.84mg/l.
- Total Hardness ($CaCO_3$/l) of 111.21mg/l.

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

10.3.38. Borehole locality 7B

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

- pH of 7.32.
- TDS of 626.70mg/l.
- Total Hardness ($CaCO_3$/l) of 325.09mg/l.

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

- NO_3 of 16.20mg/l.

10.3.39. Borehole locality 8A

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

- pH of 7.11.
- TDS of 837.51mg/l.
- Total Hardness ($CaCO_3$/l) of 492.03mg/l.

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

- NO_3 of 16.30mg/l.

10.3.40. Borehole locality 15D

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

- pH of 7.19.
- TDS of 782.93mg/l.
- Total Hardness ($CaCO_3$/l) of 574.02mg/l.

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

10.3.41. Borehole locality 16B

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

- pH of 8.41.
- TDS of 523.98mg/l.
- Total Hardness ($CaCO_3$/l) of 266.32mg/l.

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

- NO_3 of 13.50mg/l.

10.3.42. Borehole locality 17C

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

- pH of 7.83.
- TDS of 972.69mg/l.
- Total Hardness ($CaCO_3$/l) of 541.75mg/l.

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

- Cl of 321.0mg/l.

10.3.43. Borehole locality 24A

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

- pH of 7.34.
- TDS of 660.30mg/l.
- Total Hardness ($CaCO_3$/l) of 377.88mg/l.

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

- NO_3 of 20.10mg/l.

10.3.44. Borehole locality Kal2-1

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

- pH of 7.18.
- TDS of 1384.84mg/l.
- Total Hardness ($CaCO_3$/l) of 838.22mg/l.

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

- Electrical Conductivity 217.0mS/m.
- TDS of 1384.84mg/l.
- NO_3 of 24.50mg/l.
- Ca of 244.0mg/l.

10.3.45. Borehole locality RTBH01

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

- pH of 7.03.
- TDS of 2938.56mg/l.
- Total Hardness ($CaCO_3$/l) of 1469.85mg/l.

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

- Electrical Conductivity 526.0mS/m.
- TDS of 2938.56mg/l.
- Cl of 1812.0mg/l.
- Na of 501.04mg/l.
- Ca of 436.263mg/l.
- Mg of 92.40mg/l.
- Ba of 2.10mg/l.

10.3.46. Borehole locality RTBH04

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

- pH of 6.28.
- TDS of 1635.86mg/l.
- Total Hardness ($CaCO_3$/l) of 350.18mg/l.

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

- Electrical Conductivity 293.0mS/m.
- TDS of 1635.86mg/l.
- SO_4 of 648.0mg/l.
- Na of 428.11mg/l.
- Al of 0.43mg/l.
- Mn of 1.86mg/l.

10.3.47. Borehole locality RTBH05

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

- pH of 9.59.
- TDS of 443.51mg/l.
- Total Hardness ($CaCO_3$/l) of 9.95mg/l.

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

- pH of 9.59.
- F of 6.32mg/l.

10.3.48. Borehole locality RTBH08

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

- pH of 8.38.
- TDS of 362.51mg/l.
- Total Hardness ($CaCO_3$/l) of 49.66mg/l.

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

10.3.49. Borehole locality RTBH10

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

- pH of 7.56.
- TDS of 497.21mg/l.
- Total Hardness ($CaCO_3$/l) of 141.51mg/l.

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

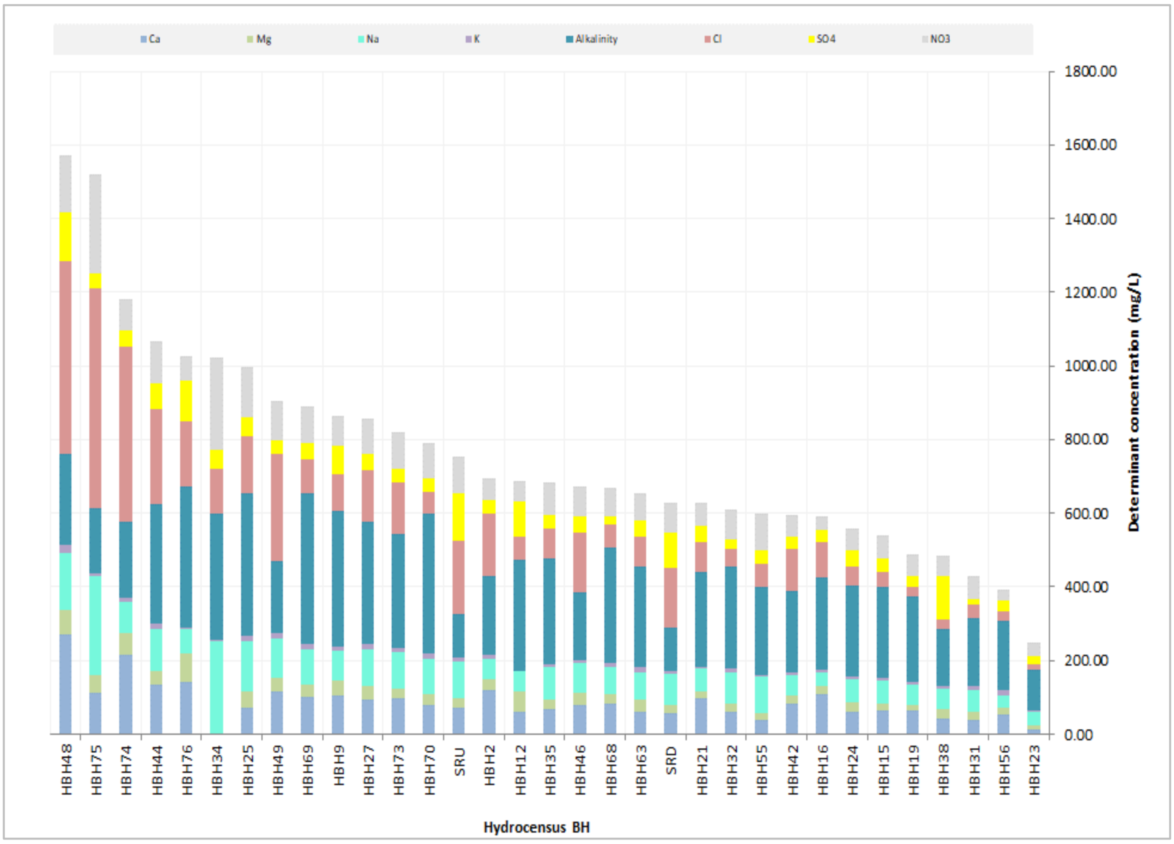


Figure 10-1 **Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of hydrocensus samples analysed (2022).**

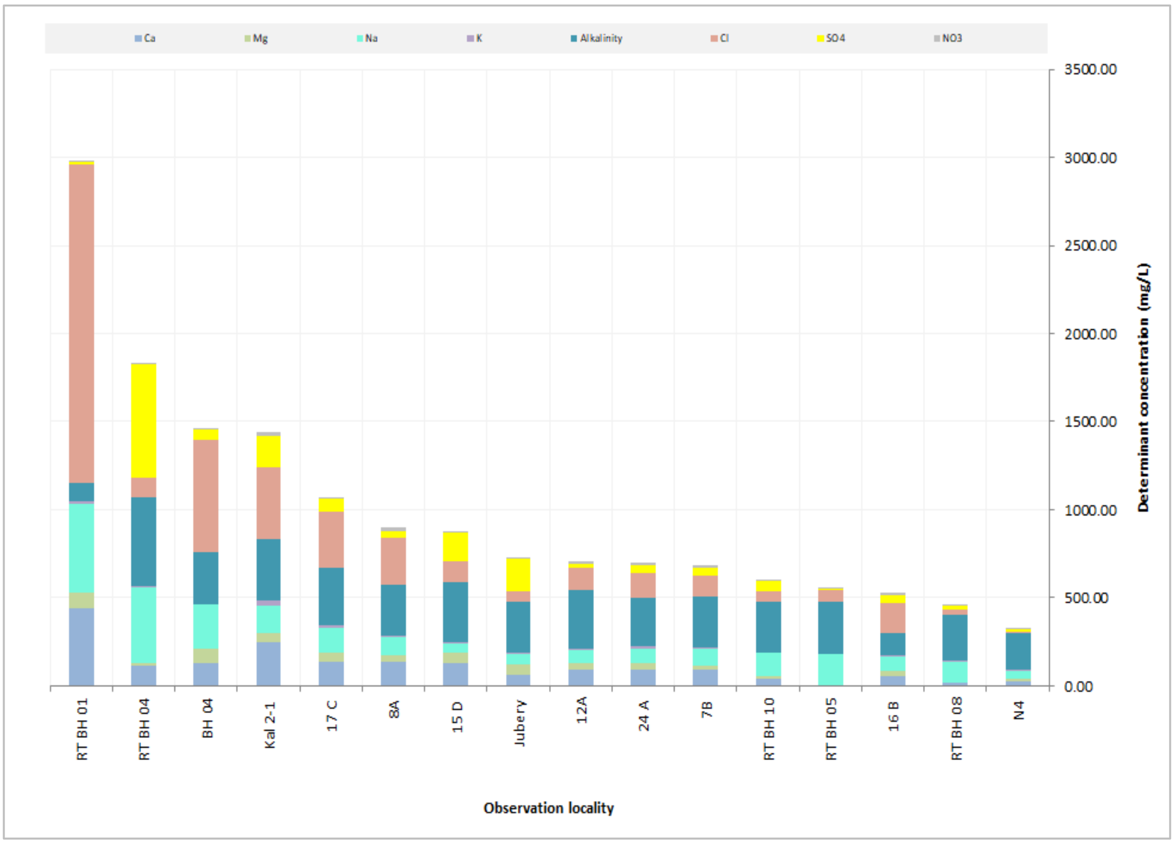


Figure 10-2 **Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of hydrocensus samples analysed (2024).**

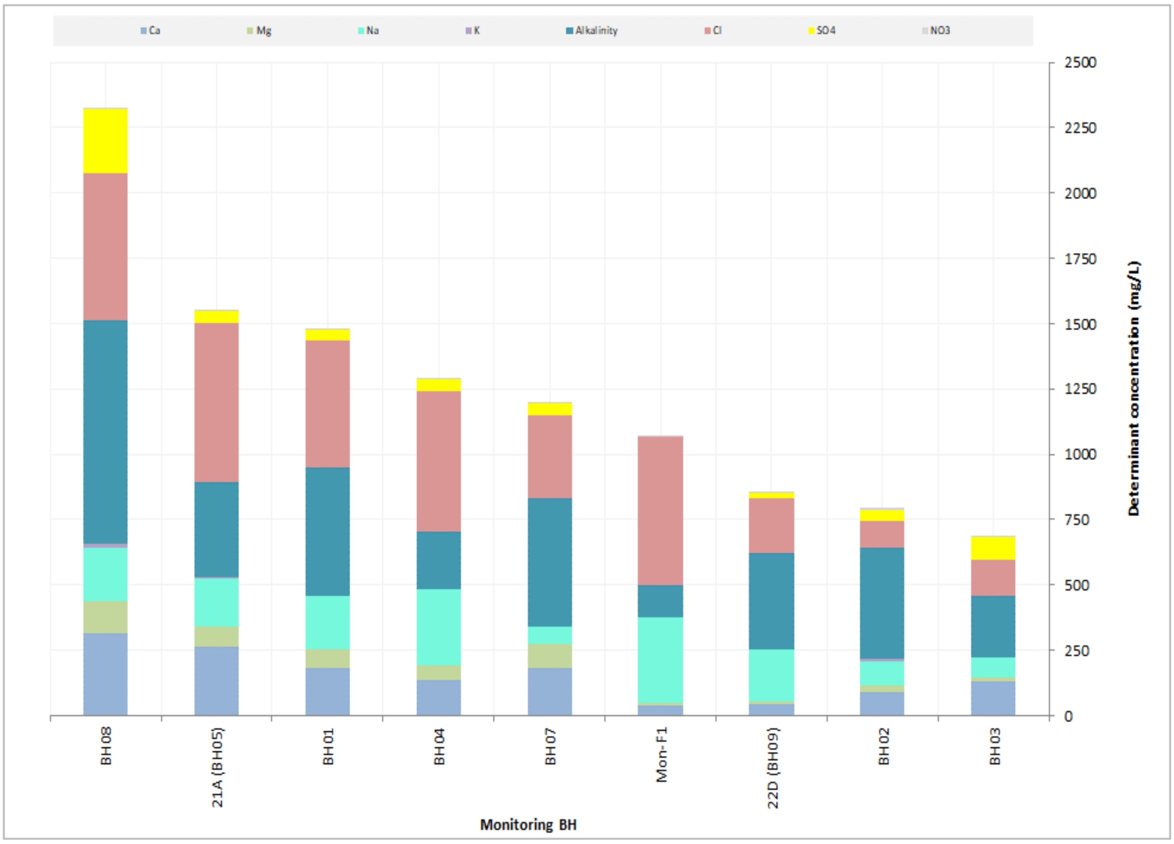


Figure 10-3 **Hydrochemistry: Composite bar-chart indicating groundwater major anion cation composition of monitoring borehole samples analysed.**

Table 10-7 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (2022).

Determinant	Unit	Risk	SANS 241:2015 limits	HBH 2	HBH 9	HBH 12	HBH 15	HBH 16	HBH 19	HBH 21	HBH 23	HBH 24	HBH 25	HBH 27
Physical determinants														
Colour	-	-	-	Clear	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	21.00
General parameters														
pH	-	Operational	≥5.0 ≤ 9.5	7.60	7.51	7.33	7.55	7.48	7.44	7.24	8.32	7.52	7.40	7.47
EC	mS/m	Aesthetic	≤170.0	92.80	75.20	88.30	67.80	89.30	126.00	116.00	32.80	74.70	136.00	120.00
TDS		Aesthetic	≤ 1 200.0	537.38	449.27	511.56	420.78	539.41	646.73	686.31	174.51	462.11	747.67	671.76
Total Alkalinity	CaCO3/l	-	-	301.00	246.00	250.00	232.00	256.00	216.00	367.00	112.00	248.00	389.00	330.00
Total Hardness	mg/l	-	-	375.86	236.78	361.56	219.26	323.10	417.83	430.64	70.00	258.30	360.76	390.20
Anions														
Cl	mg/l	Aesthetic	≤300.0	61.10	40.70	97.70	25.10	84.00	167.00	98.50	13.80	52.50	152.00	141.00
SO_4	mg/l	Acute health	≤500.0	95.70	36.40	33.20	31.30	43.50	39.60	77.80	22.80	42.10	53.90	42.40
F	mg/l	Acute health	≤1.50	0.13	0.14	<0.09	<0.09	<0.09	<0.09	<0.09	0.25	<0.09	<0.09	<0.09
NO_3< N	mg/l	Acute health	≤12.0	6.16	**16.30**	**12.80**	**18.80**	**16.90**	**21.70**	11.40	1.59	**14.30**	8.06	9.92
PO_4	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	0.11	<0.03	<0.03	<0.03	<0.03	0.39	<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	**3.89**	<0.45
Cations and metals														
Na	mg/l	Aesthetic	≤200.0	55.20	63.20	36.50	57.10	61.20	55.90	80.10	36.70	60.80	135.00	98.60
K	mg/l	Aesthetic	≤50.0	2.88	6.69	6.20	5.95	4.92	9.60	12.60	4.10	7.86	15.90	15.90
Ca	mg/l	Aesthetic	≤150.0	58.50	62.50	110.00	63.40	97.40	120.00	106.00	13.90	60.40	70.10	93.60
Mg	mg/l	Operational	70.0	55.80	19.60	21.10	14.80	19.40	28.70	40.30	8.57	26.10	45.10	38.00
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
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	0.03
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
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
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
Zn	mg/l	Acute health	5.0	<0.01	<0.01	<0.01	0.44	0.01	<0.01	<0.01	<0.01	0.02	0.01	0.04

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.

"<" below detection limit

Shaded cells exceed SANS 241:2015 drinking water guidelines.

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

Determinant	Unit	Risk	SANS 241:2015 limits	HBH 31	HBH 32	HBH 34	HBH 35	HBH 38	HBH 42	HBH 44	HBH 46	HBH 48	HBH 49	HBH 55
Physical determinants														
Colour	-	-	-	Clear	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	21.00
General parameters														
pH	-	Operational	≥5.0 ≤ 9.5	7.47	7.52	8.17	7.37	7.12	7.23	7.40	7.62	7.05	7.72	7.91
EC	mS/m	Aesthetic	≤170.0	65.30	85.20	119.00	95.00	67.60	87.50	149.00	103.00	**255.00**	133.00	75.70
TDS		Aesthetic	≤ 1 200.0	410.94	528.42	635.87	546.79	417.21	478.99	848.64	613.93	**1558.04**	806.77	462.33
Total Alkalinity	CaCO3/l	-	-	184.00	276.00	345.00	284.00	153.00	219.00	324.00	182.00	246.00	195.00	238.00
Total Hardness	mg/l	-	-	189.05	249.77	7.48	281.13	205.38	291.82	491.49	333.20	946.03	444.52	178.29
Anions														
Cl	mg/l	Aesthetic	≤300.0	35.80	50.30	120.00	81.20	25.20	114.00	259.00	162.00	**523.00**	292.00	61.10
SO_4	mg/l	Acute health	≤500.0	17.80	25.20	52.80	39.40	119.00	35.90	70.40	46.60	135.00	36.70	39.60
F	mg/l	Acute health	≤1.50	<0.09	<0.09	0.49	<0.09	0.42	<0.09	<0.09	<0.09	<0.09	<0.09	0.11
NO_3< N	mg/l	Acute health	≤12.0	**26.20**	**24.60**	<0.35	**14.50**	11.10	6.58	5.19	**21.10**	**53.50**	**19.70**	**12.80**
PO_4	mg/l	Acute health	≤5.0	0.06	<0.03	<0.03	0.10	<0.03	<0.03	0.35	0.26	0.21	0.16	0.15
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
Cations and metals														
Na	mg/l	Aesthetic	≤200.0	59.80	81.70	**251.00**	86.50	56.50	57.60	113.00	78.90	154.00	107.00	96.70
K	mg/l	Aesthetic	≤50.0	9.34	12.60	1.19	9.72	8.14	7.48	15.50	10.20	23.60	12.10	6.67
Ca	mg/l	Aesthetic	≤150.0	39.10	58.80	1.61	67.40	43.00	82.40	134.00	80.50	**272.00**	117.00	37.10
Mg	mg/l	Operational	70.0	22.20	25.00	0.84	27.40	23.80	20.90	38.10	32.10	64.80	37.00	20.80
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
Fe	mg/l	Acute health	2.0	0.08	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	<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
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
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

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

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

Determinant	Unit	Risk	SANS 241:2015 limits	HBH 56	HBH 63	HBH 68	HBH 69	HBH 70	HBH 73	HBH 74	HBH 75	HBH 76	SRD	SRU
Physical determinants														
Colour	-	-	-	Clear	Brownish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Brownish	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
General parameters														
pH	-	Operational	≥5.0 ≤ 9.5	8.47	7.78	7.58	7.40	8.17	7.83	7.56	7.83	7.49	7.42	7.38
EC	mS/m	Aesthetic	≤170.0	54.50	89.90	93.90	114.00	97.50	108.00	**189.00**	**208.00**	143.00	85.50	105.00
TDS		Aesthetic	≤ 1 200.0	354.36	530.94	527.78	698.14	630.74	664.41	1132.04	**1230.35**	942.94	506.36	613.94
Total Alkalinity	CaCO3/l	-	-	189.00	273.00	312.00	409.00	379.00	308.00	204.00	174.00	384.00	116.00	119.00
Total Hardness	mg/l	-	-	208.12	288.56	310.88	387.80	323.66	351.60	782.31	479.80	669.22	235.90	290.92
Anions														
Cl	mg/l	Aesthetic	≤300.0	23.90	82.00	61.50	94.20	58.50	140.00	**477.00**	**598.00**	175.00	162.00	196.00
SO_4	mg/l	Acute health	≤500.0	29.10	46.20	23.60	44.30	38.10	39.10	44.90	42.70	112.00	96.10	131.00
F	mg/l	Acute health	≤1.50	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	1.20	0.38	0.13	0.10
NO_3< N	mg/l	Acute health	≤12.0	**14.80**	**13.00**	**13.80**	**15.70**	**19.90**	**14.90**	**26.30**	10.30	**30.20**	0.92	1.22
PO_4	mg/l	Acute health	≤5.0	0.84	<0.03	<0.03	<0.03	<0.03	<0.03	0.04	<0.03	0.03	0.09	0.13
NH_3	mg/l	Acute health	≤1.5	<0.45	0.60	<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	31.60	74.00	76.00	97.50	95.10	98.90	82.30	268.00	65.00	82.30	98.60
K	mg/l	Aesthetic	≤50.0	16.30	11.90	10.70	13.60	13.90	11.60	13.60	9.13	4.76	9.58	11.40
Ca	mg/l	Aesthetic	≤150.0	53.86	61.80	80.80	99.40	78.00	97.60	**216.00**	112.00	143.00	57.20	70.00
Mg	mg/l	Operational	70.0	17.88	32.60	26.50	33.90	31.30	26.20	59.00	48.60	**75.80**	22.60	28.20
Al	mg/l	Operational	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**1.18**	<0.01
Fe	mg/l	Acute health	2.0	0.02	<0.01	0.06	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	**0.94**	**1.05**
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.03	0.04
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
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
Zn	mg/l	Acute health	5.0	<0.01	0.03	0.04	0.02	<0.01	<0.01	<0.01	<0.01	2.43	<0.01	<0.01

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

Table 10-10 Hydrochemistry: Groundwater quality evaluation of hydrocensus samples analysed (2024).

Determinant	Unit	Risk	SANS 241:2015 limits	BH 04	Jubery	12A	N4	7B	8A	15D	16B
Physical determinants											
Colour	-	-	-	Clear	Brownish	Clear	Clear	Clear	Clear	Clear	Clear
Temperature	°C	-	-	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
General parameters											
pH	-	Operational	≥5.0 ≤ 9.5	7.77	7.85	7.63	7.83	7.32	7.11	7.19	8.41
EC	mS/m	Aesthetic	≤170.0	254.00	95.10	107.00	40.30	105.00	147.00	126.00	93.00
TDS		Aesthetic	≤ 1 200.0	1337.58	616.77	611.14	236.85	626.70	837.52	782.93	523.98
Total Alkalinity	CaCO3/l	-	-	294.00	285.00	333.00	208.00	292.00	286.00	340.00	126.00
Total Hardness	mg/l	-	-	643.40	387.07	367.65	111.22	325.10	492.04	574.03	266.33
Anions											
Cl	mg/l	Aesthetic	≤300.0	640.00	58.40	125.00	9.09	117.00	267.00	120.00	169.00
SO_4	mg/l	Acute health	≤500.0	54.70	185.00	26.60	11.10	45.30	39.30	158.00	46.00
F	mg/l	Acute health	≤1.50	0.15	0.10	<0.09	0.29	<0.09	<0.09	<0.09	<0.09
NO_3< N	mg/l	Acute health	≤12.0	<0.35	2.80	11.30	<0.35	16.20	16.30	11.80	13.50
PO_4	mg/l	Acute health	≤5.0	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NH_3	mg/l	Acute health	≤1.5	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals											
Na	mg/l	Aesthetic	≤200.0	252.00	65.00	79.00	47.90	94.90	99.70	49.00	76.10
K	mg/l	Aesthetic	≤50.0	5.12	6.15	5.36	5.52	8.48	13.30	10.90	10.80
Ca	mg/l	Aesthetic	≤150.0	132.00	62.00	91.00	27.90	88.80	139.00	125.00	55.70
Mg	mg/l	Operational	70.0	76.20	56.40	34.10	10.09	25.10	35.20	63.60	30.90
Al	mg/l	Operational	0.3	<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
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Ba	mg/l	Chronic health	0.7	0.72	0.05	0.13	0.06	0.13	0.23	0.07	0.10
B	mg/l	Chronic health	2.4	0.25	0.08	0.05	0.04	0.04	0.04	0.04	0.02
Cd	mg/l	Chronic health	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	mg/l	Chronic health	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (VI+)	mg/l	Chronic health	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
U	mg/l	Chronic health	0.03	<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
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Acute health	5.0	0.02	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01

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

Determinant	Unit	Risk	SANS 241:2015 limits	17C	24A	Kal 2-1	RT BH 01	RT BH 04	RT BH 05	RT BH 08	RT BH 10
Physical determinants											
Colour	-	-	-	Clear	Clear	Clear	Greyish	Grey	Clear	Brownish	Clear
Temperature	°C	-	-	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
General parameters											
pH	-	**Operational**	**≥5.0 ≤ 9.5**	7.38	7.34	7.18	7.03	6.28	**9.59**	8.38	7.56
EC	**mS/m**	**Aesthetic**	**≤170.0**	169.00	113.00	**217.00**	**526.00**	**293.00**	80.00	61.60	84.70
TDS		**Aesthetic**	**≤ 1 200.0**	972.69	660.30	**1384.84**	**2938.56**	**1635.87**	443.51	362.52	497.21
Total Alkalinity	**CaCO3/l**	-	-	330.00	276.00	350.00	102.99	505.00	294.00	258.00	288.00
Total Hardness	**mg/l**	-	-	541.76	377.89	838.23	1469.85	350.19	9.95	49.67	141.51
Anions											
Cl	**mg/l**	**Aesthetic**	**≤300.0**	**321.00**	141.00	**407.00**	**1812.00**	108.00	66.00	28.80	63.00
SO_4	**mg/l**	**Acute health**	**≤500.0**	70.00	40.30	176.00	11.80	**648.00**	8.37	25.10	56.50
F	**mg/l**	**Acute health**	**≤1.50**	<0.09	<0.09	<0.09	0.36	0.20	**6.32**	1.23	0.10
NO_3< N	**mg/l**	**Acute health**	**≤12.0**	9.75	**20.10**	**24.50**	0.37	<0.35	<0.35	1.90	3.49
PO_4	**mg/l**	**Acute health**	**≤5.0**	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NH_3	**mg/l**	**Acute health**	**≤1.5**	<0.45	3.89	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Cations and metals											
Na	**mg/l**	**Aesthetic**	**≤200.0**	141.00	84.60	156.00	**501.04**	**428.11**	177.00	122.00	133.00
K	**mg/l**	**Aesthetic**	**≤50.0**	14.50	10.40	27.20	16.20	8.88	0.45	3.28	4.19
Ca	**mg/l**	**Aesthetic**	**≤150.0**	135.00	95.10	**244.00**	**436.26**	116.00	1.99	14.30	43.20
Mg	**mg/l**	**Operational**	**70.0**	49.70	34.10	55.60	**92.40**	14.70	1.21	3.39	8.17
Al	**mg/l**	**Operational**	**0.3**	<0.01	<0.01	<0.01	<0.01	**0.43**	0.07	<0.01	<0.01
Fe	**mg/l**	**Acute health**	**2.0**	<0.01	<0.01	<0.01	0.05	0.60	0.07	0.01	<0.01
Mn	**mg/l**	**Operational**	**0.4**	<0.01	<0.01	<0.01	0.24	**1.86**	<0.01	<0.01	<0.01
Ba	**mg/l**	**Chronic health**	**0.7**	0.13	0.04	0.09	**2.10**	0.18	<0.01	0.04	0.06
B	**mg/l**	**Chronic health**	**2.4**	0.07	0.04	0.12	1.20	1.53	1.42	0.30	0.20
Cd	**mg/l**	**Chronic health**	**0.003**	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	**mg/l**	**Chronic health**	**0.05**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (VI+)	**mg/l**	**Chronic health**	**0.05**	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
U	**mg/l**	**Chronic health**	**0.03**	<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
CN	**mg/l**	**Acute health**	**0.2**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	**mg/l**	**Acute health**	**5.0**	0.02	<0.01	0.03	0.02	0.02	<0.01	<0.01	<0.01

Table 10-12 Hydrochemistry: Groundwater quality evaluation of monitoring samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	BH01	BH02	BH04	21A (BH05)	BH07	BH08	22D (BH09)	Mon-F1
General parameters											
pH	-	Operational	≥5.0 ≤ 9.5	7.14	7.22	7.50	7.05	6.97	7.05	7.88	8.26
EC	mS/m	Aesthetic	≤170.0	**328.00**	117.10	**325.00**	**398.00**	**286.10**	**505.00**	126.20	**214.90**
TDS		Aesthetic	≤ 1 200.0	**1653.00**	676.00	**1662.00**	**2140.00**	**1511.00**	**2559.00**	697.00	1098.00
Total Alkalinity	CaCO3/l	-	-	488.00	427.00	216.60	366.00	488.00	854.00	366.00	122.00
Total Hardness	mg/l	-	-	739.00	328.00	571.00	983.00	826.00	1280.00	147.00	127.00
Anions											
Cl	mg/l	Aesthetic	≤300.0	**488.00**	101.00	**540.00**	**609.00**	**318.00**	**566.00**	210.00	**568.00**
SO_4	mg/l	Acute health	≤500.0	39.00	43.00	43.00	44.00	48.00	246.00	23.00	0.29
F	mg/l	Acute health	≤1.50	0.06	0.04	0.11	0.07	0.04	0.04	0.88	0.12
NO_3< N	mg/l	Acute health	≤12.0	3.80	6.40	0.02	0.02	0.02	6.60	0.02	0.02
NH_3	mg/l	Acute health	≤1.5	0.01	0.04	1.20	1.10	0.07	0.01	0.17	0.52
Cations and metals											
Na	mg/l	Aesthetic	≤200.0	**205.00**	93.00	**288.00**	183.00	67.00	**208.00**	200.00	**327.00**
K	mg/l	Aesthetic	≤50.0	3.00	9.00	4.20	3.90	2.90	12.00	1.90	2.70
Ca	mg/l	Aesthetic	≤150.0	**183.00**	87.00	137.00	**262.00**	**181.00**	**315.00**	43.00	40.00
Mg	mg/l	Operational	70.0	69.00	27.00	56.00	**80.00**	**91.00**	**121.00**	9.70	6.80
Al	mg/l	Operational	0.3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Fe	mg/l	Acute health	2.0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Mn	mg/l	Operational	0.4	0.01	0.10	**1.20**	**5.10**	0.11	0.02	0.05	0.09
As	mg/l	Acute health	0.01	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Zn	mg/l	Acute health	5.0	0.54	0.04	0.01	0.04	0.04	0.18	0.04	0.04

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.

"<" below detection limit

Shaded cells exceed SANS 241:2015 drinking water guidelines.

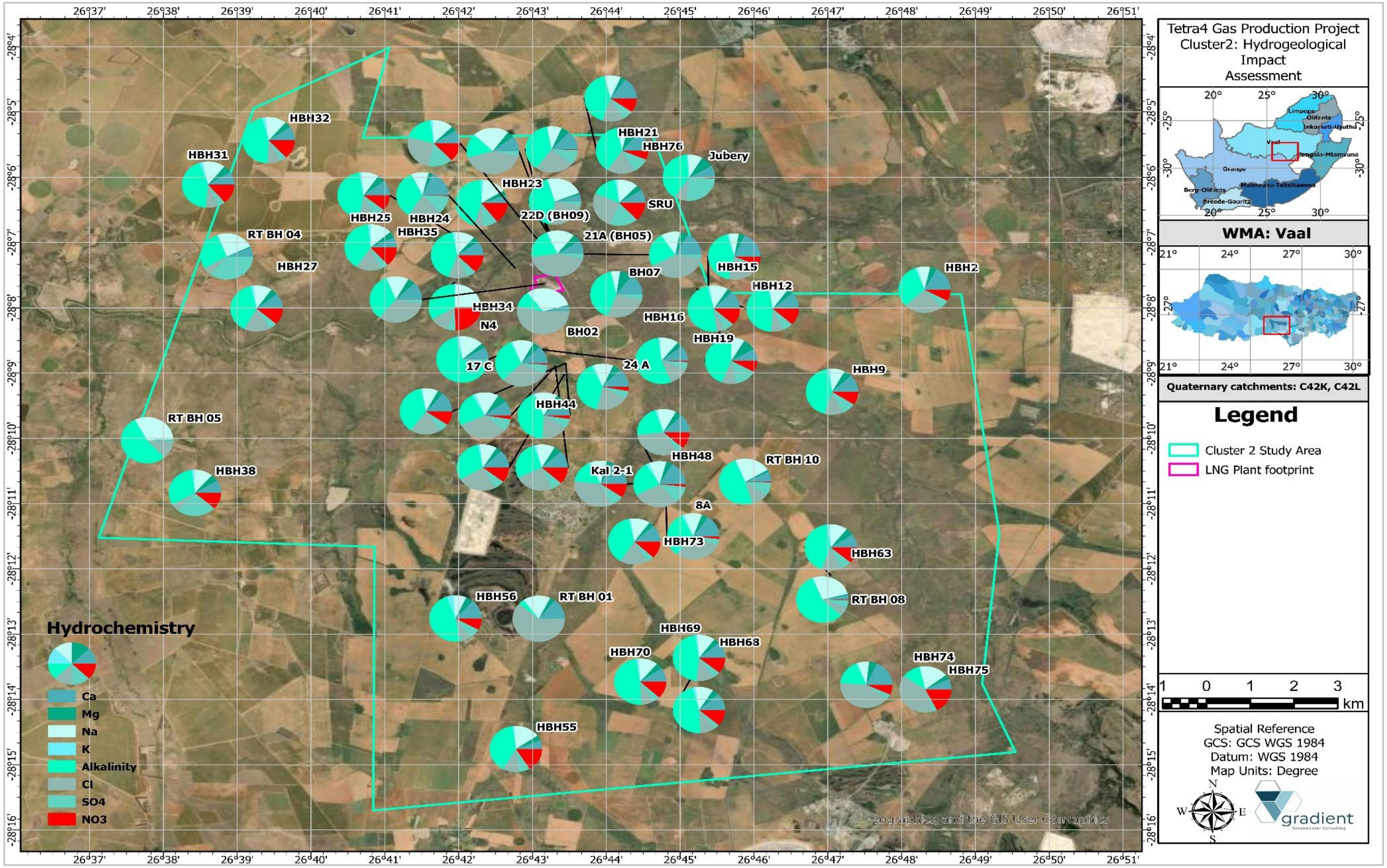


Figure 10-4 **Hydrochemical analysis spatial distribution (mg/l).**

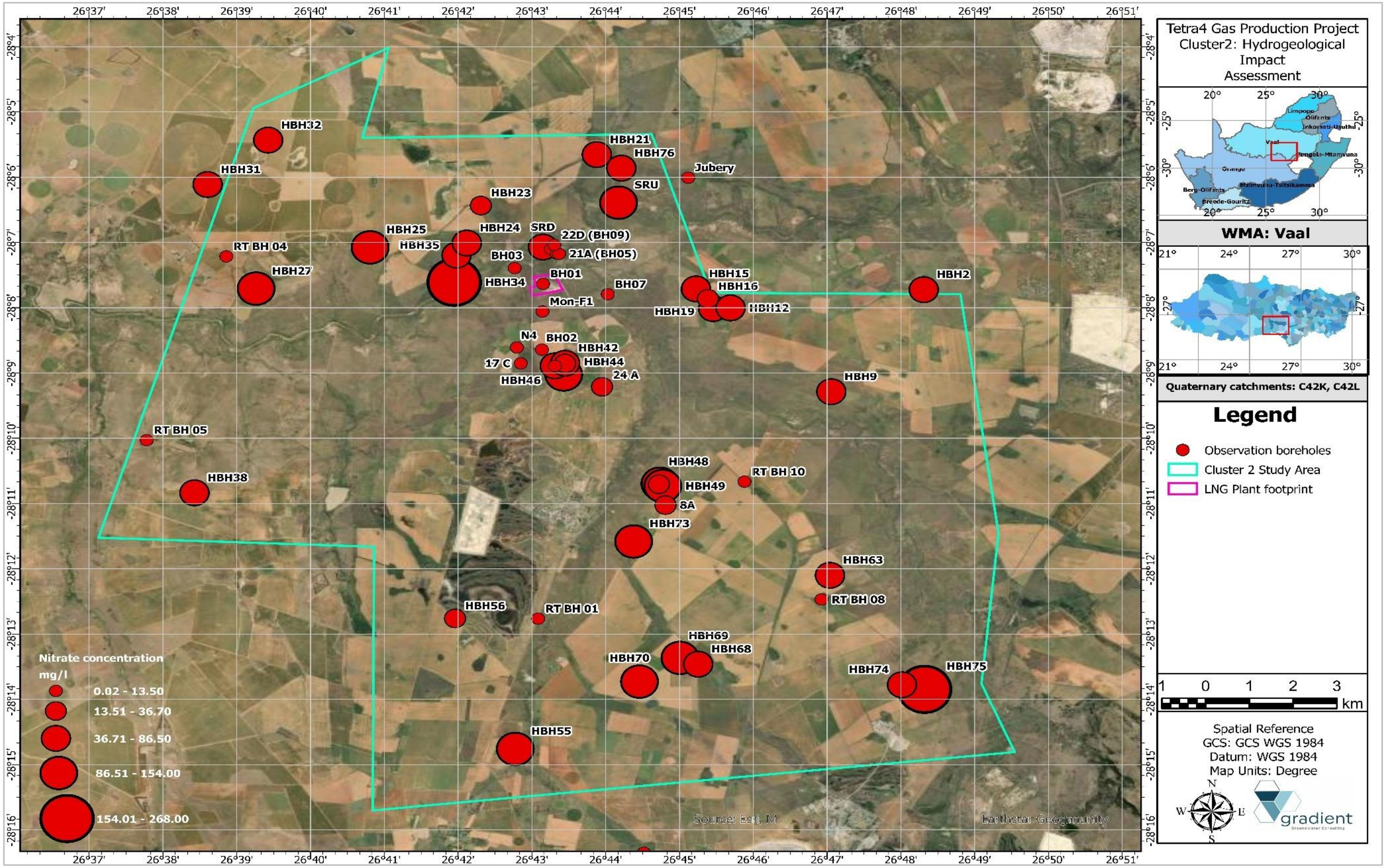


Figure 10-5 **Nitrate (NO_3) spatial distribution (mg/l).**

10.4. 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.

10.4.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots as summarised in Figure 10-6. 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 10-7 depicts a piper diagram developed from the water quality analysis results. Most water samples analysed suggest no cation dominance while the dominant anion is either chloride (sodium or chloride enrichment) or carbonate/bicarbonate (recently recharged water). Accordingly, three distinct categories can be observed, Category A: Calcium-Bi-carbonate dominance which suggest a recently recharged and unimpacted groundwater environment (majority of samples), Category B: Calcium-Magnesium-Chloride dominance which indicate a static and disordinate environment (Majority of current Tetra4 monitoring boreholes, HBH48, HBH49, HBH74, HBH75 as well as newly drilled boreholes RTBH08 and RTBH10), Category C: Sodium-Potassium-Chlorine dominance which indicate an area of sodium and chlorine brines (HBH34, BH09 and Kal2-1) as well as Category D: Sodium-Potassium-Bi-carbonate dominance which indicate an area of dynamic groundwater environments (RTBH01, RTBH04, RTBH05 and BH04).

The surface water samples analysed can be categorized as having Calcium-Magnesium-Chloride dominance which indicates a static and disordinate environment, one would except a more Calcium-Bi-carbonate signature from an unpolluted surface water source, however baseflow discharge present from the saline groundwater resource will have an impact on the salinity of the surface water resources as is evident. Figure 10-9 indicate a piper diagram comparison of major anions and cations of the deep vs shallow aquifer(s) and the Sodium-Potassium-Chloride dominance of the deep, fractured aquifer groundwater suggests extremely saline conditions as expected.

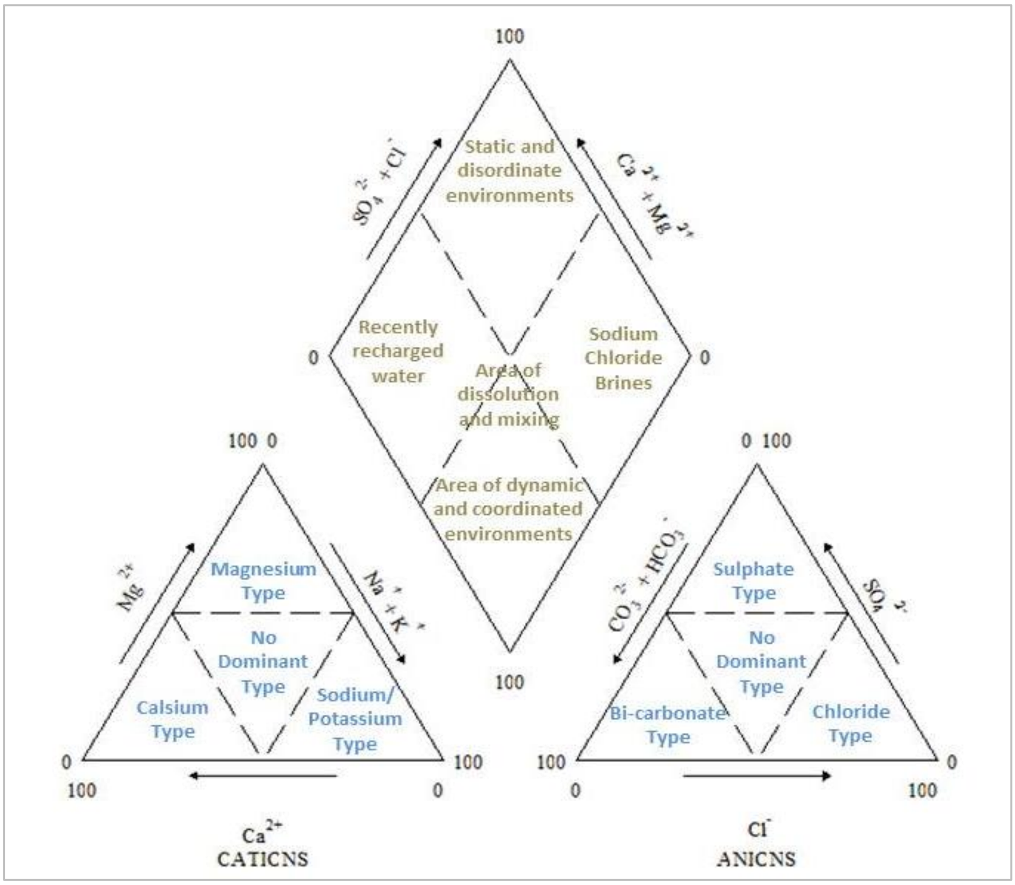


Figure 10-6 **Piper diagram indicating classification for anion and cation facies in terms of ion percentages**

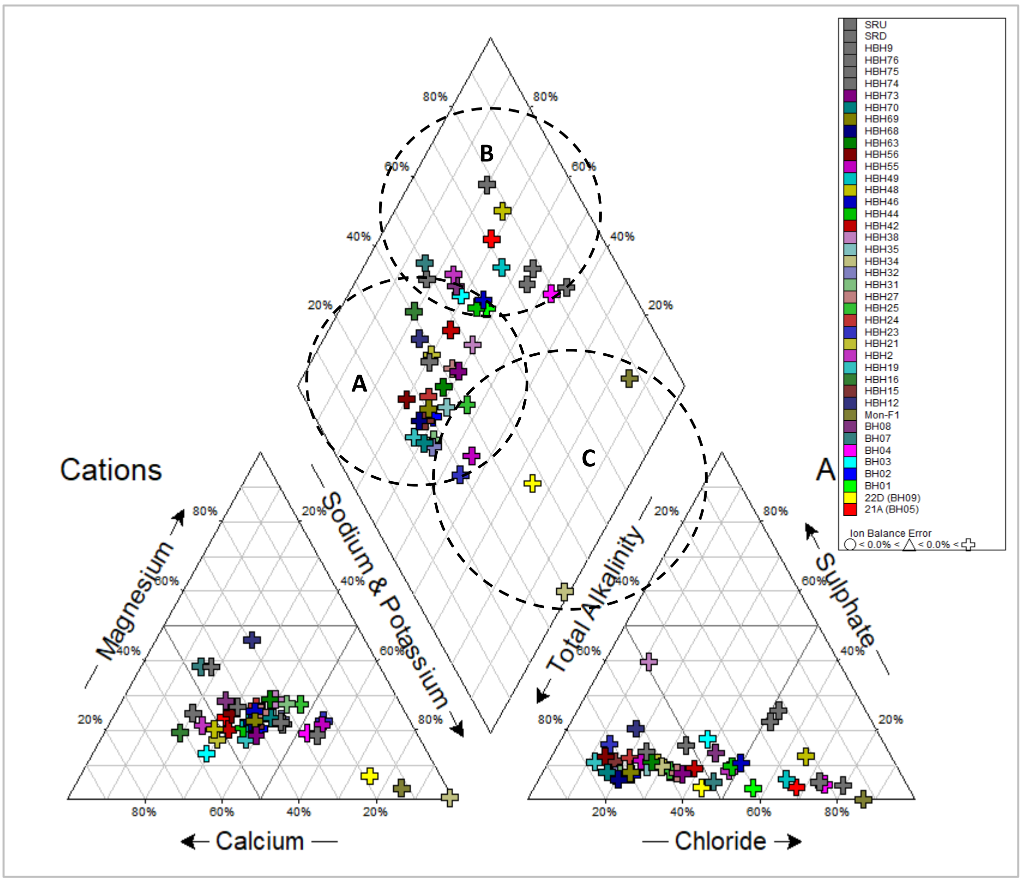


Figure 10-7 **Piper diagram indicating major anions and cations of water samples analysed.**

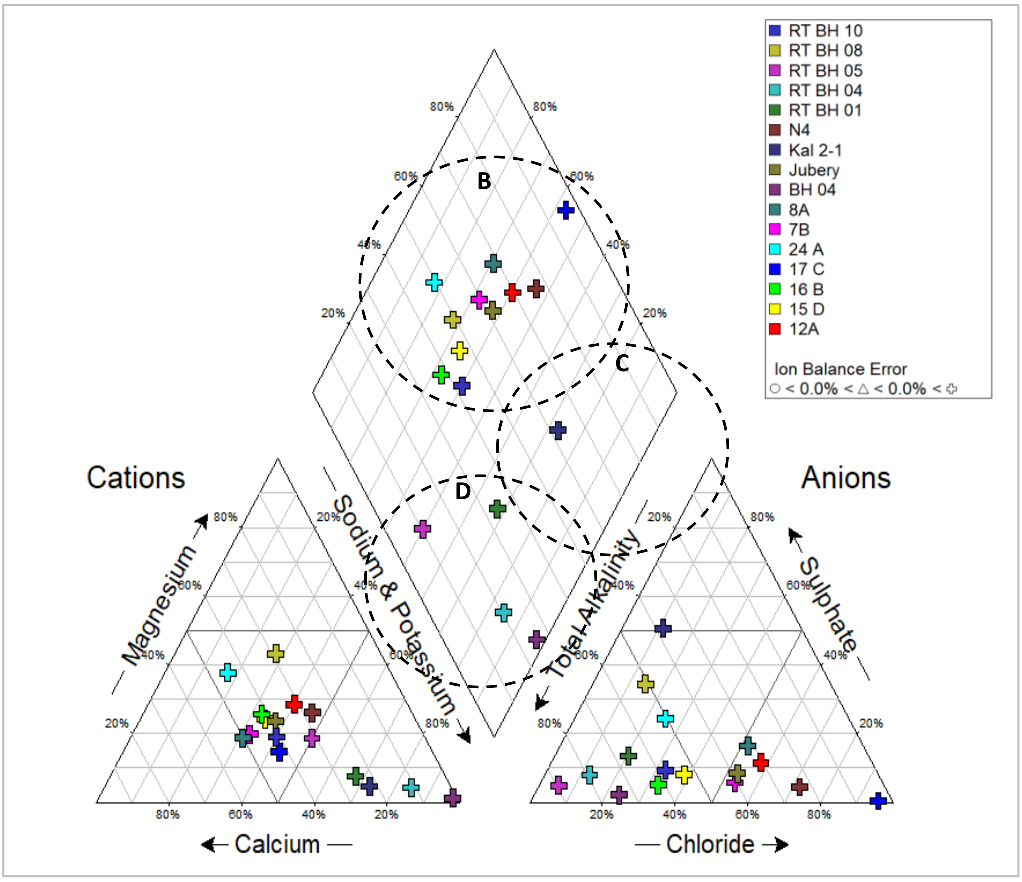


Figure 10-8 **Piper diagram indicating major anions and cations of hydrocensus water samples analysed (2024).**

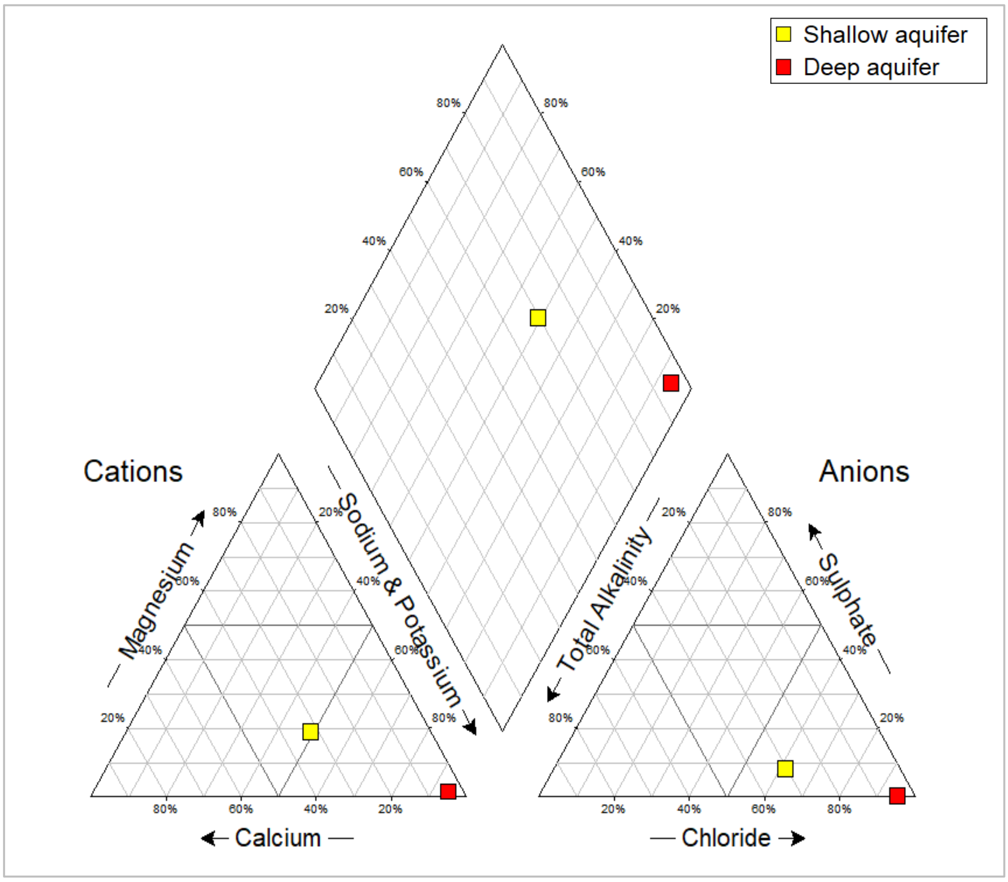


Figure 10-9 **Piper diagram indicating a comparison of major anions and cations of the deep vs shallow aquifer(s).**

10.4.2. 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 10-10 and Figure 10-11 depicts Stiff diagrams compiled from the hydrocensus groundwater sampling analysis while Figure 10-12 indicate Stiff diagrams compiled from the monitoring water quality data evaluated. It is evident that borehole localities HBH48, HBH49, HBH74 and HBH75 indicate a different ion composition and geometry compared the other groundwater sampling localities and suggest two different aquifer or hydrostratigraphical units being targeted, possibly a deeper, more stagnant water source. Monitoring localities BH01, BH04, BH05, BH07, BH08 as well as Kal 2-1 also suggests a higher salt load with sodium-chloride enrichment and may also represent a deeper aquifer unit being targeted. Newly established site characterisation boreholes RTBH 01 and RTBH04 suggest a higher salt load with sodium-chloride enrichment and may also represent a deeper aquifer unit being targeted (Refer to Figure 10-13). Figure 10-14 indicate a Stiff diagram comparison of major anions and cations of the deep vs shallow aquifer(s) and the Sodium-Potassium-Chloride dominance of the deep, fractured aquifer groundwater show extremely saline conditions. Figure 10-15 indicate a Stiff diagram comparison of major anions and cations of the upstream vs downstream surface water samples analysed. A slight decrease in salt load is evident which might be attributed to recently recharged groundwater discharging as baseflow into the surface water feature i.e., Sandriver being a gaining stream.

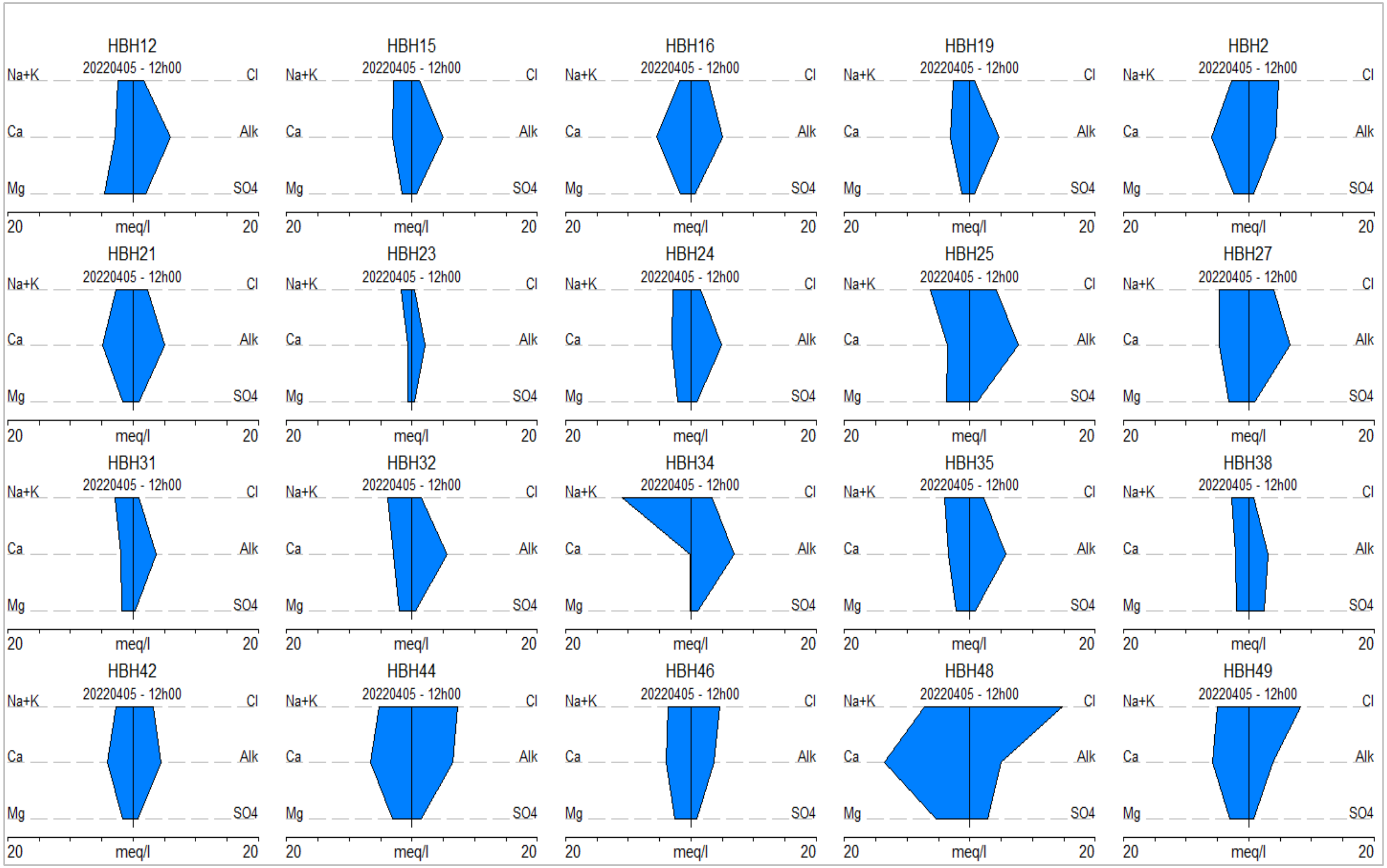


Figure 10-10 Stiff diagrams representing the hydrocensus groundwater sampling localities analysed.

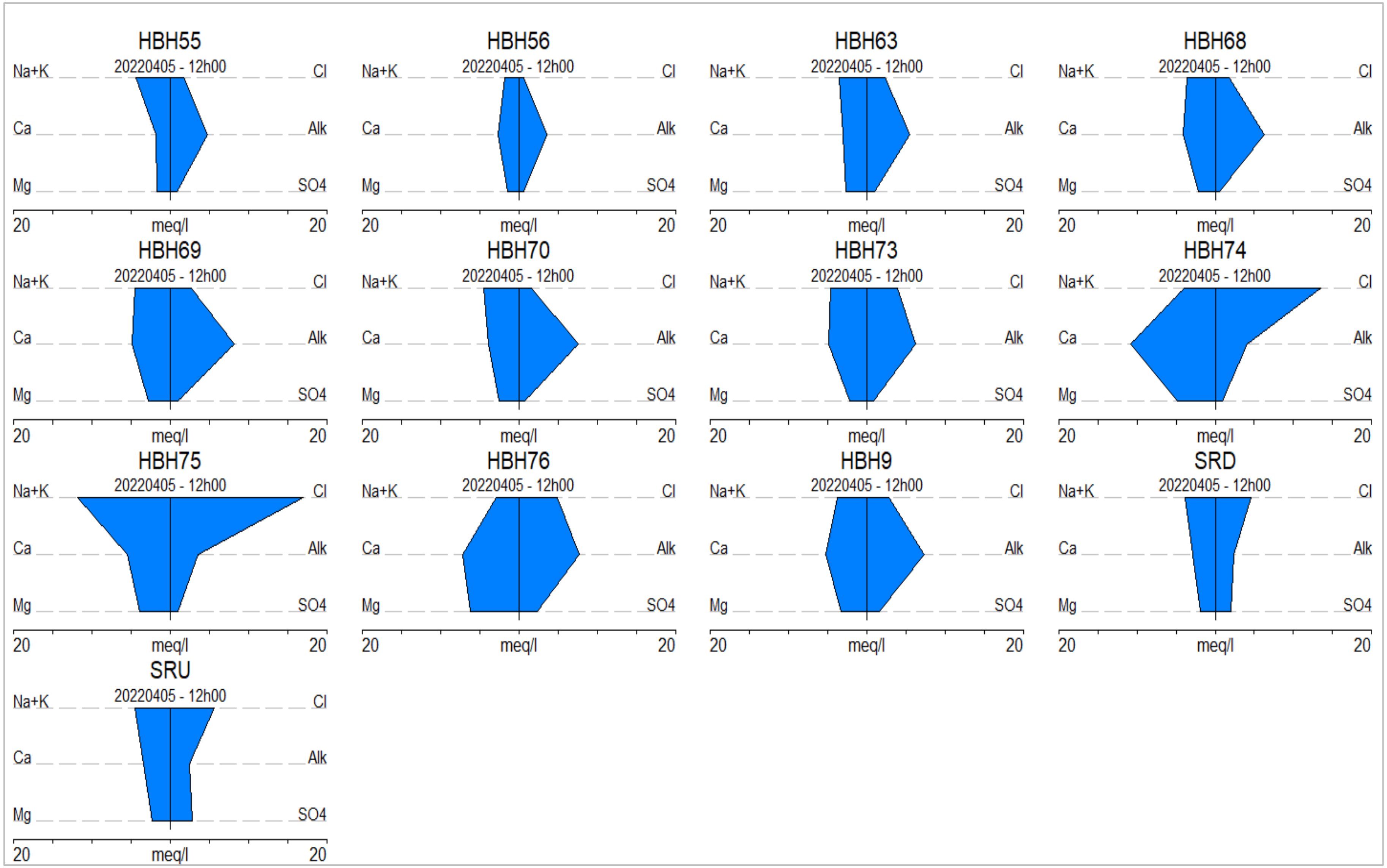


Figure 10-11 **Stiff diagrams representing the hydrocensus groundwater sampling localities analysed.**

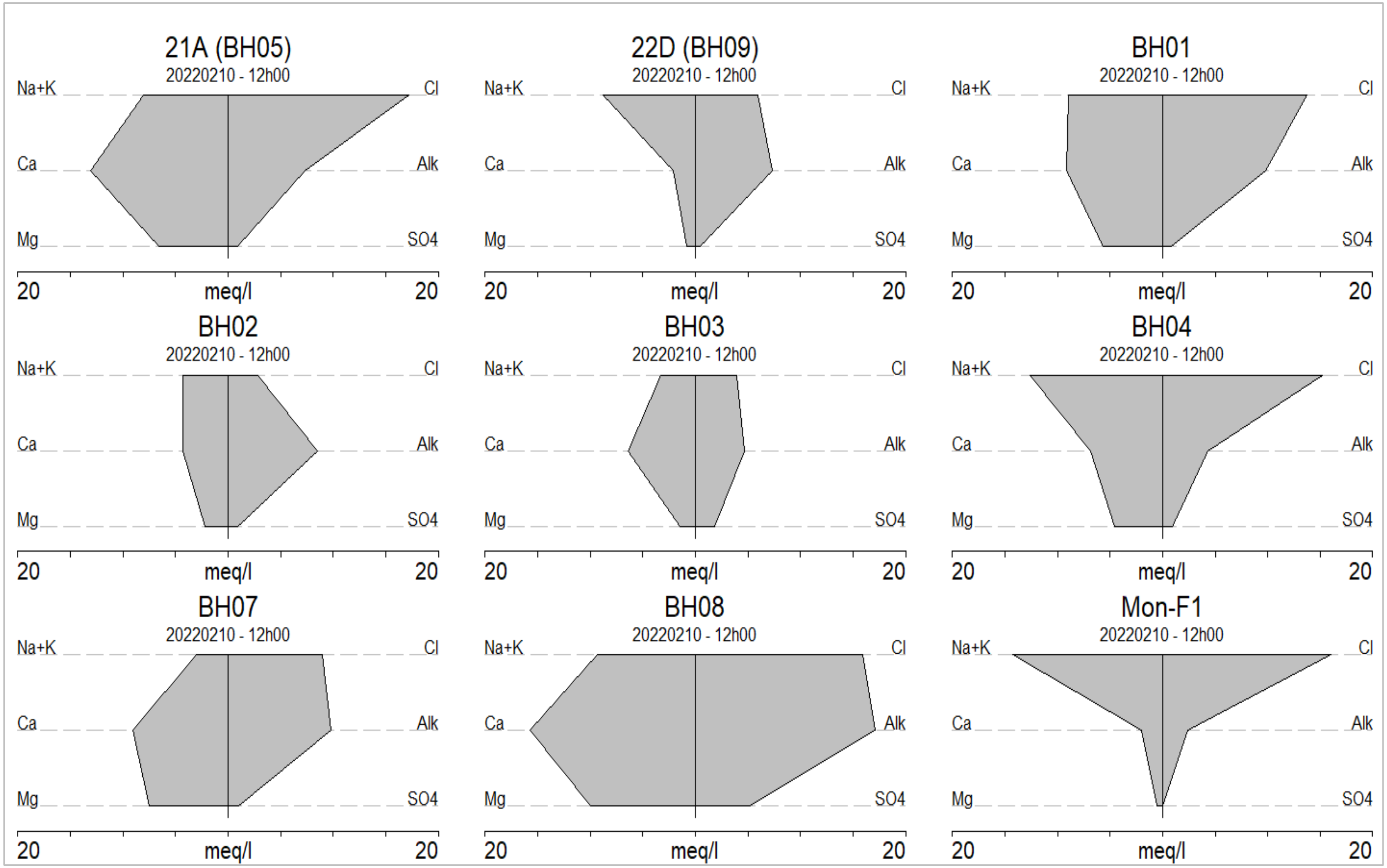


Figure 10-12 Stiff diagrams representing the monitoring borehole groundwater sampling localities analysed.

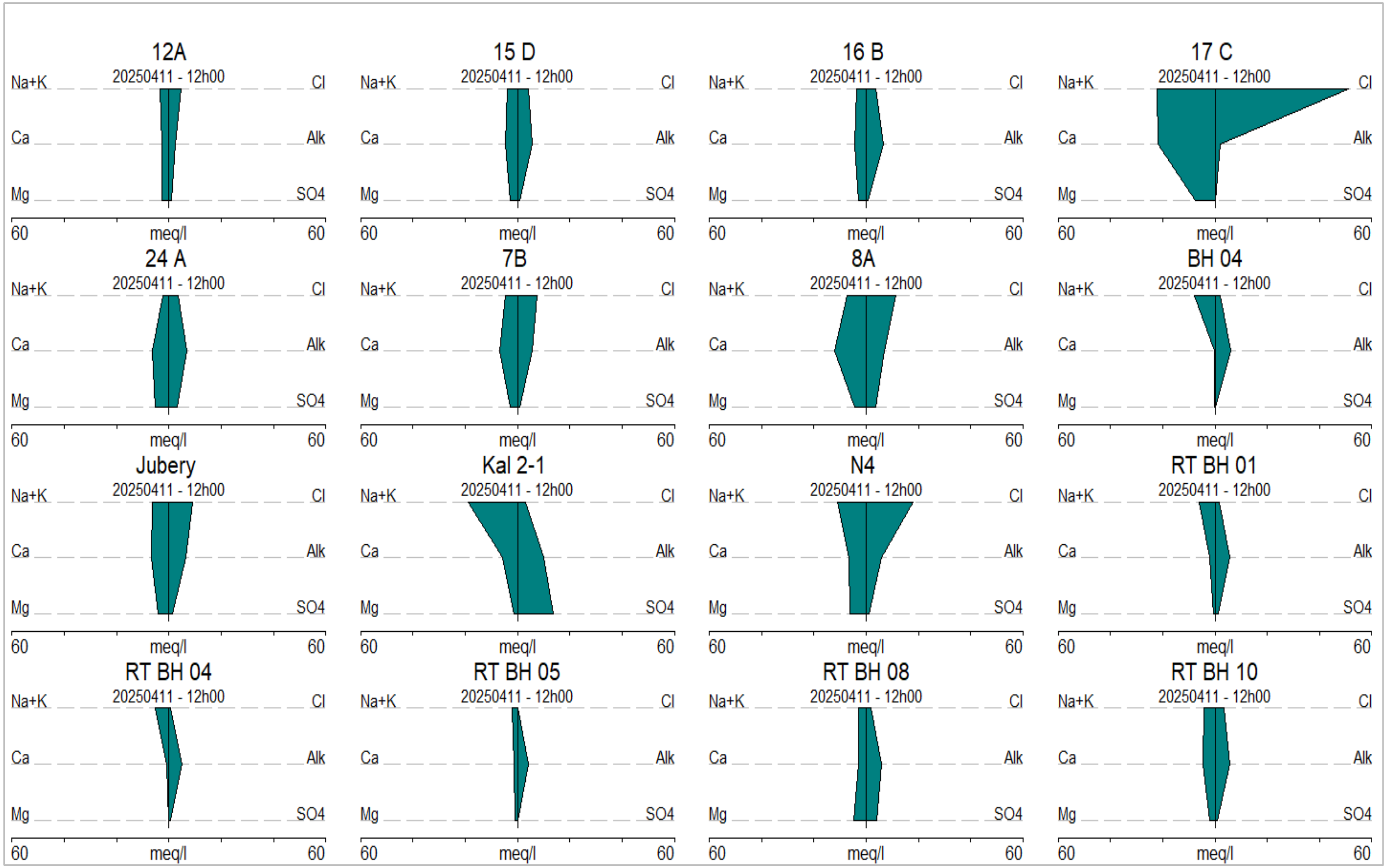


Figure 10-13 Stiff diagrams representing the monitoring borehole groundwater sampling localities analysed.

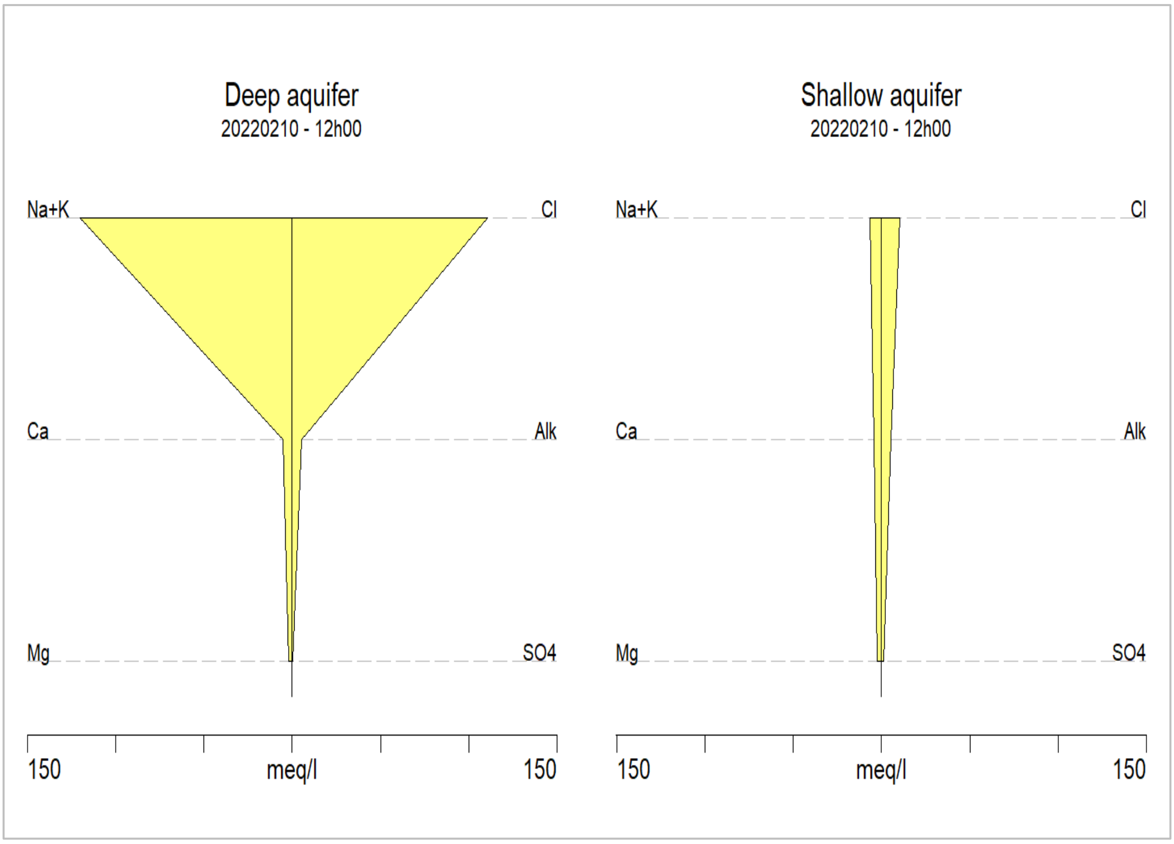


Figure 10-14 **Stiff diagrams indicating a comparison in major ion composition of the deep vs shallow aquifer(s).**

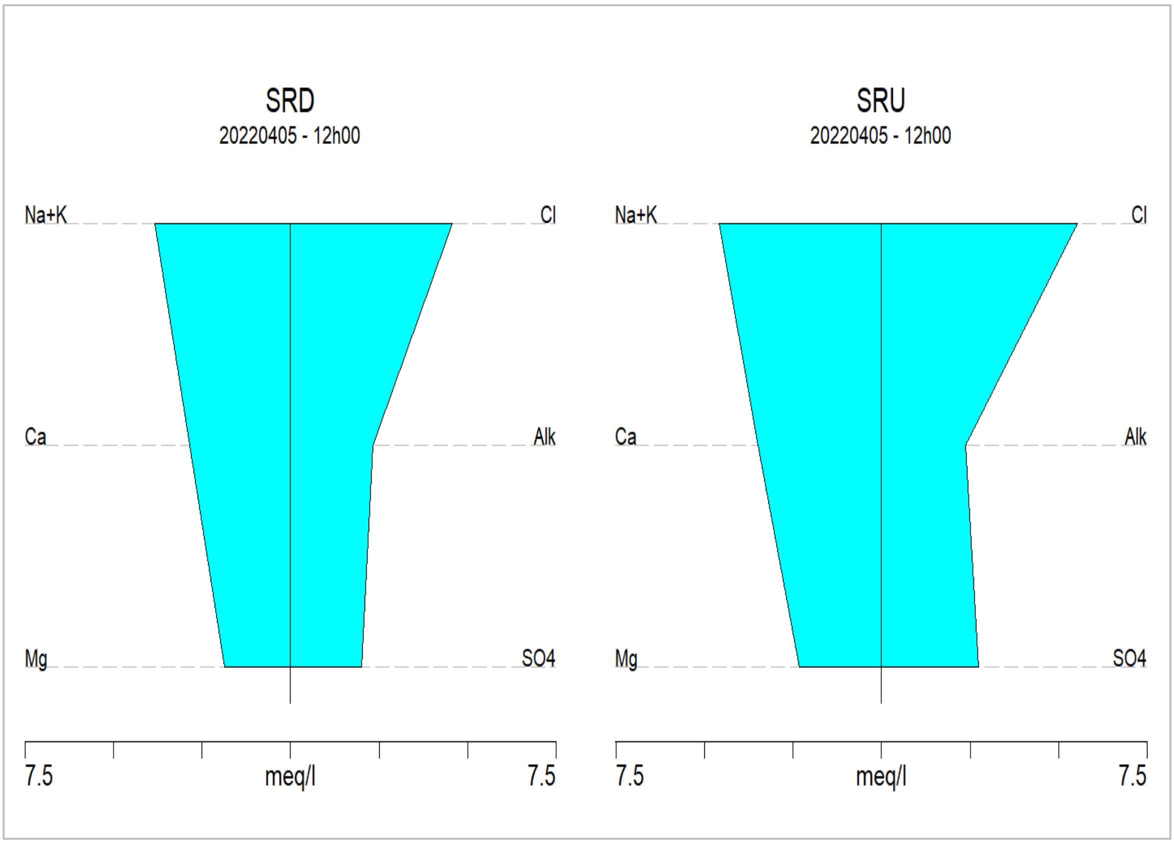


Figure 10-15 **Stiff diagrams indicating a comparison in major ion composition of the upstream vs downstream samples taken from the Sandrivier.**

10.4.3. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems as depicted in Figure 10-16. 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). The majority of the newly established site characterisation boreholes can be classified as Field03 i.e., associated with Na ion exchange between groundwater and aquifer material because of contamination effects from a source rich in Na (potentially interaction with the deeper, saline aquifer).

Borehole localities BH07, BH08, HBH38, HBH44 and HBH46 can be classified as Field05, suggesting old stagnant NaCl dominated water that has mixed with clean water. Borehole localities HBH48, HBH74 and 8A can be classified as Field07 (that indicates NO_3 or Cl) while BH01, BH05, BH49, 7B, 12A, N4 as well as 17C as Field08 (old stagnant NaCl-dominated water) or Mon-F1, BH04 and BH75 as Field09 (very old stagnant water). The latter suggests more stagnant and older water which may indicate a deeper aquifer or hydrostratigraphical units being targeted (Figure 10-17 andFigure 10-18).

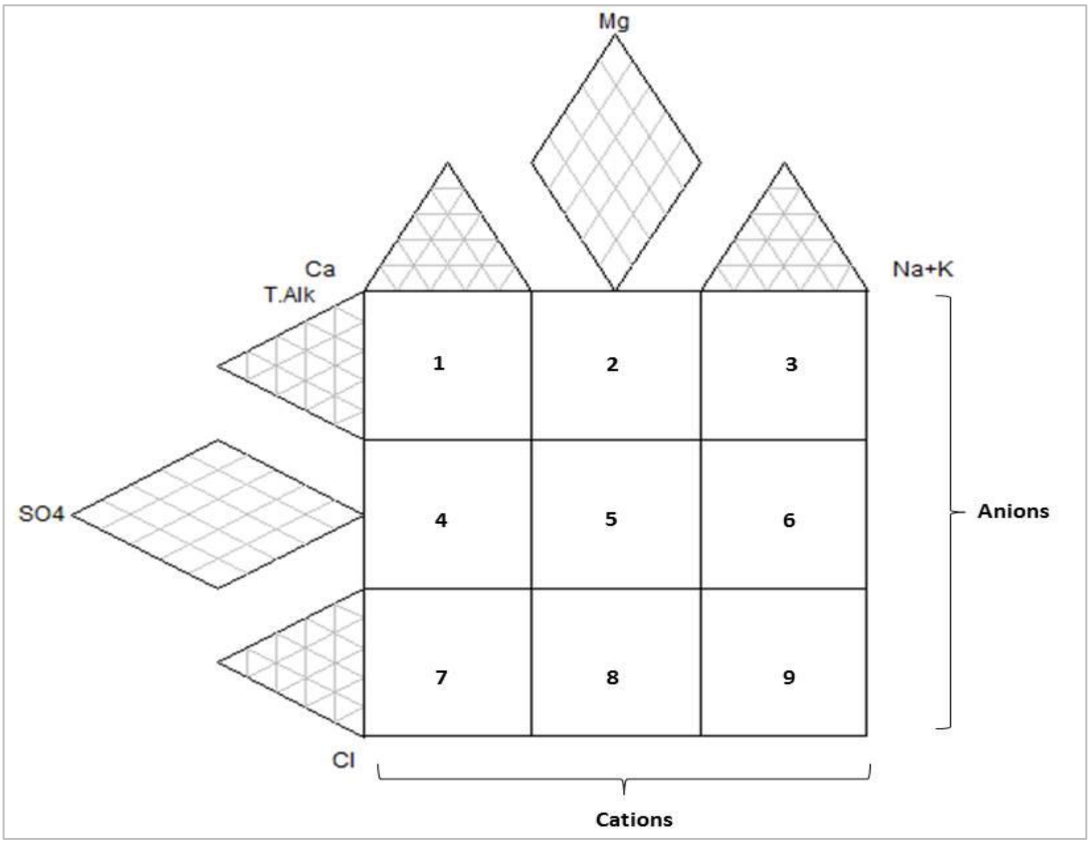


Figure 10-16 Extended Durov diagramindicating major anions and cations.

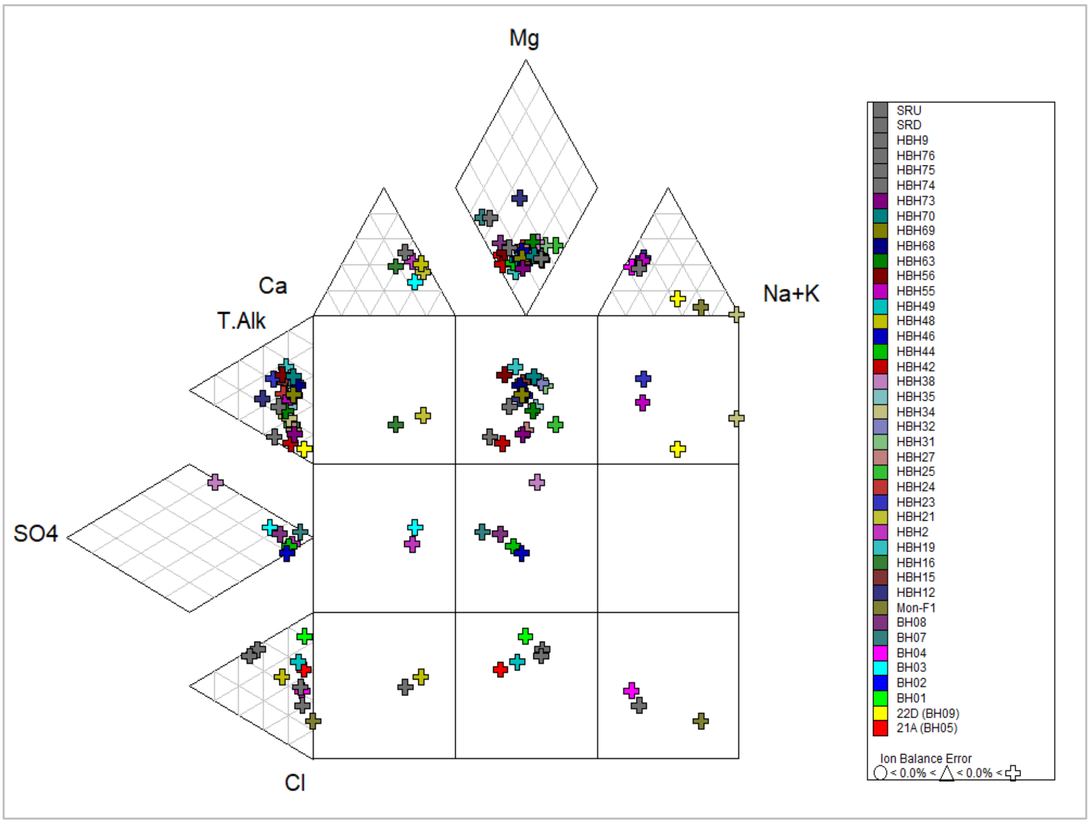


Figure 10-17 Extended Durov diagram of hydrocensus water samples analysed (2022).

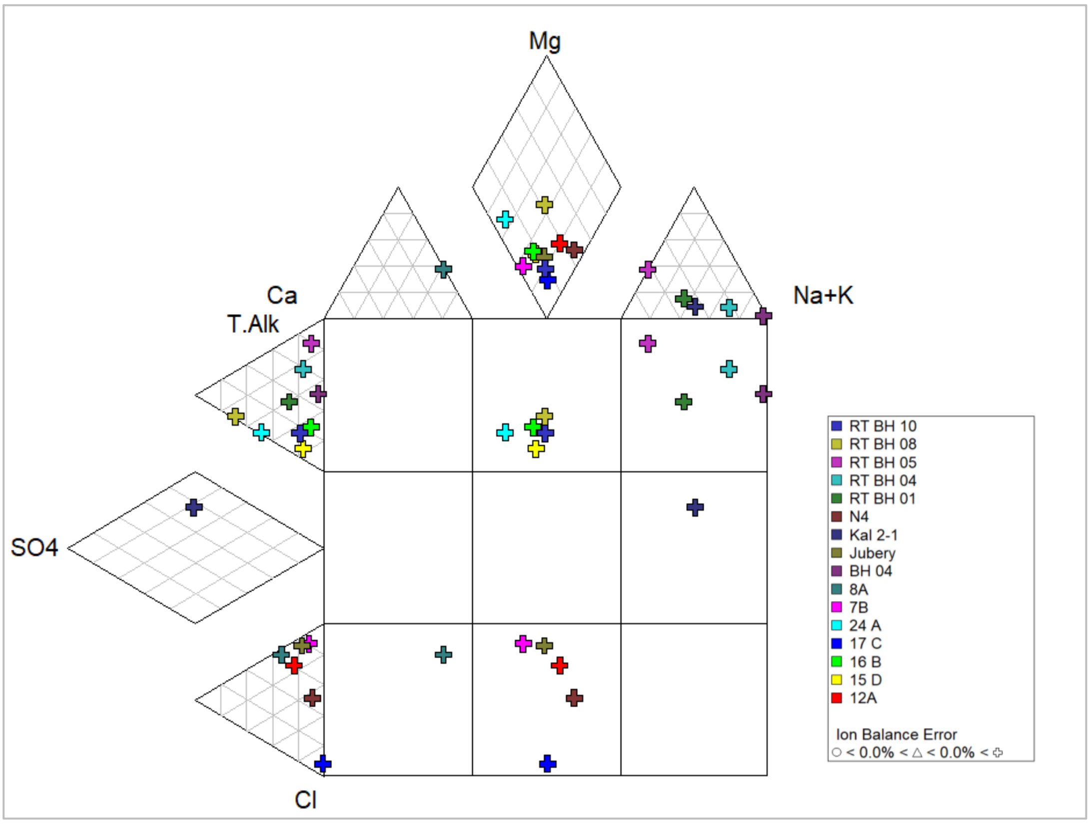


Figure 10-18 **Extended Durov diagram of hydrocensus water samples analysed (2024).**

Figure 10-19 indicates a Schoeller diagram of the water samples analysed and highlights the main hydrochemical species as being Sodium-Chloride.

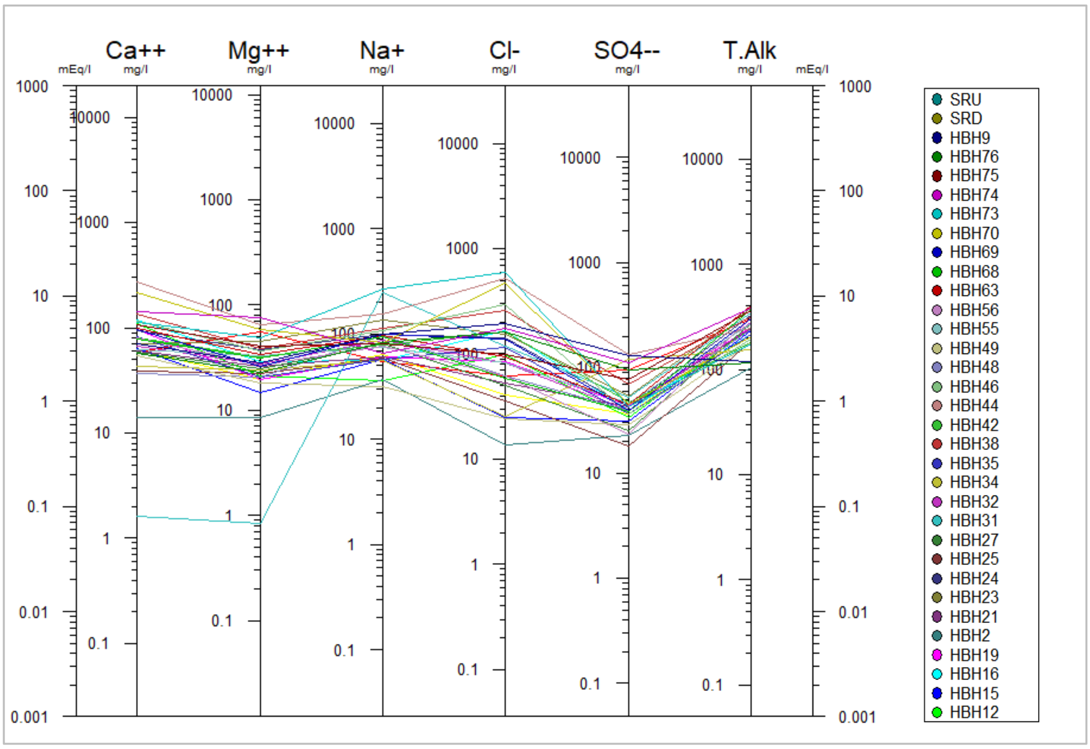


Figure 10-19 **Schoeller diagram of water samples analysed.**

10.5. Radioactivity analysis

In order to evaluate the risk of groundwater containing radioactive substances, earmarked boreholes were subjected to analysis of radionuclides (Gross Alpha and Beta Radioactivity). This method covers the measurement of gross alpha and gross beta particle activities in drinking water. It should be noted that the method is a screening technique for monitoring drinking water supplies for alpha and beta particle activities according to the limits set forth under the Safe Drinking Water Act, PL 93-523, 40 FR 34324, and thereby determining the necessity for further analysis. If radionuclides are present in groundwater, they can be accumulated in the environment and pose a potential hazard to human health since radionuclides and their decay products can be absorbed by the human body through the food chain or water intake (Baeza et al., 2011, Orloff et al., 2004, Poskas et al., 2019). Refer to Table 10-13 for a summary of the radioactivity analyses results (Gross Alpha/Beta activity) compared to World Health Organisation (WHO) guidelines with a spatial distribution map depicted in Figure 10-20[12]. It is noted that the overall ambient groundwater quality with reference to radioactive substances is good with the majority of boreholes analysed falling below the WHO limits for Gross Alpha/Beta activity. It is however observed that borehole 11A suggests elevated Gross Alpha activity i.e., 7.57Bq/l which is above the WHO limit of 0.50Bq/l. It should be noted that this borehole is situated in relatively close proximity to a mine tailings disposal facility, which may potentially hold radioactive material sourced from mining processes. As this method provides a rapid screening measurement to indicate whether specific analyses are required, it is suggested that this borehole sample undergo further analysis in order to determine the exact radioactive species and associated risk. Refer to Appendix E for the radioactivity analysis test report.

Table 10-13 Hydrochemistry: Radioactivity analyses results (Gross Alpha/Beta activity) compared to World Health Organisation (WHO) guidelines.

Radioactivity		
Parameter	**Gross Alpha**	**Gross Betha**
WHO Limits	**≤0.50 Bq/L**	**≤1.00 Bq/L**
BH04	<0.18	0.34
11A**	**7.57**	0.58
25A	0.31	0.30
BR26B	<0.061	<0.24
7A	0.27	0.66
OB	0.41	0.65
15A	0.39	0.52
Mon_MVD_RE_1	<0.075	<0.24
Geometric Mean	**0.16**	**0.47**
Harmonic Mean	**0.12**	**0.38**
5th Percentile	**0.06**	**0.24**
95th Percentile	**0.56**	**2.40**
Standard deviation	**0.19**	**0.95**

Shaded cells exceed WHO drinking water guidelines.
****Adjusted or corrected water sample radioactivity by applying the K-40 activity rule as per WHO recommendation**

[12] It should be noted that the samples submitted for analysis are representative of the shallow aquifer being targeted for water supply purposes.

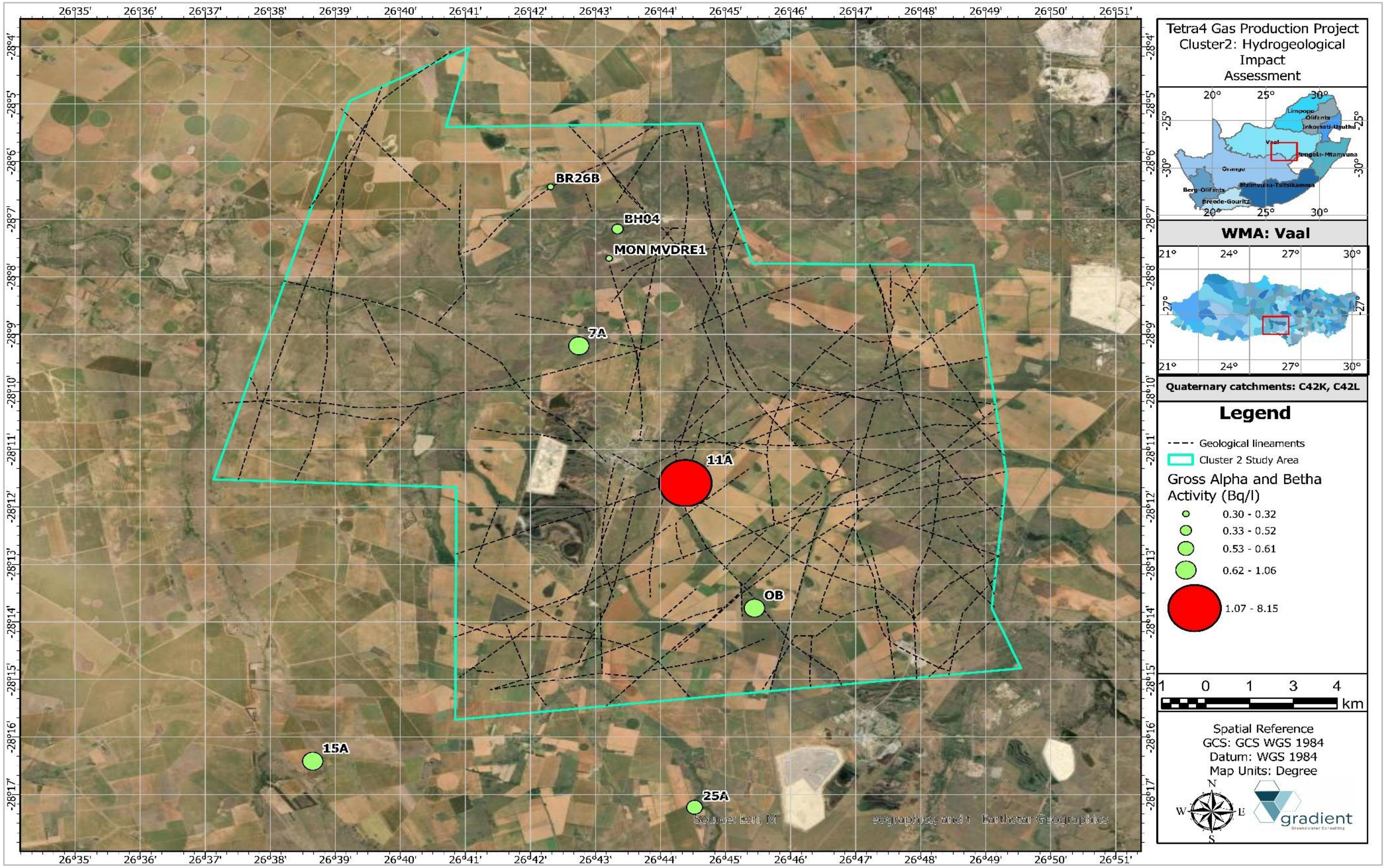


Figure 10-20 **Spatial distribution map of boreholes analysed fro Gross Alpha and Beta activity.**

11. GEOCHEMICAL CHARACTERISATION

The primary objective of this geochemical assessment is to determine the chemical nature and character of the overburden and drilling material and evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for Acid Rock Drainage (ARD) occurring. Geochemical characterisation in the form of Acid Base Accounting (ABA), Sulphur speciation as well as static leach tests was performed on all samples collected. Geochemical test methodologies applied are summarised in Table 11-1. Refer Appendix F for geochemical analysis laboratory certificates.

Table 11-1 Geochemical analysis test methodologies.

Test procedure	Objectives	Methodology
Acid-base accounting (ABA) test	Determine the balance between the acid production and acid consumption properties of the sampled material.	ASTM D3987
Sulphur Speciation	To determine the sulphide content of samples analysed.	ASTM E1915-11
Total element analysis	Microwave-assisted digestion with hydrofluoric (HF), nitric (HNO3) and hydrochloric (HCl) acid mixture for subsequent determination of elements (total digestion of the solid waste prior to elementary analysis).	EN 13656
Distilled water leach: Australian Standard Leaching, ICP-OES/MS	To determine chemicals of concern that may potentially leach from sample.	Based on ASTM D3987-12 with additional ICP-OES/MS and IC analysis.

11.1. Sampling

A total of six samples were collected for geochemical testing and analysis. Refer to Table 11-2 for a description of samples analysed as discussed below.

i. T4GC01: Sandstone core samples representing the Volksrust Formation of the Karoo Supergroup collected from exploration drilling phase.

ii. T4GC02: Shale/ siltstone core samples representing the Volksrust Formation of the Karoo Supergroup collected from exploration drilling phase.

iii. T4GC03: Dwyka Tillite core samples representing the base of the Karoo Supergroup core samples collected from exploration drilling phase.

iv. T4GC04: Dolerite core samples representing the Karoo Dolerite Suite intrusions of the Karoo Supergroup collected as core samples from exploration drilling phase.

v. T4GC05: Lava core samples representing the Ventersdorp Supergroup collected from exploration drilling phase.

vi. T4GC06: Quartzite core samples representing the Witwatersrand Supergroup collected from percussion drilling chips.

Table 11-2 Description of geochemical samples analysed.

Sample ID	Sample type	*	Test procedure	Description	Photo
T4GC01	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Sandstone core samples representing the Volksrust Formation of the Karoo Supergroup collected from exploration drilling phase.	
T4GC02	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Shale/ siltstone core samples representing the Volksrust Formation of the Karoo Supergroup collected from exploration drilling phase.	
T4GC03	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Dwyka Tillite core samples representing the base of the Karoo Supergroup core samples collected from exploration drilling phase.	
T4GC04	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Dolerite core samples representing the Karoo Dolerite Suite intrusions of the Karoo Supergroup collected as core samples from exploration drilling phase.	
T4GC05	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Lava core samples representing the Ventersdorp Supergroup collected from exploration drilling phase.	
T4GC06	Composite sample of geological core		ABA, Sulphur speciation, Distilled water leach (DW 1:20 (LC), Total elements (TC))	Quartzite core samples representing the Witwatersrand Supergroup collected from percussion drilling chips.	

11.2. Acid rock drainage

Acid rock drainage (ARD) (or acid mine drainage, AMD) is considered the most significant environmental issue related to mine environmental impact management. As ARD has the potential to impact significantly on surface and groundwater quality, it is necessary to quantify the potential that the excavated material may have to generate ARD as part of the geochemical characterisation process. Acid rock drainage is produced through the natural oxidation of sulfidic minerals by air and water, accelerated by bacterial action (*thiobacillus*); thus, exposed sulphide-bearing tailings/discard (and waste rock / overburden) are prone to ARD generation. Pyrite and pyrrhotite are the main ARD generating sulphide minerals and are found in many deposits associated with coal. The resulting acid leaches other heavy and toxic metals into the ARD (Weisener et al., 2003). Coal mining is associated with ARD and mining activities usually expose pyrite to oxidising agents such as oxygen and ferric iron (Fe^{3+}). During the oxidation process of sulphide ores, the sulphidic component (S^{2-}) in pyrite is oxidised to sulphate (SO_4^{2-}); acidity (H^+) is generated, and ferrous iron (Fe^{2+}) ions are released. The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

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

Reaction 1

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

The highly soluble Fe^{2+} species oxidise to relatively insoluble ferric iron (Fe^{3+}) in the presence of oxygen – the reaction is slow but is increased by microbial activity:

Reaction 2.

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

Fe^{3+} is then hydrolysed by water (at pH >3) to form the insoluble precipitate ferrihydrite Fe $(OH)_3(s)$ (also known as yellow-boy) and more acidity:

Reaction 3.

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

In addition to reacting directly with oxygen, pyrite may also be oxidised by dissolved Fe^{3+} to produce additional Fe^{2+} and acidity:

Reaction 4.

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

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

Reaction 5.

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

Leaching from carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity (H^+), sulphates (SO_4^{2-}) and ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron species and the movement of other conservative contaminants with groundwater in a downgradient direction from the source. The resulting acidity will mobilise reactive metal contaminants which will create a pollution plume and can migrate in a downgradient direction polluting aquifers and surfacing at seepage points, contaminating surface waters along the way. Within wetland systems, oxidation of Fe^{2+} to Fe^{3+} will result in the precipitation of ferric hydroxide (FeOH), typically as a gel, which can coat the reactive surfaces of the plants and sediment, thereby greatly reducing the ability of the wetland to remove pollutants by adsorption. In addition, the high salt load is often toxic to aquatic life.

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

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

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

- A rock with NNP < 0 kg $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg $CaCO_3$/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg $CaCO_3$/t to 20 kg $CaCO_3$/t exists that is defined as a "grey" area in determining the net acid generation or neutralization potential of a rock. Material with an NNP above this range is classified as R*ock Type IV - No Potential for Acid Generation,* and material with an NNP below this range as *Rock Type I - Likely Acid Generating*. Table 11-3 summarises the deduced acid generating potential based on the net neutralising potential (NNP).

Further screening criteria could be used that attempts to classify the rock in terms of its net potential for acid production or neutralization.

- Table 11-4 summarises the criteria against which the acid forming potential is measured based on the neutralisation potential ratio (NPR) as proposed by Price (1997).
- Soregaroli and Lawrence (1998) further states that samples with less than 0.3% sulphide sulphur are regarded as having insufficient oxidisable sulphides to sustain long term acid generation. According to Li (2006) material with an S% of below 0.1% has no potential for acid generation. Therefore, material with a %S of above 0.3%, is classified as Rock Type I - Likely Acid Generating, 0.2-0.3% is classified as Rock Type II, 0.1-0.2% is classified as Rock Type III, and below 0.1% is classified as Rock Type IV - No Potential for Acid Generation (Table 11-5).

Table 11-3 Net Neutralising Potential (NPP) guideline.

Net neutralising potential (NNP) NNP = NP-AP	Acid generating potential
< -20.0	Likely to be acid generating.
> 20.0	Not likely to be acid generating.
Between -20.0 and 20.0	Uncertain range.

Table 11-4 Neutralisation Potential Ratio (NPR) guidelines (Price, 1997).

Potential for acid generation	NP: AP screening criteria	Comments
Rock Type I. Likely Acid Generating.	< 1:1	Likely AMD generating.
Rock Type II. Possibly Acid Generating.	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides.
Rock Type III. Low Potential for Acid Generation.	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficient reactive NP
Rock Type IV. No Potential for Acid Generation. >4:1 No further AMD testing required unless materials are to be used	> 4.1	No further AMD testing required unless materials are to be used as a source of alkalinity.

Table 11-5 Rock classification according to S% (Afetr Li, 2006).

Classification	Acid forming potential	Criteria
Type I	Likely acid generating	Total S (%) > 0.3%
Type II	Potential acid forming	Total S (%) 0.2 - 0.3%
Type III	Intermediate	Total S (%) 0.1 - 0.2%
Type IV	No potential for acid generation	Total S (%) <0.1 %

11.3. Results and discussion

The ABA analysis as well as sulphur speciation results are summarised in Table 11-6 and Figure 11-1provide a comparison of sulphide percentage vs NPR while Figure 11-2 indicate NP:AP ratios of the respective sample. Refer to Table 11-7 for a summary of AMD potential per sample evaluated. To follow is a brief summary of the potential risk of relevant samples analysed to cause ARD.

11.3.1. Sample T4GC01

The sandstone sample analysed record a very low sulphide content of <0.003% with a high positive NNP value of 35.58. This sample indica6te the highest NPR ratio of all samples and is calculated at 49.86 (>4:1) which suggest that the material consists of adequate buffering capacity with low to no potential for acid generation. It can be concluded that the material analysed suggest no potential for acidic drainage and indicate a very low salt load.

11.3.2. Sample T4GC02

The shale sample analysed record a low sulphide content of 0.012% with a slightly negative NNP value of -0.71. This sample indica6te the highest NPR ratio of all samples and is calculated at 0.0 suggest that the material analysed has limited buffering capacity and may possibly be AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides. Due to the low sulphide content, it can be concluded that the material analysed suggest very potential for acidic drainage and indicate a very low salt load.

11.3.3. Sample T4GC03

The Dwyka tillite sample analysed record a very low sulphide content (lowest off all the samples analysed) of <0.004% with a positive NNP value of 11.11. The NPR ratio of 21.42 (>4:1) suggest that the material consists of adequate buffering capacity with low to no potential for acid generation. It can be concluded that the material analysed suggest no potential for acidic drainage and indicate a very low salt load.

11.3.4. Sample T4GC04

The dolerite sample analysed record a low sulphide content of 0.057% with a positive NNP value of 11.74. The NPR ratio of 6.64 (>4:1) suggest that the material consists of adequate buffering capacity with low to no potential for acid generation. It can be concluded that the material analysed suggest no potential for acidic drainage and indicate a very low salt load.

11.3.5. Sample T4GC05

The lava sample analysed record a very low sulphide content of 0.009% with a positive NNP value of 17.59. The NPR ratio of 22.01 (>4:1) suggest that the material consists of adequate buffering capacity with low to no potential for acid generation. It can be concluded that the material analysed suggest no potential for acidic drainage and indicate a very low salt load.

11.3.6. Sample T4GC06

The quartzite sample analysed record a low sulphide content of 0.018% with a positive NNP value of 12.90. The NPR ratio of 5.20 (>4:1) suggest that the material consists of adequate buffering capacity with low to no potential for acid generation. It can be concluded that the material analysed suggest no potential for acidic drainage and indicate a very low salt load.

Table 11-6 ABA test results summary table.

Sample ID	Lithology	Paste pH	Total Sulphur (%)	Sulphide (%)	Acid Potential (AP) CaCO3 (kg/t)	Neutralising Potential (NP)) CaCO3 (kg/t)	Net Neutralising Potential (NNP) CaCO3 (kg/t)	Neutralising Potential Ration (NPR) (NP/AP)
T4GC01		10.050	0.023	0.007	0.728	36.31	35.58	49.86
T4GC02		10.060	0.023	0.012	0.709	0.00	-0.71	0.00
T4GC03		10.410	0.017	0.004	0.519	11.11	10.59	21.42
T4GC04		10.480	0.057	0.015	1.769	11.74	9.97	6.64
T4GC05		10.080	0.027	0.009	0.838	18.43	17.59	22.01
T4GC06		9.840	0.098	0.018	3.069	15.97	12.90	5.20

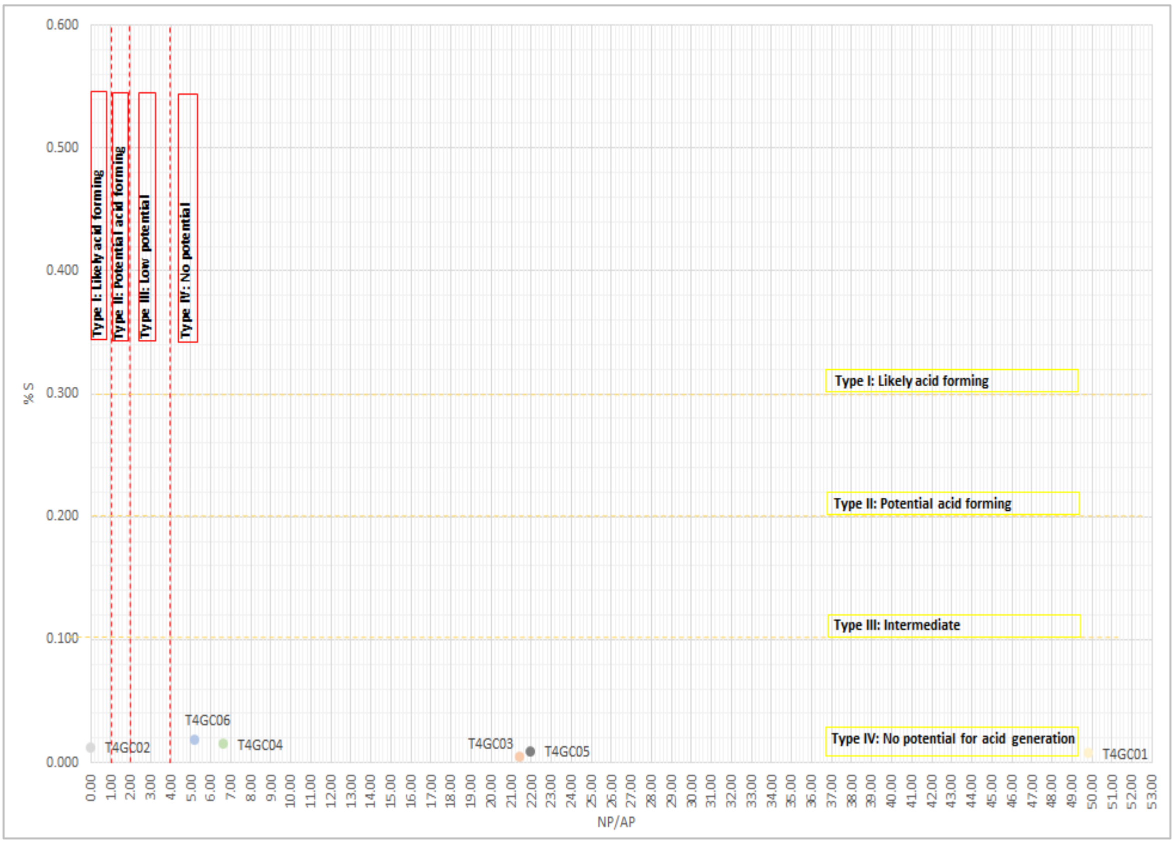


Figure 11-1 **Classification of samples in terms of %S (samples below 3%) and NP/AP.**

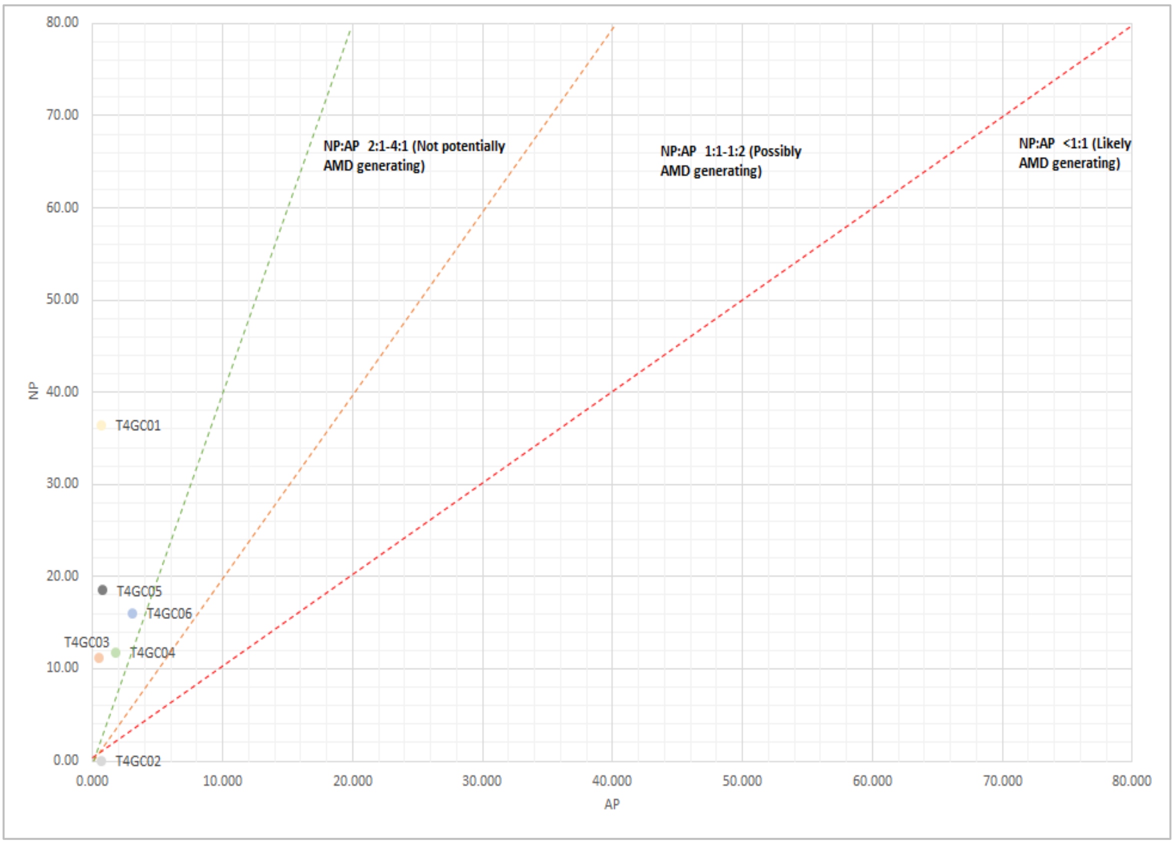


Figure 11-2 **Comparison graph: NP vs. AP.**

Table 11-7 Summary table: ARD potential per sample analysed.

Sample	%S >0.3 NP/AP < 2.0	%S > 0.3 NP/AP > 2.0	%S < 0.1 - 0.3 NP/AP < 2.0	%S < 0.1 - 0.3 NP/AP > 2.0	%S < 0.1 NP/AP < 2.0	%S < 0.1 NP/AP > 2.0
T4GC01						
T4GC02						
T4GC03						
T4GC04						
T4GC05						
T4GC06						
Potential for ARD						
	Likely/possibly acid generating. High salt load.	Medium potential for acid generation. Medium to high salt load	Low to medium potential for acid generation. Low to medium salt load.	Very low potential for acid generation. Very low to low salt load.	No potential for acidic drainage. Very low salt load.	No potential for acidic drainage. Very low/no salt load.

11.4. Waste assessment

Potential waste material collected from drilling chips and core collected from the exploration drilling phase were submitted for geochemical characterisation to identify the chemical substances present in the material through analysis of the total concentrations (TC) and leachable concentrations (LC) in order to assess the material type and class. A total of thirty (30) samples were collected and composited into ten (10) samples representative of each identified lithology. Refer to Appendix F for waste classification report. Below a discussion on the major lithologies evaluated:

i. Sample 06: Percussion drill chips consisting of shale, dolerite and sandstone formations.

ii. Sample 07: Percussion drill chips consisting of lava and quartzite formations.

iii. Sample 11: Percussion drill chips consisting of soil and shale formations.

iv. Sample 21: Percussion drill chips consisting of overburden, soil, conglomerate, shale, mudrock formations.

The waste classification system is based on the Australian State of Victoria's waste classification system for disposal, which uses the Australian Standard Leaching Procedure (ASLP) to determine the leachable concentrations (LC) of pollutants in a particular waste (DEA, 2013a). The process includes identifying the chemical substances present in the material through analysis of the total concentrations (TC) and leachable concentrations of samples taken. These results are compared to threshold limits i.e., leachable concentrations threshold (LCT) and total concentrations threshold (TCT) specified in R635. The waste assessment was conducted in line with the following approach as summarised below:

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

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

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

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

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

Waste types and categories are summarised in Table 11-8 while the TC and LC threshold limits, according to Section 6 of R635, are presented in Table 11-9 and Table 11-10 below. While R635 is relevant to Landfill disposal (and not specifically relevant to Mineral Waste) it does provide important limits to determine the degree of hazardousness of the material. From a legislative point of view these limits and guidelines are not enforceable, however are applied as part of the risk-based approach.

Table 11-8 Waste types.

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

Table 11-9 Total Concentration Threshold (TCT) Limits (mg/kg).

Elements	TCT0 (mg/kg)	TCT1 (mg/kg)	TCT2 (mg/kg)
Metal ions			
As	5.80	500.00	2 000.00
B	150.00	15 000.00	60 000.00
Ba	62.50	6 250.00	25 000.00
Cd	7.50	260.00	1 040.00
Co	50.00	5 000.00	20 000.00
Cr (Total)	46 000.00	800 000.00	n.a
Cr (VI)	6.50	500.00	2 000.00
Cu	16.00	19 500.00	78 000.00
Hg	0.93	160.00	640.00
Mn	1 000.00	2 500.00	100 000.00
Mo	40.00	1 000.00	4 000.00
Ni	91.00	10 600.00	42 400.00
Pb	20.00	1 900.00	7 600.00
Sb	10.00	75.00	300.00
Se	10.00	50.00	200.00
V	150.00	2 680.00	10 720.00
Zn	240.00	160 000.00	640 000.00
Inorganic ions			
TDS			
Chloride			
Sulphate as SO_4			
NO_3 as N			
Fluoride	100.00	10 000.00	40 000.00
Cyanide	14.00	10 500.00	42 000.00

Notes: TCT1 limits, where appropriate, have been derived from the land remediation values for commercial/ industrial land determined by the Department of Environmental Affairs "Framework for the Management of Contaminant Land ", March 2010. The TCT2 limits by multiplying TCT1 by a factor of 4, as used by the Environmental Protection Agency, Australian State of Victoria. If South African limits for TCT1 were unavailable, in general, the limits published by the Environmental Protection Agency, Australian State of Victoria have been used. Some TC limits have been adjusted because of various attenuation factors that are observed in landfills. Where available, the TCT0 limits have been obtained from SA Soil Screening Values that are protective of water resources. If not available, the State Victoria value for fill material, (EPA Victoria, Classification of Wastes) has been selected. If limits were not available in these references a conservative value was obtained by dividing the TCT1 value by 100.

Table 11-10 Leachable Concentration Threshold (LCT) Limits (mg/l).

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

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

Figure 11-3 indicate a bar-chart comparison of the Total Concentration analysis of elements per sample whereas Figure 11-4 show a bar-chart comparison of Leachable Concentrations analysis per sample. Dominant total concentrations above prescribed thresholds include Arsenic (As), Barium (Ba) as well Copper (Cu) whereas Arsenic (As) was observed as the dominant leachate concentration above prescribed thresholds. To follow is a brief summary of the waste assessment per sampled material.

11.4.1. Sample 06

The following element(s) fall above the prescribed thresholds in terms of the TC values: Ba (>TCT0) while no elements fall above the prescribed thresholds in terms of the LC values. The sample analysed suggest that TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination. Refer to Table 11-11 for a summary of total elements and leachate results compared to TC and LC thresholds.

11.4.2. Sample 07

The following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0), Cu (>TCT0) as well as Ni (>TCT0) while leachable concentration following above the prescribed thresholds in terms of the LC values: As (>LCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination. Refer to Table 11-12 for a summary of total elements and leachate results compared to TC and LC thresholds.

11.4.3. Sample 11

The following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0) as well as Cu (>TCT0) while leachable concentration following above the prescribed thresholds in terms of the LC values: As (>LCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination. Refer to Table 11-13 for a summary of total elements and leachate results compared to TC and LC thresholds.

11.4.4. Sample 21

The following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0) as well as Cu (>TCT0) while no elements fall above the prescribed thresholds in terms of the LC values. The sample analysed suggest that TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination. Refer to Table 11-14 for a summary of total elements and leachate results compared to TC and LC thresholds.

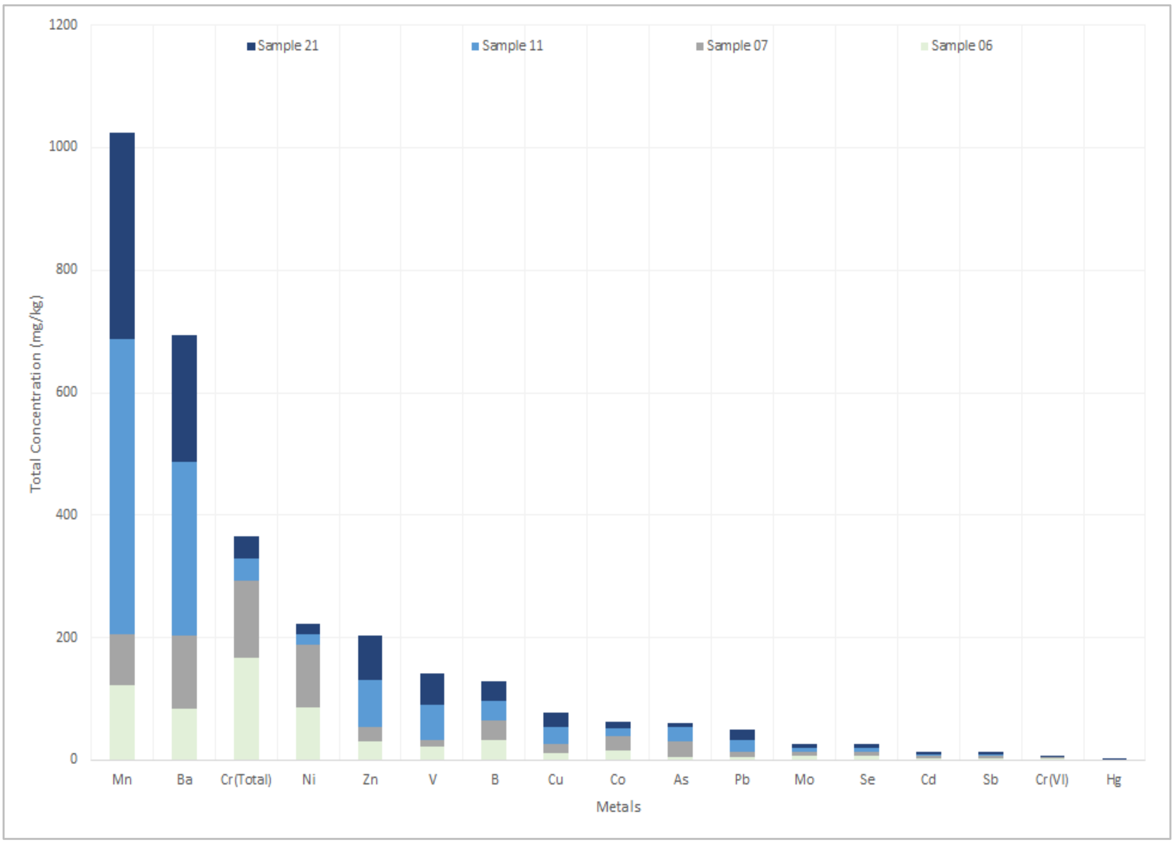


Figure 11-3 **Comparison of Total Concentration analysis of Elements.**

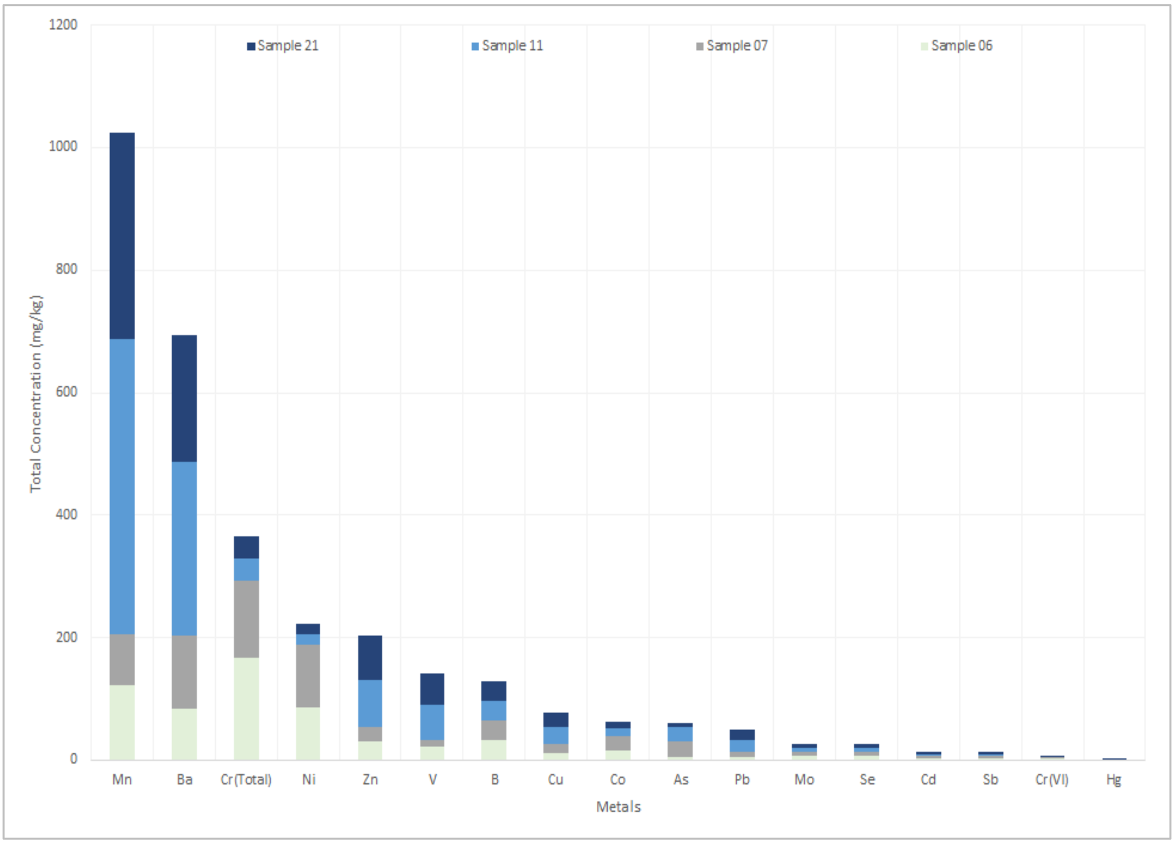


Figure 11-4 **Comparison of Leachable Concentrations analysis of samples.**

Table 11-11 Leachable Concentration (LC) and Total Concentration (TC) results of Sample 06 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0
Metal ions															
As	4.35	< 0.01		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32	< 0.5		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	83.62	< 0.05		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.2	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	14.81	< 0.05		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	167.60	< 0.05		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	10.82	0.12		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	< 0.3	< 0.005		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	122.80	< 0.05		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	< 6.4	< 0.05		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	85.74	< 0.05		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	5.20	< 0.01		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	< 3.2	< 0.01		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	< 6.4	< 0.01		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	21.09	< 0.05		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	29.75	0.08		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	9.45	7.70													
TDS		50.00			1000.00			12500.00			25000.00			100000.00	
Chloride		<2.00			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.29			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.50			11.00			550.00			1100.00			4400.00	
Fluoride	21.76	0.32		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	1.55	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

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

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

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

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 11-12 Leachable Concentration (LC) and Total Concentration (TC) results of Sample 07 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0
Metal ions															
As	25.46	0.02		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32	< 0.5		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	119.20	< 0.05		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.2	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	23.76	< 0.05		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	126.40	< 0.05		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	16.31	0.13		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	< 0.3	< 0.005		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	82.11	< 0.05		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	< 6.4	< 0.05		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	102.30	< 0.05		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	7.75	< 0.01		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	< 3.2	< 0.01		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	< 6.4	< 0.01		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	12.09	< 0.05		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	23.47	0.10		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	8.80	7.50													
TDS		<10.00			1000.00			12500.00			25000.00			100000.00	
Chloride		<2.00			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.13			250.00			12500.00			25000.00			100000.00	
NO_3 as N		5.75			11.00			550.00			1100.00			4400.00	
Fluoride	10.45	0.29		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<1.55	<0.05		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

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

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

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

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 11-13 Leachable Concentration (LC) and Total Concentration (TC) results of Sample 11 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0
Metal ions															
As	24.38	0.04		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32	< 0.5		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	284.80	0.11		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.2	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	12.34	< 0.05		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	34.56	< 0.05		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	27.70	0.19		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	< 0.3	< 0.005		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	482.80	0.07		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	< 6.4	< 0.05		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	18.51	< 0.05		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	19.55	< 0.01		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	< 3.2	< 0.01		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	< 6.4	< 0.01		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	58.08	< 0.05		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	78.49	0.10		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	10.19	8.29													
TDS		100.00			1000.00			12500.00			25000.00			100000.00	
Chloride		4.01			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		19.43			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<2.22			11.00			550.00			1100.00			4400.00	
Fluoride	7.70	0.39		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	3.71	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes
LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes
LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes
LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes
LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 11-14 Leachable Concentration (LC) and Total Concentration (TC) results of Sample 21 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0
Metal ions															
As	7.34	0.01		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	< 32	< 0.5		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	205.60	< 0.05		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	< 3.2	< 0.003		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	11.04	< 0.05		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	36.90	< 0.05		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	< 2	< 0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	23.08	0.13		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	< 0.3	< 0.003		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	336.70	0.07		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	< 6.4	< 0.05		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	16.09	< 0.05		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	17.10	< 0.01		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	< 3.2	< 0.01		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	< 6.4	< 0.01		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	50.42	< 0.05		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	71.58	0.09		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	9.75	7.78													
TDS		86.00			1000.00			12500.00			25000.00			100000.00	
Chloride		4.78			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		15.63			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.50			11.00			550.00			1100.00			4400.00	
Fluoride	34.00	0.81		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<1.55	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes
LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes
LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes
LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes
LC > LCT3 or TC > TCT2: Type 0 Wastes

12. OPERATIONAL WATER AND MASS LOAD BALANCE

The following section summarises the main water balance components and water reticulation network.

12.1. Water balance components

The following water management components were included as part of the water balance reticulation network as summarised in Table 12-1:

i. LNG production plant
ii. Evaporation dam.

Table 12-1 Water balance components.

Facility/ Component	Contact/Clean water cycle	Footprint (m^2)**	Description
LNG production plant	Contact	280 000.00	LNG plant
Evaporation dam	Contact	1750.00	Lined evaporation dam situated at LNG plant

**It should be noted that footprints are approximations only and do not represent surveyed areas.

The following section summarises the water and salt balance per component. Refer to Table 12-2 for a summary of the water and salt balance calculations while Figure 12-1 and Figure 12-2 depicts respective reticulation flow diagrams.

12.2. Evaporation dam

This facility is a lined waste water storage facility receiving brine from the LNG production plant. To follow is a brief description of the water and salt balance components.

12.2.1. Water balance

Major inflows to this facility include brine water sourced from the LNG production plant (1.30m^3/d) as well as direct precipitation reporting to the facility (2.53m^3/d), while the only major outflow is water loss due to evaporation which accounts to 4.83m^3/d. It is assumed that this is a closed-circuit system and that stormwater from the local catchment is channelled away from this facility. Due to the high evaporation signature, this component indicates a negative water balance i.e., nett water consumption. Accordingly, the risk to overflow and spillage is minimised.

12.2.2. Salt balance

Major salt load contribution to this facility includes dissolved salts in the brine reticulated from the LNG production plant (1.13E^{+01}kg/d) as well as dissolved salts in direct precipitation reporting to the facility (5.06E^{-02}kg/d). As salts cannot be removed from the system via evaporation, this component indicates a positive salt balance i.e., nett salt make. Accordingly, build-up of salts are expected, which should be managed.

Table 12-2 Operational water and salt balance summary table (Daily average).

Description	Input salt load (kg/d)	Input volume (m^3/d)	Water balance component	Output volume (m^3/d)	Output salt load (kg/d)	Description
Municipal water supply	3.00E-02	1.50E+00	LNG Production Plant	1.30E+00 2.00E-01	1.13E+01 1.73E+00	Saline water reticulated to evaporation dam Process water consumption
Water balance (m^3/d)			0.00E+00			**Neutral water balance**
Salt balance (kg/d)	3.00E-02	1.50E+00	-1.30E+01	1.50E+00	1.30E+01	**Negative salt balance**
Direct precipitation Saline water reticulated from LNG Plant	5.06E-02 1.13E+01	2.53E+00 1.30E+00	Evaporation Dam	4.83E+00	0.00E+00	Evaporation
Water balance (m^3/d)			-1.00E+00			**Negative water balance**
Salt balance (kg/d)	1.13E+01	3.83E+00	1.13E+01	4.83E+00	0.00E+00	**Positive salt balance**

Negative balance
Positive balance
Water balance figures
Salt balance figures

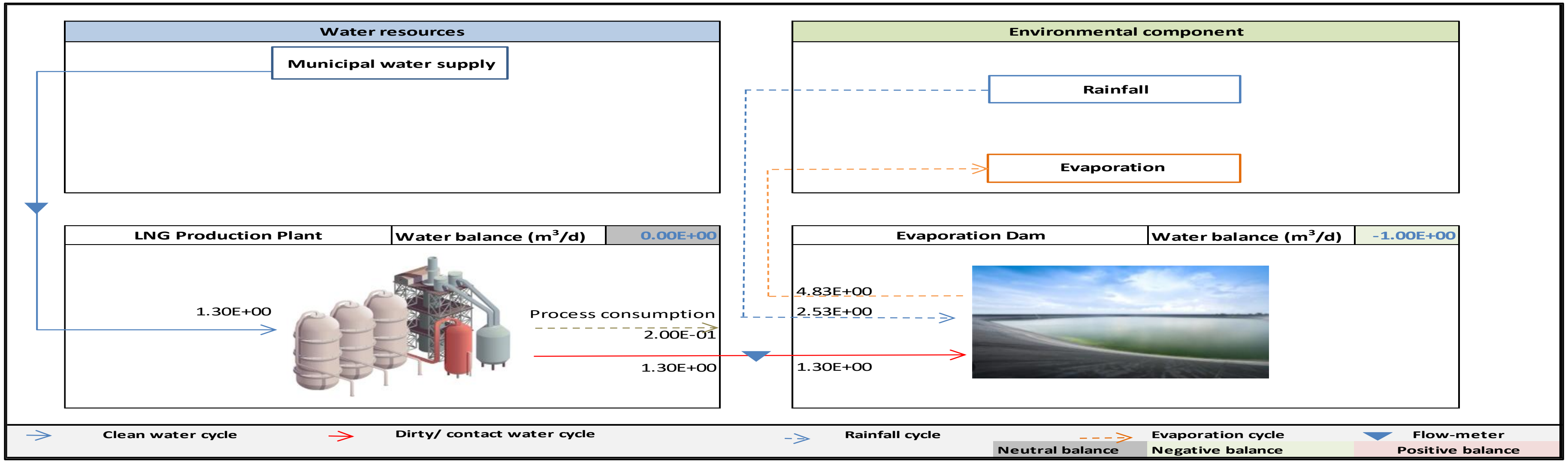


Figure 12-1 **Operational water balance flow diagram (Daily average).**

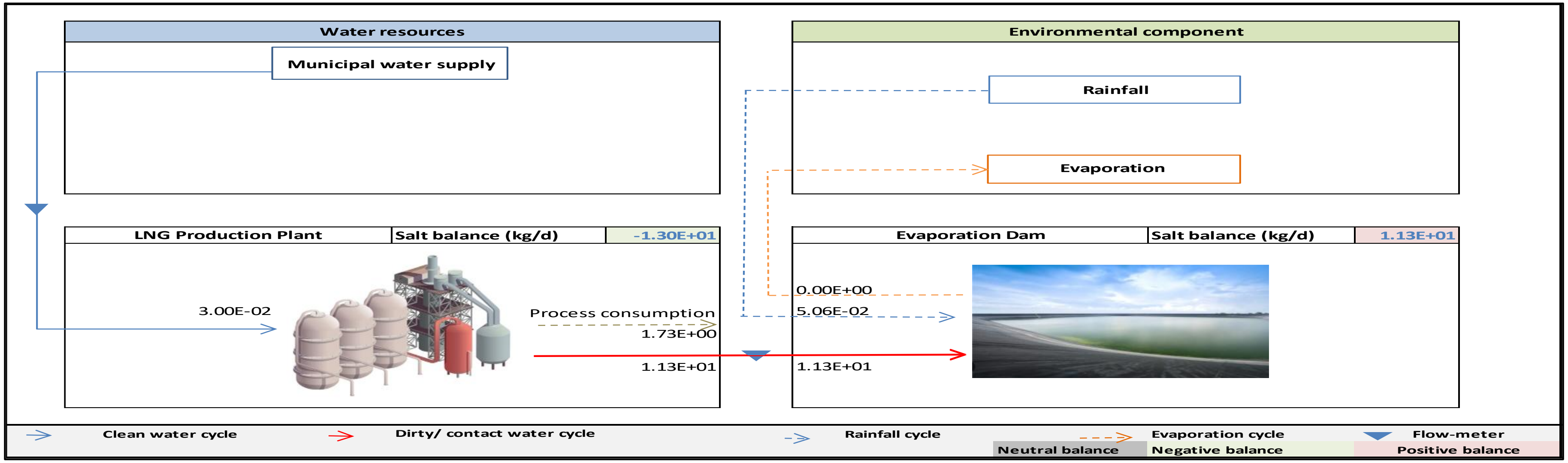


Figure 12-2 **Operational salt balance flow diagram (Daily average).**

13. 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 of this study 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 as summarised in Table 13-2.

Equation 13-1 GMQ Index.

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

13.1. 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**" (DWS, 2013). Site characterisation phase conducted, confirms the host aquifer to be a minor aquifer. It should however be noted that the shallow, intergranular aquifer is important to local groundwater users as it forms the sole source of water supply in the region (Lea, 2017). Furthermore, the primary riparian zone aquifer is classified as a major aquifer system due to its highly permeable nature as well as good water quality. The classifications and definitions for each aquifer system are summarised in Table 13-1.

Table 13-1 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.

13.2. Aquifer vulnerability

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

13.3. Aquifer susceptibility

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

Table 13-2 Groundwater Quality Management Index.

Aquifer system Management qualification Class	**Points**	**Aquifer vulnerability Classification 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**

13.4. 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. Risk ratings used as part of the index are summarised in Table 13-3. The DRASTIC index (DI) can be computed using the following formula.

Equation 13-2 DRASTIC Index (Di).

$$\mathbf{Di} = \boldsymbol{DrD\lambda + RrR\lambda + ArA\lambda + Sr\,S\lambda + TrT\lambda + IrI\lambda}$$

where:

D = Depth to Water Table

R = Recharge

A = Aquifer media.

S = Soil media.

T = Topographic aspect.

I = Impact of vadose zone media.

C = Conductivity.

Table 13-3 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 13-4 below (Lynch et al, 1994).

Table 13-4 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

Topography (T_R)

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

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

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

According to the DRASTIC index methodology applied, the proposed activities and associated infrastructure's risk to groundwater pollution of the aquifer system(s), is rated as "**Moderate**", **Di = 109**, (refer to Table 13-5).

Table 13-5 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) = 109				

13.5. Source-pathway-receptor evaluation

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors. The pollution linkage concept relies on the identification of a potential pollutant (i.e., source) on-site which is likely to have the potential to cause harm on a receptor by means of a pathway by which the receptor may be exposed to the contaminant (Figure 13-1).

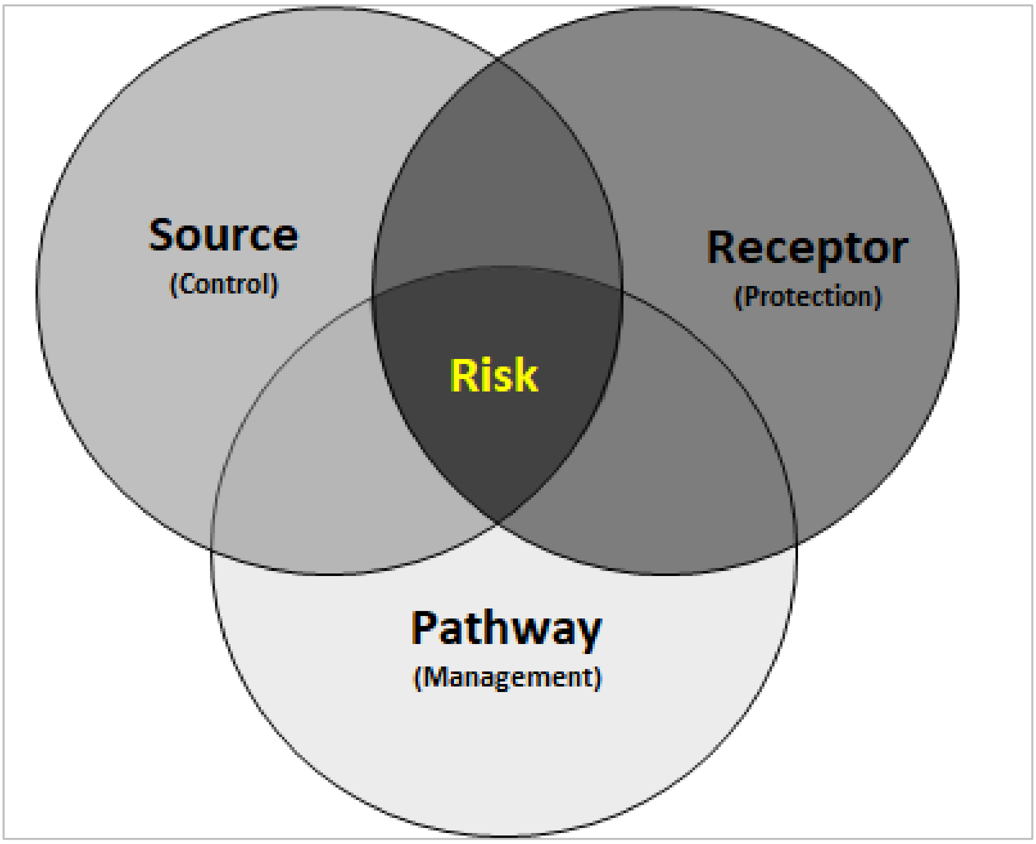


Figure 13-1 Source pathway receptor principle.

13.5.1. 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 production phase.

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

iii. Migration of contaminants from the plant expansion waste facilities and associated infrastructure, such as the evaporation dam, into local water resources and host aquifers.

13.5.2. 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 production wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

13.5.3. Potential receptors

The following receptors were identified:

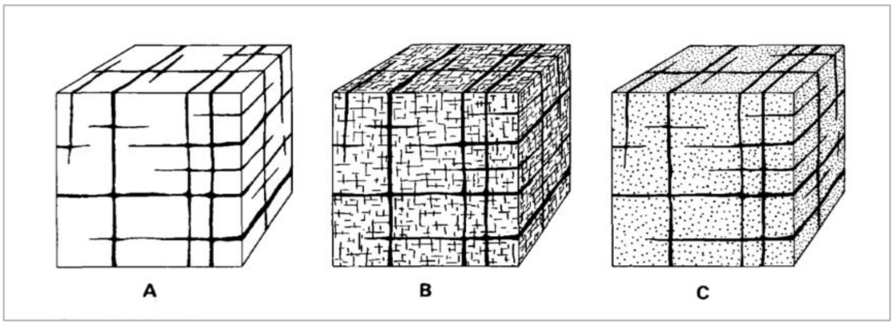
i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s).

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.

14. 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 14-1 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 14-2 depicts a south- north cross section of the study area (unmitigated, worst-case scenario) whereas Figure 14-3 depicts a south- north cross section of the study area (mitigated scenario). Refer to Figure 15-2 for spatial reference.



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

Figure 14-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

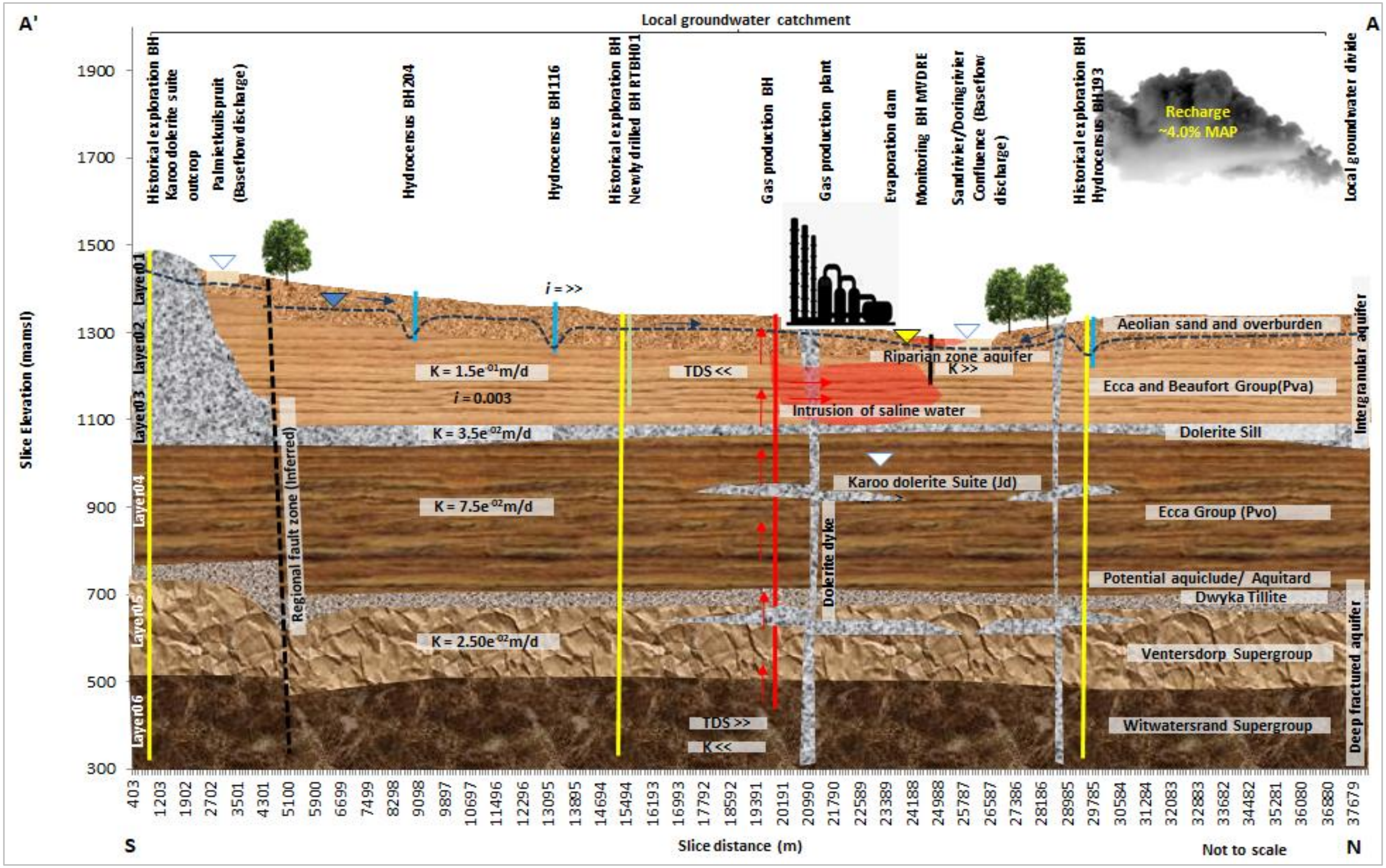


Figure 14-2 Hydrogeological conceptual model: South- North cross section – Pre-mitigation (A'-A') (Refer to Figure 15-2).

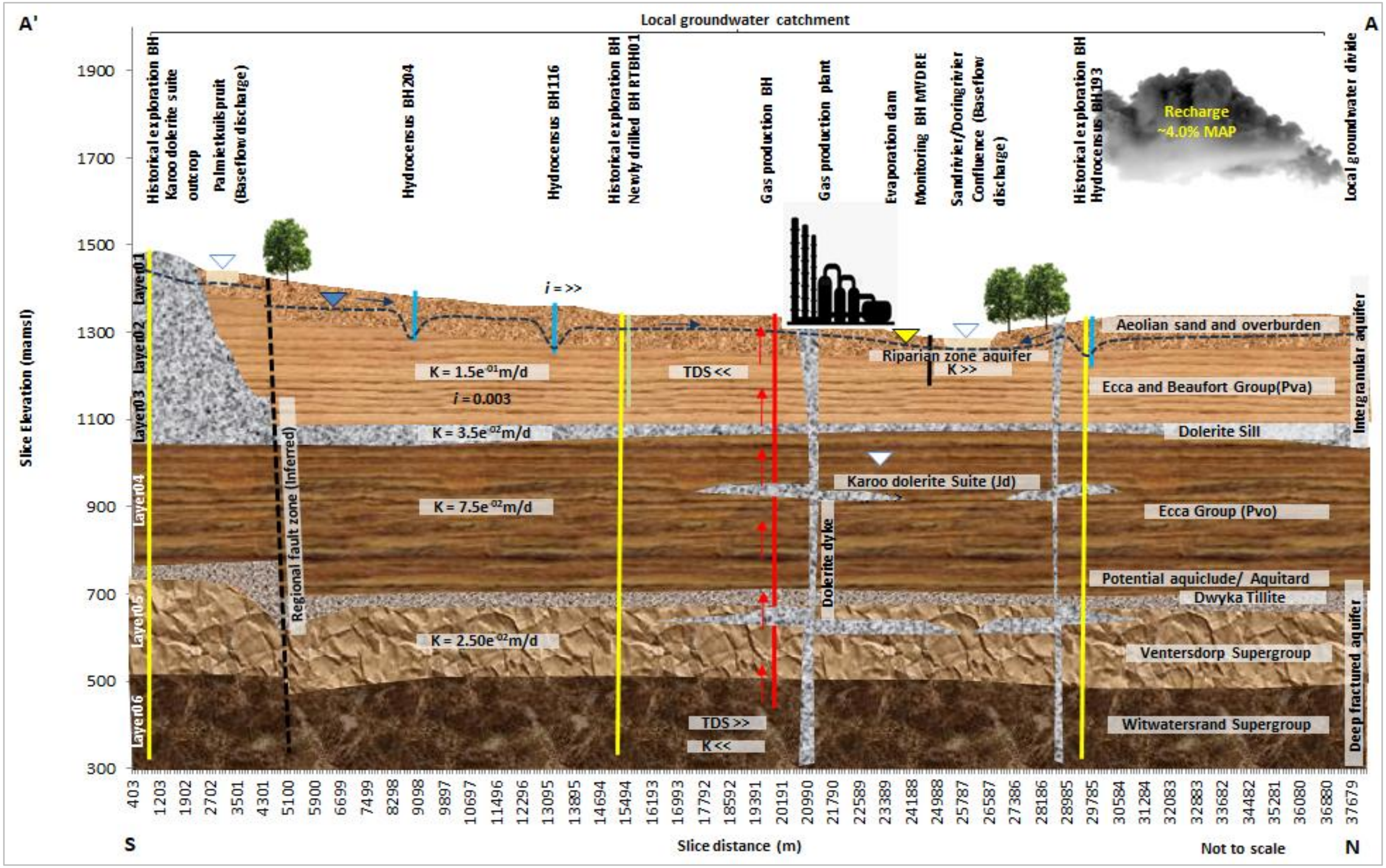


Figure 14-3 **Hydrogeological conceptual model: South- North cross section – Post-mitigation (A-A') (Refer to Figure 15-2).**

15. 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.

15.1. Approach to modeling

The typical workflow and modelling approach employed is summarised in Figure 15-1 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 production well have been simulated to serve as a worst-case scenario in order to formulate adequate mitigation and management measures.

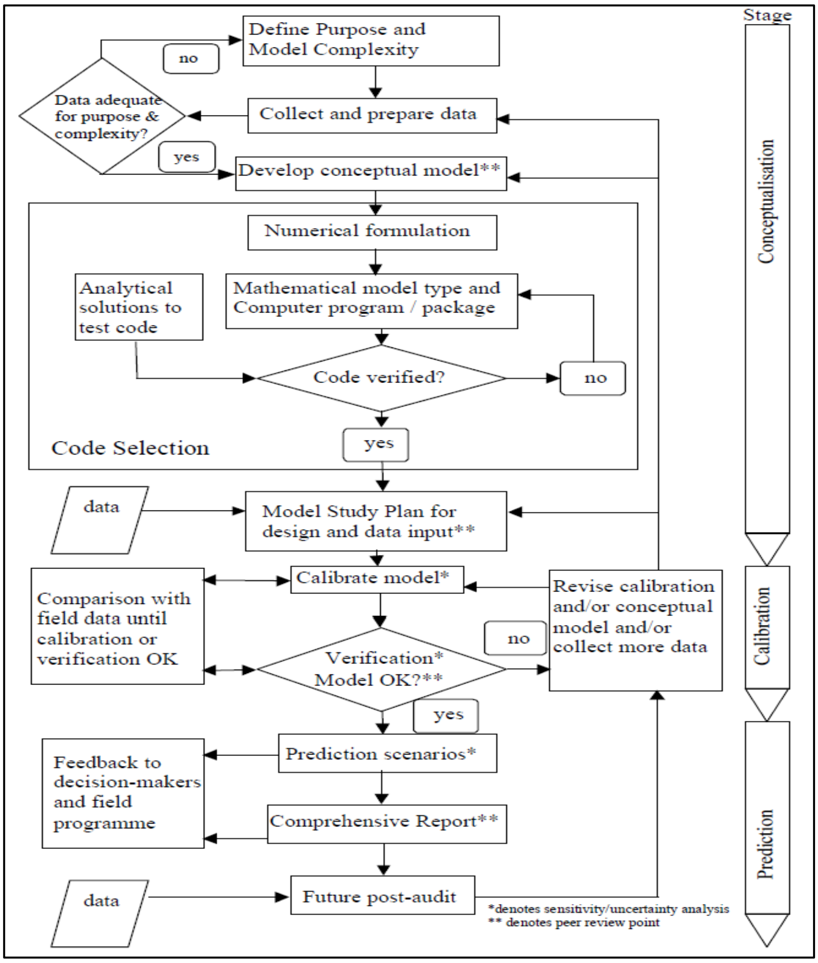


Figure 15-1 **Workflow numerical groundwater flow model development.**

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 15-1 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).

15.2. 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.

15.3. Model development

15.3.1. Model domain

A model grid was created with global origin X: -27445.86[m] and Y: -3112627.03[m] using triangular prism type of elements. The model has a width of 30 224[m], height of 37 800.9[m], depth of 1413.95[m] and spans an area of $7.32e^{+08}m^2$ with a volume of ~$8.81e^{+11}m^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e., discharge zones and no-flow zones (Figure 15-2). Figure 15-3 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 15-4 and Figure 15-5 shows the model finite element mesh (FEM) construction. Figure 15-6 and Figure 15-7 depicts a respective cross section on which the hydrogeological conceptual model is based on.

15.3.2. Model construction

The model was constructed from FEM and consist of six layers i.e., seven slices, 493 507 triangular prism elements per layer, a total of 2 961 042 elements for the model domain, with 247 484 nodes per slice a total of 1 732 388 nodes for the model domain. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 0.80%.
- Interior holes: 0.
- Obtuse angled triangles: 0.30% > 120°, 4.30% > 90°.

15.3.3. Model layers

The groundwater model consists of six layers (seven 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 15-1, (Refer to Table 5-2 and Figure 5-12):

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 = ~250.0m).

iii. Layer 03: Karoo Dolerite Suite (Sill) which may potentially act as an aquitard (Average thickness = 30.0m).

iv. Layer 04: 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 Dwyka Tillite (may also potentially act as an aquitard)) (Average thickness = ~200.0m).

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 Supergroup Lava (Average thickness = ~500.0m).

vi. Layer 06: A deep fractured aquifer (confined) where groundwater flow will be dictated by transmissive fracture zones that occur in the competent host rock of the Witwatersrand Supergroup Quartzite (Average thickness = ~300.0m).

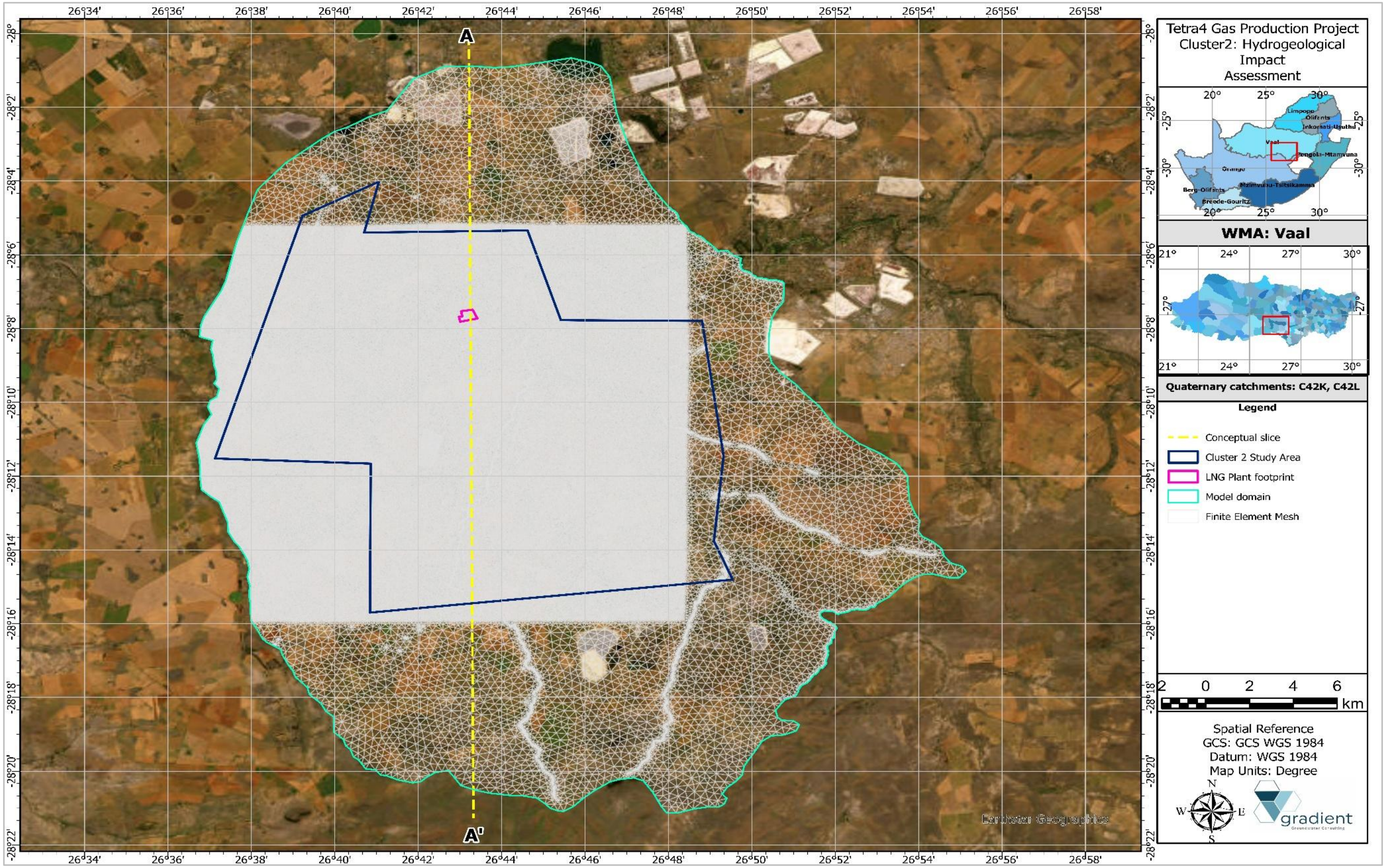


Figure 15-2 **Model domain: Aerial extent.**

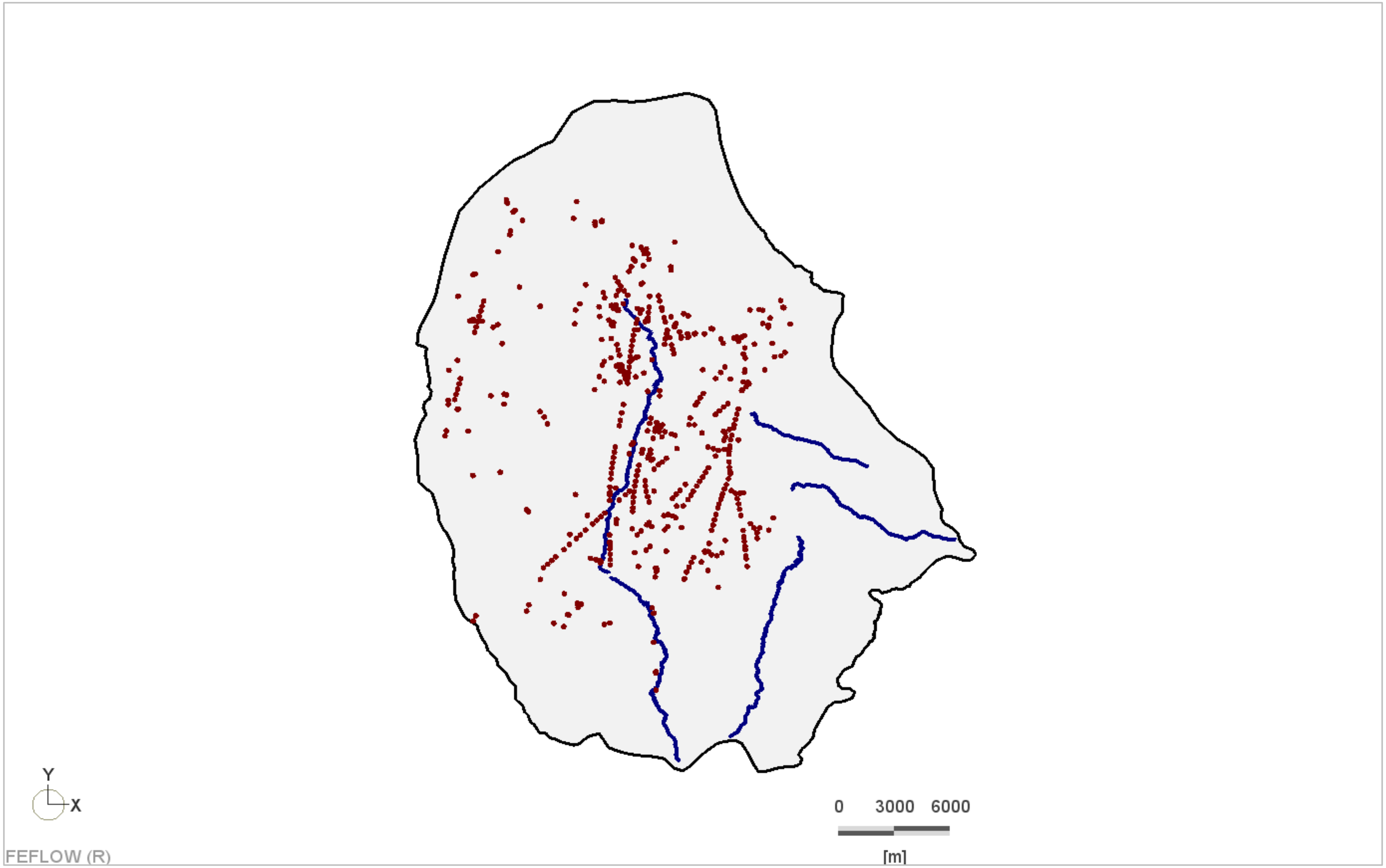


Figure 15-3 **Model domain: Supermesh view.**

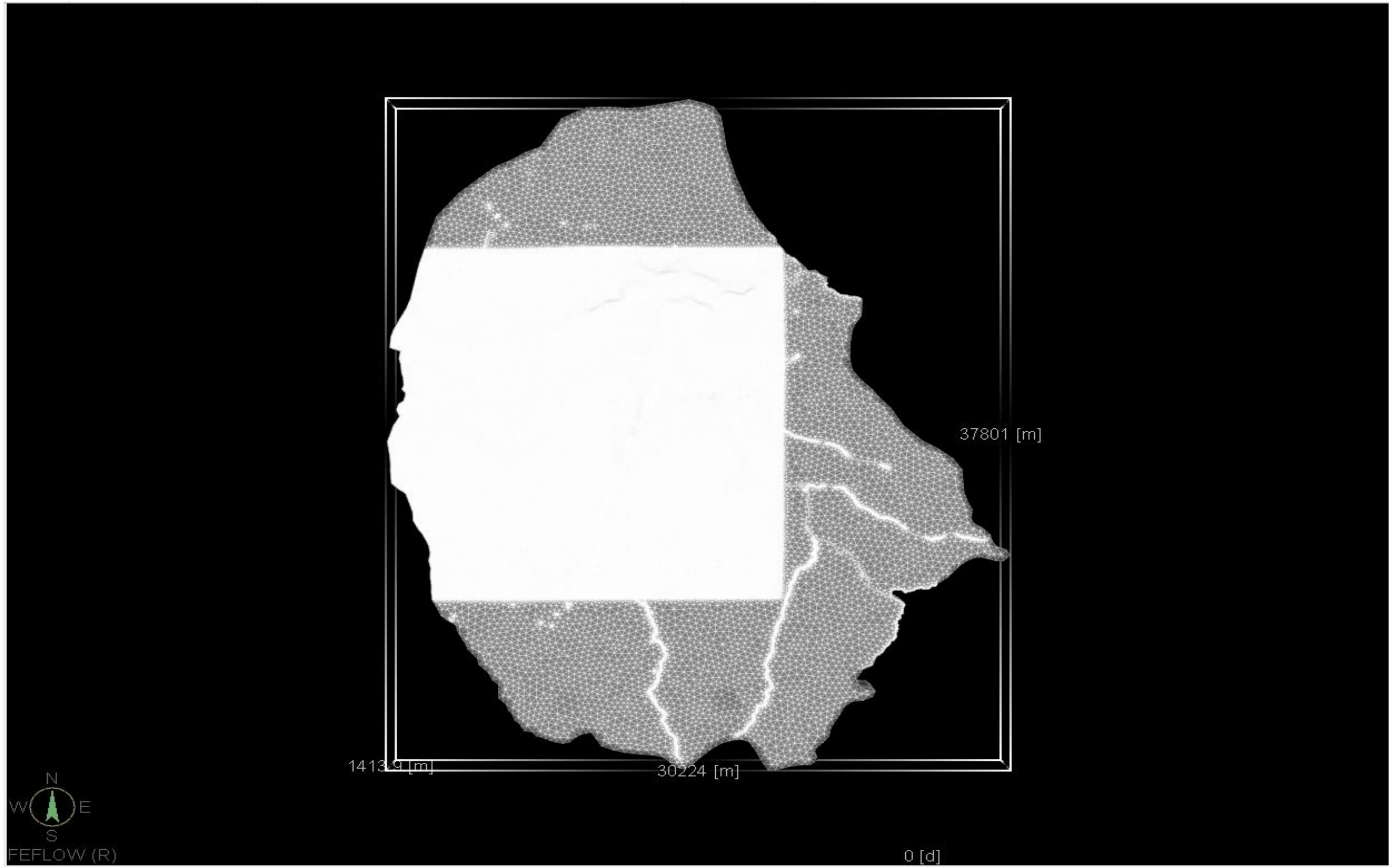


Figure 15-4 **Model domain 3-D FEM mesh in a plan view depicting a plan-view orientation .**

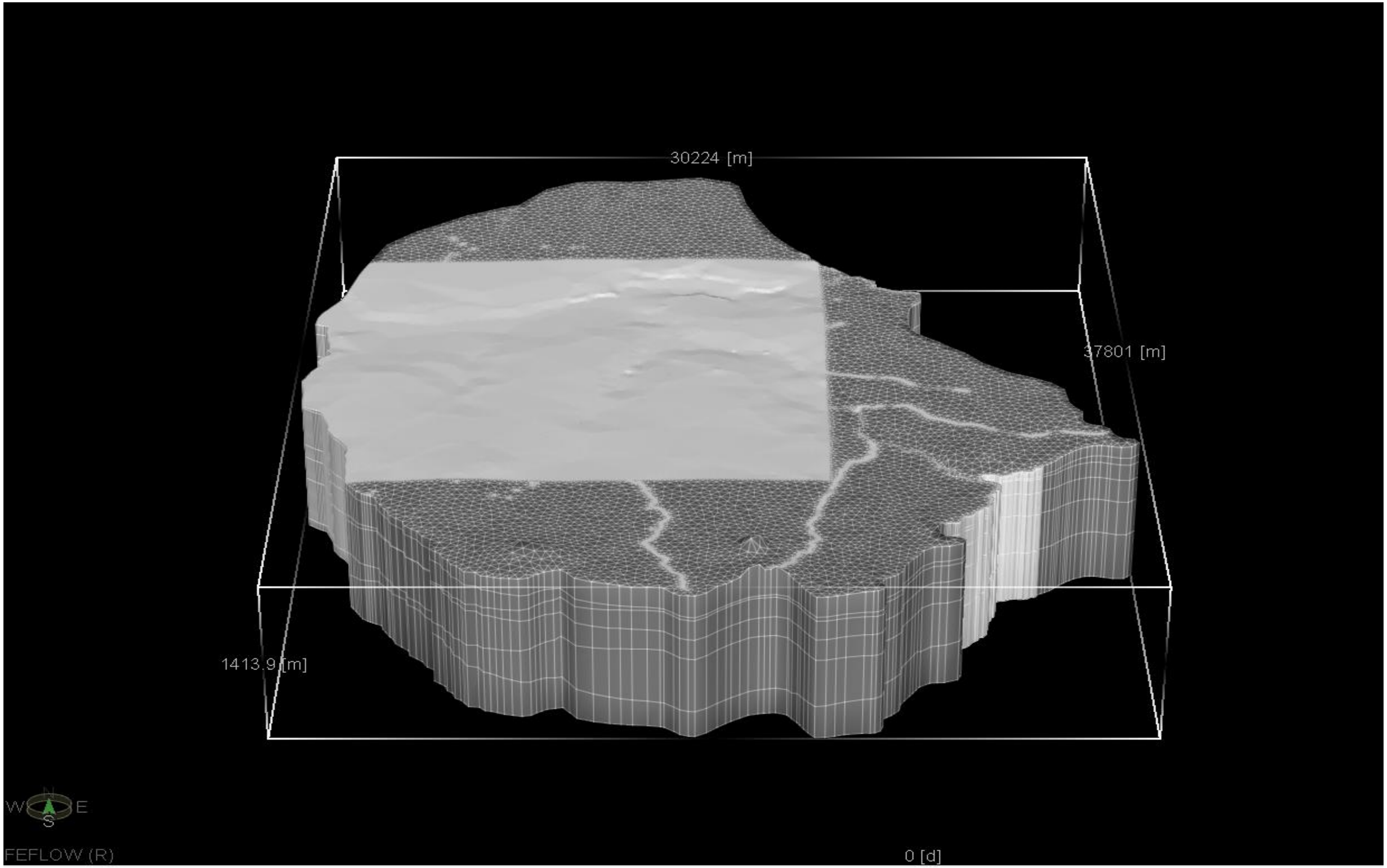


Figure 15-5 **Model domain 3-D FEM mesh depicting a plan view and cross sectional view in a south-north orientation.**

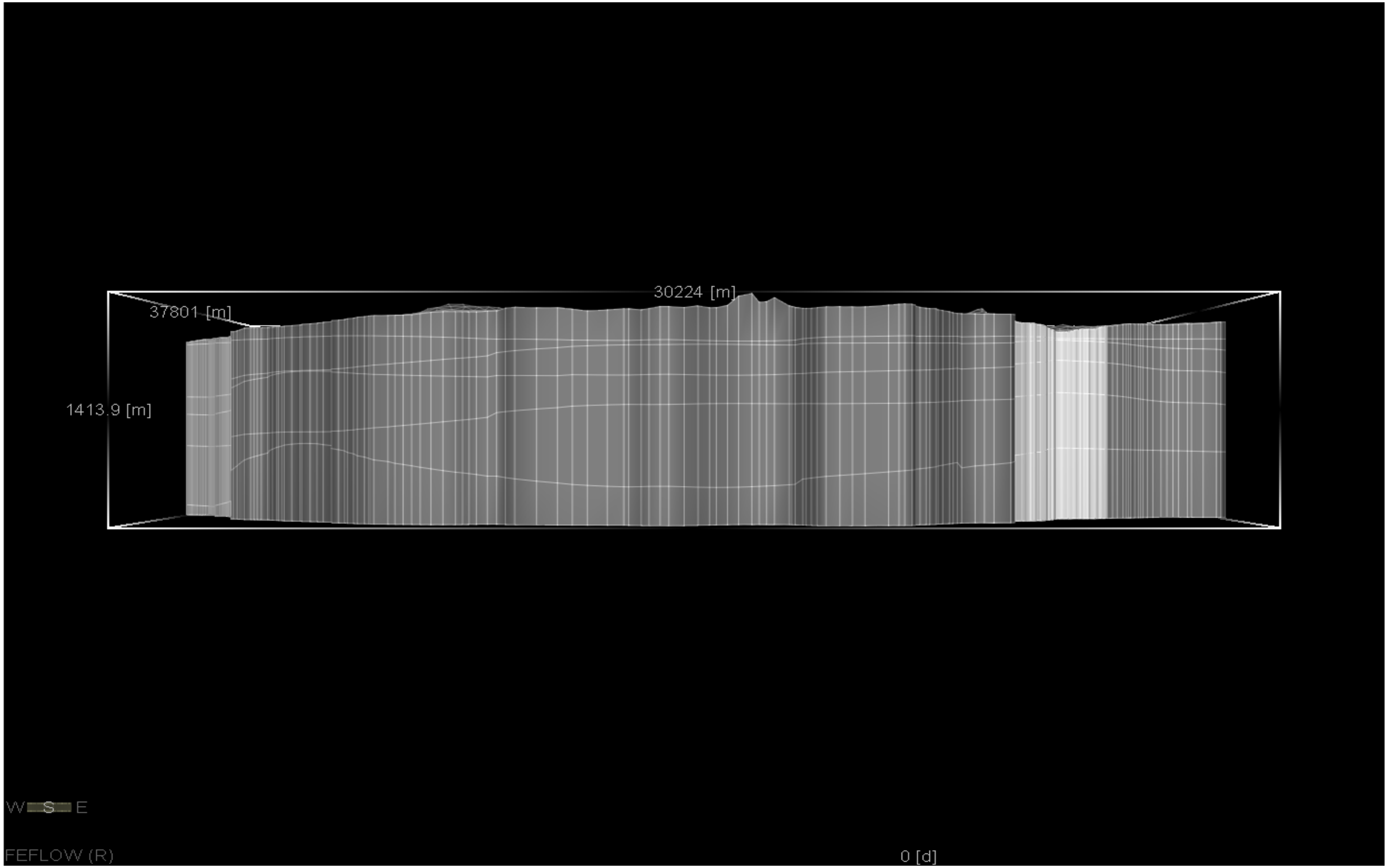


Figure 15-6 **Model domain 3-D FEM mesh view depicting a cross sectinal view in a south-north orientation.**

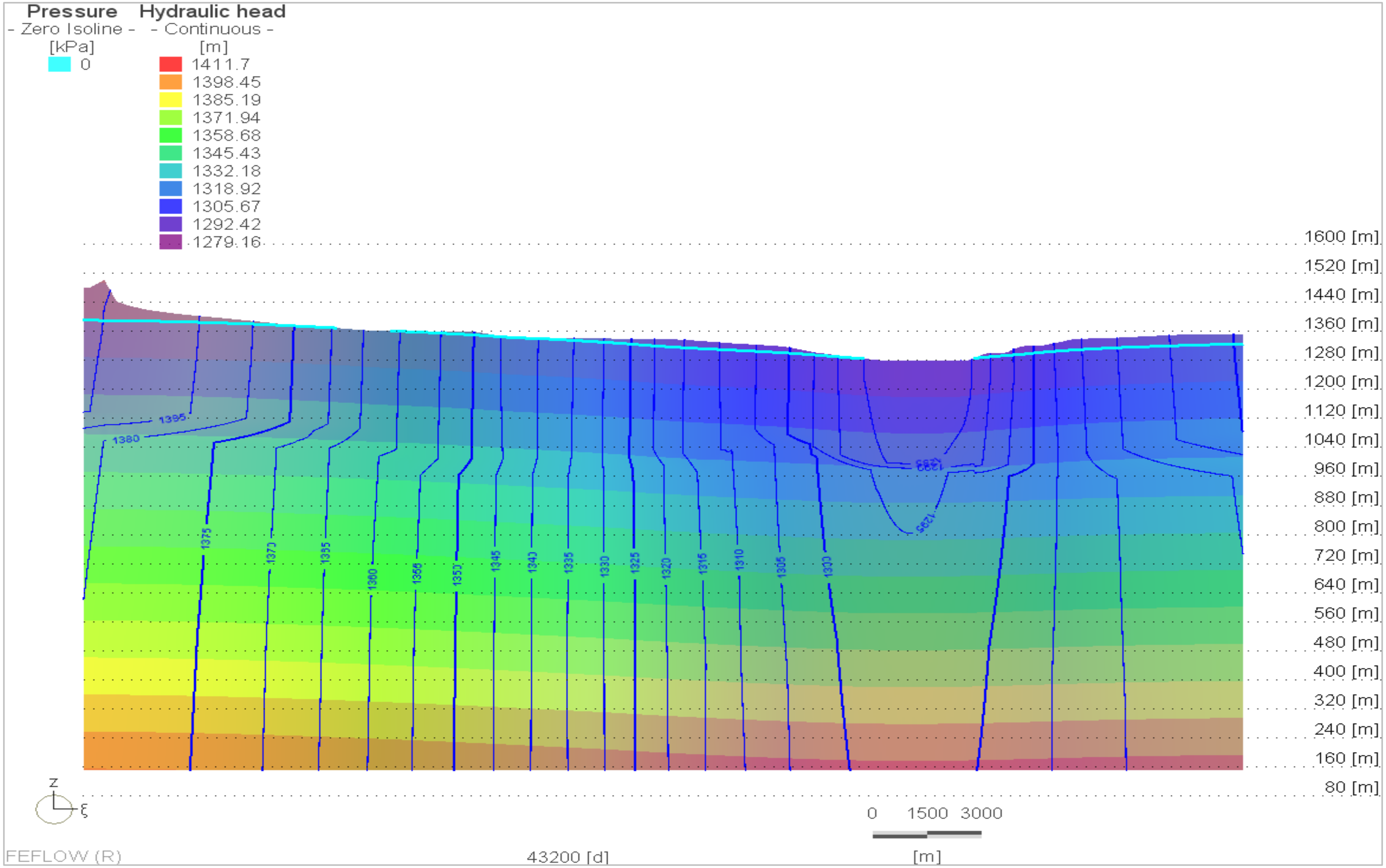


Figure 15-7 **Model domain 3-D FEM mesh view (cross sectional view southwest-northeast orientation of conceptual slice A-A').**

15.3.4. 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 as well as Doringrivier were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[13]. Figure 15-12 indicates different boundary conditions assigned within the model domain.

15.4. 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[14] as depicted in Figure 15-13. Table 15-1 provides a summary of aquifer hydraulic parameter values per layer.

15.4.1. Hydraulic Conductivity

The average hydraulic conductivity (K) value assigned for the shallow, intergranular aquifer is calculated at $2.45E^{-01}$m/d ranging from $5.50E^{-01}$m/d for loose alluvial deposit sediments associated with local drainages, $1.13E^{-01}$m/d for the weathered Beaufort Group formations, $1.50E^{-01}$m/d for the weathered Ecca Group formations, $3.50E^{-02}$m/d for the more competent Karoo dolerite formations to $3.75E^{-01}$m/d for the more permeable geological lineaments[15] traversing the study area. The average hydraulic conductivity for the deeper, fractured aquifer is calculated at $5.60E^{-02}$m/d. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in Figure 15-8. 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.

15.4.2. Sources and sinks

The primary source to groundwater is through recharge. An approximation of recharge for the model domain is estimated at between ~6.5.0mm/a assigned for denser Karoo dolerite formations, ~10.0mm/a assigned for Beaufort Group formations, ~15.0mm/a assigned for Ecca Group formations and 35.0mm/a assigned for loose alluvial deposit sediments associated with local drainages as indicated in Figure 15-9 below. Major

[13] Refer to "gaining stream" assumption.

[14] 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.

[15] 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.

sinks from the model domain include groundwater abstraction from privately owned and community boreholes[16] as well as groundwater discharge to baseflow. Also refer to Section 6.3.4 of this report.

15.4.3. Storativity and specific storage

Specific storage values were assigned per hydrostratigraphical units and ranges between $1.00E^{-04}$ for denser Karoo dolerite formations to $1.00E^{-01}$ for loose alluvial deposit sediments associated with local drainages as indicated in Figure 15-10 below.

15.4.4. Porosity

A porosity value ranging from 10.0% (loose alluvial deposits), 2.0-3.0% (Weathered Beaufort Group and Ecca Group aquifer) to 0.10% (denser Karoo matrix of the deeper aquifer) was assigned per model layer as shown in Figure 15-11 below.

15.4.5. 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.

15.4.6. Longitudinal and Transversal Dispersivities

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15.4.7. 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 15-2 Diffusion coefficient.

$$D_{\text{eff}} = \theta \cdot \tau \cdot D_{\text{free}}$$

where:

θ = porosity

τ = tortuosity (≤ 1)

D_free = free-water diffusion coefficient

[16] The volume of groundwater abstraction from boreholes is based on data recorded during the hydrocensus as well an assumption for the entire model catchment.

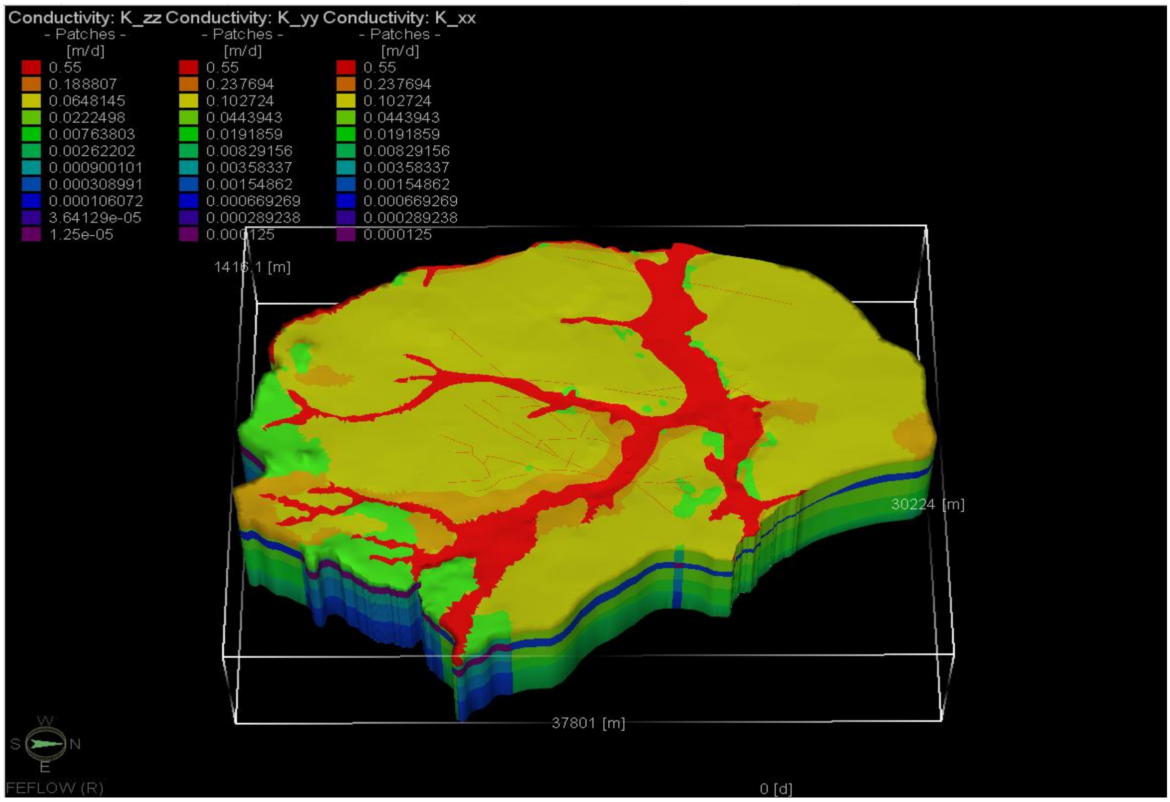


Figure 15-8 **Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.**

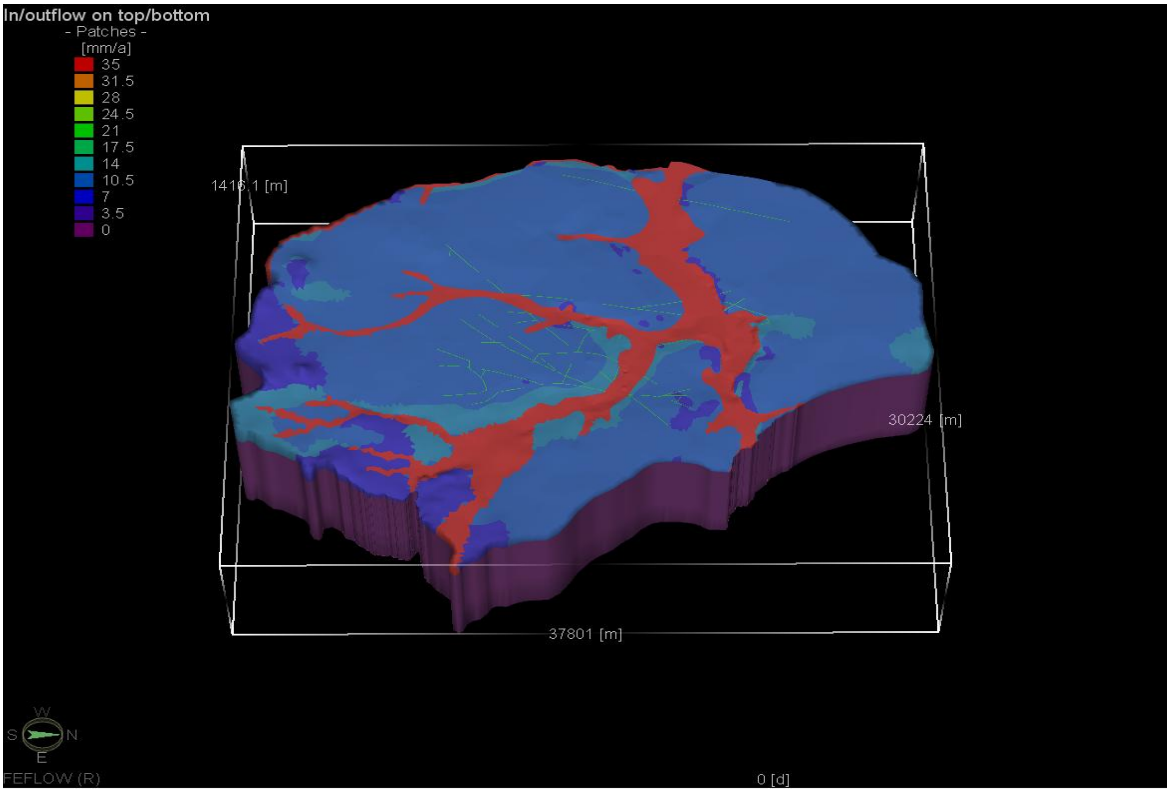


Figure 15-9 **Model development: Numerical groundwater flow model: Recharge distribution.**

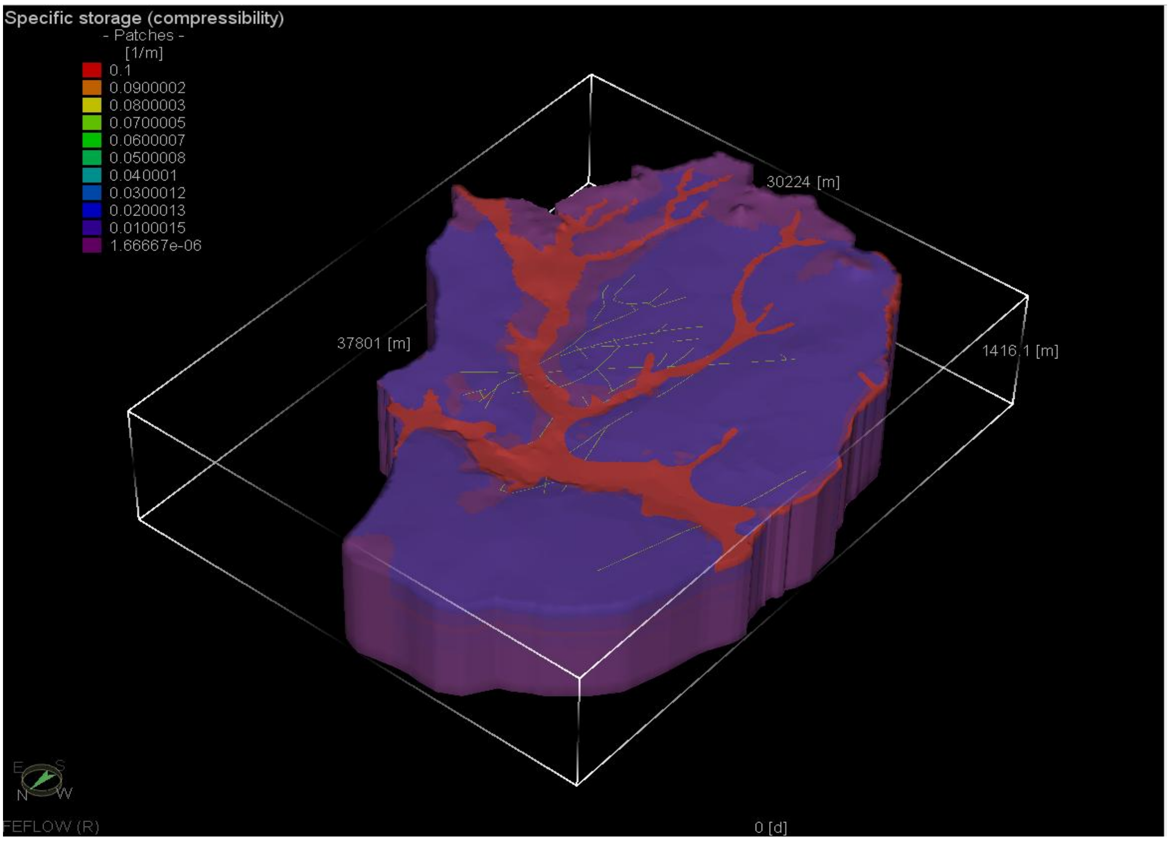


Figure 15-10 **Model development: Numerical groundwater flow model: Specific storage distribution.**

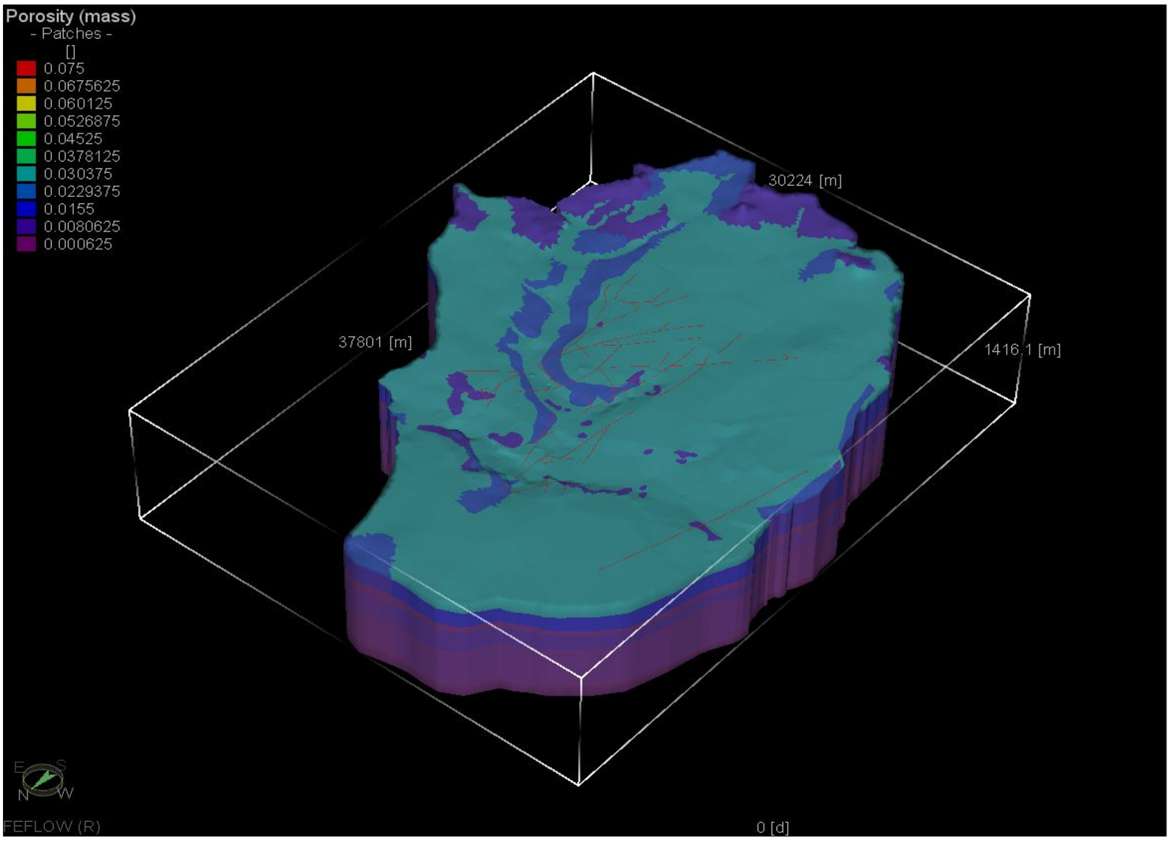


Figure 15-11 **Model development: Numerical groundwater flow model: Porosity distribution.**

Table 15-1 Model set-up: Hydraulic Parameters.

Model Layer	Hydrostratigraphic unit	Approximate layer thickness (m)	Hydraulic Conductivity (K) Kx,y 1:1 (m/d)	Hydraulic Conductivity (K) Kz 1:10 (m/d)**	Recharge (Re) In/Outflow on top/bottom (mm/a)	Specific storage (Sc) Sc (1/m)	Porosity (n)
Layer 01	Alluvial deposits	20.00	5.50E-01	5.50E-01	35.0	1.00E-01	1.00E-01
	Volksrust Fm, Ecca Grp		1.50E-01	1.50E-02	15.0	1.00E-02	3.00E-02
	Adelaide Sbgrp, Beaufort Grp		1.13E-01	1.13E-02	10.0	1.00E-03	2.00E-02
	Karoo Dolerite Suite		3.50E-02	3.50E-03	6.5	1.00E-04	6.25E-04
	Geological lineaments		3.75E-01	3.75E-02	17.5	7.50E-02	7.50E-02
Layer 02	Volksrust Fm, Ecca Grp	250.00	7.50E-02	7.50E-03	0.0	5.00E-03	1.50E-02
	Adelaide Sbgrp, Beaufort Grp		5.63E-02	5.63E-03		5.00E-04	1.00E-02
	Karoo Dolerite Suite		1.75E-02	1.75E-03		5.00E-05	3.13E-04
	Geological lineaments		1.88E-01	1.88E-02		3.75E-02	3.75E-02
Layer 03	Karoo Dolerite Suite (Sill)	30.00	1.13E-03	1.13E-04	0.0	1.50E-04	3.00E-03
Layer 04	Volksrust Fm, Ecca Grp	200.00	5.00E-02	5.00E-03	0.0	2.50E-03	7.50E-03
	Adelaide Sbgrp, Beaufort Grp		3.75E-02	3.75E-03		2.50E-04	5.00E-03
	Karoo Dolerite Suite		1.17E-02	1.17E-03		2.50E-05	1.56E-04
	Geological lineaments		1.25E-01	1.25E-02		1.88E-02	1.88E-02
Layer 05	Ventersdorp Supergroup Lava	500.00	2.50E-02	2.50E-03	0.0	1.25E-04	2.50E-03
Layer 06	Witwatersrand Supergroup Quartzite	300.00	1.25E-02	1.25E-03	0.0	6.25E-05	1.25E-03

****Notes: Anisotropy of the alluvial, riparian zone aquifer was set at a 1:1 ratio**

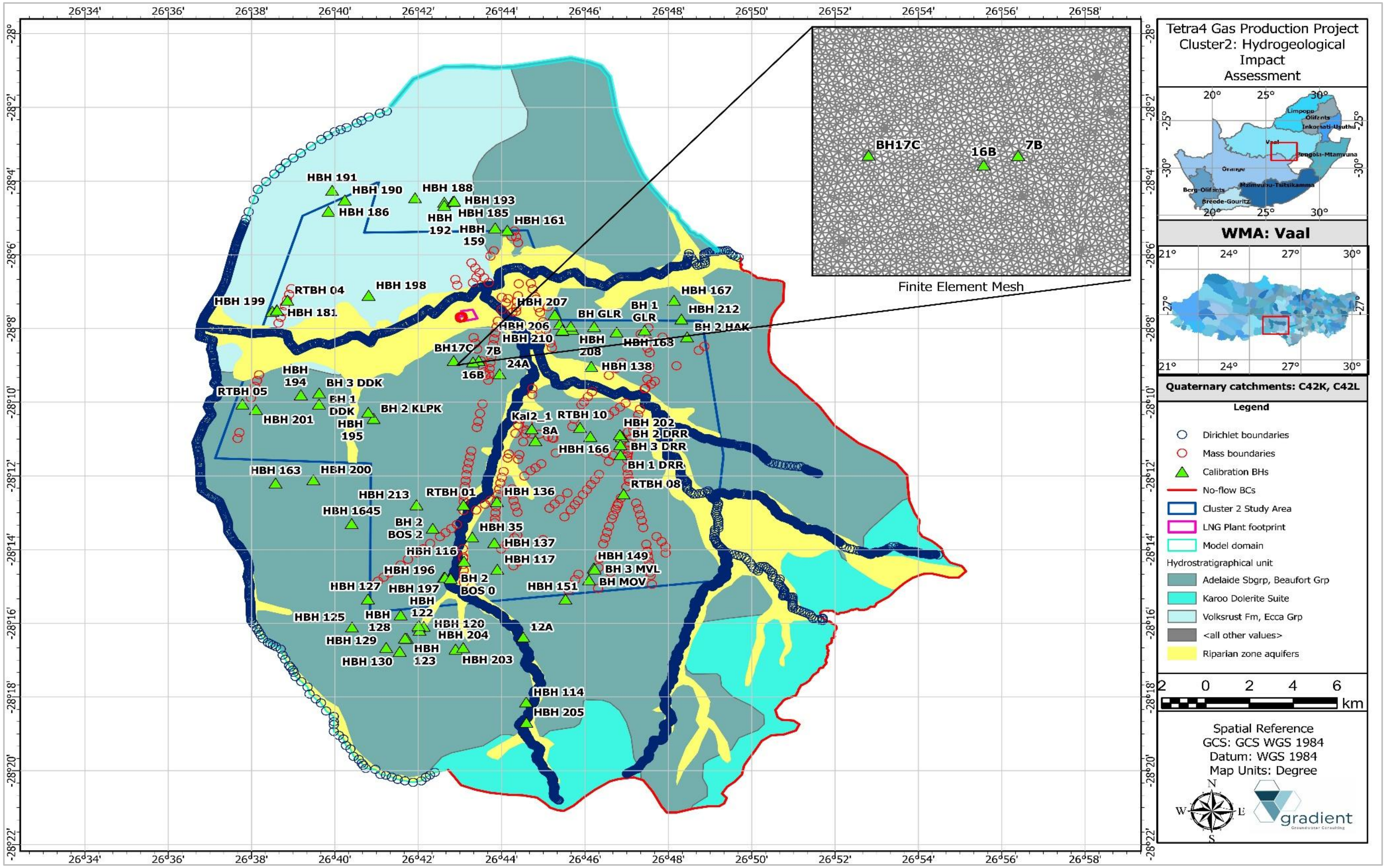


Figure 15-12 **Hydrostratigraphic units and model boundary conditions.**

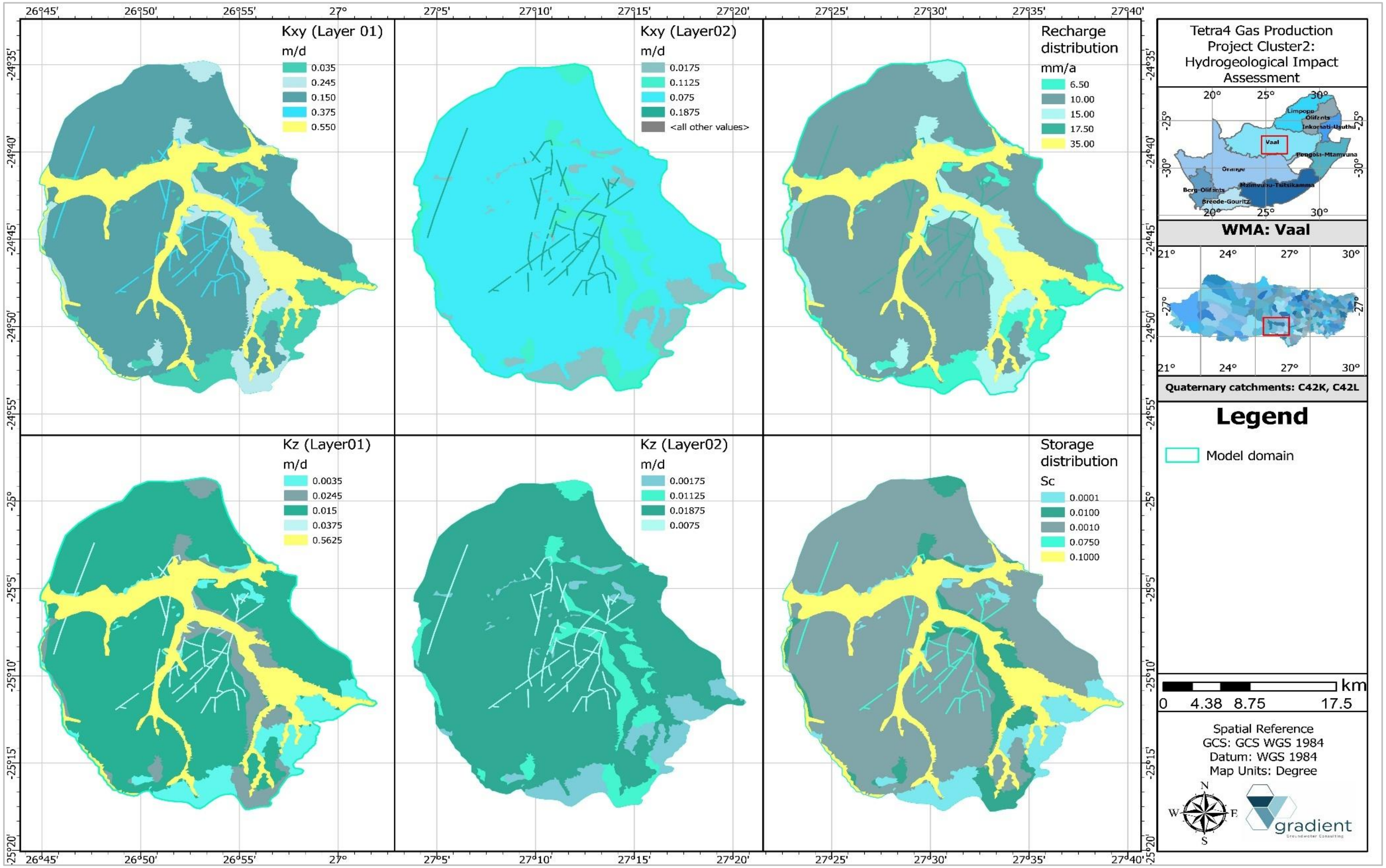


Figure 15-13 **Numerical groundwater flow model: Hydraulic properties.**

15.5. Model calibration

15.5.1. 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 15-2. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.96 was obtained (refer to Figure 15-14, Figure 15-15 and Figure 15-16) while Figure 15-17 indicate calibration error margin per borehole observation locality.

Figure 15-18 and Figure 15-19 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): 3.94m.

ii. Mean Absolute Error (MAE): 7.69m.

iii. Normalised Root Mean Square Deviation (NRMSD): 8.15% i.e., represents the deviation between observed and calibration water levels across the model domain.

Table 15-2 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)
HBH 161	1320.07	2.20	1317.87	1301.44	16.43	16.43	270.07
HBH 159	1326.36	8.04	1318.32	1303.33	15.00	15.00	224.92
HBH 190	1315.61	3.36	1312.25	1310.46	1.80	1.80	3.24
HBH 191	1313.35	4.11	1309.24	1310.76	-1.52	1.52	2.31
HBH 186	1314.19	6.20	1307.99	1308.76	-0.77	0.77	0.59
HBH 188	1328.55	3.69	1324.86	1312.35	12.51	12.51	156.48
HBH 192	1337.04	6.19	1330.85	1311.09	19.76	19.76	390.62
HBH 185	1340.00	8.10	1331.90	1311.70	20.20	20.20	408.14
HBH 193	1340.00	8.61	1331.39	1311.73	19.66	19.66	386.55
HBH 199	1303.75	6.44	1297.31	1289.75	7.55	7.55	57.05
HBH 180	1305.31	10.00	1295.31	1290.08	5.23	5.23	27.37
HBH 181	1305.24	10.78	1294.46	1290.02	4.44	4.44	19.73
HBH 194	1301.79	11.74	1290.05	1303.68	-13.63	13.63	185.65
BH 2 KLPK	1318.92	5.51	1313.41	1319.60	-6.19	6.19	38.26
HBH 195	1312.24	3.86	1308.38	1317.37	-8.99	8.99	80.79
HBH 196	1360.68	13.15	1347.53	1360.32	-12.79	12.79	163.69
HBH 197	1360.40	14.15	1346.25	1360.31	-14.05	14.05	197.54
BH 2 BOS 0	1360.00	11.73	1348.27	1360.04	-11.77	11.77	138.60
BH 2 BOS 2	1361.19	5.22	1355.97	1349.36	6.61	6.61	43.67
HBH 137	1360.07	0.00	1360.07	1352.63	7.44	7.44	55.33
HBH 136	1342.58	7.19	1335.39	1338.93	-3.54	3.54	12.55
BH MOV	1376.42	6.78	1369.64	1363.81	5.83	5.83	34.02
HBH 149	1372.93	3.08	1369.85	1360.53	9.33	9.33	86.97
BH 3 MVL	1373.20	6.78	1366.42	1360.78	5.65	5.65	31.88
HBH 198	1307.48	19.40	1288.08	1294.17	-6.09	6.09	37.08
HBH 163	1346.62	12.21	1334.41	1334.33	0.08	0.08	0.01
HBH 200	1345.18	4.34	1340.84	1336.21	4.63	4.63	21.45
HBH 1645	1362.89	6.84	1356.05	1349.49	6.57	6.57	43.13
HBH 201	1312.87	8.96	1303.91	1306.99	-3.08	3.08	9.46
HBH 166	1342.11	4.41	1337.70	1318.74	18.96	18.96	359.32
BH 2 DDR	1329.49	4.53	1324.96	1317.07	7.89	7.89	62.28
BH 2 DRR	1329.47	5.39	1324.08	1317.12	6.97	6.97	48.53
BH 3 DRR	1334.02	5.01	1329.01	1320.09	8.91	8.91	79.44
BH 1 DRR	1339.76	5.52	1334.24	1323.69	10.55	10.55	111.27
HBH 202	1329.76	8.20	1321.56	1316.65	4.91	4.91	24.16
HBH 203	1385.45	13.31	1372.14	1379.53	-7.39	7.39	54.58
HBH 204	1385.57	18.13	1367.44	1379.23	-11.79	11.79	139.05
HBH 205	1413.65	8.41	1405.24	1396.02	9.22	9.22	85.06
HBH 114	1402.83	0.00	1402.83	1392.81	10.01	10.01	100.28
HBH 123	1380.32	5.15	1375.17	1375.72	-0.56	0.56	0.31
HBH 124	1380.11	4.69	1375.42	1375.59	-0.17	0.17	0.03
HBH 130	1387.81	4.60	1383.21	1378.17	5.04	5.04	25.44
HBH 129	1390.03	5.89	1384.14	1376.87	7.27	7.27	52.79
HBH 128	1383.07	5.56	1377.51	1370.59	6.92	6.92	47.93
HBH 127	1399.84	5.50	1394.34	1366.69	27.65	27.65	764.62
HBH 119	1379.76	7.34	1372.42	1373.31	-0.89	0.89	0.79
HBH 120	1379.05	5.14	1373.91	1373.17	0.74	0.74	0.55
HBH 118	1379.96	13.85	1366.11	1373.93	-7.82	7.82	61.16
HBH 122	1379.75	5.37	1374.38	1373.09	1.29	1.29	1.66
HBH 116	1360.00	6.06	1353.94	1356.87	-2.93	2.93	8.57
HBH 117	1365.56	4.70	1360.86	1360.32	0.54	0.54	0.29
HBH 151	1380.00	3.21	1376.79	1369.31	7.47	7.47	55.84
BH GLR 734	1314.28	6.98	1307.30	1299.77	7.53	7.53	56.72
BH 1 GLR 734	1320.63	11.58	1309.05	1304.93	4.12	4.12	17.01

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)
HBH 168	1318.19	6.55	1311.64	1302.89	8.76	8.76	76.68
HBH 206	1313.91	4.95	1308.96	1293.98	14.98	14.98	224.38
HBH 207	1308.09	15.20	1292.89	1290.85	2.04	2.04	4.17
HBH 208	1318.94	25.20	1293.74	1297.29	-3.55	3.55	12.60
HBH 209	1317.23	14.93	1302.30	1296.61	5.68	5.68	32.29
HBH 210	1316.30	11.65	1304.65	1295.60	9.04	9.04	81.79
HBH 211	1316.46	15.89	1300.57	1295.53	5.04	5.04	25.39
HBH 212	1328.07	15.87	1312.20	1309.70	2.51	2.51	6.28
BH 2 HAK	1340.00	9.46	1330.54	1313.53	17.01	17.01	289.27
HBH 138	1313.54	6.45	1307.09	1301.59	5.50	5.50	30.23
HBH 167	1311.02	8.86	1302.16	1306.04	-3.88	3.88	15.05
HBH 213	1359.10	24.33	1334.77	1344.13	-9.36	9.36	87.61
12A	1380.97	3.87	1377.10	1379.02	-1.92	1.92	3.69
BH17C	1309.35	9.54	1299.81	1298.57	1.24	1.24	1.54
7B	1313.74	9.89	1303.85	1298.76	5.09	5.09	25.92
Kal2_1	1324.49	12.24	1312.25	1313.06	-0.81	0.81	0.65
16B	1316.16	12.12	1304.04	1299.35	4.70	4.70	22.06
24A	1317.56	5.71	1311.85	1301.90	9.95	9.95	99.03
8A	1332.75	7.70	1325.05	1318.20	6.85	6.85	46.92
RTBH 01	1341.13	8.57	1332.56	1340.21	-7.66	7.66	58.63
RTBH 04	1309.66	7.00	1302.66	1292.10	10.56	10.56	111.47
RTBH 05	1307.45	8.93	1298.52	1303.54	-5.02	5.02	25.24
RTBH 08	1350.17	4.29	1345.88	1337.41	8.47	8.47	71.74
RTBH 10	1342.94	5.52	1337.42	1315.79	21.63	21.63	467.77
Average	**1342.37**	**8.23**	**1334.14**	**1330.19**	**3.94**	**7.69**	**91.09**
Minimum	**1301.79**	**0.00**	**1288.08**	**1289.75**	**-14.05**	**0.08**	**0.01**
Maximum	**1413.65**	**25.20**	**1405.24**	**1396.02**	**27.65**	**27.65**	**764.62**
Correlation			**0.96**				
∑					**307.61**	**599.93**	**7105.22**
1/n					**3.94**	**7.69**	**91.09**
Root Mean Square Deviation (RMSD)					**1.99**	**2.77**	**9.54**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**8.15**

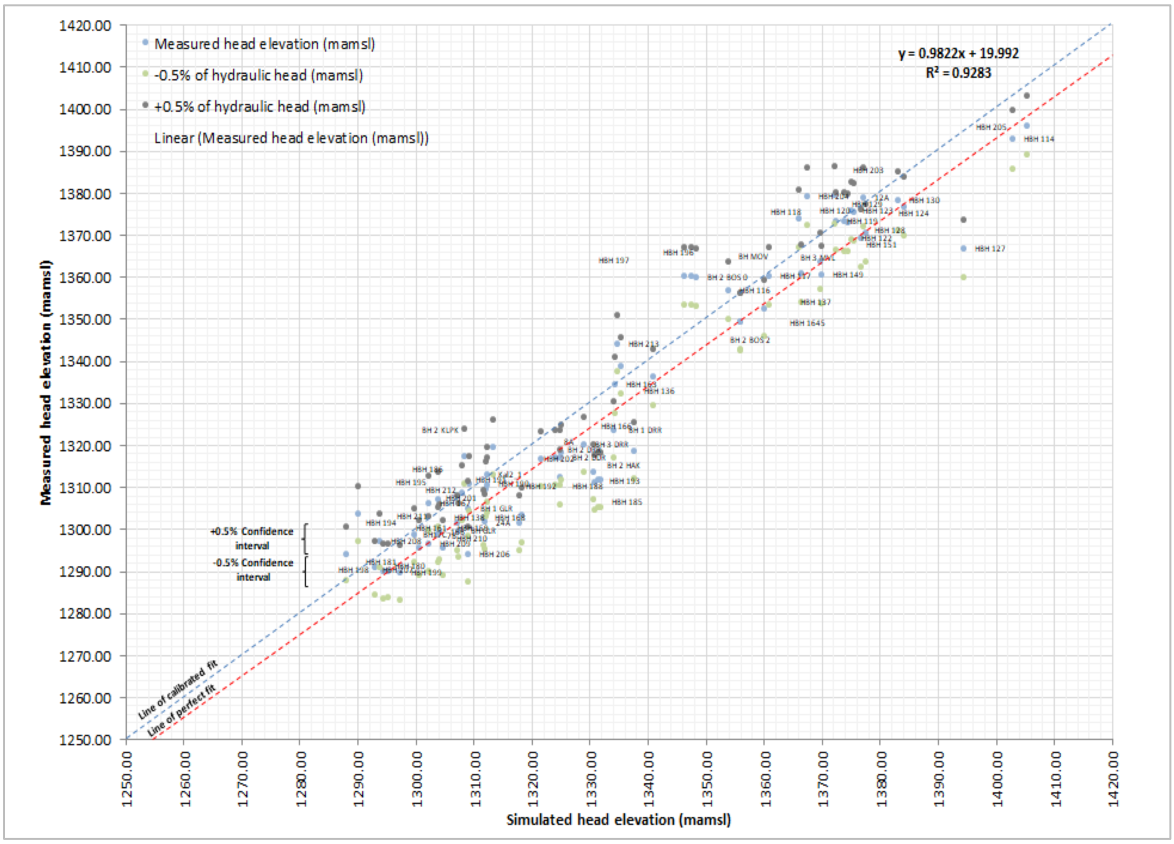


Figure 15-14 **Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.**

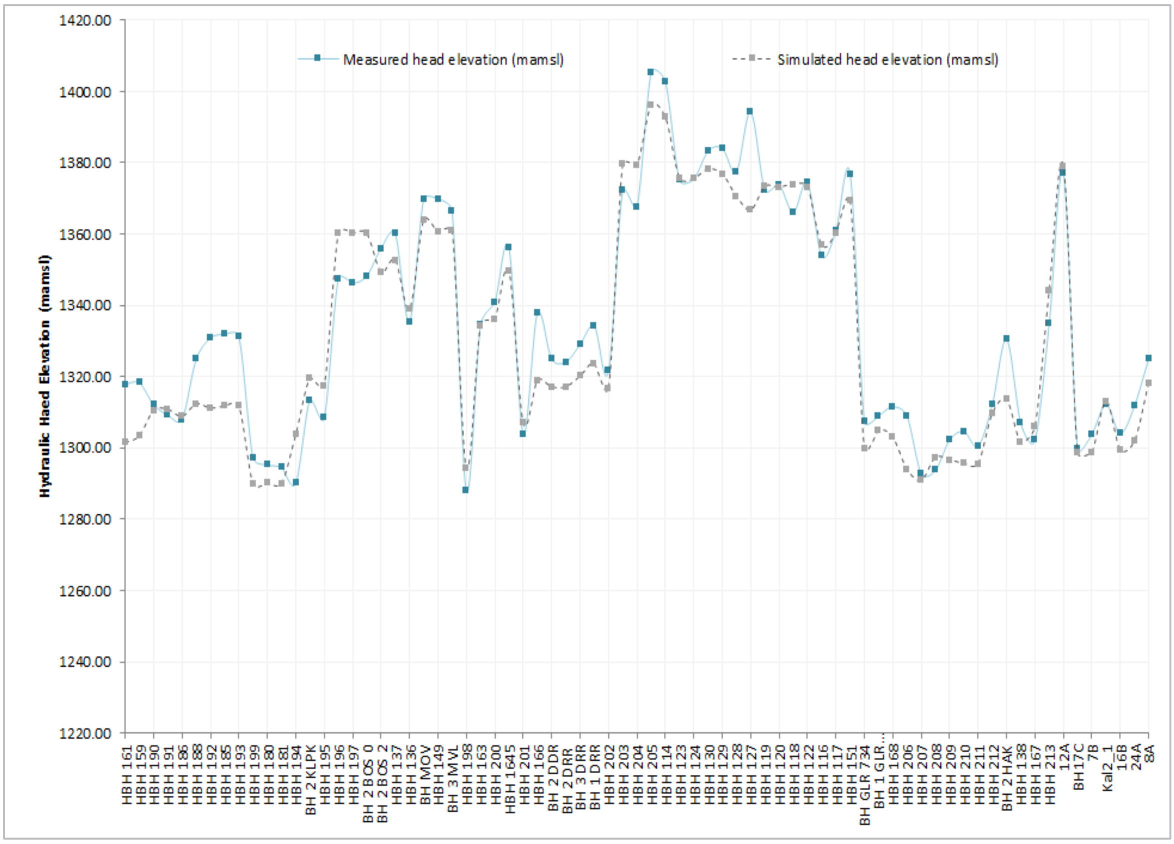


Figure 15-15 **Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.**

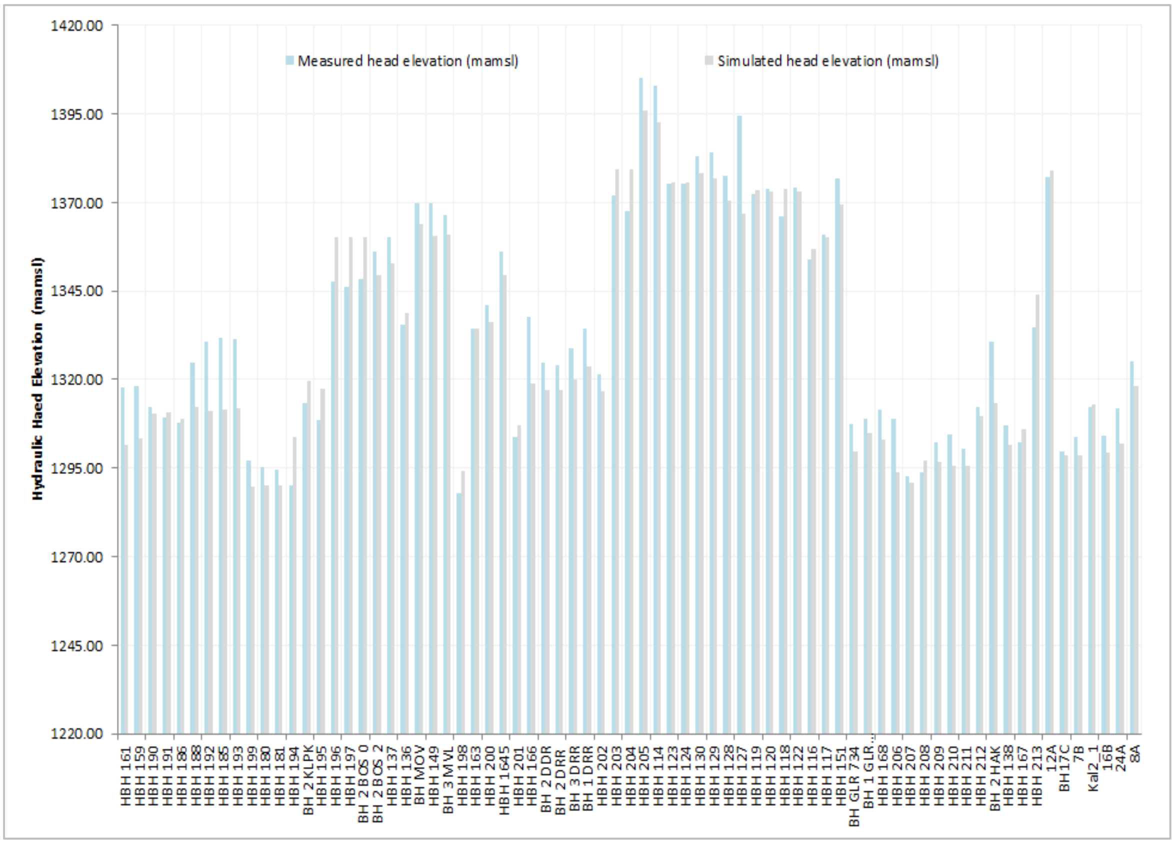


Figure 15-16 **Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.**

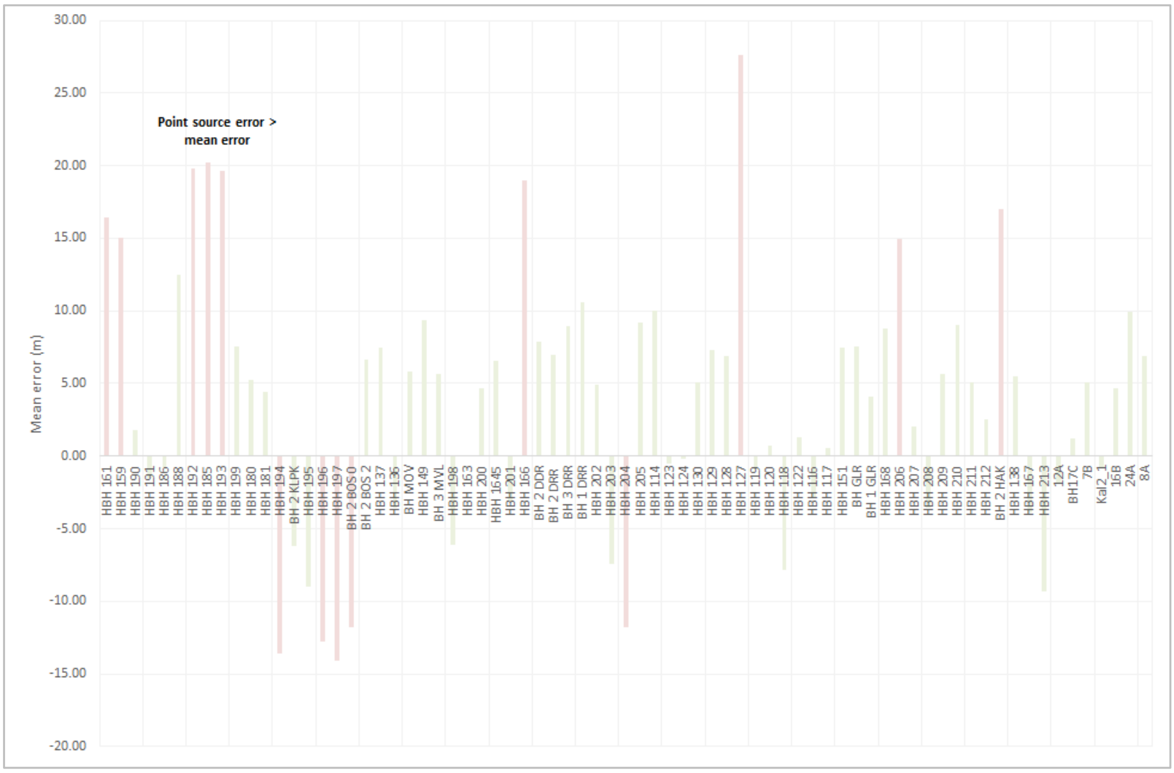


Figure 15-17 **Model steady state calibration: Bar-chart of simulated vs. measured hydraulic head elevation.**

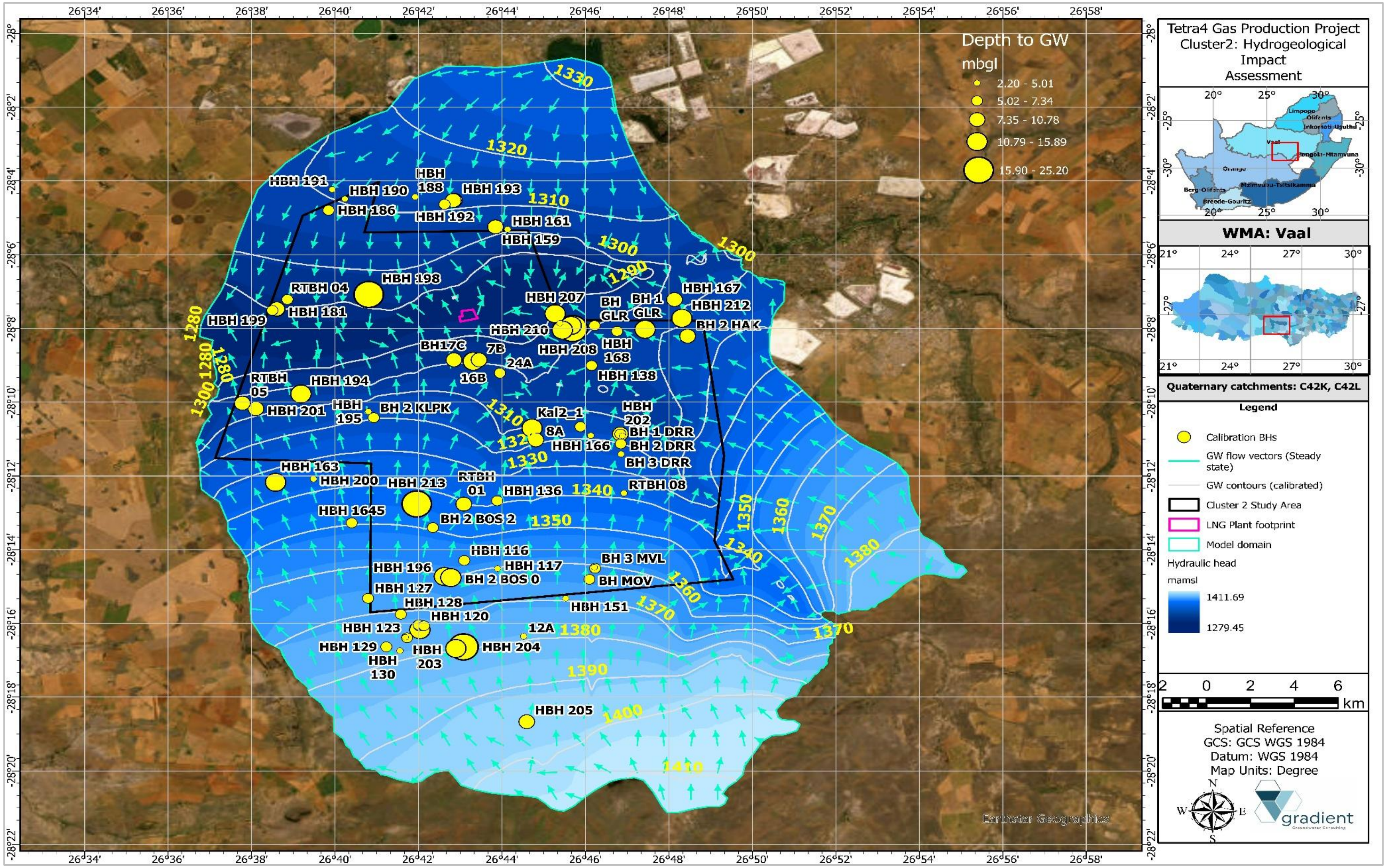


Figure 15-18 Model calibration: steady state hydraulic heads and groundwater flow direction.

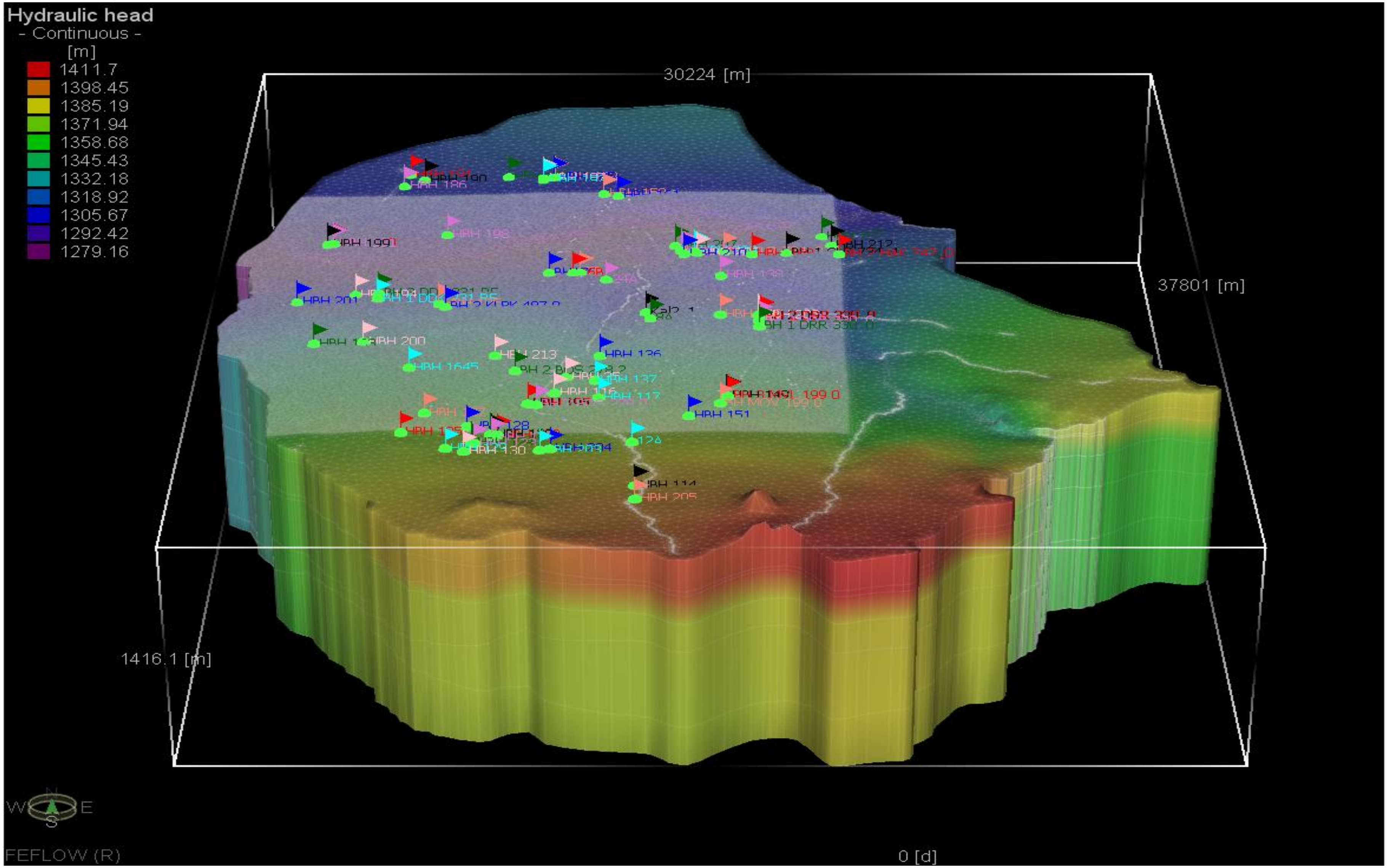


Figure 15-19 **Model calibration: steady state hydraulic head distribution.**

15.5.2. Transient state calibration

The calibrated steady state groundwater flow model was refined and adjusted to simulate and reflect current on-site conditions. Under transient conditions, the groundwater flow equation is modified to include storativity. Groundwater drawdown of recently performed constant discharge pump tests were simulated by varying aquifer storativity values until an acceptable fit between the measured and simulated hydraulic heads were obtained. Refer to Figure 15-20 (R^2 = 0.99) and Figure 15-21 (R^2 = 0.98)) for time-series curves of simulated vs measured hydraulic head elevation of on-site monitoring boreholes.

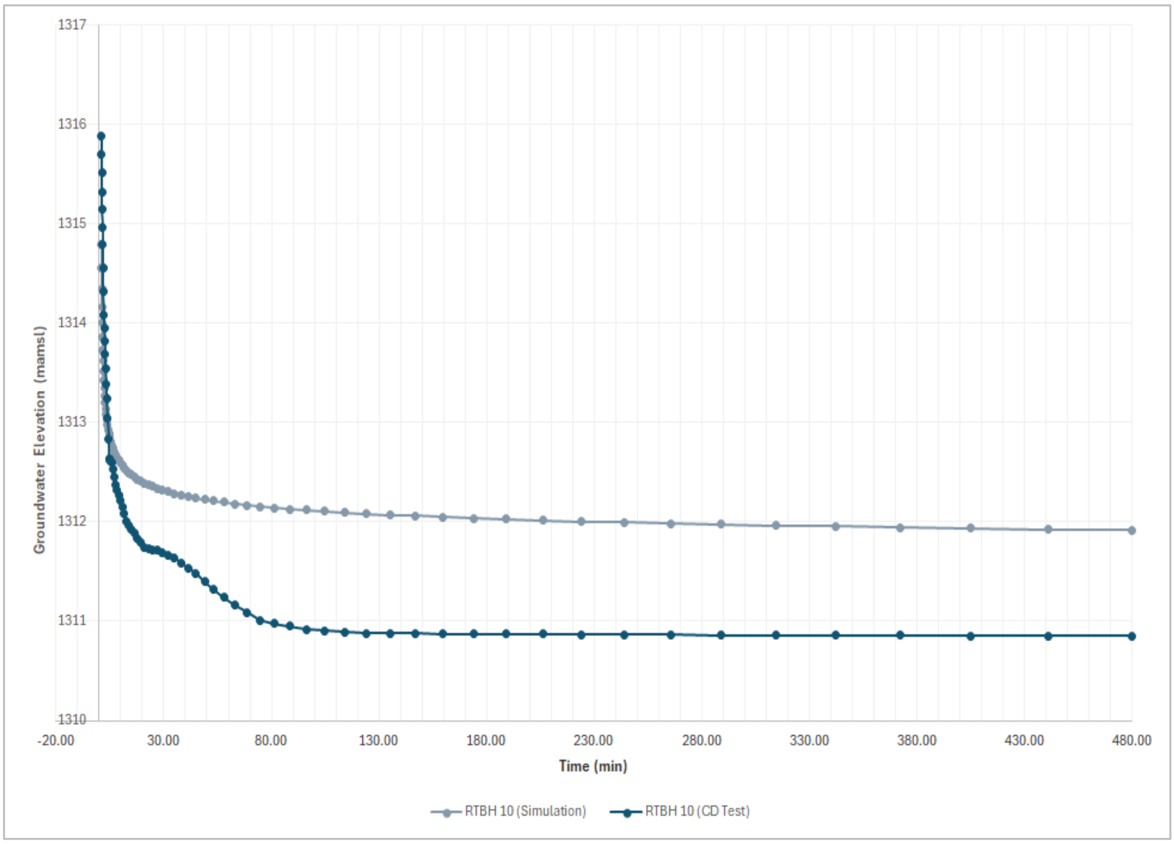


Figure 15-20 **Model transient state calibration: Simulated CD pump test on borehole RTBH10.**

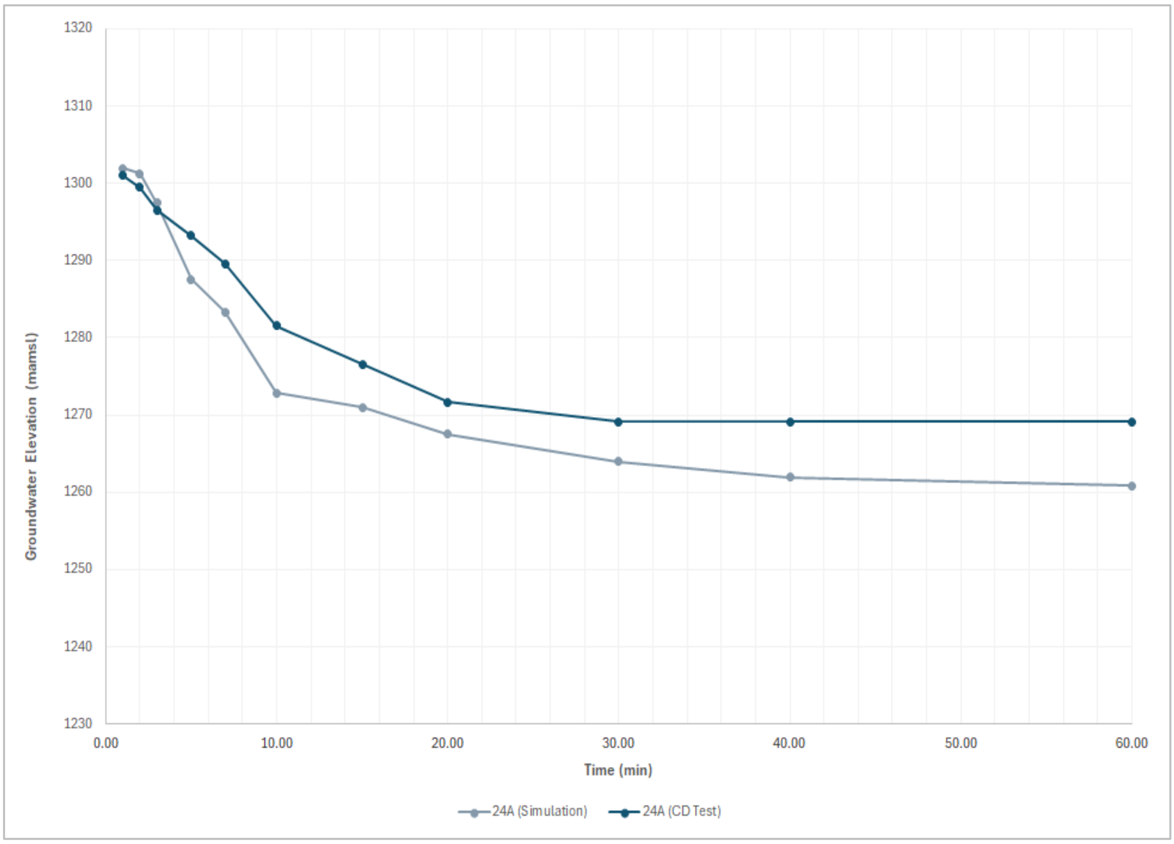


Figure 15-21 **Model transient state calibration: Simulated CD pump test on monitoring boreole 24A.**

15.5.3. 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 15-2 it is noted that the model tends to be more sensitive to a downward variation in recharge and an increase in hydraulic conductivity (Figure 15-22, Figure 15-23 and Figure 15-24)[17]. Porosity is an intrinsic value of seepage velocity and hence contamination migration. In order to verify the sensitivity of the calibrated model in terms of the porosity, the latter was adjusted while the impact on the pollution plume migration at relevant on-site borehole were evaluated as shown in Figure 15-25 . It is noted that the model tends to be sensitive to a variation in porosity ratios assigned and, as such, it is recommended that bulk mass density tests be performed on all newly acquired rock samples in order to verify the effective porosity to be incorporated in the pollution plume migration model update.

[17]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.

Table 15-3 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	0.96	0.96	0.95	0.95	0.97
Mean Error	3.94	-5.54	17.15	16.47	-5.54
Mean Abs Error	7.69	7.64	17.36	16.68	7.75
RMSD	9.54	9.88	20.70	19.89	9.97
NRMSD	8.15%	8.43%	17.67%	16.98%	8.51%

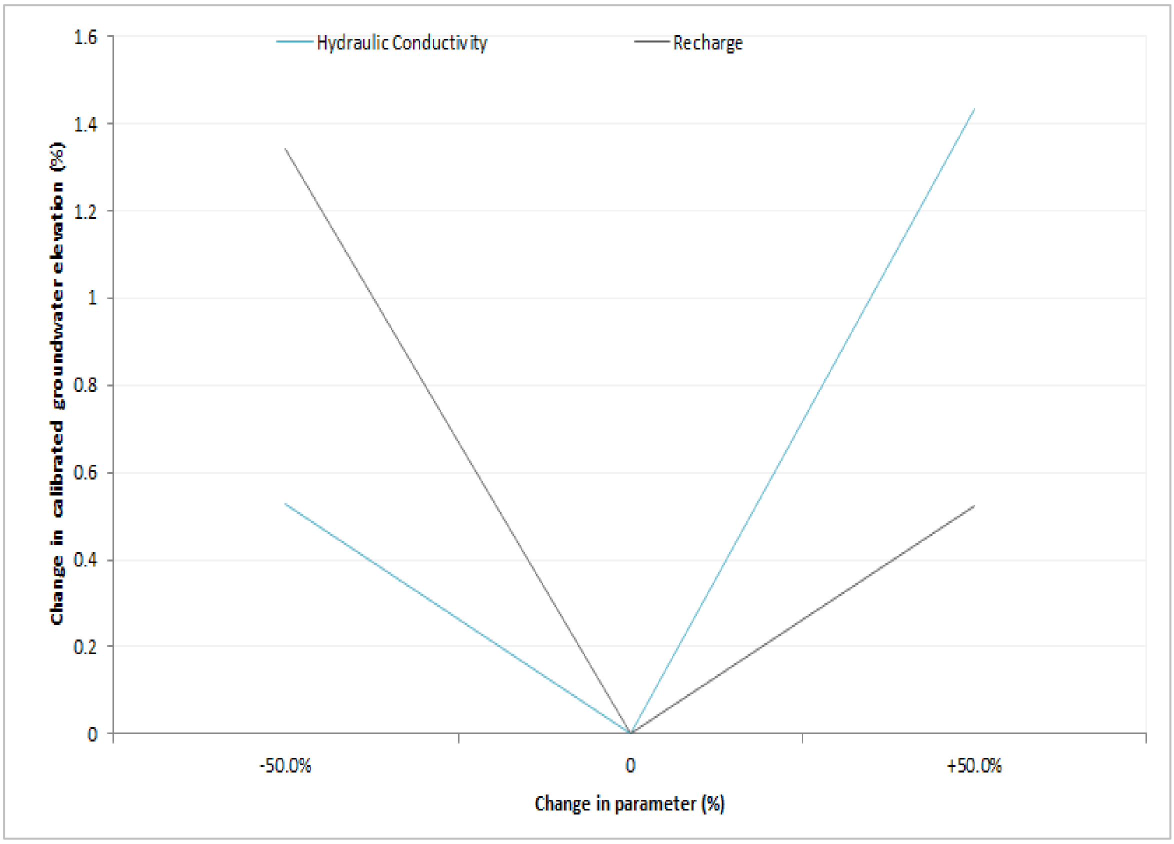


Figure 15-22 Model steady state calibration: sensitivity analysis for monitoring locality HBH117.

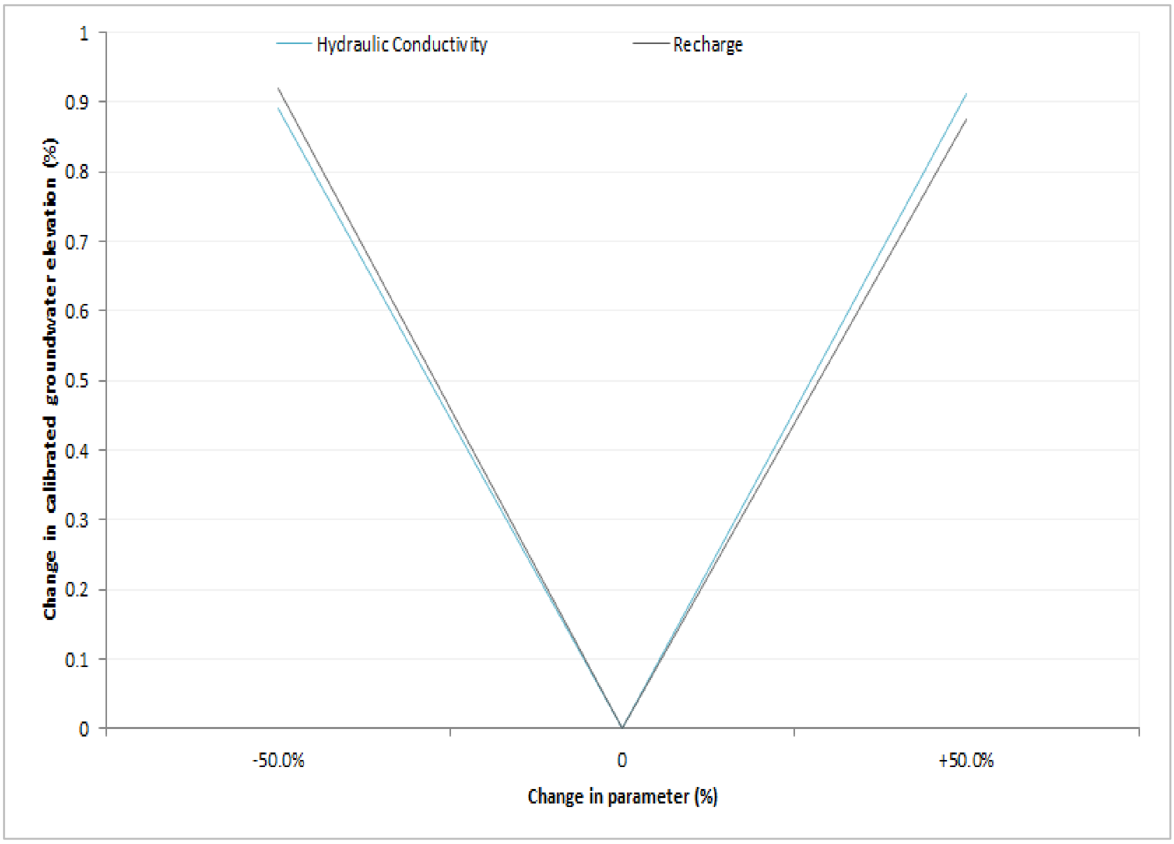


Figure 15-23 Model steady state calibration: sensitivity analysis for monitoring locality HBH191.

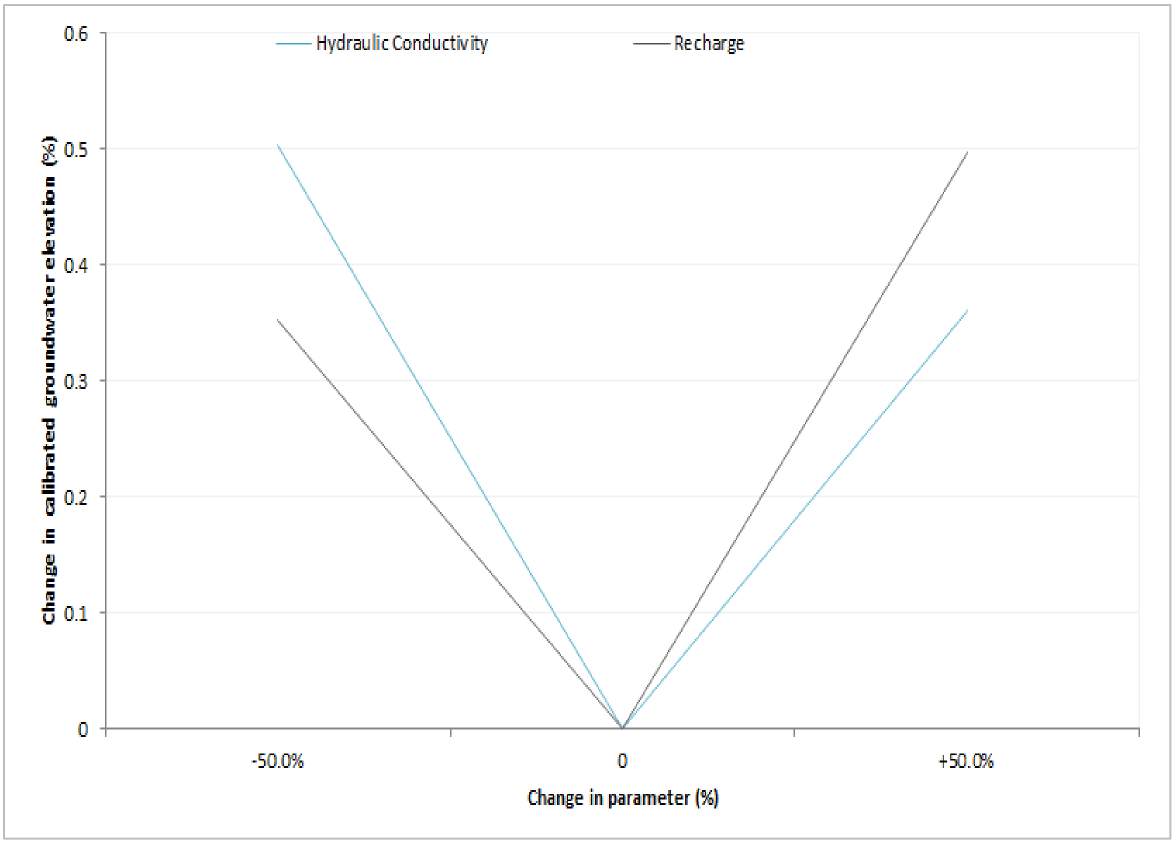


Figure 15-24 Model steady state calibration: sensitivity analysis for monitoring locality 17C.

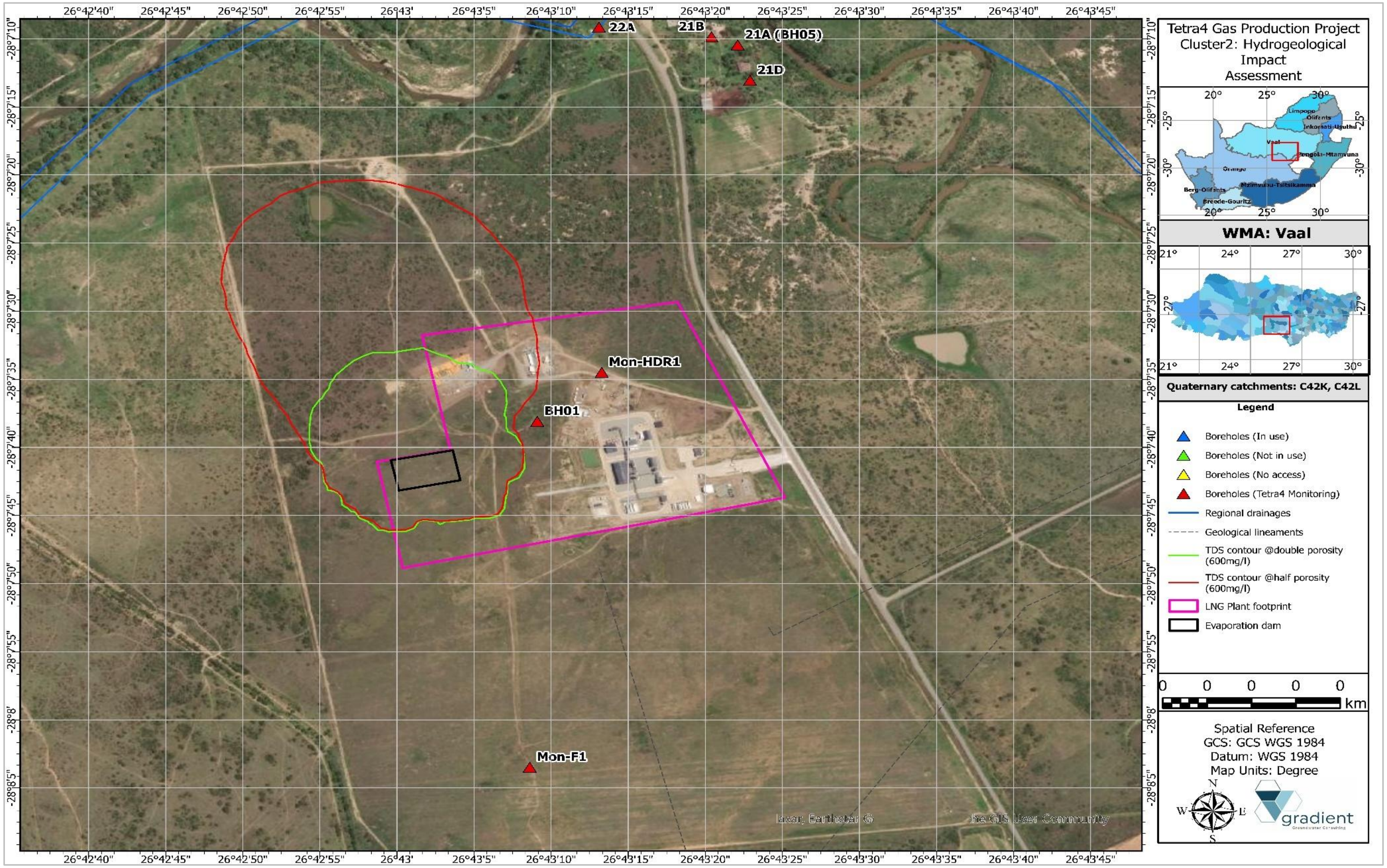


Figure 15-25 **Model steady state calibration: sensitivity analysis for porosity.**

15.6. 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 15-3 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]

15.7. Numerical mass transport model

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

Equation 15-4 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[18];

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.

[18] This investigation and contaminant transport model are based on a “worst-case” scenario and as such, it is assumed that no decay and/or retardation are taking place in the aquifer.

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

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

Various source terms and contaminant proxies were applied as part of the mass transport migration simulations and include saline groundwater emanating from the deep, fractured aquifer from leaking gas production boreholes (TDS = 7 832.0 mg/l - based on hydrochemical analysis of water samples representing this aquifer unit) as well as contaminated water emanating at the plant footprint and evaporation dam(s) (TDS = 7 832.0 mg/l). Pulles et al (2005) indicates that the groundwater associated with the Ventersdorp and Central Rand Group 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 production boreholes. The drilling and operation of gas production wells could result in the migration of stray gas from the deep-seated fracture zones to formations higher up in the geological sequence. This impact has been recorded in the US where hydraulic fracturing, dewatering or a combination of these has occurred (Jackson et al, 2013). It should be stated that Tetra4 does not intend to undertake hydraulic fracturing or any well stimulation and the existing dataset suggests that no dewatering of produced water 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 production zone(s) is separated from the shallow and potable Karoo aquifer by very low permeability shale formations which will act as an aquitard towards any groundwater and stray gas migration. This is however provided that well construction, including cementation and the installation of steel casing, is sound. As such, the impact assessment evaluated represents a worst-case scenario and simulates the eventual occurrence once stray gas does reach the shallow aquifer. The mechanisms by which stray gas can migrate into the shallower potable Karoo aquifer include (*iLEH*, 2017):

- Leakage of stray gas along poorly sealed gas production wells;
- Gas leakage because of an overpressure event and barrier (casing and cementation) failure; and
- Migration of gas from deep-seated fracture zones along fractures and faults.

As methane gas reaches saturation in water at 28 milligrams per litre (mg/L) at atmospheric pressure (Eltschlager and others, 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 15-4:

i. **Scenario 01:** Steady state water balance (∞).
ii. **Scenario 02a:** Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the operational gas production phase.
iii. **Scenario 02b:** Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the operations gas production phase.
iv. **Scenario 03:** Migration of the TDS pollution plume emanating from the evaporation dam footprint area during the operational gas production phase.
v. **Scenario 04a:** 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 04b:** Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios).
vii. **Scenario 05:** Migration of the TDS pollution plume emanating from the evaporation dam footprint area during the post-closure and decommissioning phase (50-year and 100-year scenarios).
viii. **Scenario 06**: Mitigation and Management – Evaluating the effect of implementation of a liner or barrier system underneath the evaporation dam on the TDS pollution plume migration.
ix. **Scenario 07**: Evaluating the effect of climatic change i.e., wet vs. dry cycle rainfall scenarios on the TDS pollution plume migration.

Table 15-4 Summary of model stress-periods.

Stress period	Description
Year01 – Year20	Gas production WUL operational phase
Year 21 – Year 71	50-years post closure
Year 72 – Year 121	100-years post closure

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

Table 15-5 summarises the groundwater catchment water balance representing baseline steady state conditions. Recharge is assumed the only source of inflow to the system and has been simulated at $2.79E^{+04}m^3/d$, while the largest loss to the groundwater system is via groundwater contribution to baseflow, $2.78E^{+04}m^3/d$. Water captured as storage equates to $3.20E^{+02}m^3/d$ while water released from storage is calculated as $2.44E^{+04}m^3/d$. The imbalance of the delineated aquifer unit, ignoring internal transfer, is calculated at $1.50E^{+02}m^3/d$.

Table 15-5 Catchment water balance: Scenario 01 – Steady state baseline water balance.

Scenario 01 – Steady State Catchment Groundwater Balance			
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	2.79E+04	0.00E+00	2.79E+04
GW component of baseflow/ Dirichlet boundary conditions (m^3/d)	0.00E+00	2.78E+04	-2.78E+04
Storage Capture(-)/Release(+)(m^3/d)	3.20E+02	2.44E+02	7.52E+01
Imbalance ignoring internal transfer (m^3/d)	0.00E+00	1.50E+02	-1.50E+02
Total (m^3/d)	**1.04E+05**	**1.04E+05**	**0.00E+00**

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

This scenario summarises the simulated point source pollution plume migration of saline groundwater emanating from the deep, fractured aquifer should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the operational phase (20-year period).

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

The TDS pollution plume extend covers a total area of approximately 634.4ha in the Karoo formations, reaching a maximum distance of ~150.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 182.37ha, reaching a maximum distance of ~250.0m propagating in a radial pattern from the gas production borehole(s) after a simulation period of 20-years (refer to Figure 15-29). The pollution plume footprints reported on seems like a large area, however this is the combined zone of impact which is actually scattered throughout the study area and focussed in close proximity to proposed gas exploration and production boreholes. It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters.

The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer. It can be observed that regional geological lineaments acts as preferred pathways for groundwater flow and contaminant transport mechanisms.

Figure 15-28 indicates the expected flow pathways of particles derived from the source points and it is evident that the pollution plume migration in the denser Karoo formations is sluggish while movement in the unconsolidated alluvial deposits of the riparian zone suggest a larger flux. Figure 15-26 summarises a time-series graph of the TDS mass load contribution to down-gradient receptors. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the SANS241:2015 threshold ranging between 400.0-1200.0mg/l, however borehole locality HBH136 suggest an increase in dissolved solids up to a concentration of >5000.0mg/l due to its proximity to the proposed production boreholes. Figure 15-27 summarises a time-series graph of the TDS mass load contribution to conceptually placed receptors situated in close proximity to simulated gas production boreholes (positioned 50m and 100m from the production boreholes). It can be observed that the TDS mass load contribution ranges between ~1000.0mg/l to approximately 2500.0mg/l with the mass load contribution a function of the distance to the source or gas production borehole.

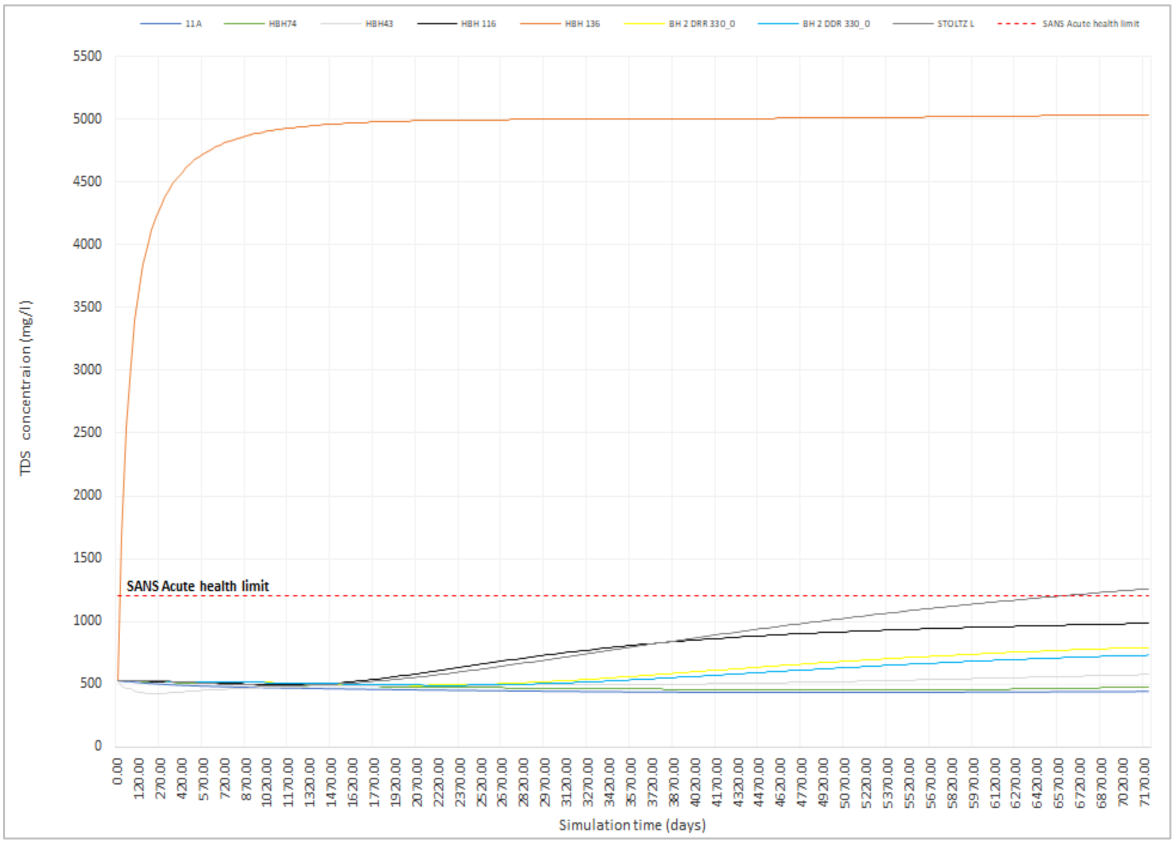


Figure 15-26 **Scenario 02a: Time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targetting the potable shallow, intergranular aquifer (Operational phase).**

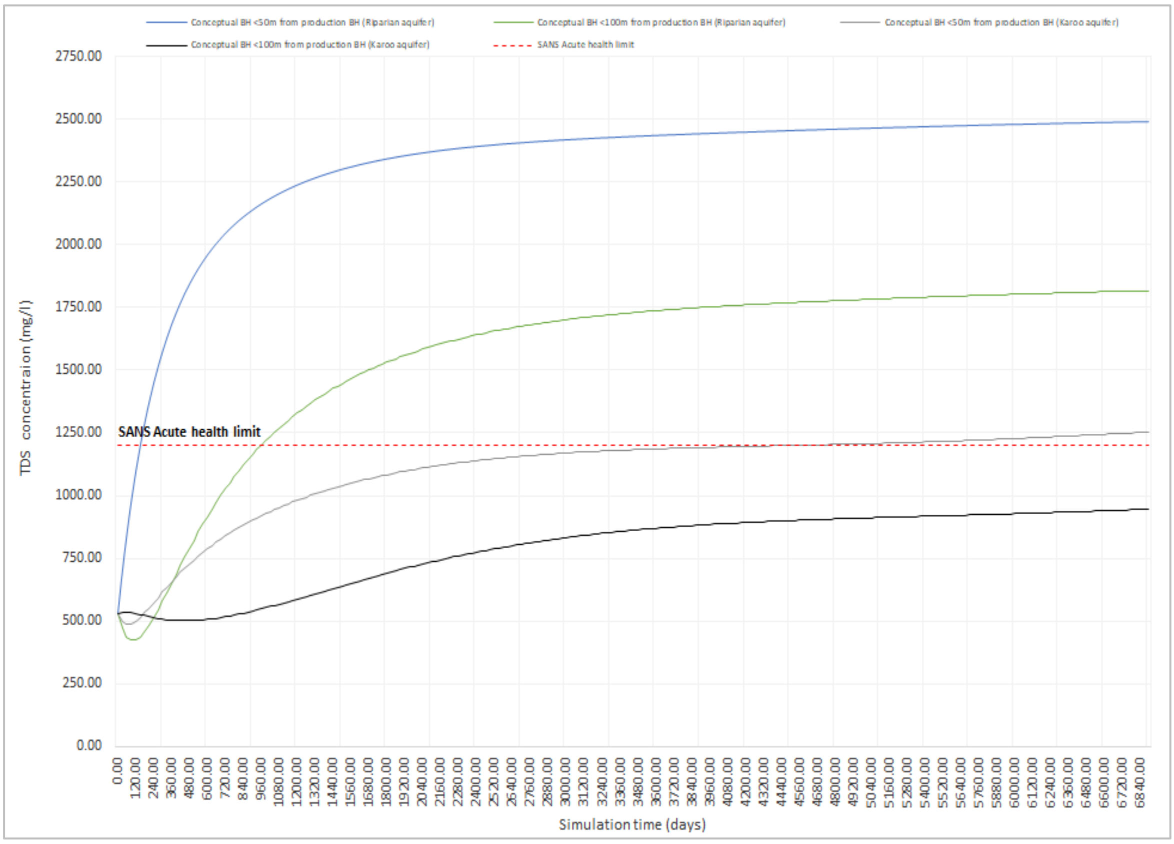


Figure 15-27 **Scenario 02a: Time-series graph indicating the TDS mass load contribution of deeper, fractured (saline) aquifer on conceptual receptors in close proximity to simulated production boreholes (Operational phase).**

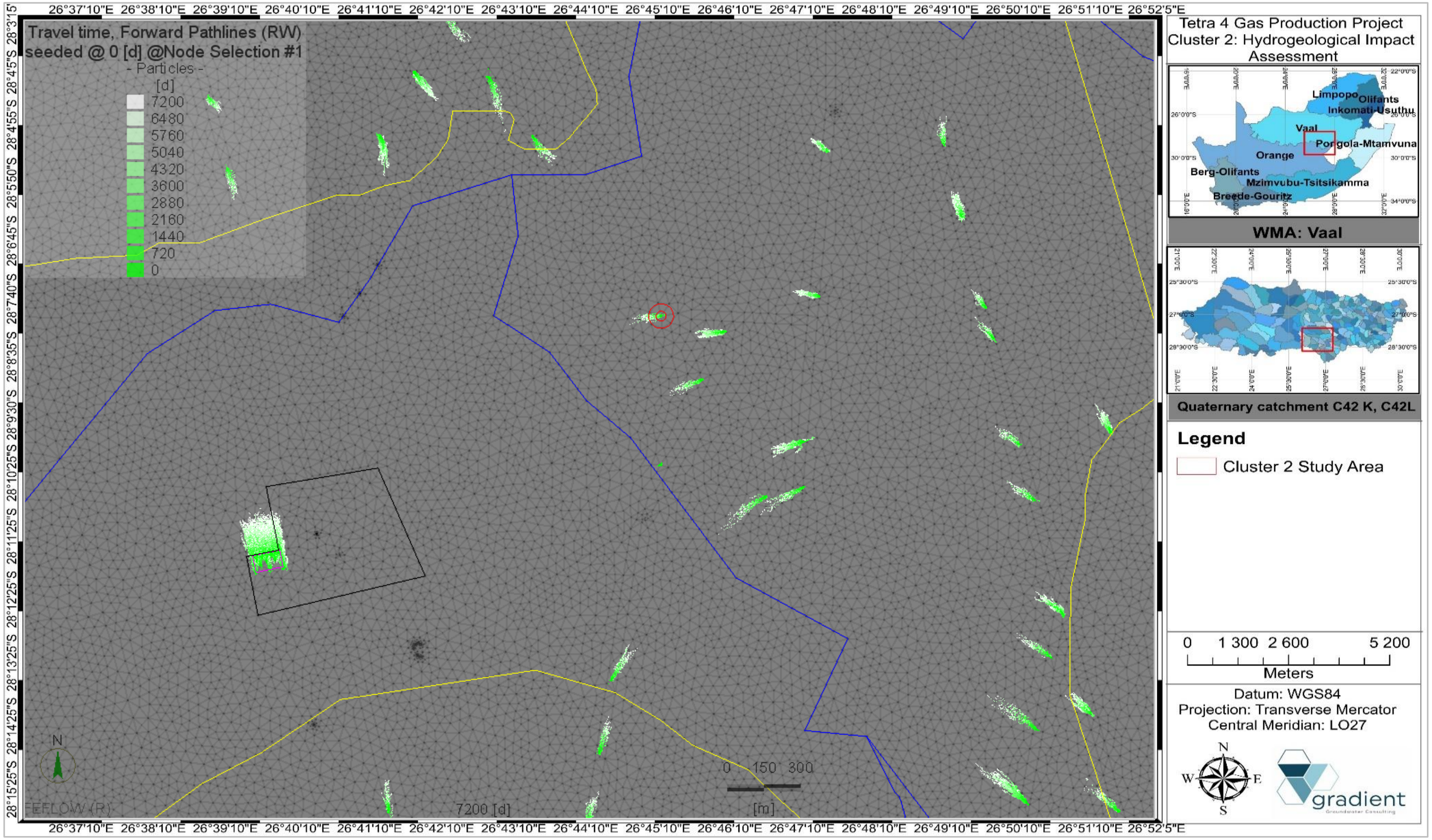


Figure 15-28 **Scenario 02: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating from leaking boreholes within the intergranular aquifer (Operational phase).**

Figure 15-29 **Scenario 02a: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through the intergranular aquifer (Operational phase).**

15.7.3. Scenario 02b: Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the operational gas production phase

This scenario summarises the simulated point source pollution plume migration of stray methane (CH_4) gas emanating from the production zone should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes.

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

The (CH_4) pollution plume extend covers a total area of approximately 848.29ha in the Karoo formations, reaching a maximum distance of ~180.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 246.43ha, reaching a maximum distance of ~300.0m propagating in a radial pattern from the gas production borehole(s) after a simulation period of 20-years (refer to Figure 15-32). It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes Mon 2057, 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer.

Figure 15-30 summarises a time-series graph of the CH_4 mass load contribution to down-gradient receptors. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the EPA safety threshold (2011) of 10.0mg/l ranging between 0.12-3.90mg/l, however borehole locality HBH136 suggest an increase in the CH_4 concentration of >17.0mg/l due to its proximity to production boreholes. Figure 15-31 summarises a time-series graph of the CH_4 mass load contribution to conceptually placed receptors situated in close proximity to simulated gas production boreholes (positioned 50m and 100m from the production boreholes). It can be observed that the CH_4 mass load contribution ranges between 2.08mg/l to approximately 7.66mg/l with the mass load contribution a function of the distance to the source or gas production borehole.

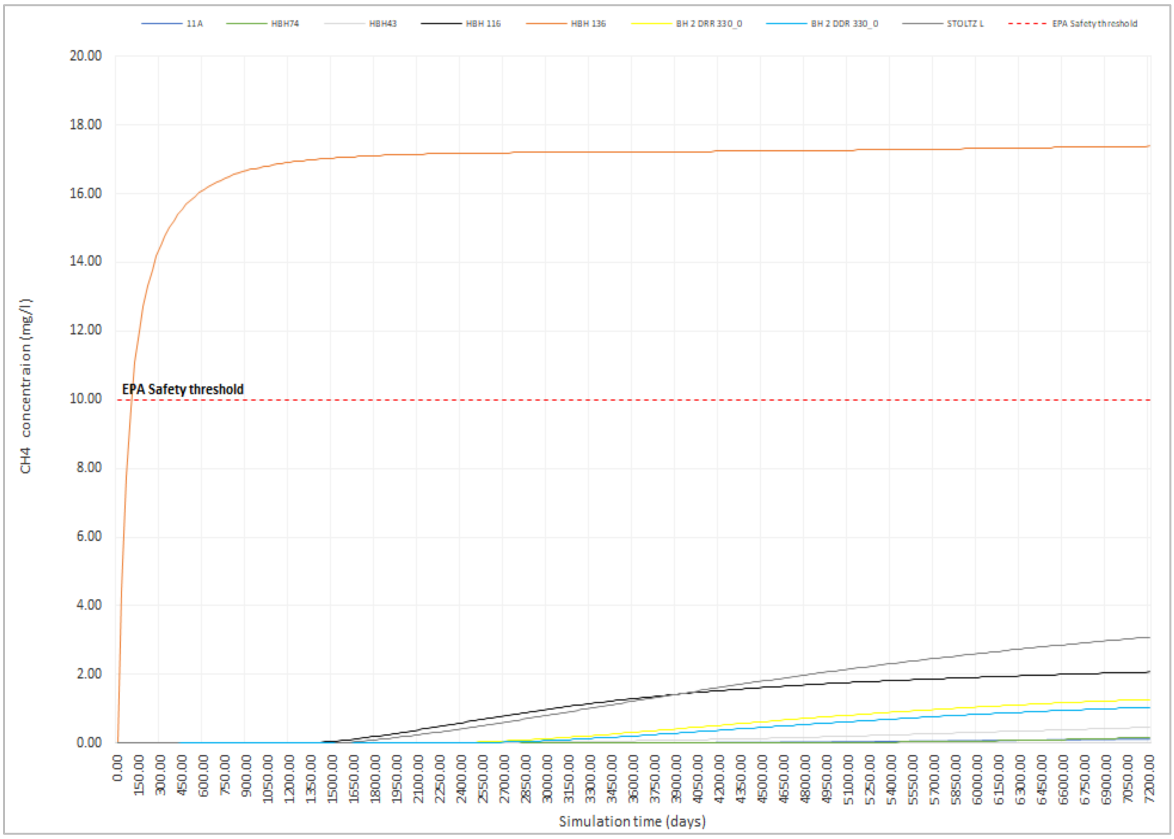


Figure 15-30 **Scenario 02b: Time-series graph indicating the CH_4 mass load contribution of the production zone on observation boreholes targetting the potable shallow, intergranular aquifer (Operational phase).**

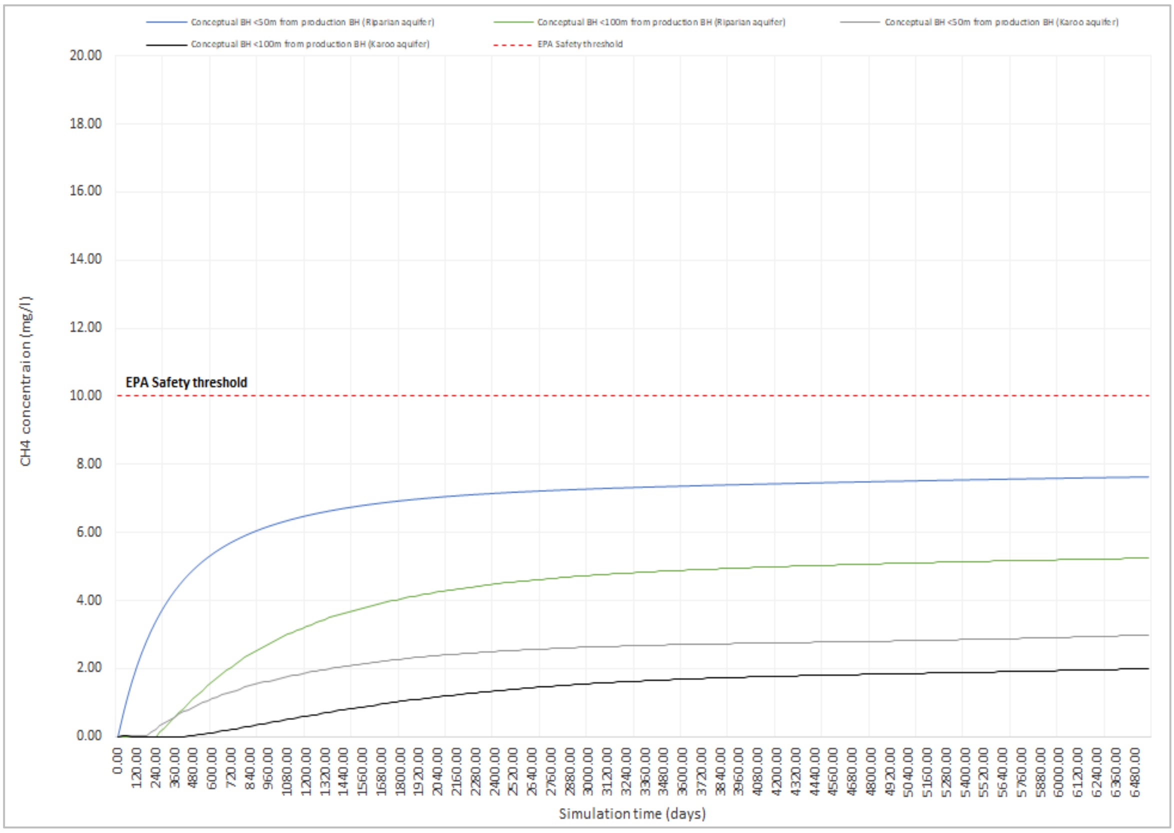


Figure 15-31 **Scenario 02b: Time-series graph indicating the CH_4 mass load contribution of the production zone on conceptual receptors targetting the shallow, intergranular aquifer (Operational phase).**

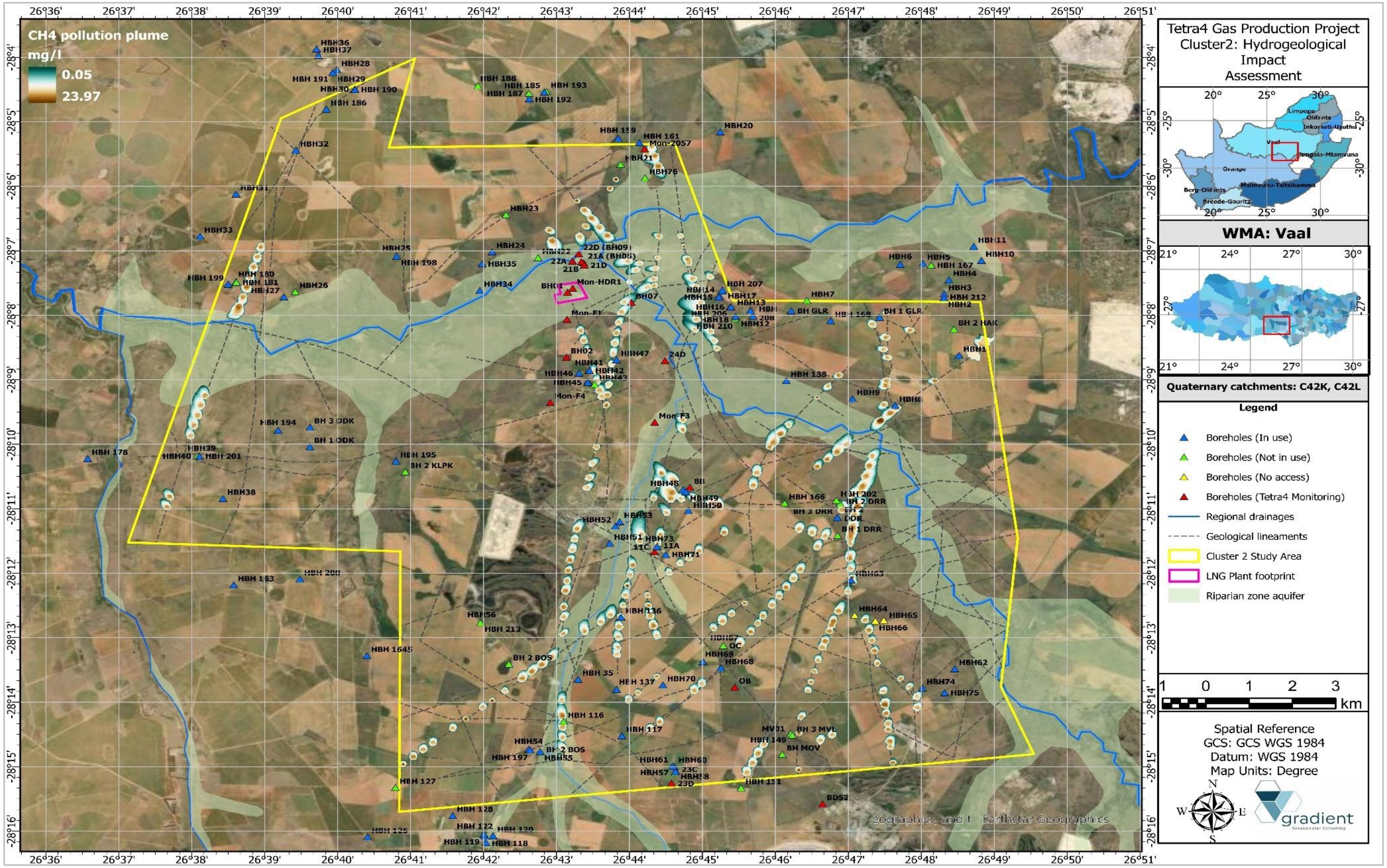


Figure 15-32 **Scenario 02b: CH_4 pollution plume migration of contaminants originating from the production zone migrating through the intergranular aquifer (Operational phase).**

15.7.4. Scenario 03: Migration of the TDS pollution plume emanating from the evaporation dam footprint area during the operational gas production phase

This scenario summarises the simulated pollution plume migration from the evaporation dam footprint for the operational phase. It should be noted that, although an appropriate liner and barrier system will be implemented underneath the evaporation dam, a cautious approach i.e., "worst-case" scenario have been followed during the modelling of the unlined scenario (unmitigated scenario).

The TDS pollution plume extend covers a total area of approximately 23.89ha reaching a maximum distance of ~550.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 20-years as depicted in Figure 15-36. Figure 15-35 indicates the expected flow pathways of particles derived from the evaporation dam footprint. The simulation indicates that no neighbouring boreholes or local drainages are expected to be impacted on during the operational phase. Monitoring boreholes which might potentially be intercepted by the pollution plume include BH01 as well as Mon-HDR01.

Figure 15-33 summarises a time-series graph of the TDS mass load contribution to down-gradient receptors[19]. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration of between 1750.0 – 2500.0mg/l, and is a function of the receptor distance from the source. Figure 15-34 depicts a model cross section of the pollution plume migration within the simulated aquifer. It is evident that the mass transport of the pollution plume is mostly limited to the shallow, intergranular aquifer, however may also migrate to the deeper, fractured aquifer over time.

[19] Conceptual boreholes were used as receptors as no boreholes are situated in the direct down-gradient vicinity of the plant footprint.

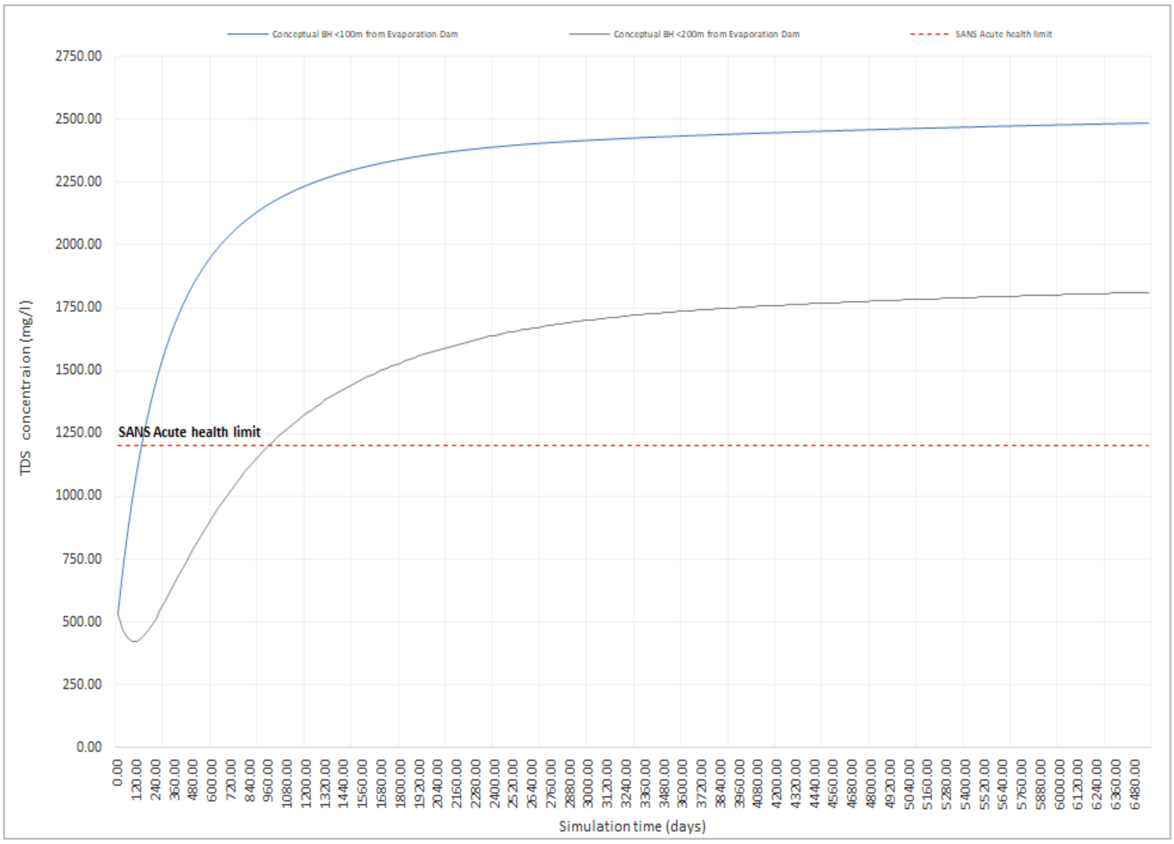


Figure 15-33 **Scenario 03: Time-series graph indicating the TDS mass load emenating from the plant footprint on down-gradient observation boreholes targetting the potable shallow, intergranular aquifer (Operational phase).**

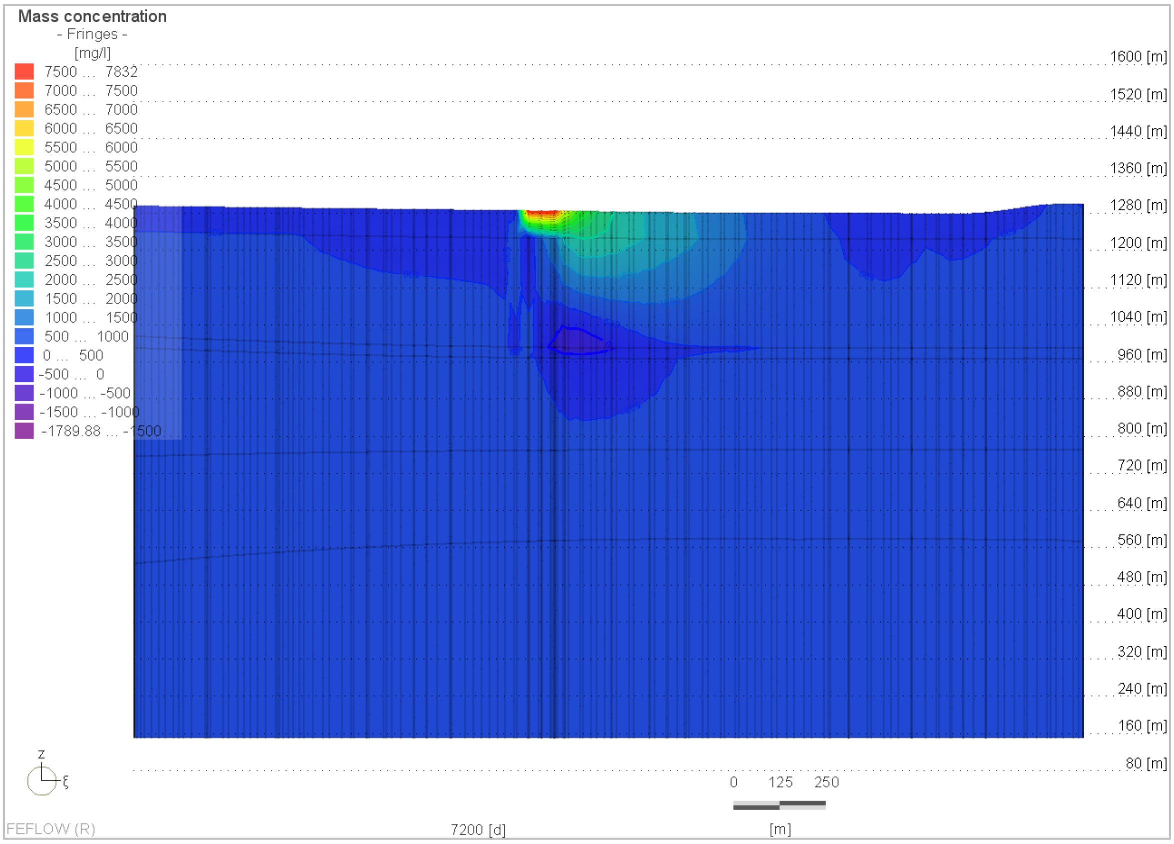


Figure 15-34 **Scenario 03: Model domain 3-D FEM mesh view (cross sectional view south-north orientation A-A') of the TDS pollution plume originating at the evaporation dam footprint (Operational phase).**

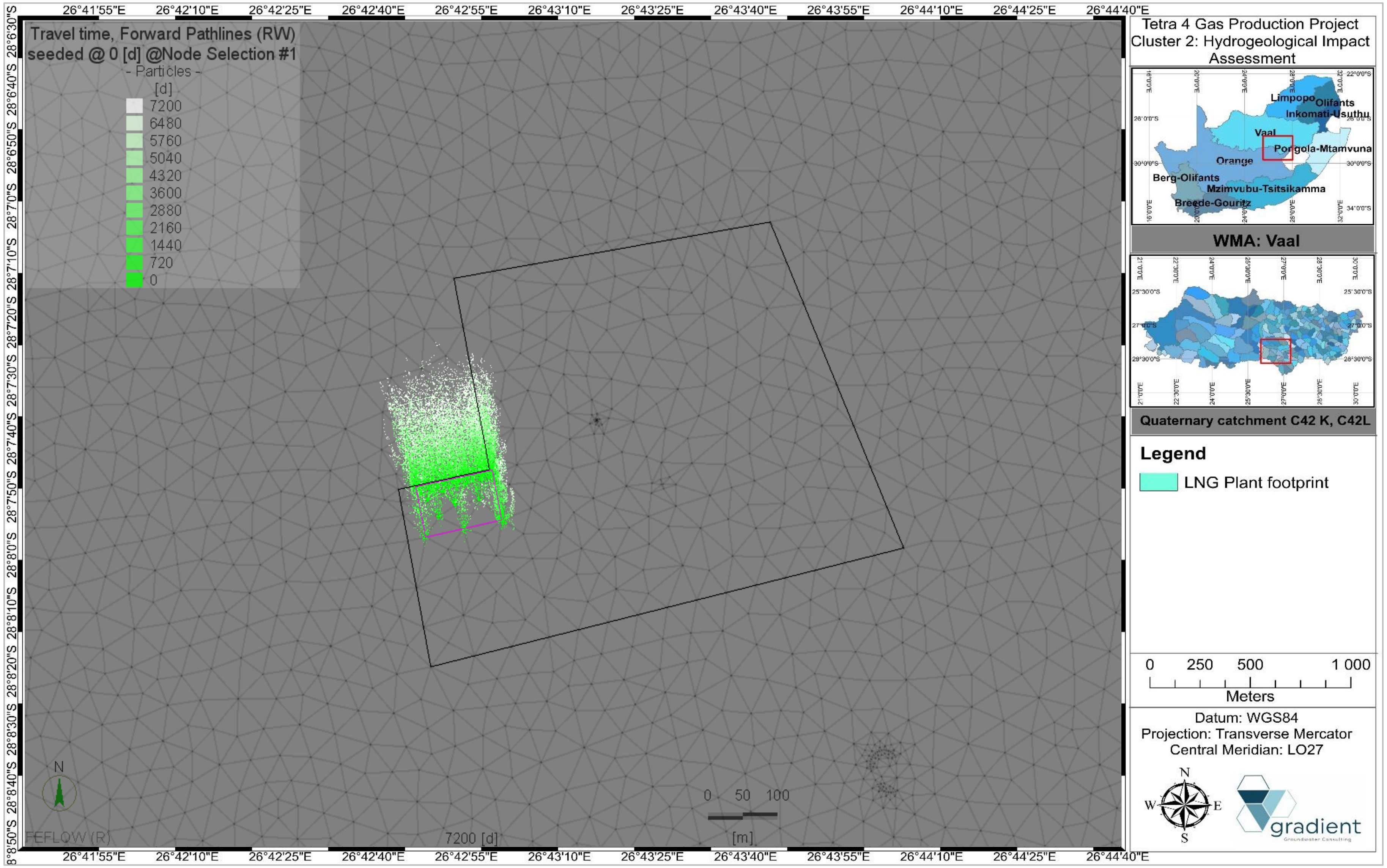


Figure 15-35 **Scenario 03: Simulated particle tracking of contaminants originating from the evaporation dam footprint within the intergranular aquifer (Operational phase).**

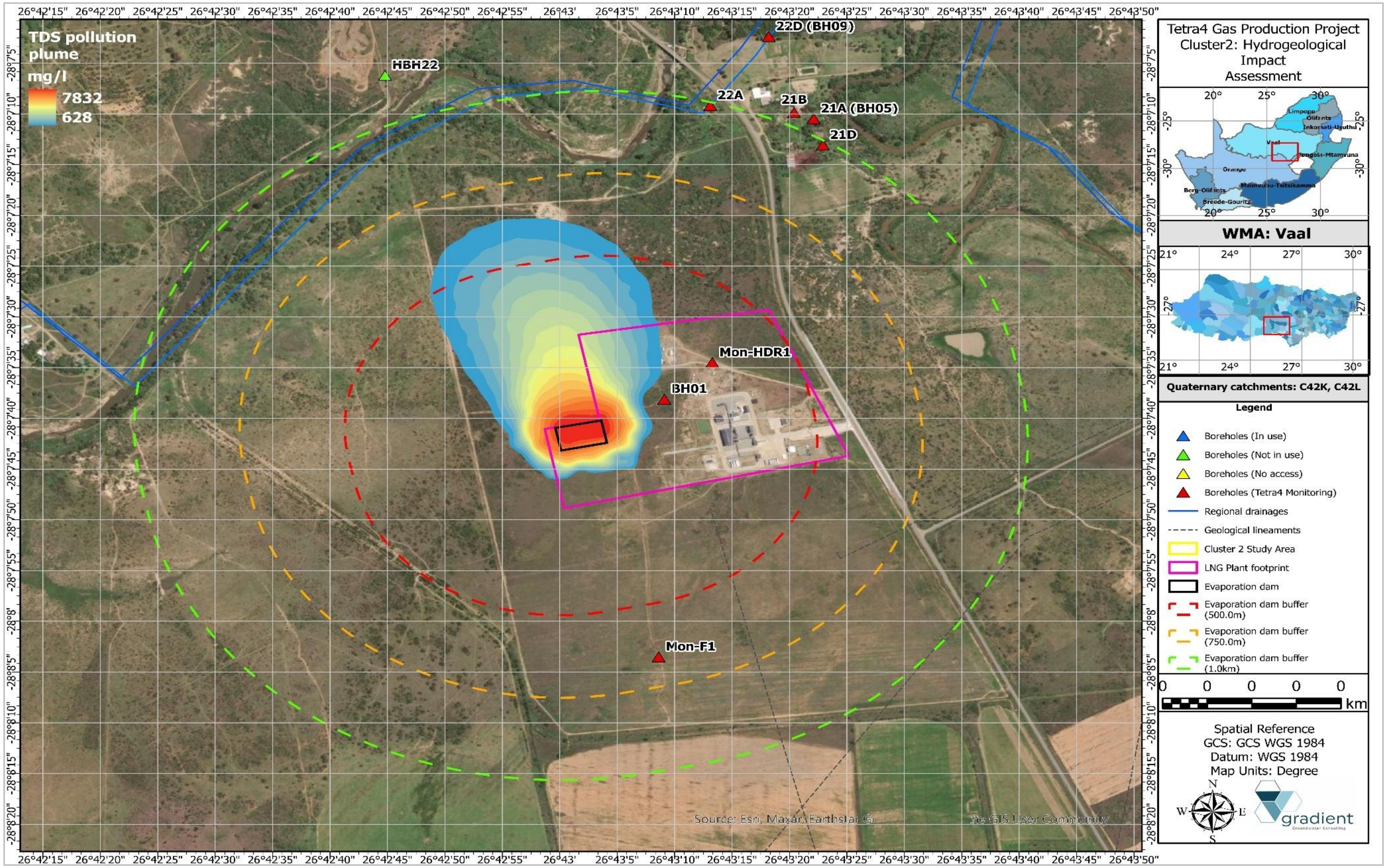


Figure 15-36 **Scenario 03: TDS pollution plume migration of contaminants originating from the evaporation dam footprint within the intergranular aquifer (Operational phase).**

15.7.5. Scenario 04a: 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 gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase.

After a post-closure simulation period of 50years, the TDS pollution plume extend covers a total area of approximately 1030.26ha in the Karoo formations, reaching a maximum distance of ~180.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 229.56ha, reaching a maximum distance of ~280.0m propagating in a radial pattern from the gas production borehole(s).

After a post-closure simulation period of 100years, the TDS pollution plume extend covers a total area of approximately 1326.98ha in the Karoo formations, reaching a maximum distance of ~220.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The TDS pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 266.26ha, reaching a maximum distance of ~300.0m propagating in a radial pattern from the gas production borehole(s) (refer to Figure 15-39). It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer.

Figure 15-38 indicates the expected flow pathways of particles derived from the source points and it is evident that the pollution plume migration in the denser Karoo formations is sluggish while movement in the unconsolidated alluvial deposits of the riparian zone suggest a larger flux. Figure 15-37 summarises a time-series graph of the TDS mass load contribution to down-gradient receptors. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the SANS241:2015 threshold ranging between ~400.0-1036.0mg/l, however borehole localities HBH136 and Stoltz L suggest an increase in dissolved solids with concentrations ranging between 1690.0 to up to 5117.0mg/l due to its proximity to production boreholes.

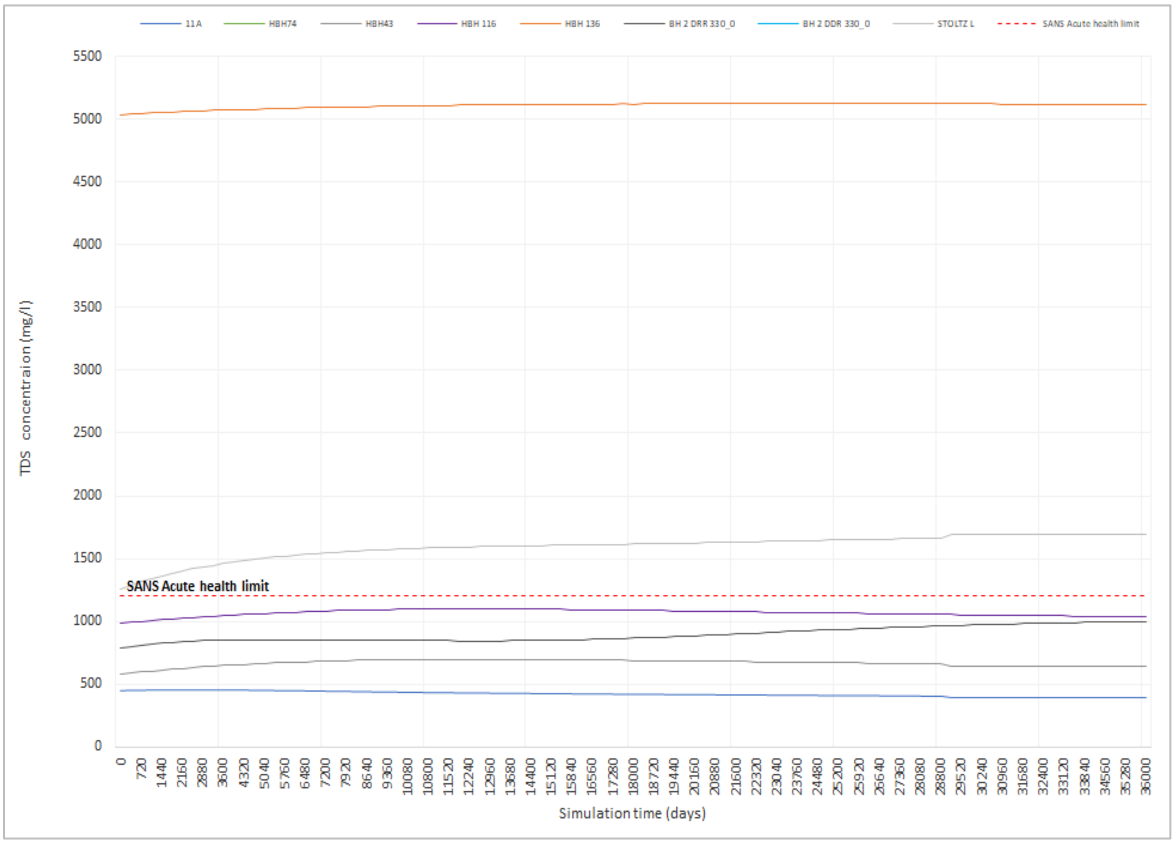


Figure 15-37 **Scenario 04a: Time-series graph indicating the TDS mass load contribution of deeper, fractured and saline aquifer on observation boreholes targetting the potable shallow, intergranular aquifer (Post-closure phase).**

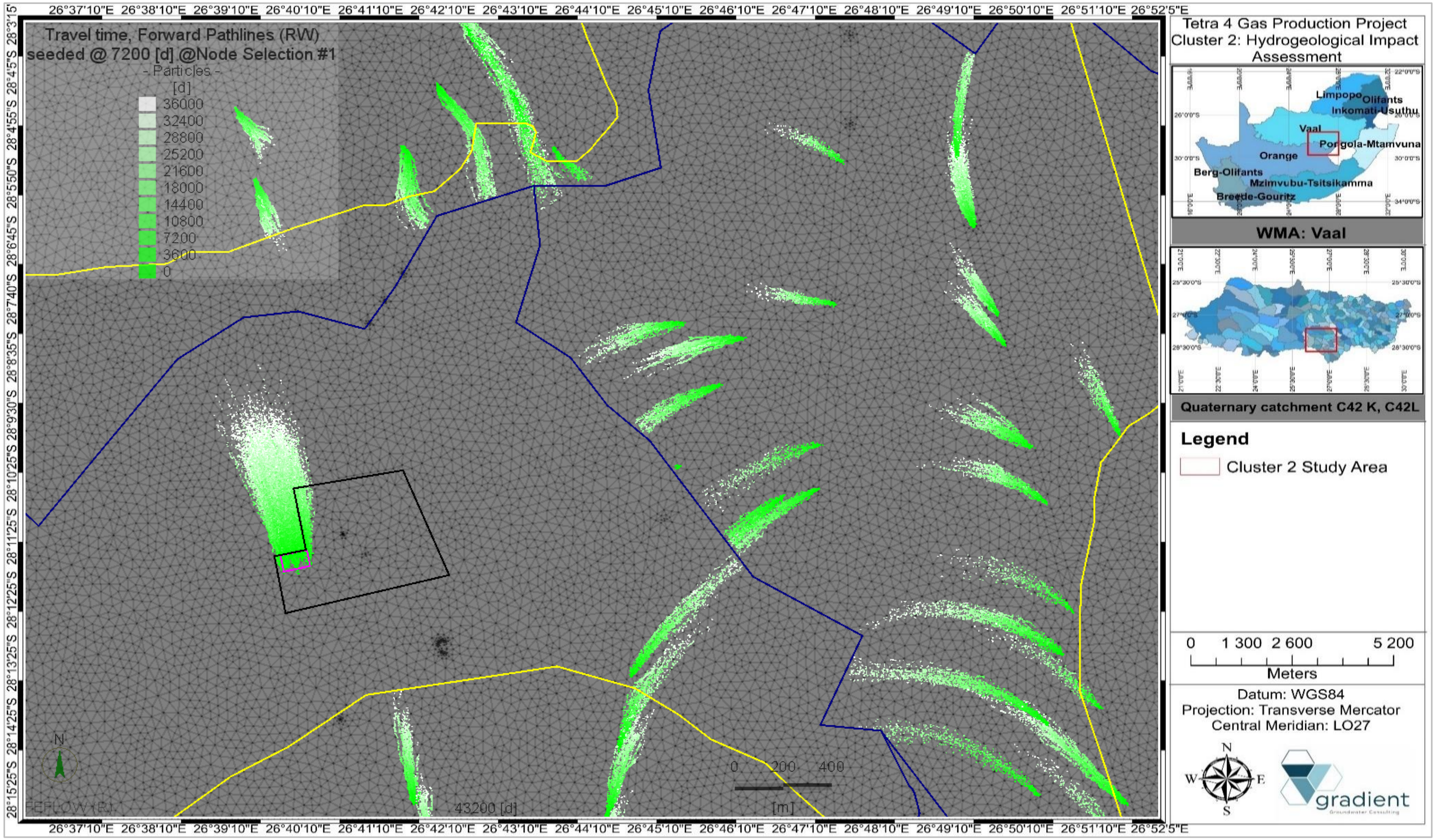


Figure 15-38 **Scenario 04: Simulated particle tracking of contaminants originating from the deeper, fractured aquifer migrating from leaking boreholes within the intergranular aquifer (Post-closure phase).**

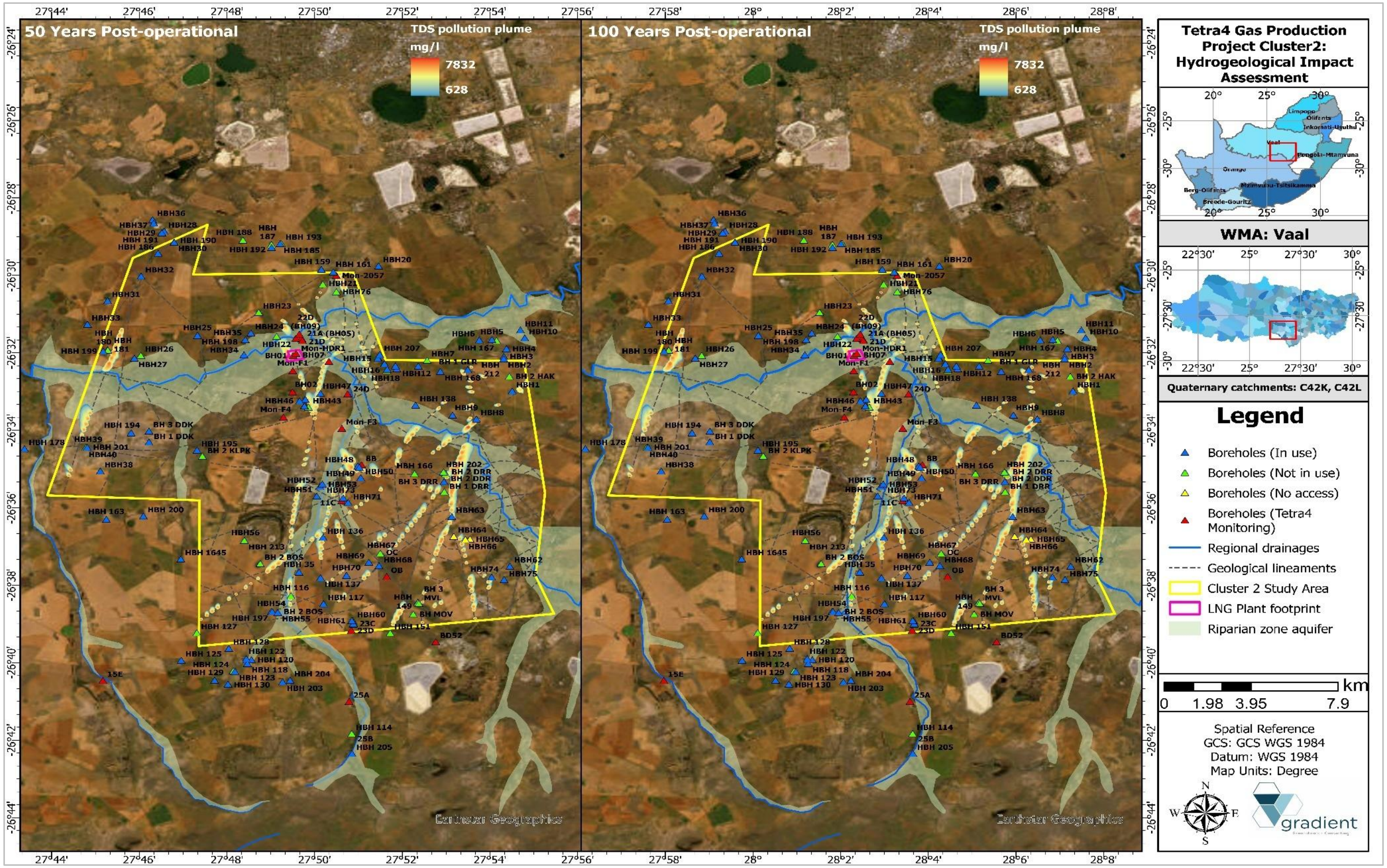


Figure 15-39 **Scenario 04a: TDS pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through the intergranular aquifer (Post-closure phase).**

15.7.6. Scenario 04b: Migration of stray methane (CH_4) gas emanating from the production zone to the overlying, potable aquifer(s) during the post-closure and decommissioning phase (50-year and 100-year scenarios)

This scenario summarises the simulated point source pollution plume migration from of stray methane (CH_4) gas emanating from the production zone should the integrity of the gas production boreholes be jeopardised i.e., leaking boreholes for the post-closure phase.

After a post-closure simulation period of 50years, the CH_4 pollution plume extend covers a total area of approximately 1399.68ha in the Karoo formations, reaching a maximum distance of ~220.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 459.83ha, reaching a maximum distance of ~320.0m propagating in a radial pattern from the gas production borehole(s).

After a post-closure simulation period of 100years, the CH_4 pollution plume extend covers a total area of approximately 1755.20ha in the Karoo formations, reaching a maximum distance of ~270.0m in a general north to northeastern direction (southern catchment) and a southwestern direction (northern catchment) propagating in a radial pattern from the gas production borehole(s) towards the lower laying drainage system. The CH_4 pollution plume extend within the alluvial, riparian zone aquifer covers a total area of approximately 571.57ha, reaching a maximum distance of ~350.0m propagating in a radial pattern from the gas production borehole(s) (refer to Figure 15-41). It is noted that the pollution plume does slightly extend beyond the project boundary towards the northern and western perimeters. The simulation indicates that the following neighbouring boreholes will potentially be intercepted by the simulated pollution plume HBH08, HBH43, HBH63, HBH74, HBH116, HBH136, BH2 DDR, BH2 DRR as well as Stoltz L while monitoring boreholes Mon 2057, 11A and BH07 will potentially be impacted on. It is furthermore noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer.

Figure 15-40 summarises a time-series graph of the CH_4 mass load contribution to down-gradient receptors. It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the EPA safety threshold (2011) of 10.0mg/l ranging between 0.35-5.07mg/l, however borehole locality HBH136 suggest an increase in the CH_4 concentration of >17.0mg/l due to its proximity to production boreholes.

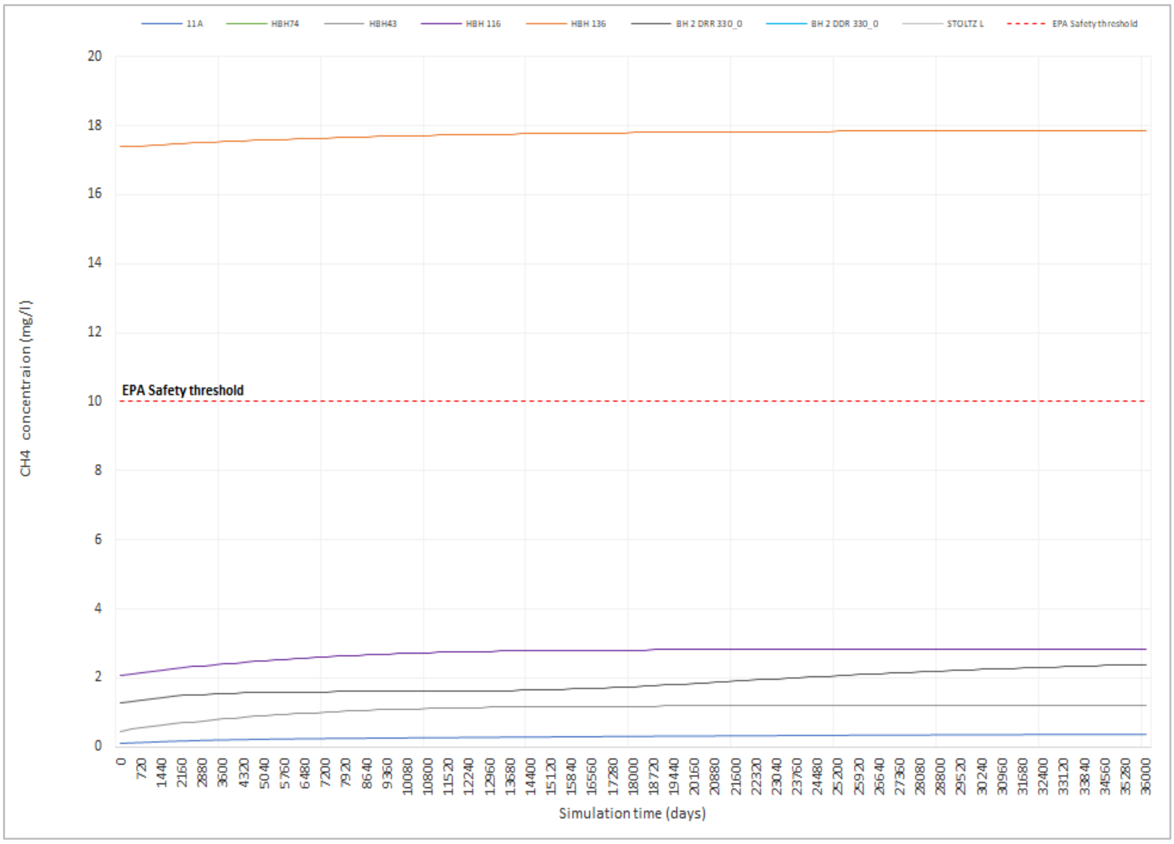


Figure 15-40 **Scenario 04b: Time-series graph indicating the CH4 mass load contribution of waste facilities on down-gradient receptors.**

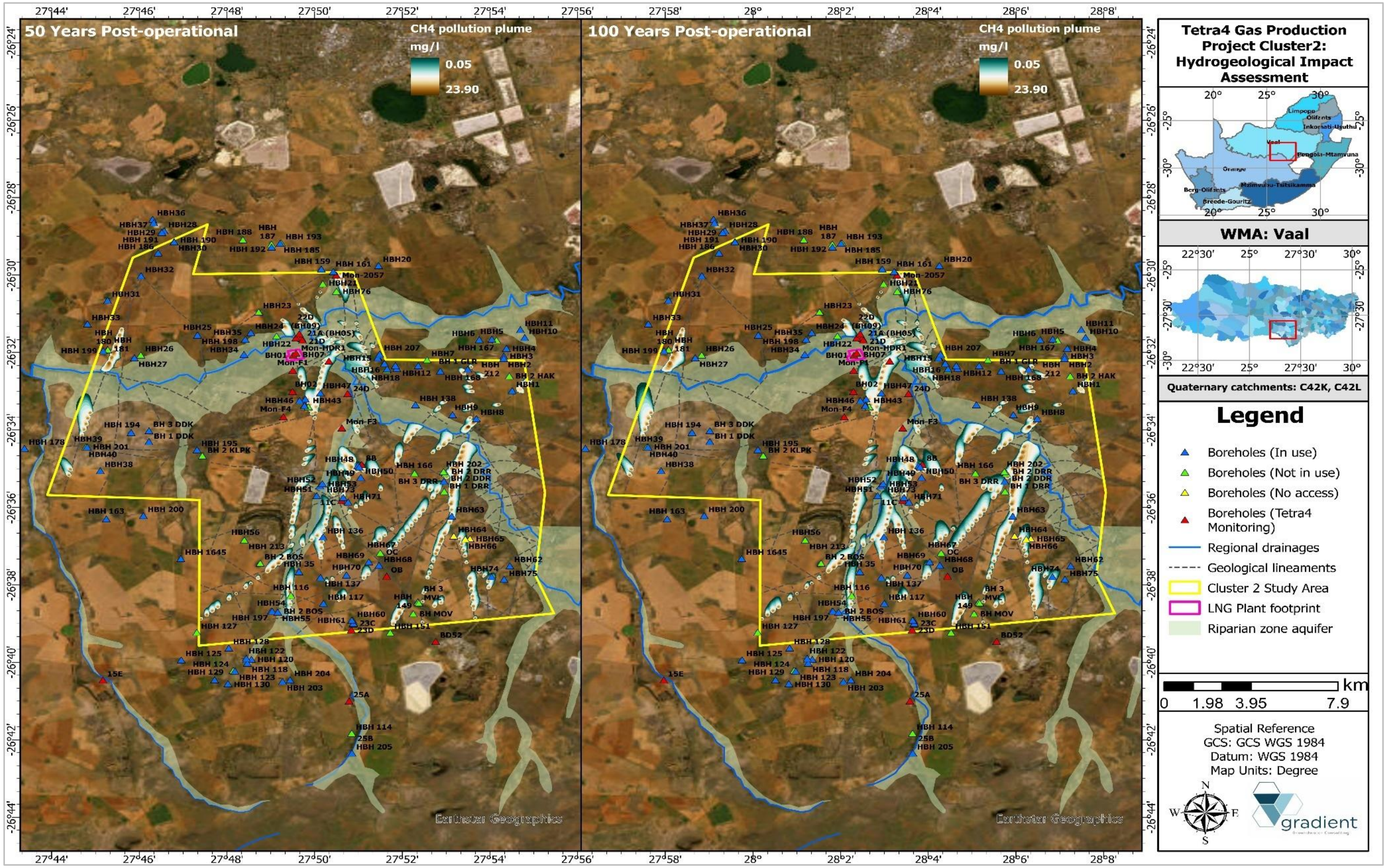


Figure 15-41 **Scenario 04b: CH_4 pollution plume migration of contaminants originating from the deeper, fractured aquifer migrating through the intergranular aquifer (Post-closure phase).**

15.7.7. Scenario 05: Migration of the TDS pollution plume emanating from the plant footprint area during the post-closure and decommissioning phase (50-year and 100-year scenarios)

This scenario summarises the simulated pollution plume migration from the evaporation dam footprint for the post-closure phase. The TDS pollution plume extend covers a total area of approximately 43.03ha reaching a maximum distance of ~950.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 50-years and covers a total area of approximately 52.90ha reaching a maximum distance of ~1050.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 100-years as depicted in Figure 15-44.

Figure 15-43 indicates the expected flow pathways of particles for the post-closure simulation period, and it is evident that the pollution plume potentially reaches the local drainages system down-gradient of the evaporation dam footprint during the post-closure phase.

Figure 15-42 summarises a time-series graph of the TDS mass load contribution to down-gradient receptors. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration above the SANS 241:2015 limit of 1200.0mg/l for the post-closure simulation period with the mass load contribution a function of the distance to the source or evaporation dam footprint.

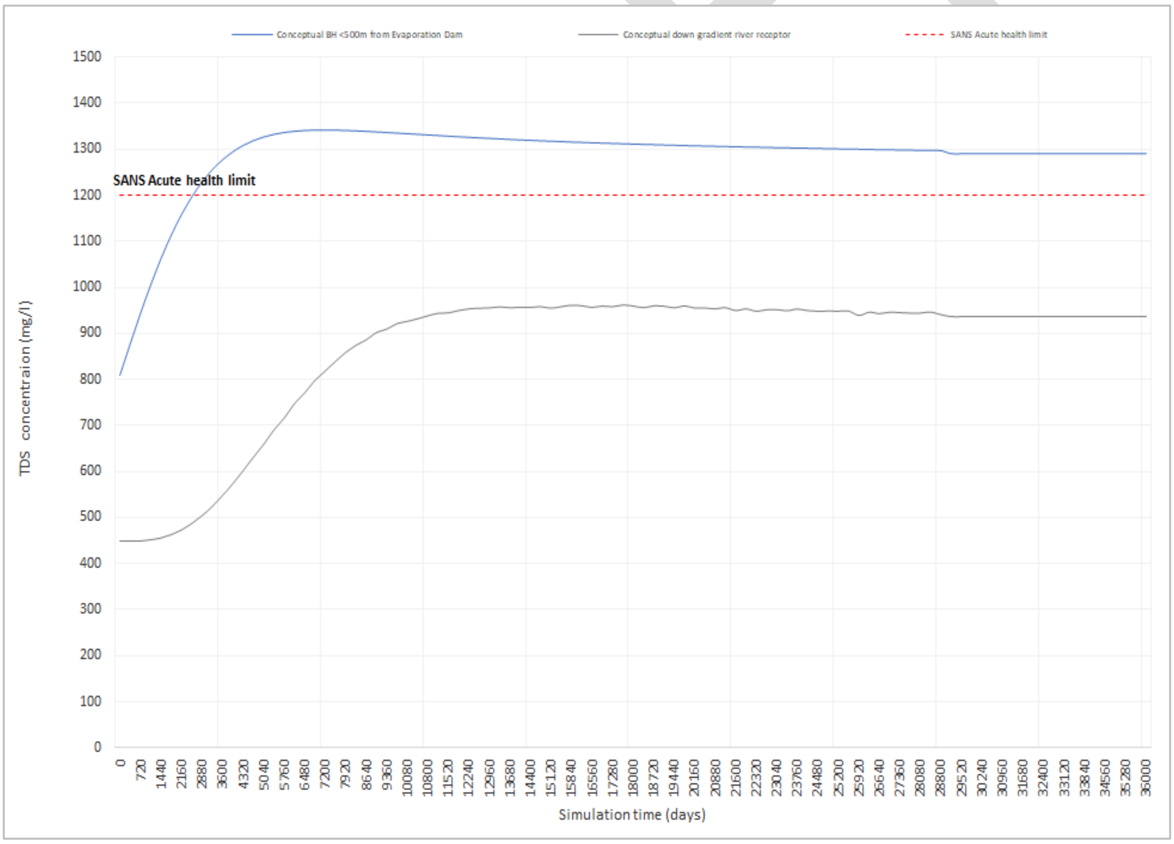


Figure 15-42 **Scenario 05: Time-series graph indicating the TDS mass load emenating from the evaporation dam footprint on down-gradient observation boreholes targetting the potable shallow, intergranular aquifer (Post-closure phase).**

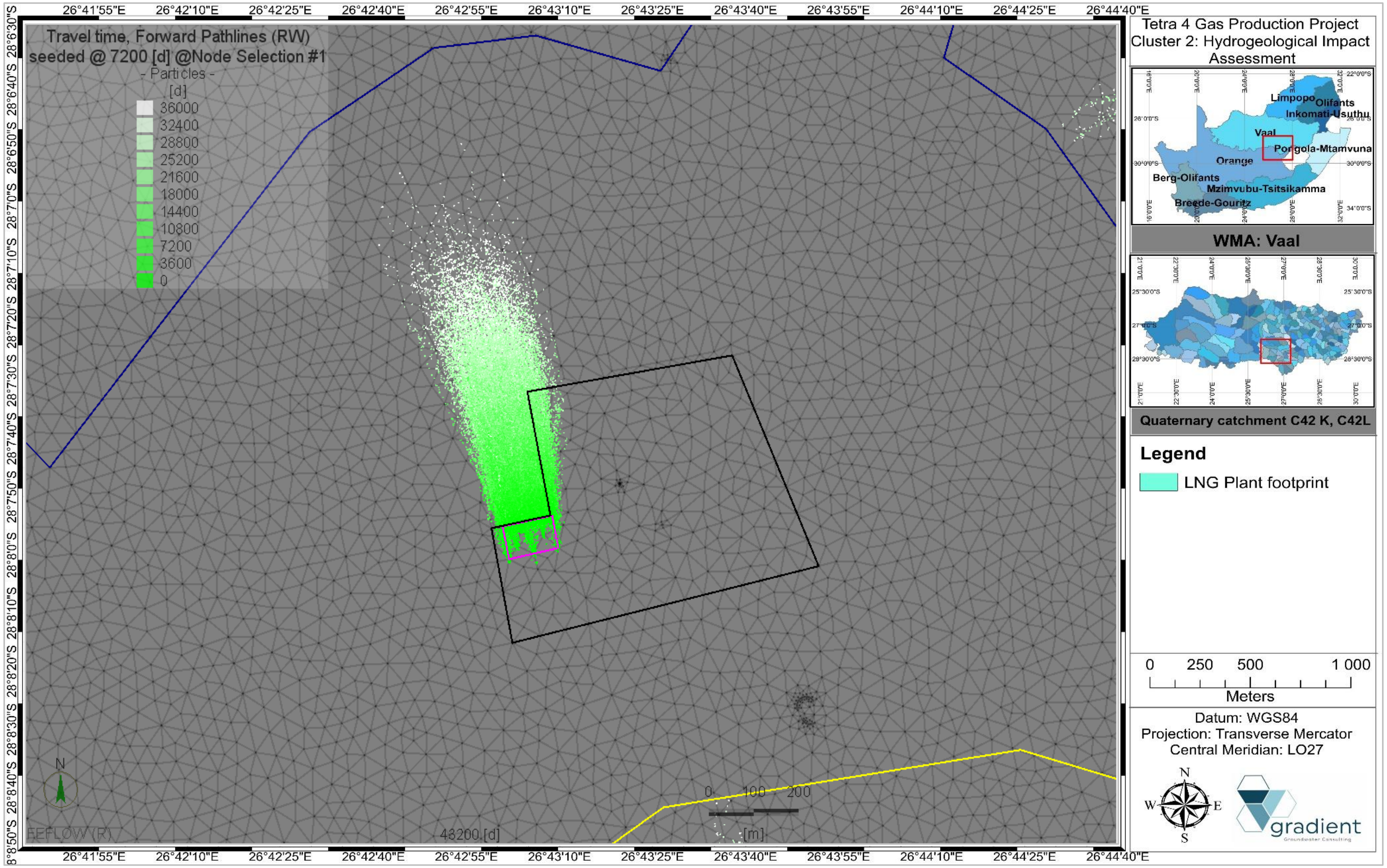


Figure 15-43 **Scenario 05: Simulated particle tracking of contaminants originating from the evaporation dam footprint within the intergranular aquifer (100-years post-closure).**

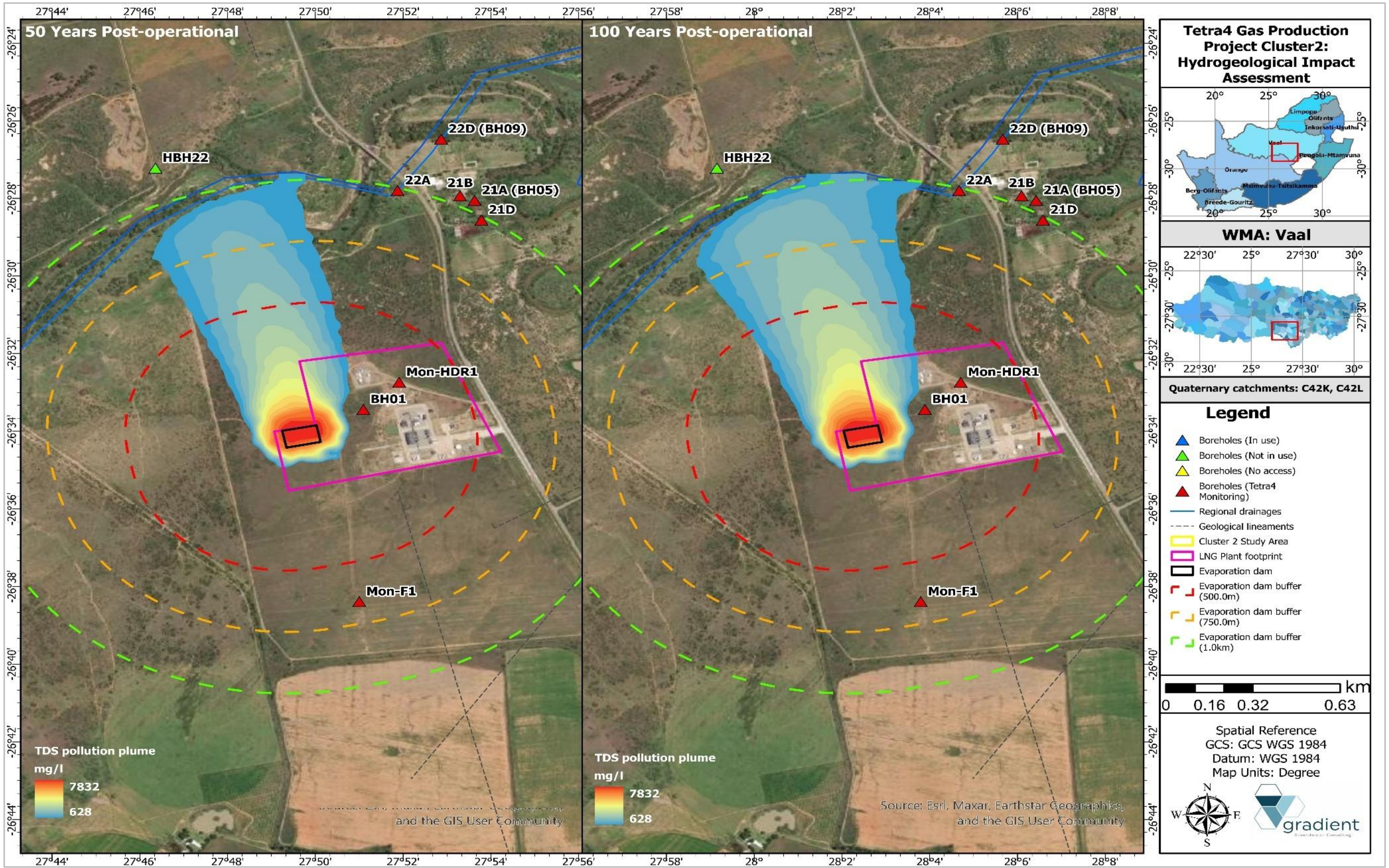


Figure 15-44 **Scenario 05: TDS pollution plume migration of contaminants originating from the evaporation dam footprint within the intergranular aquifer (Post-closure phase).**

15.7.8. Scenario 06: Mitigation and management - Evaluating the effect of implementation of a liner or barrier system underneath the evaporation dam on the TDS pollution plume migration

An alternative management and mitigation scenario was simulated to evaluate the remedial options available. A passive management scenario evaluating what the mitigating effect of a liner or barrier system implemented underneath the evaporation dam will have on the pollution plume migration were simulated as depicted in Figure 15-46. Table 15-6 provides a summary of the mitigatory effect and effectiveness of proposed management alternative on the pollution plume footprint while Figure 15-45 depicts the effect of the mitigation measures on the mass load contribution to observation boreholes.

It is evident that due to the lower conductivity of the liner or barrier system when implemented, the source of contamination is effectively isolated from the groundwater system in the direct vicinity of the evaporation dam footprint and reduces the simulated pollution plume by >50.0% to ~11.58ha. Accordingly, it is recommended that this remedial alternative should be considered best practise for implementation.

Table 15-6 Mitigation alternatives pollution plume areas and effectiveness.

Mitigation and management scenarios	Combined plume area (pre-mitigation)(km^2)	Combined plume area (post-mitigation)(km^2)	Improve ment (%)
Scenario 06a: implementation of a liner or barrier system underneath the evaporation dam	23.89	11.58	51.53

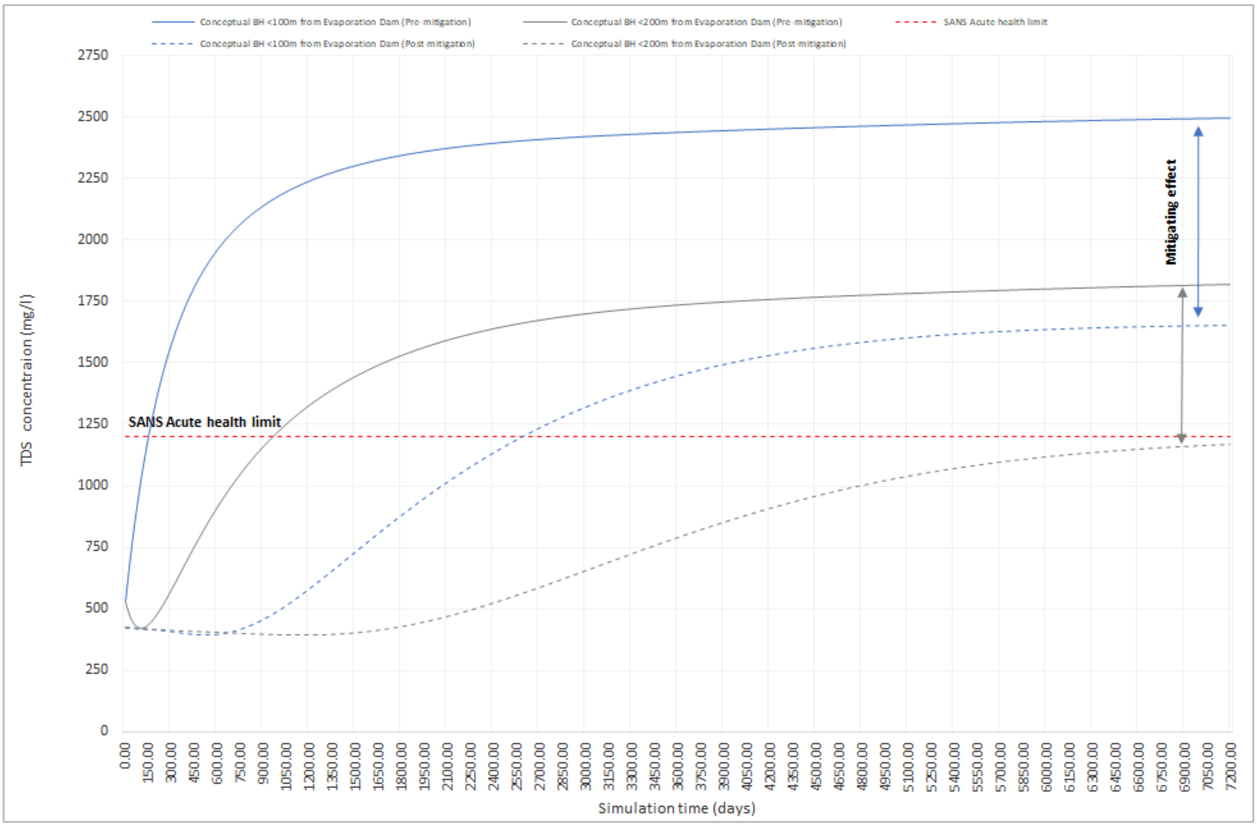


Figure 15-45 Scenario 06: Time-series graph indicating mass load contribution of the evaporation dam to conceptually placed down-gradient receptors (Pre-mitigation vs Post-mitigation).

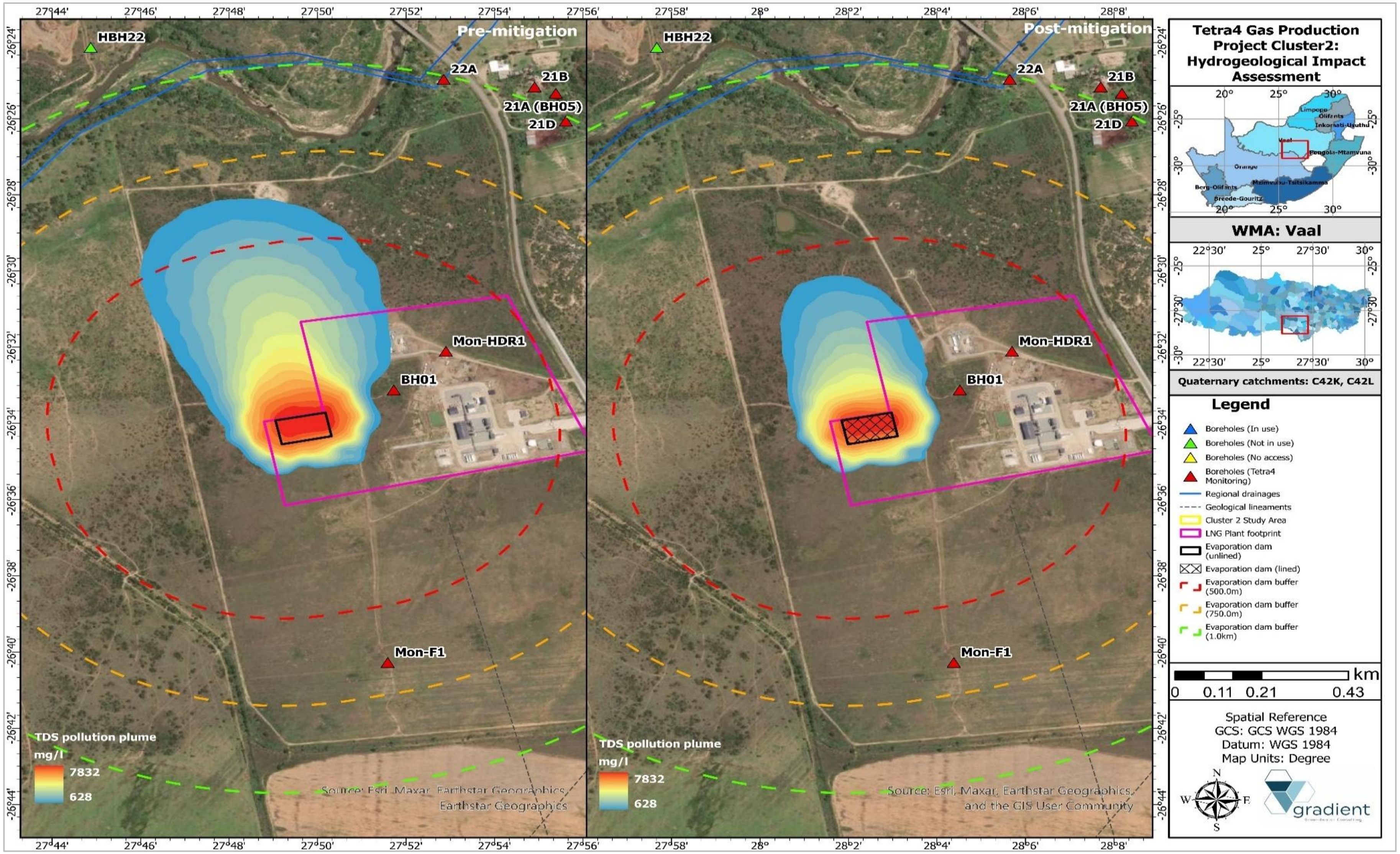


Figure 15-46 **Scenario 06: Mitigation - TDS pollution plume migration of contaminants originating from the evaporation dam footprint within the intergranular aquifer (Pre-mitigation vs Post-mitigation).**

15.7.9. Scenario 07: Evaluating the effect of climatic change i.e., wet vs. dry cycle rainfall scenarios on the TDS pollution plume migration

This scenario evaluates the effect of climatic change i.e., wet vs. dry cycle rainfall scenarios on the TDS pollution plume migration. Wet and dry rainfall season cycles may potentially have an impact on lower or higher recharge volumes reporting to the receiving aquifer and have been simulated as such.

Figure 15-47 summarises a time-series graph of the TDS mass load contribution to down-gradient receptors for wet vs. dry cycle rainfall scenarios. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration of ~2 875.0mg/l for the wet cycle rainfall scenario where the TDS mass load contribution for the dry cycle rainfall scenario increase to a concentration of ~2645.0mg/l. The latter accounts to an escalation of >8.50% which may be attributed to the higher recharge volumes associated with the wet cycle rainfall scenario. Accordingly, it can be concluded that climatic changes may significantly impact on the pollution plume migration and should be closely monitored. It is recommended that a weather station be established on-site in order to keep record of all rainfall events and assess potential climatic changes.

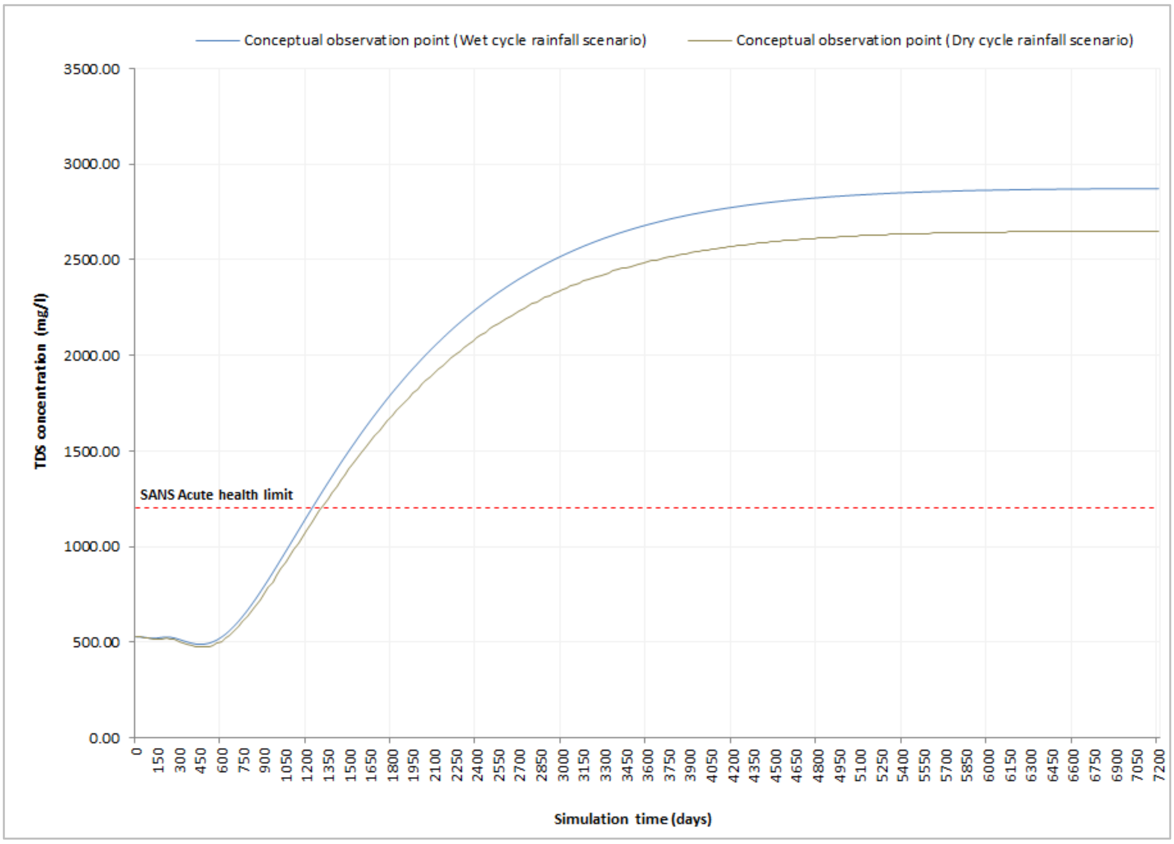


Figure 15-47 **Scenario 07: Time-series graph indicating mass load contribution of the evaporation dam to conceptually placed down-gradient receptors (Wet vs Dry cycle rainfall scenario).**

16. ENVIRONMENTAL IMPACT ASSESSMENT

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

16.1. 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.

16.2. 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 16-1 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 16-1 below with Table 16-2 summarising the probability scorings.

Table 16-1 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 16-2 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 16-2 Impact Consequence.

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

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25 as summarised in Table 16-4. These **ER** scores are then grouped into respective classes as described in Table 16-4.

Table 16-3 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 16-4 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.

16.3. 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 16-5.

Table 16-5 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 16-3 Impact Consequence.

$$\textbf{Priority} = \boldsymbol{CI + LR}$$

The result is a priority score which ranges from 3 to 9 and a consequent **PF** ranging from 1 to 2 (Refer to Table 16-6 below).

Table 16-6 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 16-7), 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 16-7 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.

16.4. Impact Identification and significance ratings

It should be noted that vast areas within the study area have been subjected to historical mining activities and, as such, reflect modified to highly modified present ecological status. A total number of >15 000 historical exploration wells have been drilled throughout the study area, some of which remain uncased and unsealed. The latter may act as preferential pathways and conduits for groundwater flow and contaminant transport mechanisms. As mentioned earlier 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. Accordingly, this already highly modified zones should form part of the impact significance rating and risk approach. Impacts and significant ratings associated different project phases are briefly discussed below.

16.4.1. Construction phase: Associated activities and impacts

Refer to Table 16-8 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 negative** without implementation of remedial measures and **low negative** with implementation of proposed mitigation measures. The main impacts associated with the construction phase activities include the following:

1. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area (Table 16-9).
2. Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality (Table 16-10).
3. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources (Table 16-11).
4. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution (Table 16-12).

Table 16-8 Impact assessment and significant rating: Construction phase summary.

Imp act	IMPACT DESCRIPTION	PRE - MITIGATION							POST - MITIGATION							IMPACT PRIORITISATION	
No.	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Priority Factor	Final score
Construction phase																	
1	Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area.	-1	2	2	2	2	2	-4.00	-1	2	2	1	2	1	-1.75	1.00	-1.75
2	Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.	-1	3	2	3	3	3	-8.25	-1	2	2	2	3	2	-4.50	1.25	-5.63
3	Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.	-1	3	5	4	4	3	-12.00	-1	2	5	4	4	2	-7.50	1.25	-9.38
4	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.	-1	3	2	3	3	3	-8.25	-1	2	2	2	3	2	-4.50	1.25	-5.63

Table 16-9 Risk assessment matrix and significant scoring: Construction phase impact 01.

Impact Name	**Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area.**				
Alternative	**Alternative 1**				
Phase	**Construction**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	1
Extent of Impact	2	2	Reversibility of Impact	2	2
Duration of Impact	2	2	Probability	2	1
Environmental Risk (Pre-mitigation)					-4.00
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. All construction should take place during the dry season, as far as possible. iii. 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. iv. Sites must be located, where possible, on previously disturbed areas. v. Every effort must be made to keep the footprint as small as possible.				
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.00
Final Significance					-1.75

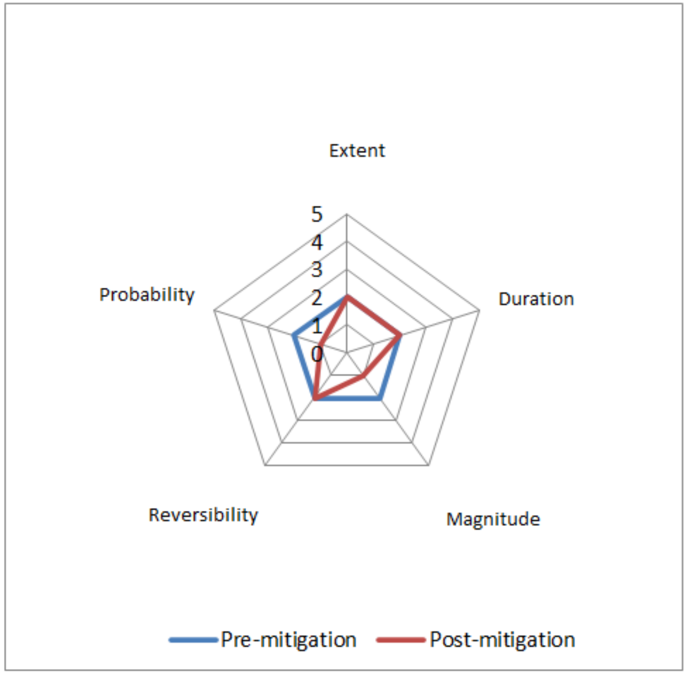


Table 16-10 Risk assessment matrix and significant scoring: Construction phase impact 02.

Impact Name	**Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.**				
Alternative	**Alternative 1**				
Phase	**Construction**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. All construction should take place during the dry season, as far as possible. iii. 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. iv. Sites must be located, where possible, on previously disturbed areas. v. 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.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-5.63

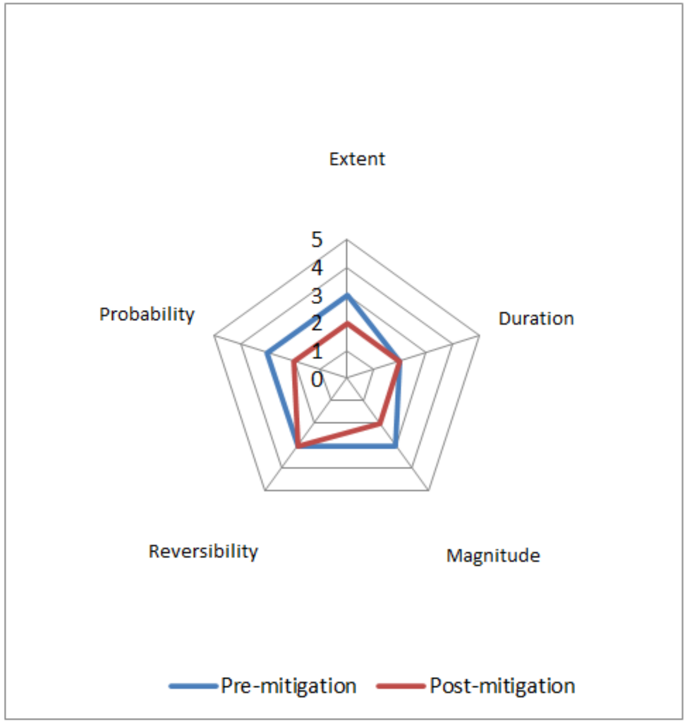


Table 16-11 Risk assessment matrix and significant scoring: Construction phase impact 03.

Impact Name	**Mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of groundwater resources.**				
Alternative	**Alternative 1**				
Phase	**Construction**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	4
Extent of Impact	3	2	Reversibility of Impact	4	4
Duration of Impact	5	5	Probability	3	2
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Mitigation Measures	i. Construction vehicles and machinery must be serviced and maintained regularly in order to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted. ii. During servicing of vehicles or equipment, especially where emergency repairs are effected outside the workshop area, a suitable drip tray must be used to prevent spills onto the soil. iii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair. iv. Workshop areas must be monitored for oil and fuel spills. v. An appropriate number of spill kits must be available and must be located in all areas where activities are being undertaken.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-9.38

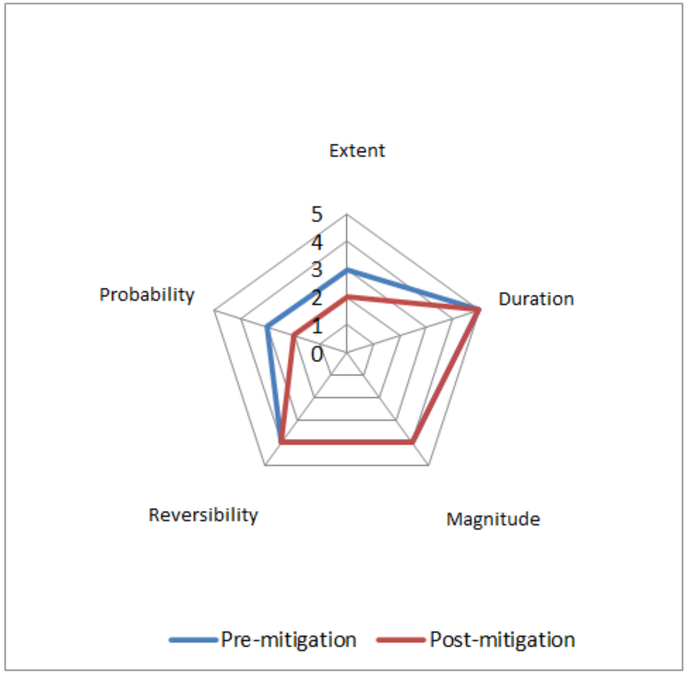
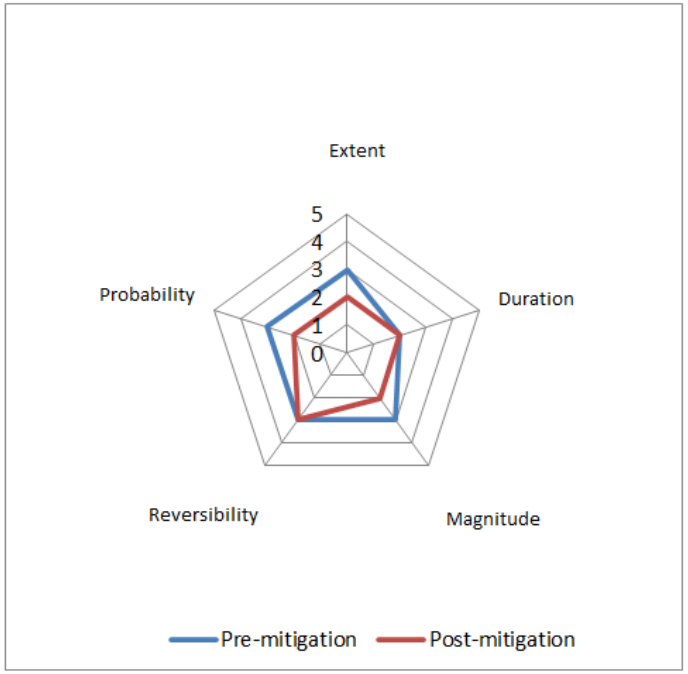


Table 16-12 Risk assessment matrix and significant scoring: Construction phase impact 04.

Impact Name	**Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.**				
Alternative	**Alternative 1**				
Phase	**Construction**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
Mitigation Measures	i. All hazardous substances used on-site should have an applicable Material Safety Data Sheet (MSDS) to provide information regarding the hazards, emergency response, protective measures and correct storage methodology. ii. Hazardous substance containment facilities to be used during operational phase should comply with the relevant hazardous substance storage legislation in order to ensure spillages are contained. iii. 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.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-5.63



16.4.2. Operational phase: Associated activities and impacts

Refer to Table 16-13 for a summary of the impact risk matrix and significance ratings for the construction phase. During the operational phase the environmental significance rating of groundwater quality impacts on down-gradient receptors are rated as **medium** to **high negative** without implementation of remedial measures and **low** to **medium negative** with implementation of proposed mitigation measures. The main impacts associated with the operational phase activities include the following:

1. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase (Table 16-14).
2. Migration of stray methane (CH_4) gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase. (Table 16-15).
3. Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams (Table 16-16).
4. Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality (Table 16-17).
5. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources (Table 16-18).
6. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution (Table 16-19).
7. Leakage of harmful substances from tanks, pipelines or other equipment may cause groundwater pollution (Table 16-20).
8. Leachate of contaminants used in the drilling mud sump(s) to the intergranular, potable aquifer(s) during the operational phase (Table 16-21).

Table 16-13 Impact assessment and significant rating: Operational phase summary.

Impact	IMPACT DESCRIPTION	PRE - MITIGATION							POST - MITIGATION							IMPACT PRIORITISATION	
No.	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Priority Factor	Final score
Operational phase																	
1	Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.	-1	3	5	5	5	4	-18.00	-1	3	5	4	4	3	-12.00	1.25	-15.00
2	Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.	-1	3	5	5	5	4	-18.00	-1	3	5	4	4	3	-12.00	1.25	-15.00
3	Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams.	-1	3	5	4	4	3	-12.00	-1	2	5	4	4	2	-7.50	1.25	-9.38
4	Poor quality leachate may emanate from the plant footprint area which may have a negative	-1	3	5	4	4	3	-12.00	-1	2	5	4	4	2	-7.50	1.25	-9.38

Impact	IMPACT DESCRIPTION	PRE - MITIGATION							POST - MITIGATION							IMPACT PRIORITISATION	
No.	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Priority Factor	Final score
	impact on groundwater quality.																
5	Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.	-1	3	2	3	3	3	-8.25	-1	2	2	2	3	2	-4.50	1.25	-5.63
6	Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.	-1	3	5	4	4	3	-12.00	-1	2	5	4	4	2	-7.50	1.25	-9.38
7	Leakage of harmful substances from tanks, pipelines or other equipment may cause groundwater pollution.	-1	3	5	4	4	3	-12.00	-1	2	5	4	4	2	-7.50	1.25	-9.38
8	Leachate of contaminants used in the drilling mud sump(s) to the intergranular, potable aquifer(s)	-1	2	3	3	4	4	-12.00	-1	1	3	2	3	3	-6.75	1.00	-6.75

Impact	IMPACT DESCRIPTION	PRE - MITIGATION							POST - MITIGATION							IMPACT PRIORITISATION	
No.	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Priority Factor	Final score
	during the operational phase.																

Table 16-14 Risk assessment matrix and significant scoring: Operational phase impact 01.

Impact Name	**Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	4
Extent of Impact	3	3	Reversibility of Impact	5	4
Duration of Impact	5	5	Probability	4	3
Environmental Risk (Pre-mitigation)					-18.00
Mitigation Measures					
Mitigation Measures	i. All exploration wells should be sealed-off with a combination of casing and grouting to ensure isolation of the saline water from the host-aquifer(s). ii. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. iii. Monitoring results should be evaluated and reviewed on a biannual basis by a registered hydrogeologist for interpretation and trend analysis for submission to the Regional Head of Department. Based on the water quality results, the monitoring network should be refined and updated every three to five years based on hydrochemical results obtained to ensure optimisation and adequacy of the proposed localities. iv. The calibrated groundwater flow model should be updated on a bi-annual basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-15.00

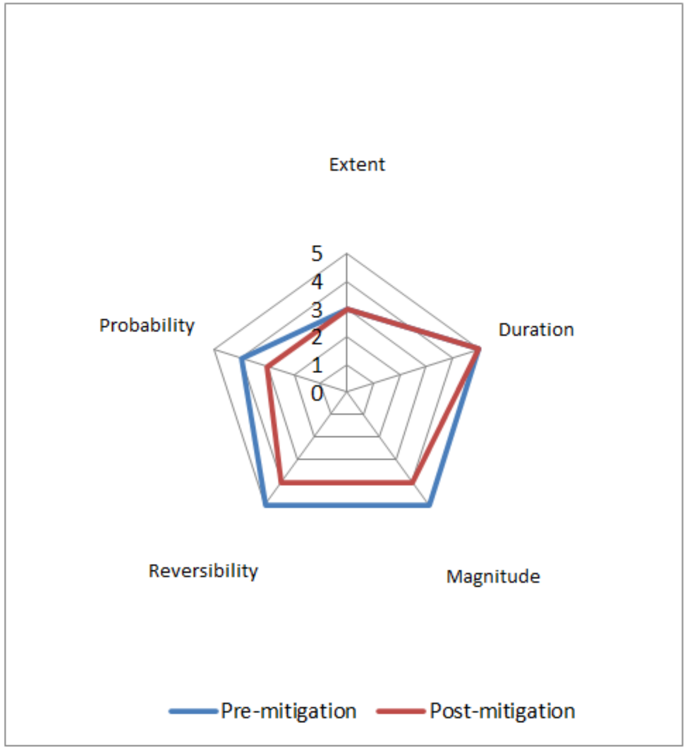


Table 16-15 Risk assessment matrix and significant scoring: Operational phase impact 02.

Impact Name	**Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas production phase.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	4
Extent of Impact	3	3	Reversibility of Impact	5	4
Duration of Impact	5	5	Probability	4	3
Environmental Risk (Pre-mitigation)					-18.00
Mitigation Measures					
Mitigation Measures	i. 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. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. iii. Monitoring results should be evaluated and reviewed on a biannual basis by a registered hydrogeologist for interpretation and trend analysis for submission to the Regional Head of Department. Based on the water quality results, the monitoring network should be refined and updated every three to five years based on hydrochemical results obtained to ensure optimisation and adequacy of the proposed localities. iv. The calibrated groundwater flow model should be updated on a bi-annual basis as newly gathered monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-15.00

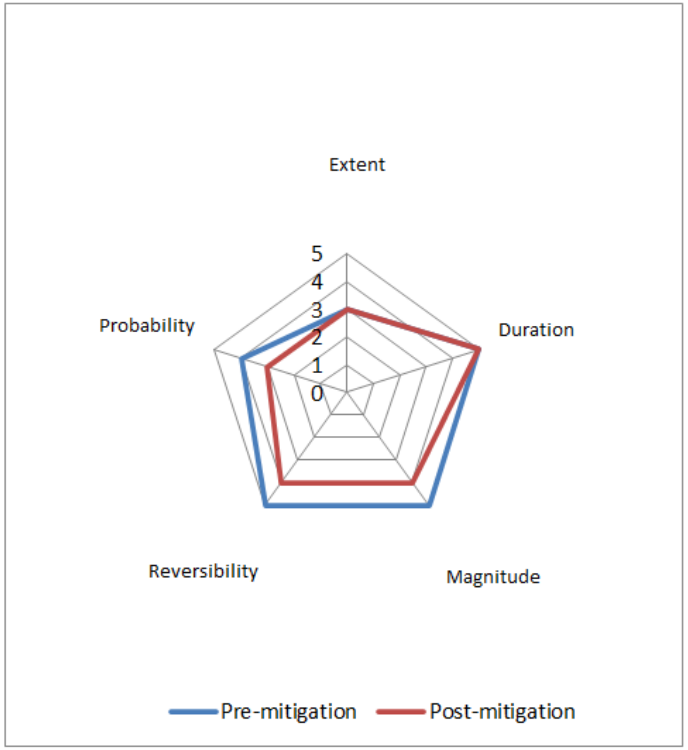


Table 16-16 Risk assessment matrix and significant scoring: Operational phase impact 03.

Impact Name	**Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	4
Extent of Impact	3	2	Reversibility of Impact	4	4
Duration of Impact	5	5	Probability	3	2
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. iii. An appropriately sized spill kit must kept onsite and available at all times. The spill kit size must be relevant to the scale of the activities involving the use of hazardous substances. iv. An appropriate number of spill kits must be available and must be located in all areas where activities are being undertaken. v. The responsible operator must have the required training to make use of the spill kit in emergency situations.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-9.38

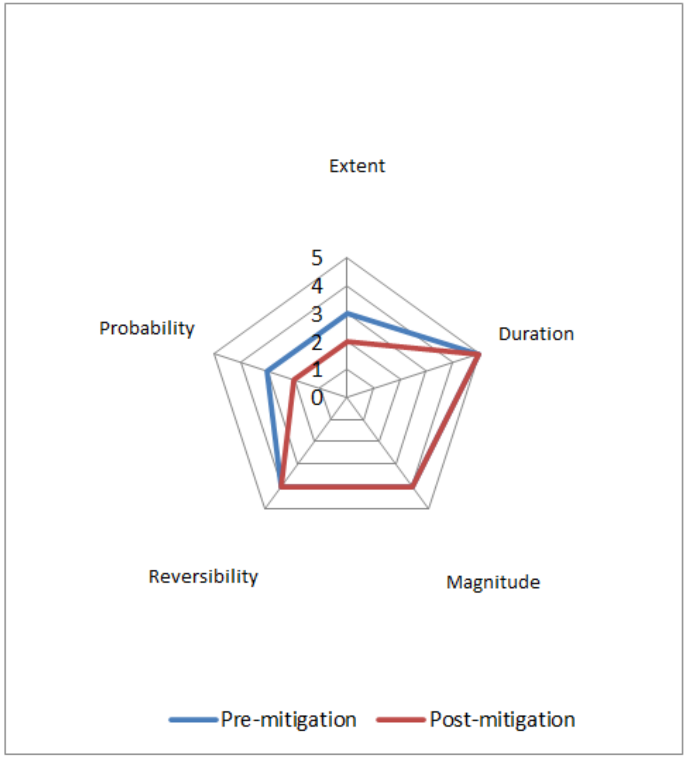


Table 16-17 Risk assessment matrix and significant scoring: Operational phase impact 04.

Impact Name	**Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	4
Extent of Impact	3	2	Reversibility of Impact	4	4
Duration of Impact	5	5	Probability	3	2
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. Plant areas must be fitted with a containment facility for the collection of dirty water. This facility must be impervious to prevent soil and groundwater contamination. Ii. iii. The plant area must have a concrete slab that is sloped to facilitate runoff into a collection sump.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-9.38

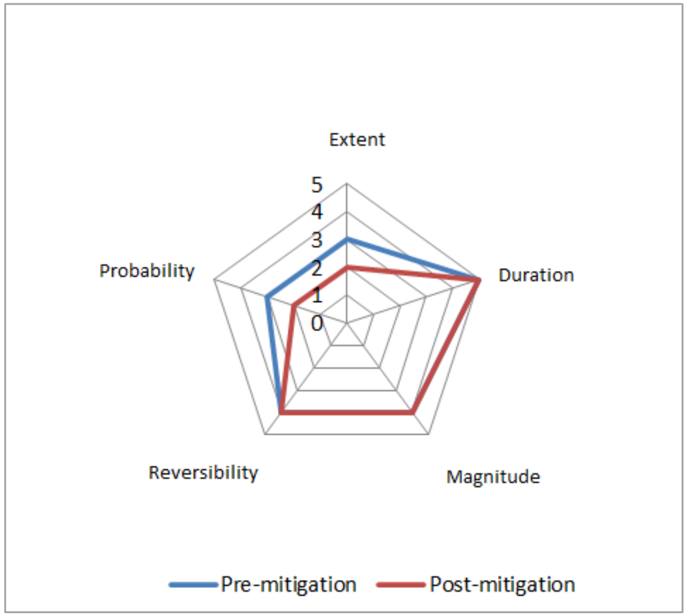


Table 16-18 Risk assessment matrix and significant scoring: Operational phase impact 05.

Impact Name	**Mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of groundwater resources.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
Mitigation Measures	i. Operational vehicles and machinery must be serviced and maintained regularly in order to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted. ii. During servicing of vehicles or equipment, especially where emergency repairs are effected outside the workshop area, a suitable drip tray must be used to prevent spills onto the soil. iii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair. iv. Workshop areas must be monitored for oil and fuel spills, and a suitable oil/water separator should be in place where maintenance work on vehicles and equipment can be performed. . v. An appropriate number of spill kits must be available and must be located in all areas where activities are being undertaken.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-5.63

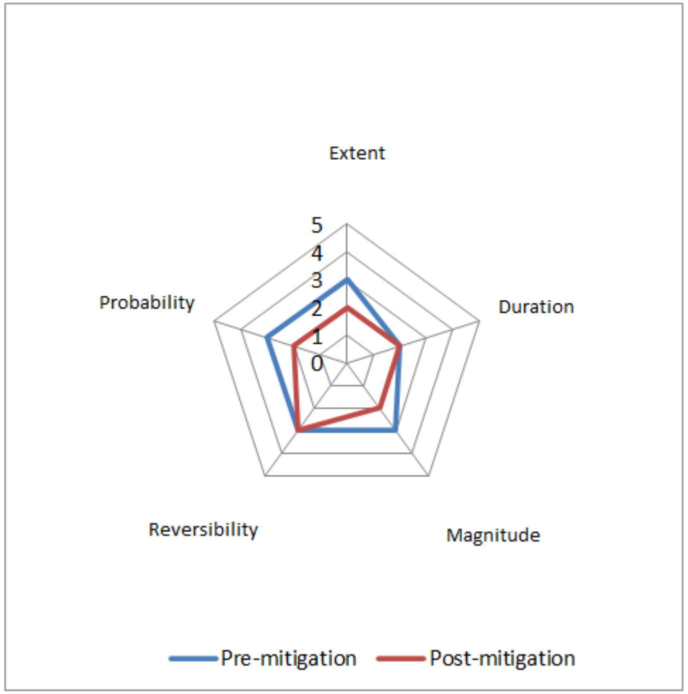


Table 16-19 Risk assessment matrix and significant scoring: Operational phase impact 06.

Impact Name	**Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
Mitigation Measures	i. All hazardous substances used on-site should have an applicable Material Safety Data Sheet (MSDS) to provide information regarding the hazards, emergency response, protective measures and correct storage methodology. ii. Hazardous substance containment facilities to be used during operational phase should comply with the relevant hazardous substance storage legislation in order to ensure spillages are contained. iii. 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. iv. An appropriately sized spill kit must kept onsite and available at all times. The spill kit size must be relevant to the scale of the activities involving the use of hazardous substances. v. The responsible operator must have the required training to make use of the spill kit in emergency situations.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-5.63

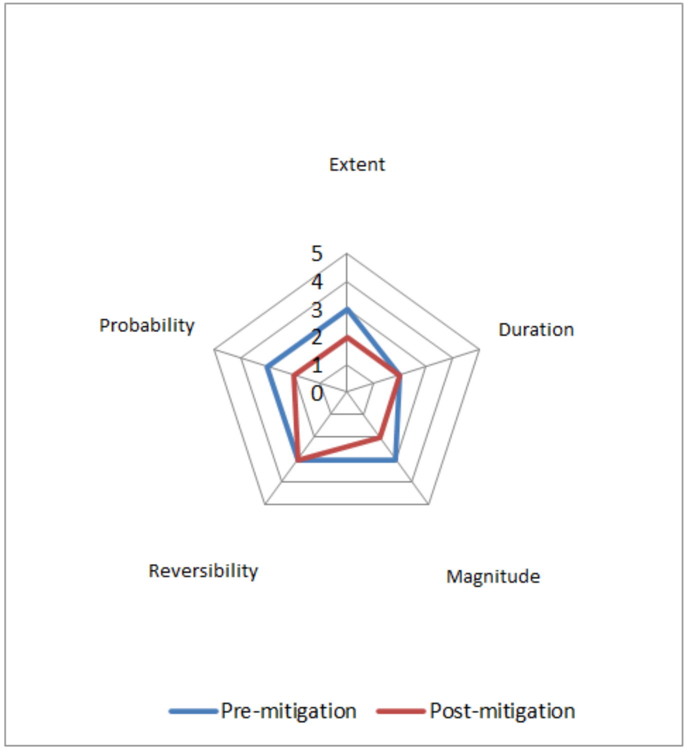


Table 16-20 Risk assessment matrix and significant scoring: Operational phase impact 07.

Impact Name	**Leakage of harmful substances from tanks, pipelines or other equipment may cause groundwater pollution.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	4
Extent of Impact	3	2	Reversibility of Impact	4	4
Duration of Impact	5	5	Probability	3	2
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Mitigation Measures	i. Leaking equipment must be repaired immediately or be removed from site to facilitate repair. ii. Annual external audits should be conducted to ensure that pipelines and waste facilities are maintained and functioning effective and according to licence conditions. iii. The Licensee shall appoint a suitably qualified and responsible person to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities in order to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively. iv. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. v. Monitoring results should be evaluated and reviewed on a biannual basis by a registered hydrogeologist for interpretation and trend analysis for submission to the Regional Head of Department. Based on the water quality results, the monitoring network should be refined and updated every three to five years based on hydrochemical results obtained to ensure optimisation and adequacy of the proposed localities.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-9.38

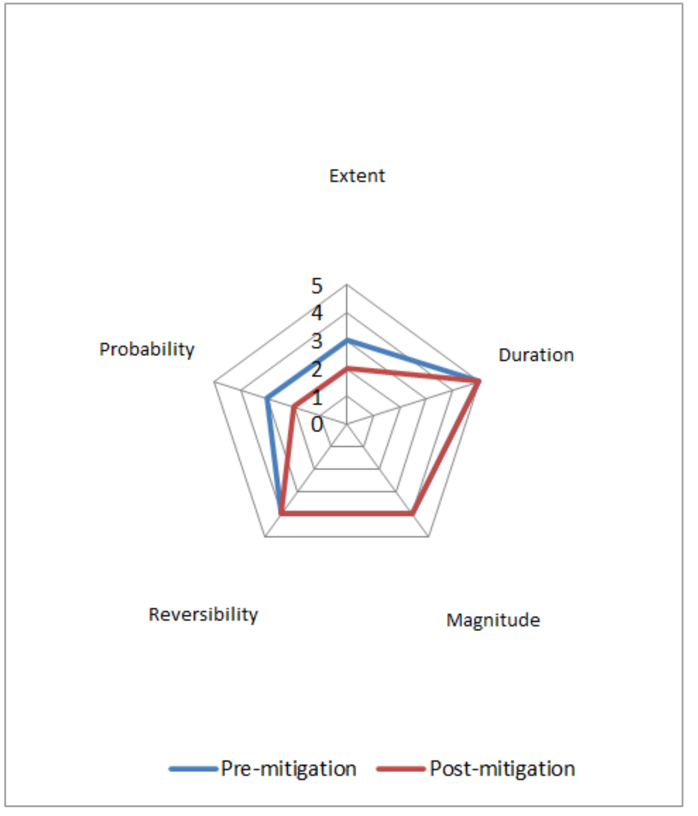
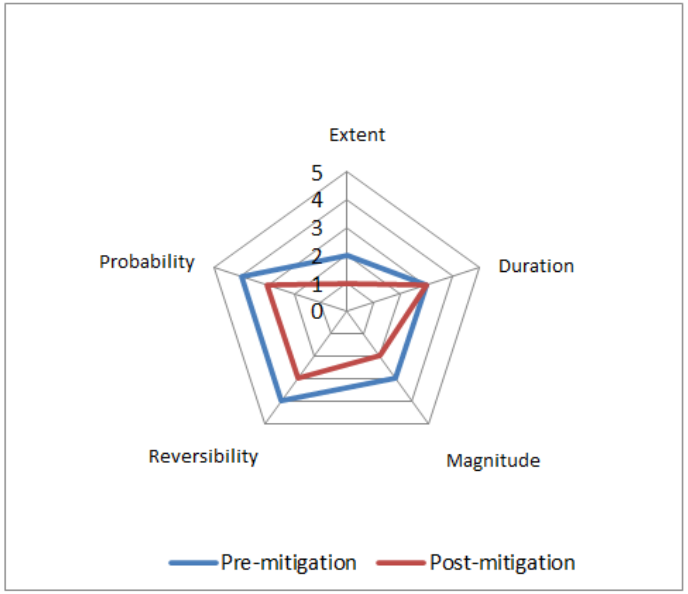


Table 16-21 Risk assessment matrix and significant scoring: Operational phase impact 08.

Impact Name	**Leachate of contaminants used in the drilling mud sump(s) to the intergranular, potable aquifer(s) during the operational phase.**				
Alternative	**Alternative 1**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	2	1	Reversibility of Impact	4	3
Duration of Impact	3	3	Probability	4	3
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Mitigation Measures	i. All actively used drill mud sumps should be adequately liner with an appropriate barrier system in order to isolate and prevent seepage of contaminants from the host aquifer. Furthermore, a biodegradeable polymer should be used as drilling lubricant. i. 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. 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.				
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.00
Final Significance					-6.75



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

Refer to Table 16-22 for a summary of the impact risk matrix and significance ratings for the construction phase. During the decommissioning and post-closure phase the environmental significance rating of groundwater quality impacts on down-gradient receptors are rated as **medium negative** without implementation of remedial measures and **low** to **medium negative** with implementation of proposed mitigation measures. The main impacts associated with the post-closure and decommissioning phase activities include the following:

1. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase (Table 16-23).
2. Migration of stray methane (CH_4) gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase (Table 16-24).
3. Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams (Table 16-25).
4. Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality (Table 16-26).
5. De-mobilisation of heavy vehicles and machinery as part of the decommissioning phase on-site may cause hydrocarbon contamination of groundwater resources (Table 16-27).

Table 16-22 Impact assessment and significant rating: Decommissioning and closure phase summary.

Impact No.	IMPACT DESCRIPTION Impact	PRE - MITIGATION Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	POST - MITIGATION Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	IMPACT PRIORITISATION Priority Factor	Final score
Decommissioning phase																	
1	Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.	-1	3	3	5	5	4	-16.00	-1	2	2	4	4	3	-9	1.25	-11.25
2	Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.	-1	3	3	5	5	4	-16.00	-1	2	2	4	4	3	-9	1.25	-11.25
3	Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams.	-1	3	3	3	4	2	-6.50	-1	2	2	2	3	1	-2.25	1.13	-2.53

Impact	IMPACT DESCRIPTION	PRE - MITIGATION							POST - MITIGATION							IMPACT PRIORITISATION	
No.	Impact	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Priority Factor	Final score
4	Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.	-1	3	3	3	4	2	-6.50	-1	2	2	2	3	1	-2.25	1.13	-2.53
5	De-mobilisation of heavy vehicles and machinery as part of the decommissioning phase on-site may cause hydrocarbon contamination of groundwater resources.	-1	3	3	3	4	2	-6.50	-1	2	2	2	3	1	-2.25	1.13	-2.53

Table 16-23 Risk assessment matrix and significant scoring: Decommissioning and closure phase impact 01.

Impact Name	**Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the borehole closure and decommissioning phase.**				
Alternative	**Alternative 1**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	4
Extent of Impact	3	2	Reversibility of Impact	5	4
Duration of Impact	3	2	Probability	4	3
Environmental Risk (Pre-mitigation)					-16.00
Mitigation Measures					
Mitigation Measures	i.Contractor to 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. -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. ii. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-11.25

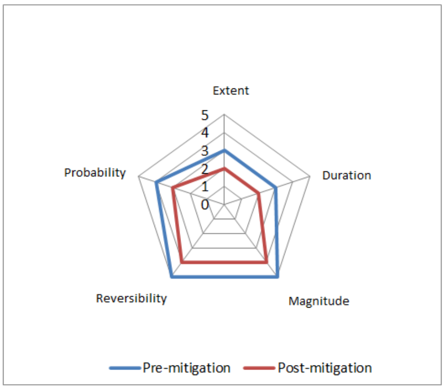


Table 16-24 Risk assessment matrix and significant scoring: Decommissioning and closure phase impact 02.

Impact Name	**Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) borehole closure and decommissioning phase.**				
Alternative	**Alternative 1**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	4
Extent of Impact	3	2	Reversibility of Impact	5	4
Duration of Impact	3	2	Probability	4	3
Environmental Risk (Pre-mitigation)					-16.00
Mitigation Measures					
Mitigation Measures	i.Contractor to 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. -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. ii. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures.				
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.25
Final Significance					-11.25

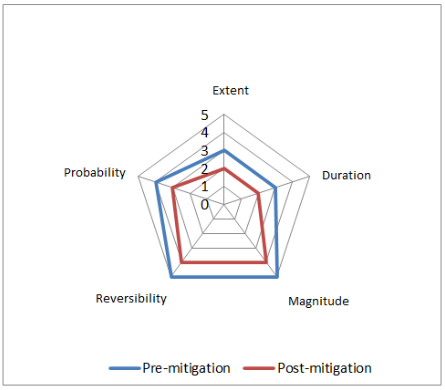


Table 16-25 Risk assessment matrix and significant scoring: Decommissioning and closure phase impact 03.

Impact Name	**Groundwater pollution as a result of wastewater spills and seepage from the evaporation dams.**				
Alternative	**Alternative 1**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	4	3
Duration of Impact	3	2	Probability	2	1
Environmental Risk (Pre-mitigation)					-6.50
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. iv. 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. v. An ECO must be appointed to oversee the rehabilitation phase, and ensure least possible harm to biodiversity and ensure compliance to the rehabilitation plan.				
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.13
Final Significance					-2.53

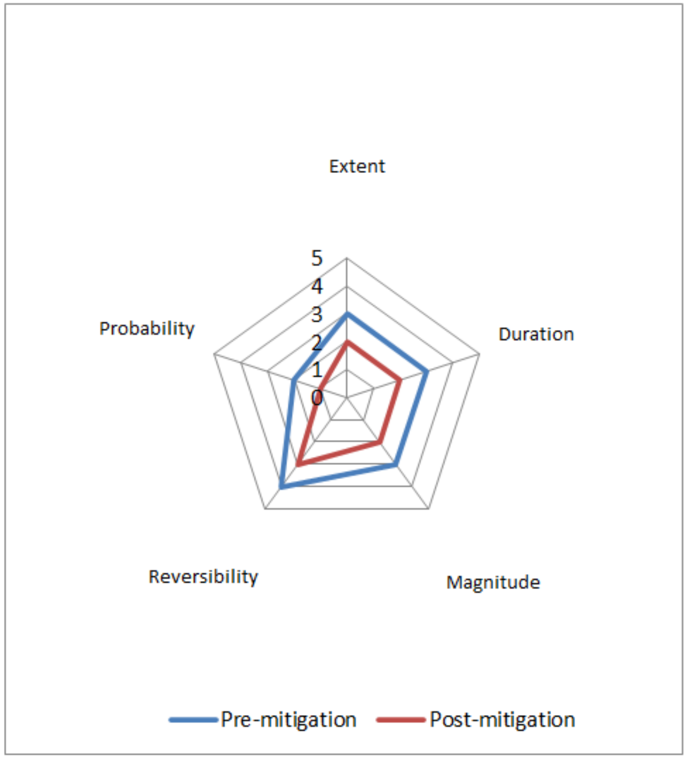


Table 16-26 Risk assessment matrix and significant scoring: Decommissioning and closure phase impact 04.

Impact Name	**Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.**				
Alternative	**Alternative 1**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	4	3
Duration of Impact	3	2	Probability	2	1
Environmental Risk (Pre-mitigation)					-6.50
Mitigation Measures					
Mitigation Measures	i. Develop a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events. ii. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures. iv. 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. v. An ECO must be appointed to oversee the rehabilitation phase, and ensure least possible harm to biodiversity and ensure compliance to the rehabilitation plan.				
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.13
Final Significance					-2.53

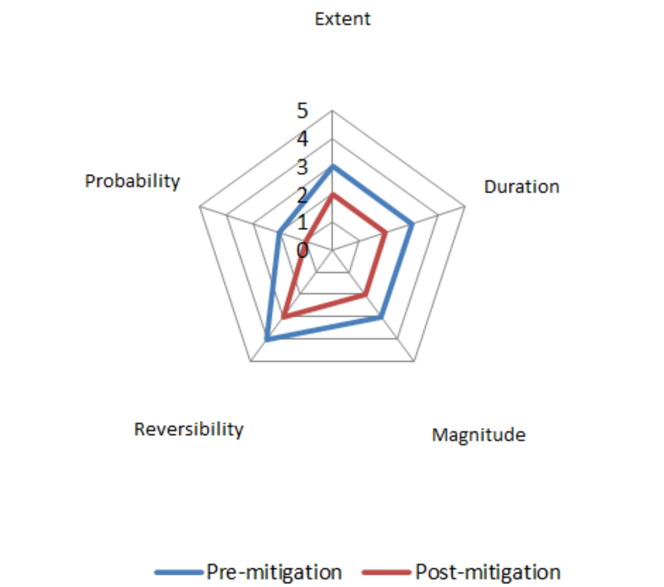
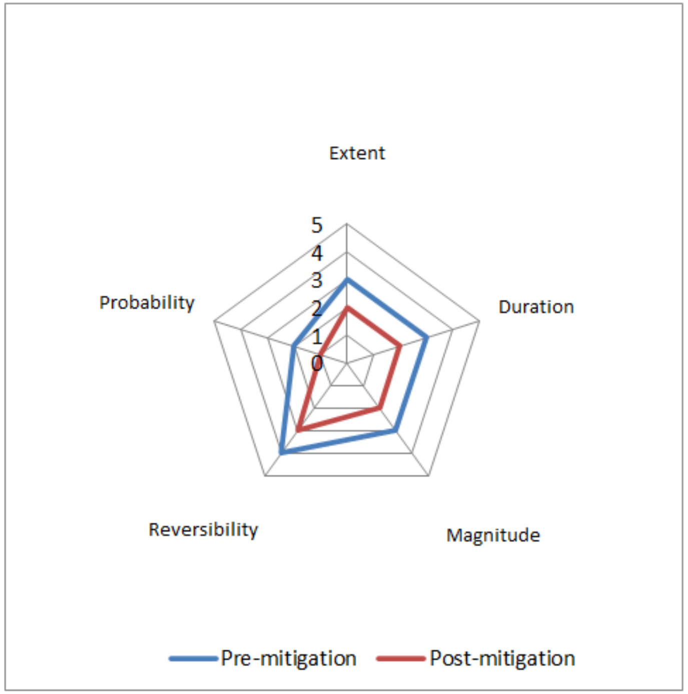


Table 16-27 Risk assessment matrix and significant scoring: Decommissioning and closure phase impact 05.

Impact Name	**De-mobilisation of heavy vehicle and machinery as part of the decommissioning phase on-site may cause hydrocarbon contamination of groundwater resources.**				
Alternative	**Alternative 1**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	2	Reversibility of Impact	4	3
Duration of Impact	3	2	Probability	2	1
Environmental Risk (Pre-mitigation)					-6.50
Mitigation Measures					
Mitigation Measures	i. Operational vehicles and machinery must be serviced and maintained regularly in order to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted. ii. During servicing of vehicles or equipment, especially where emergency repairs are effected outside the workshop area, a suitable drip tray must be used to prevent spills onto the soil. iii. Leaking equipment must be repaired immediately or be removed from site to facilitate repair. iv. Workshop areas must be monitored for oil and fuel spills, and a suitable oil/water separator should be in place where maintenance work on vehicles and equipment can be performed. . v. An appropriate number of spill kits must be available and must be located in all areas where activities are being undertaken.				
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					2
The impact may result in the irreplaceable loss (cannot be replaced or subsitituted) of resources but the value (services and/or functions) of these resources is limited.					
Prioritisation Factor					1.13
Final Significance					-2.53



16.5. Hydrogeological sensitivity

Based on the findings of this investigation and outcomes of the impact assessment a hydrogeological sensitivity map was generated, highlighting groundwater zones which will be sensitive to contamination and should form part of the monitoring protocol. Refer to Table 16-28 for a summary of identified hydrogeological sensitive areas with a spatial representation depicted in Figure 16-1.

Table 16-28 Hydrogeological sensitivity rating (after EIMS).

Sensitivity rating	Description	Hydrogeological component identified	Motivation	Weighting
Low	The inherent feature status and sensitivity is already degraded. The proposed development will not affect the current status and/or may result in a positive impact. These features would be the preferred alternative for mining or infrastructure placement.	All areas not included in either the moderately of highly sensitive zones as identified.	This area excludes groundwater receptors or sensitive areas identified as part of the assessment.	-1
Moderate	The proposed development will negatively influence the current status of the feature to a moderate degree of modification.	A zone of 450m around the proposed gas production wells situated within the primary porosity aquifer associated with alluvium material deposited in flood plains. A zone of 250m around the proposed gas production wells situated within the Karoo formations. A buffer zone of 50m along identified fault zones traverse the project area.	These aquifers cover a substantial portion of the study area and are limited to a zone of variable width and depth. The alluvial aquifer is specifically vulnerable to contamination as it there is a direct connectivity with rivers and streams and associated high permeability. This aquifer is moderately susceptible to impacts from contaminant sources originating within this buffer zone as point source pollution. The intergranular Karoo aquifer can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. Due to higher effective porosity (n) this aquifer is most susceptible to impacts from contaminant sources. This aquifer is moderately susceptible to impacts from contaminant sources originating within this buffer zone as point source pollution. Fault zones targeted as part of the gas production operation can serve as potential preferred pathways for groundwater flow and contaminant transport.	+1

Sensitivity rating	Description	Hydrogeological component identified	Motivation	Weighting
High	The proposed development will negatively influence the current status of the feature to a high degree of modification.	A zone of 350m around the proposed gas production wells situated within the riparian zone primary porosity aquifer associated with alluvium material deposited in flood plains. A zone of 150m around the proposed gas production wells situated within the Karoo formations.	These aquifers cover a substantial portion of the study area and are limited to a zone of variable width and depth. The alluvial aquifer is specifically vulnerable to contamination as it there is a direct connectivity with rivers and streams and associated high permeability. This aquifer is highly susceptible to impacts from contaminant sources originating within this buffer zone as point source pollution. The intergranular Karoo aquifer can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. Due to higher effective porosity (n) this aquifer is highly susceptible to impacts from contaminant sources originating within this buffer zone as point source pollution.	+1

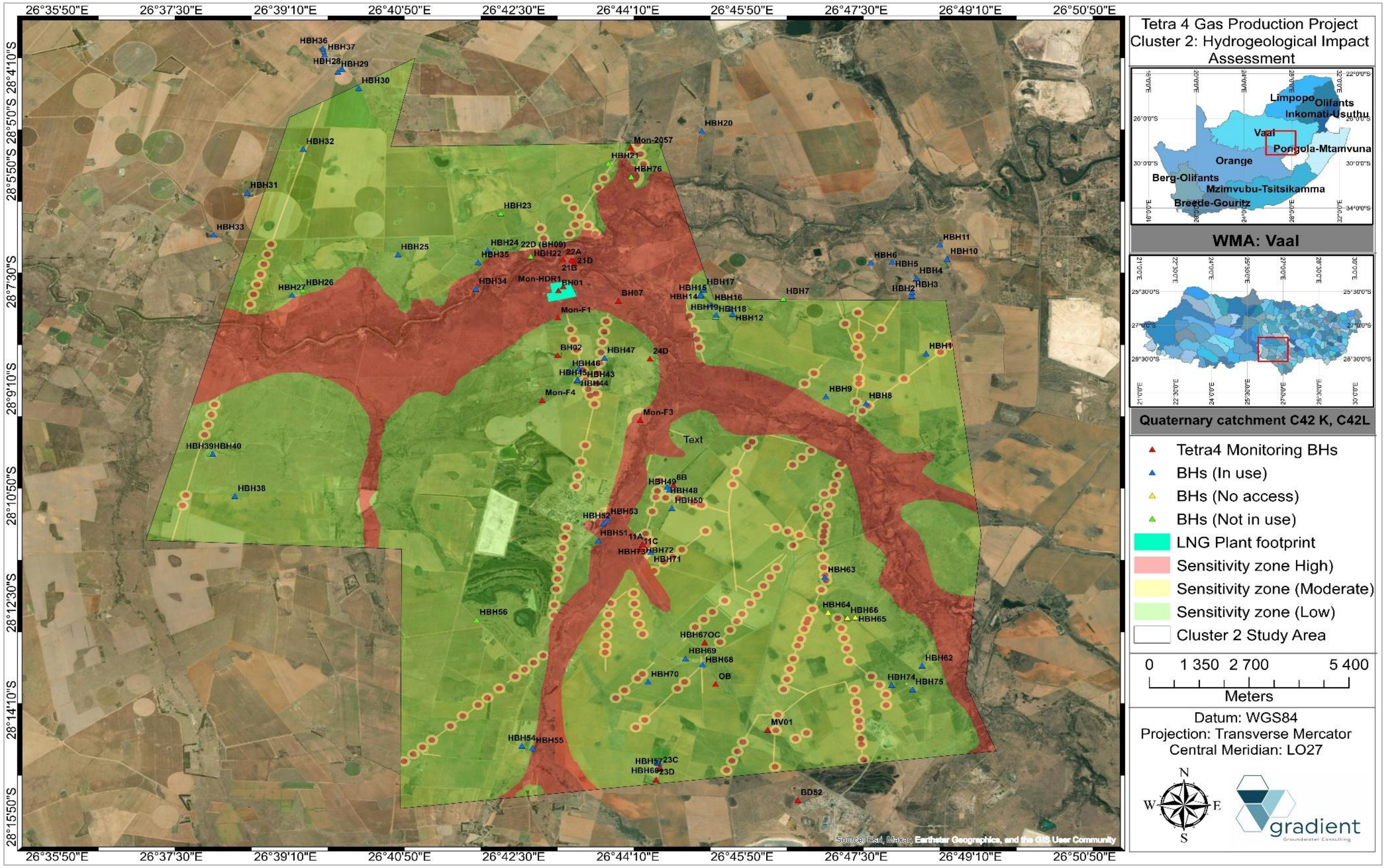


Figure 16-1 **Hydrogeological sensitivity map.**

17. GROUNDWATER MANAGEMENT PLAN

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

17.1. 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 methane gas from the deep, fractured aquifer. If the gas wells are constructed and sealed off to protect the shallow potable Karoo aquifers, the impacts associated with the project can be minimised.

ii. Groundwater pollution as a result of wastewater spills and seepage from the evaporation dan as well as plant footprint including potential leachate from hazardous chemical substances on-site.

iii. Leakage of harmful substances from tanks, pipelines or other equipment may cause groundwater pollution.

iv. Hydrocarbon contamination of groundwater resources caused by heavy vehicles and machinery on-site.

v. Leachate of contaminants used in the drilling mud sump(s) to the intergranular, potable aquifer(s) during the operational phase.

17.2. 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).

17.3. Mitigation and management

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

17.3.1. Construction phase: Management and mitigation measures

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

i. Areas where vegetation has been cleared shall be rehabilitation as soon as possible to minimise erosion. Erosion control measures should be put in place where it is deemed necessary.

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.

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

vi. All construction should take place during the dry season, as far as possible.

vii. 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.

viii. Hazardous substance containment facilities to be used during construction phase should comply with the relevant hazardous substance storage legislation to ensure spillages are contained.

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

x. 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.

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

xii. Construction vehicles and machines must be serviced and maintained regularly to ensure that oil spillages are limited.

xiii. Workshop areas must be monitored for oil and fuel spills.

xiv. 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.

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

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

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

xviii. An integrated groundwater water 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.

17.4. Operational phase: Management and mitigation measures

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

i. 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). Well design will be undertaken according to designs developed by a qualified well engineer.

ii. Daily inspections of drilling pads, pipelines, compressors and the helium plant must be implemented.

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

iv. The existing groundwater flow model should be recalibrated with 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.

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.

vi. Plant areas must be fitted with a containment facility for the collection of dirty water. This facility must be impervious to prevent soil and groundwater contamination.

vii. The plant area must have a concrete slab that is sloped to facilitate runoff into a collection sump.

viii. Hazardous substance containment facilities to be used during operational phase should comply with the relevant hazardous substance storage legislation to ensure spillages are contained.

ix. Develop and implement a stormwater management plan in accordance with GN704 to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be constructed to have adequate freeboard (0.8m below overflow level) to be able to contain water from 1:50 year rain events.

x. The evaporation dam should be adequately lined with an appropriate barrier system to isolate and prevent seepage of contaminants to the host aquifer.

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

xii. A rehabilitation plan must be developed based on site-specific issues and requirements including soft and hard engineering interventions and revegetation.

xiii. 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.

xiv. 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.

xv. 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.

17.5. 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. 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.

iii. 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.

iv. 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.

v. Development and implementation of a post-closure groundwater monitoring program evaluating hydrochemistry will serve as early warning and detection mechanism to implement mitigation measures.

vi. 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.

vii. 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.

viii. 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.

18. 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 18-1 used as guideline for the development of this water monitoring program.

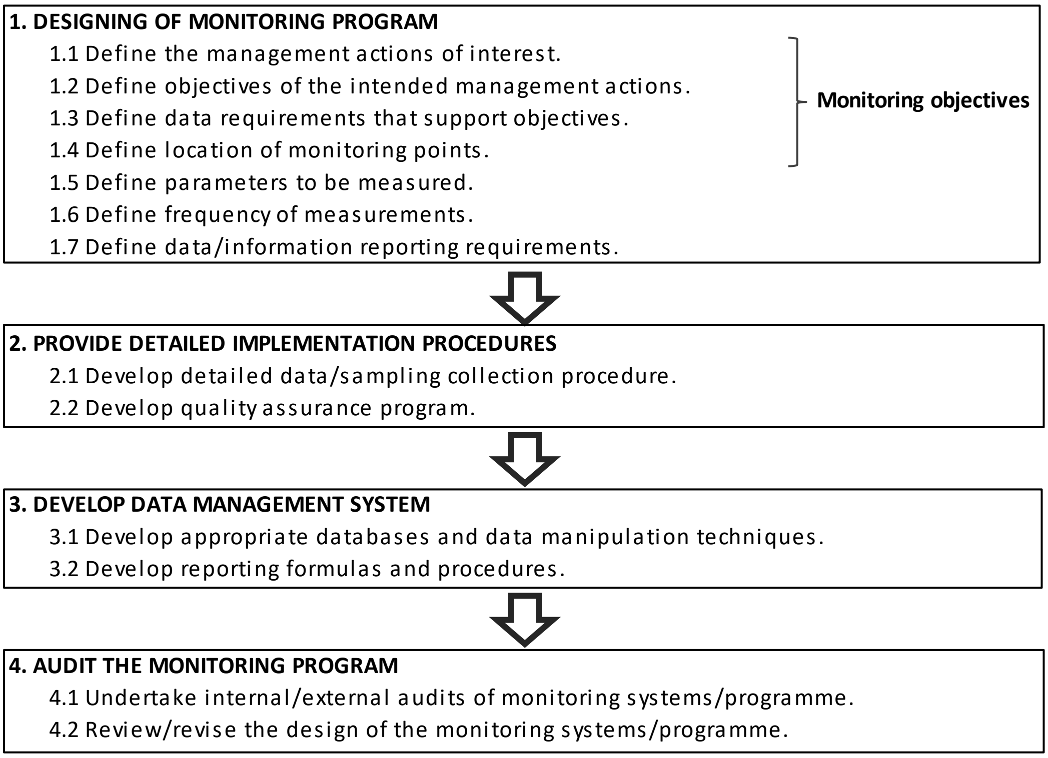


Figure 18-1 Monitoring programme (DWA, 2006).

18.1. 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 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.

18.2. Monitoring network

Tetra4 does have an existing monitoring protocol and network in place which was implemented das part of the phase I operations. It is recommended that additional monitoring boreholes be established down-gradient of the plant expansion footprint to evaluate the expected mass load contribution to environmental and groundwater receptors. Drilling localities for the three proposed new boreholes should be determined by means of a geophysical survey to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms. Table 18-1 summarises the proposed updated and revised monitoring network and program, with relevant information depicted in Figure 18-2. Privately owned, neighbouring boreholes situated within high impact risk areas have been included into the existing monitoring network on a bi-annual basis (after the wet and dry rainy seasons) whereas all other borehole identified as part of the hydrocensus user survey should be visited and analysed on an annual basis. In the event that monitoring of gas production wells indicates gas leaks, casing or cementation failure and the frequency of hydrocensus boreholes are increased to monthly, the analysis must include the full set of elements.

18.3. 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[20]. 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), 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 (VI), Arsenic (As), Copper (Cu), Uranium (U), 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.

[20] 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.

18.4. Water levels

Water levels should be monitored to evaluate the impact of existing groundwater abstraction on aquifer storage and replenishment including privately owned, neighbouring boreholes.

18.5. Monitoring frequency

Groundwater monitoring, i.e., water level measurements and quality analysis should be conducted on a quarterly basis at existing Tetra4 boreholes (including newly proposed monitoring localities down-gradient of the plant area) whereas water level and water quality monitoring at privately owned boreholes should be conducted on a bi-annual basis. Water quality reports summarising monitoring results should be submitted to the Regional Head of the Department within timeframes as stipulated in the WUL conditions.

18.6. 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 18-1 Revised monitoring network and programme.

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
Existing monitoring boreholes						
11A	-28.193137	26.739703	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	As in Section 18.3
11C	-28.19432	26.73908	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
15E	-28.277361	26.641556	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
21A (BH05)	-28.119556	26.722806	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
21B	-28.119389	26.722333	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
21D	-28.120278	26.723028	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
22A	-28.119194	26.720306	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
22D (BH09)	-28.117306	26.721722	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
23C	-28.251048	26.743863	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
23D	-28.254167	26.742944	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
24D	-28.144972	26.741444	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
25A	-28.287028	26.742056	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
25B	-28.302167	26.743083	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
8B	-28.177728	26.747135	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
BD52	-28.259487	26.777427	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
BH01	-28.127231	26.719194	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
BH02	-28.144047	26.718938	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
BH07	-28.129905	26.733792	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Mon-2057	-28.090217	26.73679	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Mon-F1	-28.134285	26.719059	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Mon-F3	-28.160855	26.739085	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Mon-F4	-28.155733	26.71523	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Mon-HDR1	-28.126232	26.720356	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
MV01	-28.241273	26.770132	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
OB	-28.229342	26.757408	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
OC	-28.218611	26.754778	Existing Tetra4 Monitoring borehole	Quarterly	Quarterly	
Existing boreholes in private use						
HBH01	-28.156508	26.794027	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	As in Section 18.3
HBH08	-28.156508	26.794027	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH27	-28.128449	26.654374	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH39	-28.169627	26.635037	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH41	-28.147466	26.724128	Borehole in private use for domestic and irrigation purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH42	-28.147499	26.724159	Borehole in private use for domestic and irrigation purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH43	-28.151021	26.7254	Borehole not in use. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH48	-28.178267	26.74558	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH49	-28.178856	26.746212	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH50	-28.183719	26.746794	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH63	-28.201657	26.783977	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH66	-28.212197	26.789505	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH72	-28.193122	26.7397	Borehole not in use. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH73	-28.193009	26.739636	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH74	-28.229587	26.800249	Borehole in private use for domestic and livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
HBH 116	-28.23821	26.71827	Private borehole not in use. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
HBH 136	-28.21125	26.73142	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
BH 2 DDR	-28.18179	26.7814	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
BH 2 DRR	-28.18186	26.78145	Borehole in private use for livestock purposes. Monitoring pollution plume migration from gas production boreholes	Bi-annually	Bi-annually	
Newly drilled monitoring boreholes						
RTBH 01	-28.212736	26.718075	Site characterisation and monitoring	Quarterly	Quarterly	As in Section 18.3
RTBH 04	-28.120242	26.647642	Site characterisation and monitoring	Quarterly	Quarterly	
RTBH 05	-28.167142	26.62966	Site characterisation and monitoring	Quarterly	Quarterly	
RTBH 08	-28.207812	26.782083	Site characterisation and monitoring	Quarterly	Quarterly	
RTBH 10	-28.177746	26.764675	Site characterisation and monitoring	Quarterly	Quarterly	
Newly proposed monitoring boreholes						
Mon BH01	-28.123973	26.721958	New monitoring borehole down-gradient of the production plant serving as Doringrivier receptor	Quarterly	Quarterly	As in Section 18.3
Mon BH02	-28.124473	26.717889	New monitoring borehole down-gradient of the production plant serving as Sandrivier receptor	Quarterly	Quarterly	
Mon BH03	-28.126838	26.716567	New monitoring borehole down-gradient of the evaporation dam serving as Sandrivier receptor	Quarterly	Quarterly	

Notes: All remaining boreholes as identified during the hydrocensus user survey conducted, should be included into the monitoring network on an annual basis.

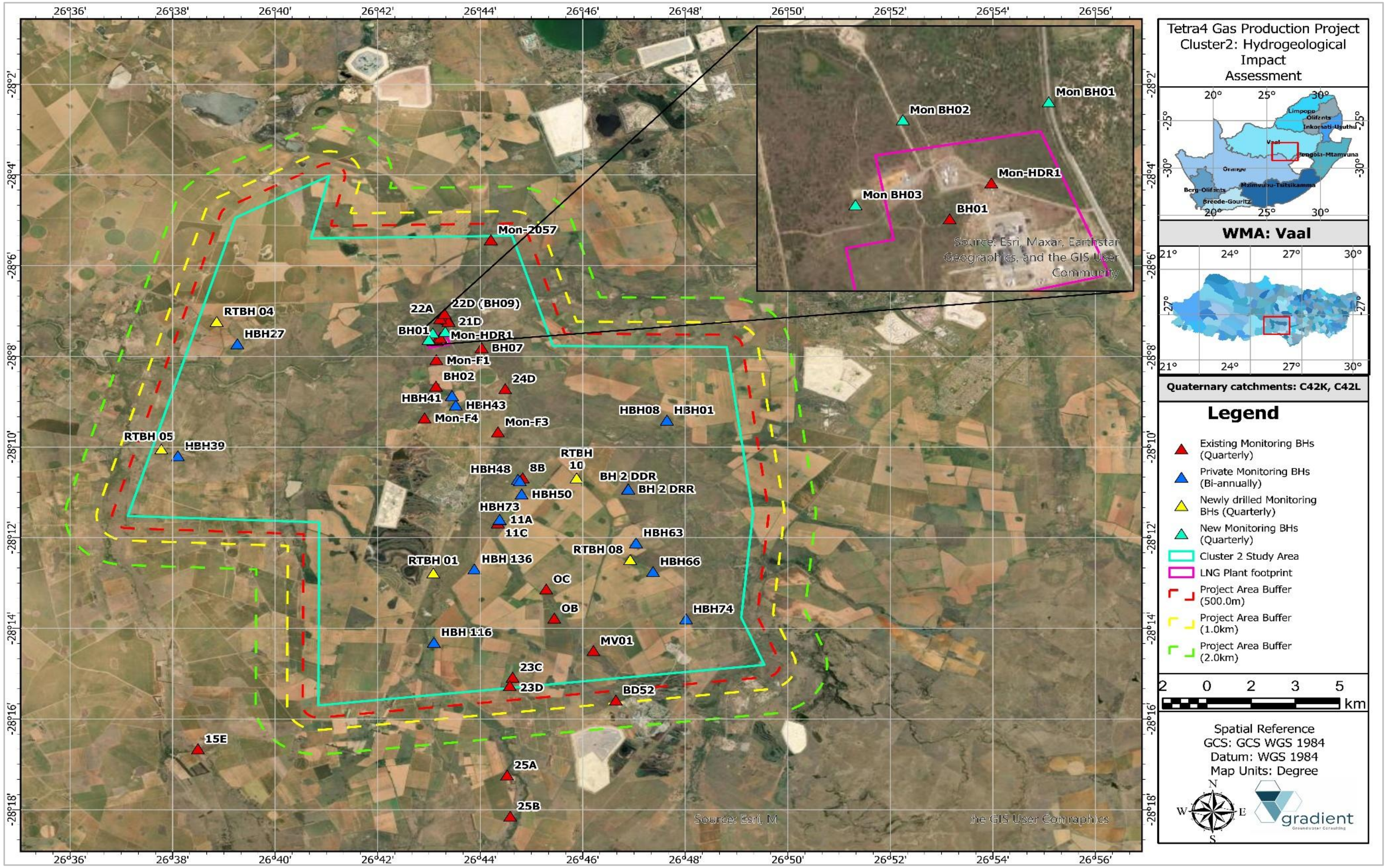


Figure 18-2 **Updated integrated groundwater monitoring network.**

19. CONCLUSIONS

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

The site is predominantly underlain by an intergranular and fractured aquifer system (d2) with the aquifer media consisting mainly of fractured and weathered compact argillaceous strata. According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the North-eastern Pan Belt region. It should be noted that the hydrogeological desktop assessment information has been confirmed by means of a site-specific aquifer characterisation phase performed. For the purposes of this investigation, four main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone:

i. **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. These aquifers cover a large portion of the study area and are limited to a zone of variable width and depth. The alluvial aquifer is specifically vulnerable to contamination as it there is a direct connectivity with rivers and streams and associated high permeability.

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

iii. **An intermediate, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults, contact zones as well as fracture zones that occur in the relatively competent Karoo Supergroup host rock. Fractured sandstones, mudstones and shales sequences are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Although generally low yielding, this aquifer is important to local groundwater users as it forms the sole source of water supply in the region (Lea, 2017).

iv. **A deeper, fractured aquifer** (semi-confined to confined) where 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 plane fractures, faults and contact zones fracture zones that occur in the relatively competent Ventersdorp and Witwatersrand Supergroups host rock. Volcanic formations of the Ventersdorp lavas can also act as aquicludes, restricting the vertical movement of groundwater. Fractured quartzites of the Witwatersrand Supergroup are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

The water in the deep aquifers is naturally saline due to their marine depositional history. It should be noted that the shallow potable Karoo aquifers are separated from deep aquifer systems associated with the Ventersdorp and Witwatersrand Supergroup formations by the 30.0m thick dolerite sill (which may act as an aquitard) that extends across the study area and by the 65.0m thick Dwyka Tillite sedimentary deposit acting as an aquiclude. It should furthermore be noted that, under natural conditions, there is very limited hydraulic connectivity between the deep, fractured and shallow, intergranular aquifers.

The site charactersiation phase conducted confirms that the permeability of the shale matrix of the host aquifer is low while the hydraulic conductivity of geological lineaments traversing the greater study area are relatively high. The latter may act as preferred pathways for groundwater flow and contaminant transport mechanisms. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e., riverbed aquifers can be orders higher than the matrices.

An approximation of recharge for the study area is estimated at ~4.0% of MAP i.e., ~21.69mm/a, ranging between ~6.0mm for the denser Beaufort formation, ~12.0mm for the Volksrust formation and >37.0mm for loose, unconsolidated sediments of alluvial deposits.

The hydrocensus user survey conducted indicates that boreholes targeting the shallow, intergranular host aquifer are largely applied for livestock watering and domestic water supply purposes and the majority of boreholes recorded are in use.

From the site investigation it can be concluded that the water levels are generally shallow with the vadose zone not extensive. During the wet-season evaluation, artesian conditions were observed at isolated boreholes which can be indicative of semi-confined to confined aquifer conditions present or perched aquifer conditions. Time-series monitoring data indicate most water levels suggest a decrease in water levels and recovering trend. The latter can be attributed the onset of the wet cycle and above average rainfall events experienced with rainfall recharge replenishing aquifer storage. It can be observed that there is a relatively quick response to rainfall, suggesting that recharge of the shallow, intergranular aquifer takes place without a prolonged lag effect. Statistical analysis indicate a relatively small coefficient of variation (CV) value for the water levels, suggesting that the local groundwater system is in quasi-steady state conditions.

A groundwater observation borehole situated within the study area have been measured at ~25.0mamsl. This confirms the hypothesis that the deep, fractured aquifer unit have been locally depressurised by years of dewatering from underground mining operations targeting these zones for gold beneficiation.

Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation for both wet-season as well as dry-season contribution (R^2 <0.98). Accordingly, it can be assumed that the regional groundwater flow, hence the pollution plume migration direction, is dictated by topography. The inferred groundwater flow direction will be 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 and Doringrivier, also in the vicinity of the proposed plant expansion footprint, will be in a general northern direction, whereas the groundwater flow direction within the northern catchment of the study area will be mostly in a south to southwestern direction. It is noted that the inferred groundwater flow direction of the deeper, fractured aquifer is in a general northern direction.

The average groundwater gradient (*i*) of the shallow, weathered aquifer in the vicinity of expansion footprints is relatively flat and calculated at a mean of 0.002 – 0.003 for both wet and dry seasons, with a maximum of 0.003 – 0.004 in a south to north orientation and a minimum of 0.001 in a general east to west orientation.

The expected seepage rate from contamination originating at the proposed plant expansion footprint as well as associated infrastructure is estimated at an average of approximately 1.20 to 1.26m/a, with a maximum distance of ~2.86m/a in a southeastern to northwestern direction.

Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater and regional drainages can be generally classified as influent or gaining stream systems. 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.

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

The hydrochemical results of the monitoring boreholes water samples analysed suggest the overall ambient groundwater quality to be moderate with a higher salt load being observed. Groundwater can be described as neutral, saline to very saline and hard to very hard.

The hydrochemical results of the newly established site characterisation boreholes water samples analysed suggest the overall ambient groundwater quality to be good (RTBH08 and RTBH10) to moderate with a higher salt load being observed at boreholes RTBH01 and RTBH04. Groundwater can be described as neutral, saline to very saline (RTBH01 and RTBH04) and hard to very hard.

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. It is noted that borehole localities with elevated NO_3 concentrations are situated within or directly down-gradient of planted crop areas as well as near surface water features.

Surface water quality can be classified as moderate to good with Aluminum (Al) and Iron (Fe) being slightly elevated. It should be noted that there is not a significant change in the downstream water quality compared to the upstream quality with an increase in Aluminum (Al), however all surface water samples analysed suggest elevated heavy metal concentrations i.e., Al and Fe.

Comparison of different hydrochemical signatures observed suggest on-site boreholes to target a shallow, inter-granular aquifer unit as well as a deeper (possibly intermediate, fractured aquifer unit) being more saline. The Sodium-Potassium-Chloride dominance of the deep, fractured aquifer groundwater suggests extremely saline conditions as expected.

In order to evaluate the risk of groundwater containing radioactive substances, earmarked boreholes were subjected to analysis of radionuclides (Gross Alpha and Beta Radioactivity). It is noted that the overall ambient groundwater quality with reference to radioactive substances is good with the majority of boreholes analysed falling below the WHO limits for Gross Alpha/Beta activity. It is however observed that borehole 11A suggests elevated Gross Alpha activity i.e., 7.57Bq/l which is above the WHO limit of 0.50Bq/l. It should be noted that this borehole is situated in relatively close proximity to a mine tailings disposal facility, which may potentially hold radioactive material sourced from mining processes.

A geochemical assessment on overburden and drilling waste material was performed in order to determine the chemical nature and character and to evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for acid rock drainage. Due to the low sulphide content, it can be concluded that the material analysed suggest very low potential for acidic drainage with a very low salt load.

Potential waste material collected were submitted for geochemical characterisation to identify the chemical substances present in the material through analysis of the total concentrations (TC) and leachable concentrations (LC) in order to assess the material type and class. Dominant total concentrations above prescribed thresholds include Arsenic (As), Barium (Ba) as well Copper (Cu) whereas Arsenic (As) was observed as the dominant leachate concentration above prescribed thresholds. All samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and poses a low risk of contamination.

A simplified water and salt balance was developed for the major water balance components of the operations. Major inflows to the evaporation dam include brine water sourced from the LNG production plant (1.30m^3/d) as well as direct precipitation reporting to the facility (2.53m^3/d), while the only major outflow is water loss due to evaporation which accounts to 4.83m^3/d. Due to the high evaporation signature, this component indicates a negative water balance i.e., nett water consumption. Major salt load contribution to this facility includes dissolved salts in the brine reticulated from the LNG production plant (1.13E^{+01}kg/d) as well as dissolved salts in direct precipitation reporting to the facility (5.06E^{-02}kg/d). As salts cannot be removed from the system via evaporation, this component indicates a positive salt balance i.e., nett salt make.

According to the aquifer classification map of South Africa the project area is underlain by a “Minor aquifer”. It should however be noted that the shallow, intergranular aquifer is important to local groundwater users as it form the sole source of water supply in the region. Furthermore, the primary riparian zone aquifer is classified as a major aquifer system due to its highly permeable nature as well as good water quality.

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 existing/proposed activities and associated infrastructure’s risk to groundwater pollution of the shallow, intergranular aquifer is rated as “Moderate”, Di = 109.

A numerical groundwater flow and mass transport migration model was developed and calibrated in steady state based on gathered site characterisation information which was applied as initial hydrogeological conditions for transient simulations.

Operational scenarios simulated suggest that the pollution plume extend within the Karoo formation aquifer covers a total area ranging between 634.0 to 848.0ha reaching a maximum distance of between 150.0m to 180.0m in a radial pattern from the gas production borehole(s) after a simulation period of 20-years.

Operational scenarios simulated suggest that the pollution plume extend within the Riparian zone aquifer covers a total area ranging between 182.0 to 246.0ha reaching a maximum distance of between 250.0m to 300.0m in a radial pattern from the gas production borehole(s) after a simulation period of 20-years. The pollution plume footprints reported on seems like a large area, however this is the combined zone of impact which is actually scattered throughout the study area and focussed in close proximity to proposed gas exploration and production boreholes.

It can be observed that the pollution plume migration in the denser Karoo formations is sluggish while movement in the unconsolidated alluvial deposits of the riparian zone suggest a larger flux. Regional geological lineaments may potentially act as preferred pathways for groundwater flow and contaminant transport mechanisms.

It is noted that the simulated pollution plume will potentially intersect local drainages i.e., Sandrivier, Doringrivier as well as Palmietkuilspruit including the associated riparian zone aquifer.

It is evident that source term mass load contribution to existing neighbouring borehole situated near the gas production boreholes is generally below the SANS241:2015 threshold ranging between 400.0-1200.0mg/l, however borehole locality HBH136 suggest an increase in dissolved solids up to a concentration of >5000.0mg/l with the mass load contribution a function of the distance to the source or gas production borehole.

A scenario was simulated with a pollution plume migration from the evaporation dam footprint for the operational phase. The TDS pollution plume extend covers a total area of approximately 23.89ha reaching a maximum distance of ~550.0m in a general north-northwest direction towards the lower laying drainage system(s) after a simulation period of 20-years. The simulation indicates that no neighbouring boreholes or local drainages are expected to be impacted on during the operational phase. Monitoring boreholes which might potentially be intercepted by the pollution plume include BH01 as well as Mon-HDR01. It is evident that the TDS mass load contribution to down-gradient receptors increase to a concentration of between 1750.0 – 2500.0mg/l, and is a function of the receptor distance from the source. It can be observed that the mass transport of the pollution plume is mostly limited to the shallow, intergranular aquifer, however may also migrate to the deeper, fractured aquifer over time.

An alternative management and mitigation scenario was simulated to evaluate the remedial options available. A passive management scenario evaluating what the mitigating effect of a liner or barrier system implemented underneath the evaporation dam will have on the pollution plume migration were simulated. It is evident that due to the lower conductivity of the liner or barrier system when implemented, the source of contamination is effectively isolated from the groundwater system in the direct vicinity of the evaporation dam footprint and reduces the simulated pollution plume by >50.0% to ~11.58ha. Accordingly, it is recommended that this remedial alternative should be considered best practise for implementation.

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

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. It should be noted that vast areas within the study area have been subjected to historical mining activities and, as such, reflect modified to highly modified present ecological status. A total number of >15 000 historical exploration wells have been drilled throughout the study area, some of which remain uncased and unsealed. The latter may act as preferential pathways and conduits for groundwater flow and contaminant transport mechanisms. Accordingly, this already highly modified zones should form part of the impact significance rating and risk approach.

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

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

In conclusion, two separate appeals were lodged against the decision of the DMRE to grant the IEA wherein certain gaps were identified as the grounds of appeal. The latter was addressed as part of an updated hydrogeological impact assessment with the outcomes summarised in this report. Although the updated study served the purpose of filling the gaps and confirming assumptions and limitations identified as part of the first phase of the investigation, it should be noted that the additional work conducted did not result in any significant or material changes to the overall impact assessment and risk rating.

20. 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 groundwater management plan 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.

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 a localised hydrocensus user survey be performed within a 500.0m radius of each proposed gas production borehole situated within the riparian zone(s) and 350.0m radius of each proposed gas production borehole situated within the Karoo formations in order to identify the presence of other sensitive groundwater receptors and/or private boreholes. Accordingly, the gas production well design must take the results of the hydrocensus into consideration, specifically with regard to the planning and placement of boreholes as part of future drilling programmes.

iv. Additional monitoring boreholes should be established down-gradient of the existing and proposed plant expansion footprints to evaluate the mass load contribution to sensitive environmental and groundwater receptors. Drilling localities should be determined by means of a geophysical survey to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.

v. It is recommended that the revised monitoring program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated 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.

vi. 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.

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

viii. It is noted that the model tends to be sensitive to a variation in porosity ratios assigned and, as such, it is recommended that bulk mass density tests be performed on all newly acquired rock samples in order to verify the effective porosity to be incorporated in the pollution plume migration model update.

ix. It is recommended that a weather station 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.

x. All preferred groundwater flow pathways which are in direct connection with surface topography such as decommissioned gas production boreholes as well as historical mining exploration boreholes should be sealed off and rehabilitated according to best practise guidelines.

21. 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 17 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 authorised 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.

22. REFERENCES

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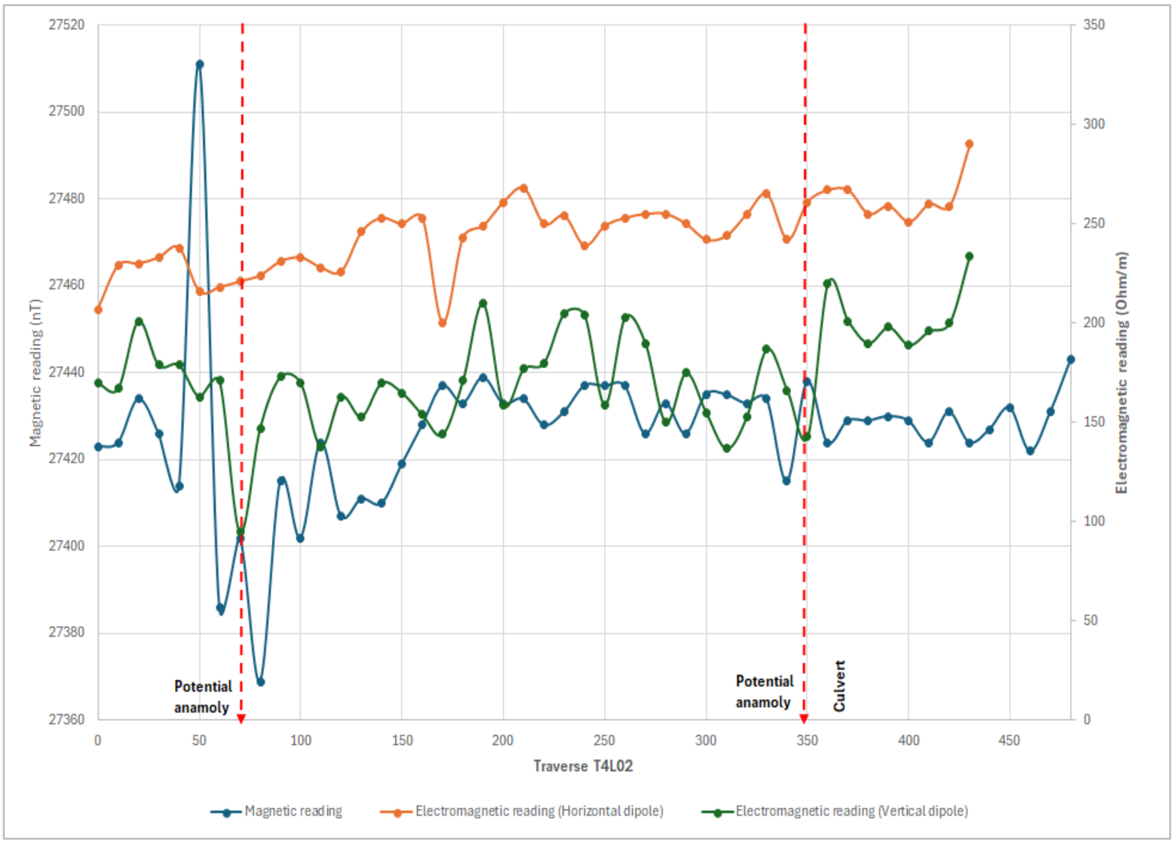
23. APPENDIX A: RAINFALL DATA (RAINFALL ZONE 4C4)

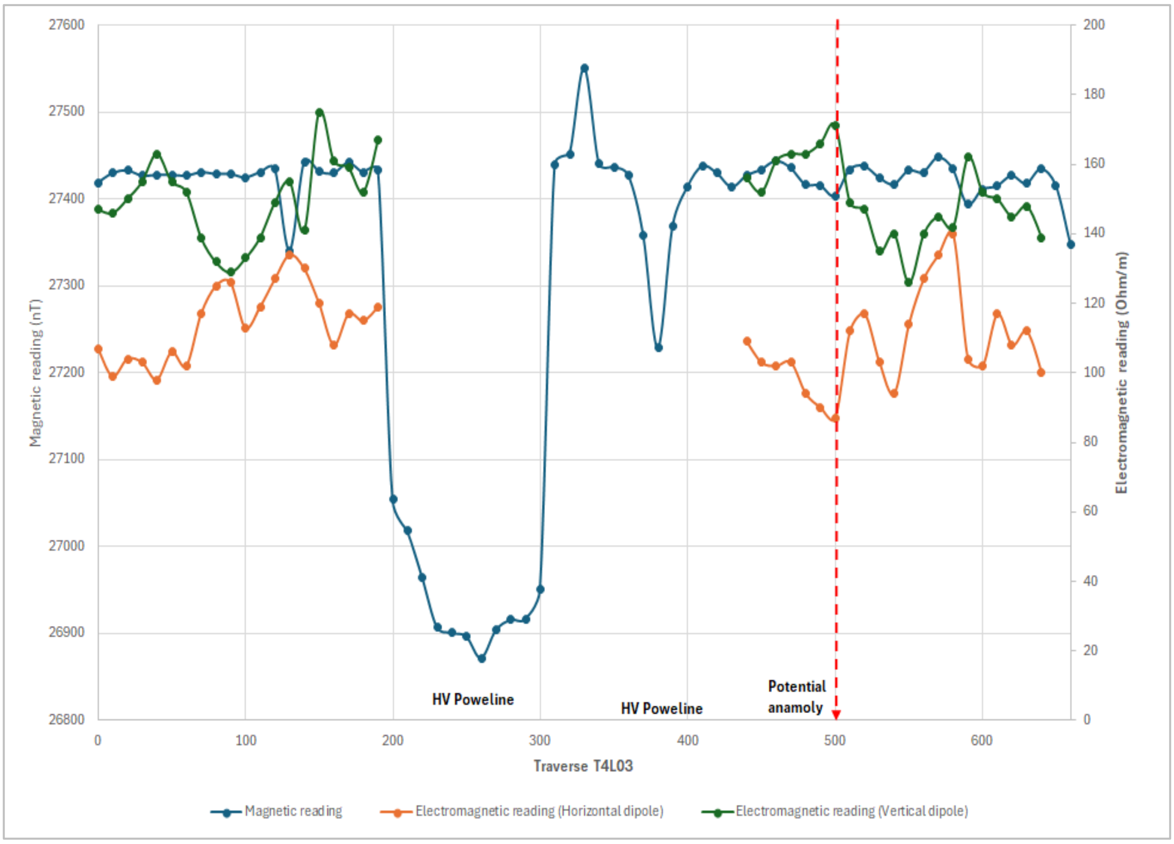
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	45.0	34.3	57.4	48.7	62.9	123.0	31.7	31.1	0.1	0.0	0.2	3.1	437.5
1921	14.7	129.2	198.3	101.3	19.0	53.2	1.4	24.4	20.4	0.0	11.8	1.3	575.0
1922	32.6	112.4	79.8	53.0	109.8	29.2	42.9	27.3	17.2	8.4	9.4	0.7	522.7
1923	36.9	40.7	14.1	72.8	63.8	107.6	11.3	3.9	0.2	0.1	3.9	62.4	417.6
1924	63.6	128.4	101.9	99.0	36.7	194.4	64.0	27.8	6.0	0.1	0.3	16.6	738.9
1925	16.1	17.0	34.2	72.8	101.4	61.1	17.6	2.5	1.0	0.1	0.4	23.3	347.6
1926	53.0	41.2	60.6	99.0	36.1	91.9	14.0	0.1	0.1	30.2	3.0	2.1	431.2
1927	39.2	22.0	66.3	141.2	40.1	102.3	38.8	0.9	0.7	0.1	4.2	21.9	477.5
1928	41.3	50.6	42.8	135.5	30.9	74.6	19.4	30.6	42.0	19.6	18.1	81.5	587.0
1929	10.7	73.7	100.8	71.6	61.1	71.8	39.1	13.8	4.0	4.7	2.9	1.3	455.5
1930	31.8	31.2	48.5	116.3	74.5	65.2	134.1	0.1	6.7	20.9	0.8	1.1	531.1
1931	73.9	119.0	32.2	26.4	83.4	58.6	8.1	1.1	1.3	0.1	0.2	9.7	413.9
1932	10.4	62.4	97.3	12.0	29.1	52.2	40.4	3.3	3.4	0.1	0.8	7.0	318.4
1933	18.0	147.8	102.0	264.8	57.4	72.6	49.0	86.7	13.1	31.3	9.9	6.1	858.7
1934	76.1	125.8	68.9	36.1	63.8	83.9	54.6	14.8	2.3	0.1	8.4	14.3	549.2
1935	20.7	95.6	81.9	66.8	75.9	104.0	35.1	30.8	0.1	0.1	0.1	0.9	511.8
1936	41.8	212.6	38.6	141.1	71.5	56.3	13.0	3.6	0.1	0.4	0.5	15.9	595.3
1937	1.5	24.2	64.1	127.2	122.1	20.6	48.1	13.3	18.8	7.6	12.5	3.0	463.1
1938	94.0	13.6	68.4	101.4	123.7	29.6	5.5	25.7	2.7	30.1	31.0	4.6	530.3
1939	61.5	85.0	27.0	30.0	68.8	88.7	44.7	10.0	13.7	0.2	0.7	23.7	453.7
1940	2.8	94.5	68.5	145.9	91.1	37.7	53.8	0.2	0.2	2.7	0.2	14.9	512.3
1941	59.6	9.8	24.9	110.0	63.9	104.7	62.5	11.1	0.1	0.1	43.9	6.7	497.1
1942	87.2	68.4	137.1	83.3	71.0	82.5	102.3	112.4	0.1	52.6	51.8	11.7	860.3
1943	103.1	155.2	135.1	67.2	140.4	52.9	0.7	16.5	51.7	0.1	0.2	38.8	761.9
1944	60.4	86.0	12.5	51.5	55.3	112.7	5.7	13.3	0.1	3.2	0.2	0.7	401.6
1945	14.3	19.2	28.0	129.3	68.0	121.8	33.3	26.6	0.1	0.1	0.1	2.0	442.6
1946	84.8	34.1	53.4	54.0	52.0	58.6	72.9	5.5	0.1	10.5	0.3	26.4	452.4
1947	39.3	60.4	129.0	86.1	38.9	214.2	67.1	15.2	0.1	0.1	0.1	4.1	654.5
1948	34.1	57.8	11.6	64.9	31.9	55.8	15.0	10.1	4.9	3.6	8.8	5.7	304.2
1949	38.1	51.0	106.5	65.1	64.8	88.2	92.0	58.1	4.9	12.2	20.1	2.9	603.9
1950	39.8	37.0	107.9	77.5	47.5	72.8	71.2	19.1	9.2	10.8	7.2	4.0	504.0
1951	45.6	18.2	24.2	54.1	91.2	47.3	21.3	0.7	2.4	30.0	0.4	7.2	342.6
1952	51.2	83.9	137.4	22.2	138.2	40.8	50.3	6.9	0.1	0.1	8.4	1.3	540.9
1953	72.4	68.5	50.1	48.6	125.3	108.8	13.1	14.8	14.0	1.6	0.1	2.4	519.8

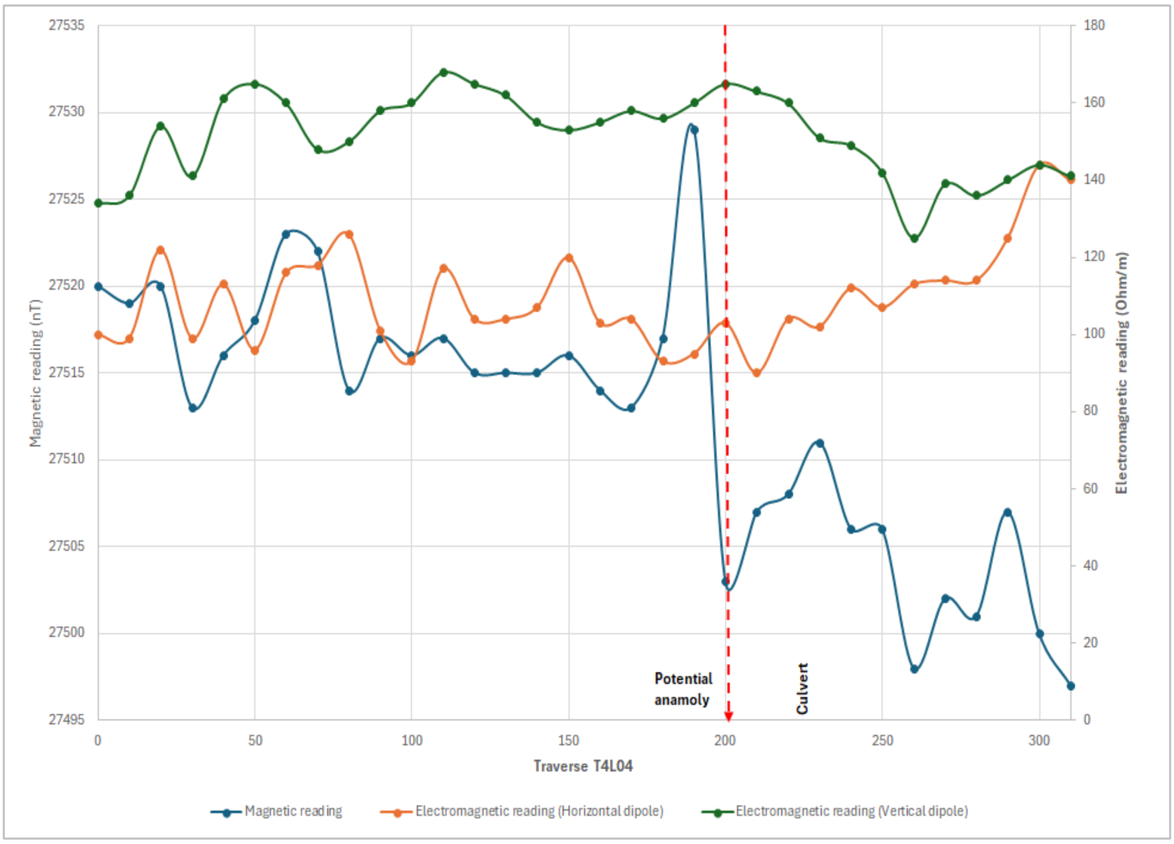
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1954	7.5	36.3	67.9	159.4	127.7	32.1	71.0	27.2	10.6	2.0	0.2	1.9	543.9
1955	38.9	50.6	86.2	35.1	161.7	103.9	15.5	40.5	0.5	0.1	0.1	19.7	552.8
1956	103.3	51.0	145.3	132.6	43.3	58.1	33.7	2.6	29.0	21.3	21.6	130.3	772.2
1957	119.3	62.5	121.1	182.5	33.4	47.6	48.6	27.6	0.4	0.0	0.1	21.9	665.0
1958	22.6	40.6	99.1	54.8	41.0	37.6	74.2	54.7	1.4	31.7	0.1	2.8	460.5
1959	57.7	49.7	79.5	37.3	70.9	75.9	50.4	7.7	3.0	14.1	24.0	10.3	480.3
1960	37.5	39.4	116.1	69.1	37.3	45.3	97.7	34.7	36.6	4.5	6.5	2.3	527.1
1961	1.3	105.6	37.9	38.6	89.4	79.6	46.2	2.5	0.1	0.0	1.1	8.4	410.6
1962	35.0	61.5	51.9	119.9	46.7	65.0	71.5	28.4	18.8	8.0	0.0	0.7	507.3
1963	34.5	83.5	51.4	48.0	29.0	99.4	36.7	6.4	21.7	0.1	14.7	1.5	426.8
1964	94.9	20.0	116.7	83.2	12.6	17.5	44.4	1.9	8.4	20.7	0.2	7.5	427.9
1965	40.2	53.5	20.9	108.8	69.9	25.1	6.9	1.4	10.2	0.1	0.3	7.3	344.3
1966	36.6	45.1	73.8	190.8	155.0	76.4	71.5	49.4	0.7	0.2	1.3	3.2	704.1
1967	52.8	75.0	34.5	22.4	15.2	68.8	56.5	56.0	0.0	2.6	14.0	1.3	399.0
1968	31.7	27.8	85.8	31.9	39.5	78.6	56.4	98.4	6.5	0.0	6.6	4.0	467.2
1969	85.8	26.9	53.9	72.4	38.1	23.9	22.1	27.9	15.1	25.1	1.7	18.6	411.4
1970	52.0	60.5	103.3	105.3	59.9	52.9	54.9	36.0	0.0	0.5	0.1	0.0	525.3
1971	31.9	47.6	87.3	123.8	140.4	98.2	22.4	5.8	8.9	0.1	0.0	0.0	566.3
1972	36.9	30.6	17.8	56.0	110.5	44.3	51.8	1.6	0.0	7.3	27.1	46.1	430.0
1973	32.8	51.8	64.4	188.4	102.3	84.3	65.8	3.7	0.4	0.0	8.8	5.2	607.9
1974	20.8	181.2	71.5	128.7	94.0	85.1	37.7	16.0	2.2	5.7	4.3	29.6	676.8
1975	22.8	95.9	96.8	154.3	129.0	69.7	46.1	23.7	17.2	0.0	0.4	24.0	679.9
1976	99.0	69.2	61.4	94.1	50.8	110.6	21.3	1.5	0.6	0.0	2.4	62.9	573.9
1977	53.9	26.5	59.8	76.1	70.9	100.2	96.7	0.0	7.7	0.5	8.2	21.9	522.5
1978	30.0	41.7	56.7	92.5	70.1	15.7	10.0	23.9	1.7	33.9	78.2	9.8	464.2
1979	35.6	92.0	42.8	31.2	79.1	55.1	11.6	4.5	0.0	0.3	1.2	90.8	444.2
1980	5.1	151.4	49.4	103.8	122.2	55.3	21.0	6.5	5.7	0.0	55.7	6.3	582.5
1981	38.3	61.5	101.3	75.7	26.5	48.8	126.9	0.9	3.7	17.9	0.0	20.7	522.2
1982	91.1	50.4	39.6	41.3	52.5	22.4	25.7	8.0	15.4	22.7	0.3	2.9	372.2
1983	95.9	99.6	31.8	47.7	22.1	79.1	10.4	19.6	0.3	1.9	21.8	3.5	433.8
1984	67.1	83.1	52.7	53.1	78.8	78.9	7.9	1.5	12.5	0.0	0.1	2.8	438.4
1985	76.9	34.2	77.2	73.0	12.8	58.6	48.6	3.5	20.6	0.0	18.0	10.0	433.3
1986	62.6	118.4	71.4	45.2	80.0	46.8	33.3	0.3	0.1	8.9	23.4	156.0	646.5
1987	25.6	116.1	58.2	29.2	117.1	174.9	78.3	23.5	8.1	3.2	5.3	31.2	670.7
1988	149.5	67.9	80.2	111.2	127.6	54.8	46.8	27.5	7.6	0.8	2.4	0.5	676.8
1989	42.9	53.8	51.4	43.8	107.6	88.9	65.3	2.1	9.6	10.4	2.7	3.0	481.4

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1990	17.5	25.8	30.8	166.8	66.7	116.7	5.4	1.5	8.0	0.5	0.0	41.0	480.7
1991	88.8	37.6	62.7	21.3	16.0	16.4	14.4	0.0	0.0	3.4	36.1	0.1	296.8
1992	51.4	170.0	39.9	64.3	82.7	46.2	27.0	3.7	0.6	0.0	7.9	2.9	496.5
1993	92.9	41.5	94.1	62.9	97.9	52.2	38.9	0.0	0.3	0.2	0.0	1.7	482.7
1994	31.6	40.5	46.8	84.0	42.9	101.6	21.3	39.1	0.4	0.0	13.1	3.8	425.1
1995	61.0	75.5	137.8	90.7	100.7	71.1	130.6	43.6	0.0	35.3	10.6	23.9	780.8
1996	58.0	129.4	49.6	124.4	39.6	110.3	97.0	61.8	10.4	25.4	6.6	28.5	740.9
1997	29.5	72.3	90.2	126.2	61.1	154.9	12.3	0.5	0.0	0.0	0.2	16.6	563.9
1998	25.3	161.7	103.5	100.7	59.4	41.3	18.5	46.5	0.5	0.0	0.1	2.6	560.1
1999	53.6	19.5	125.9	96.7	33.3	113.5	25.7	30.6	3.1	0.1	0.1	20.7	522.8
2000	95.1	54.9	123.1	41.7	45.5	85.9	120.8	28.7	20.6	3.1	24.4	3.6	647.4
2001	111.0	76.0	175.9	78.2	62.1	40.1	37.7	27.3	2.7	0.1	50.1	10.2	671.3
2002	24.4	32.9	84.2	72.9	75.2	88.7	45.1	7.4	0.0	0.0	7.6	14.3	452.6
2003	21.2	79.3	26.3	50.3	57.7	108.5	24.2	0.0	12.3	9.1	5.8	5.9	400.6
2004	11.6	31.9	60.1	145.2	72.6	48.3	31.5	21.8	2.7	0.0	0.0	0.7	426.4
2005	45.5	61.1	26.2	130.8	104.5	63.4	11.5	7.2	0.0	0.0	48.3	10.0	508.4
2006	30.3	40.8	43.6	26.8	22.2	4.6	34.2	2.3	19.5	0.0	0.0	39.8	264.1
2007	86.2	82.9	74.2	137.0	21.4	93.7	6.3	48.3	4.0	0.0	0.0	0.0	554.1
2008	59.1	148.2	41.7	85.7	97.6	36.5	4.9	56.0	19.6	10.4	8.3	8.6	576.6
2009	86.2	52.0	115.5	201.1	44.1	25.6	36.7	13.2	0.0	0.0	0.0	0.0	574.4
Geometric mean	**49.6**	**69.0**	**72.0**	**87.2**	**69.8**	**72.4**	**42.3**	**19.8**	**7.0**	**6.8**	**9.3**	**15.9**	**521.0**
Minimum	**1.3**	**9.8**	**11.6**	**12.0**	**12.6**	**4.6**	**0.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**264.1**
Maximum	**149.5**	**212.6**	**198.3**	**264.8**	**161.7**	**214.2**	**134.1**	**112.4**	**51.7**	**52.6**	**78.2**	**156.0**	**860.3**
Standard deviation	**30.3**	**42.5**	**37.8**	**47.5**	**35.7**	**37.5**	**30.8**	**22.1**	**9.7**	**11.0**	**14.8**	**25.8**	**121.5**

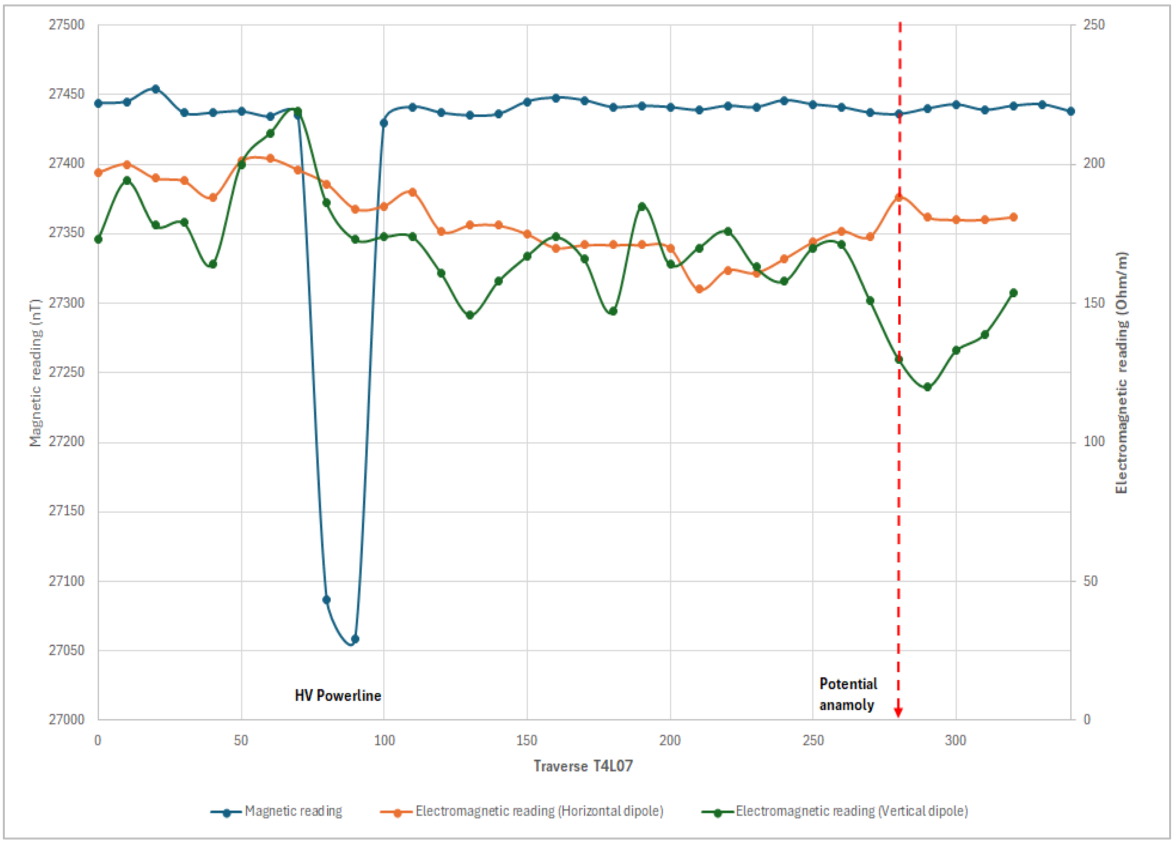
24. APPENDIX B: GEOPHYSICAL SURVEY FIELD MEASUREMENTS AND PROFILES



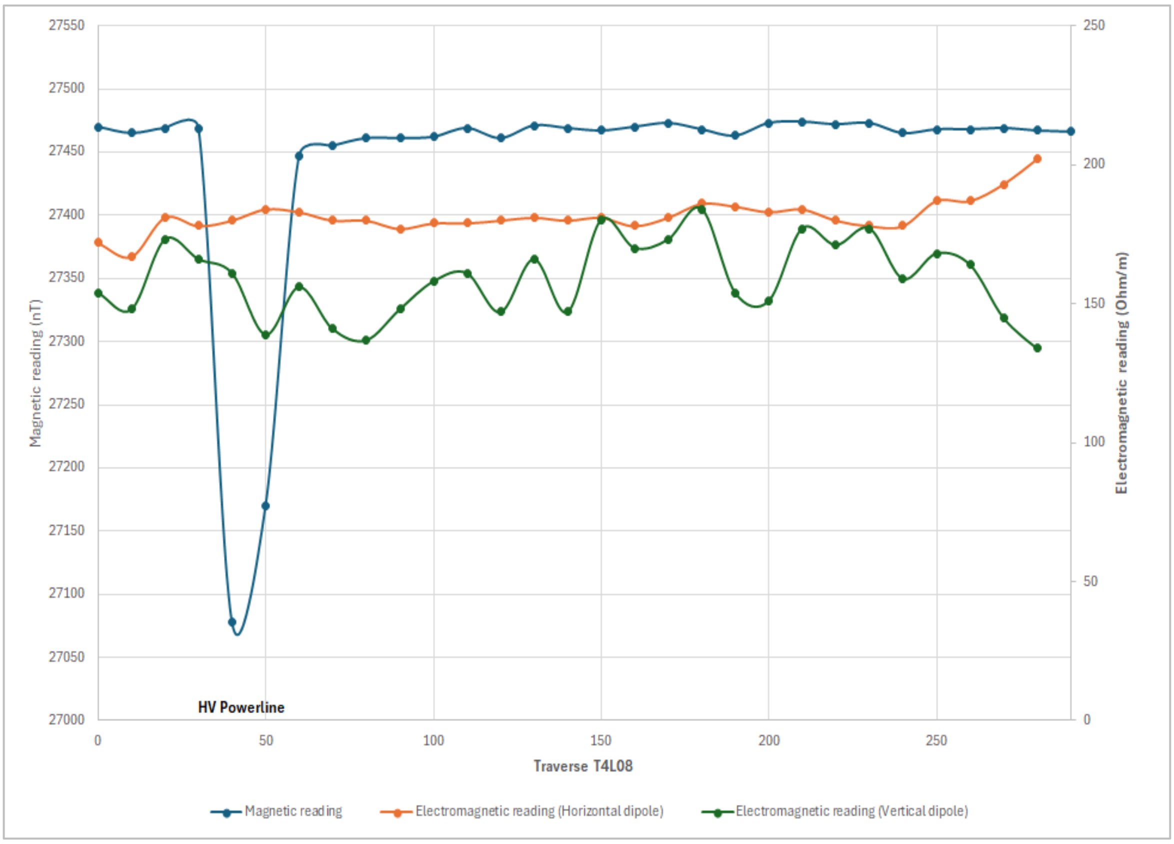




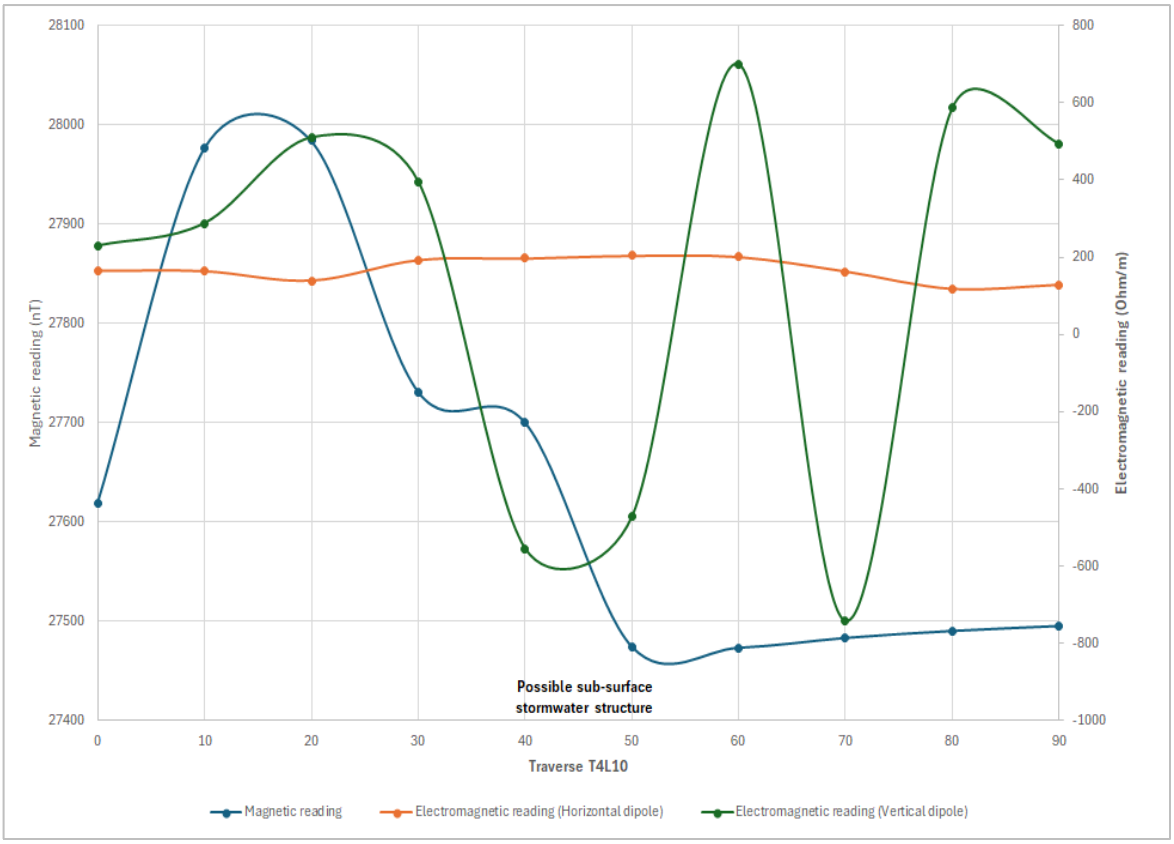
Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
Potential anamoly
Culvert
Traverse T4L04
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)



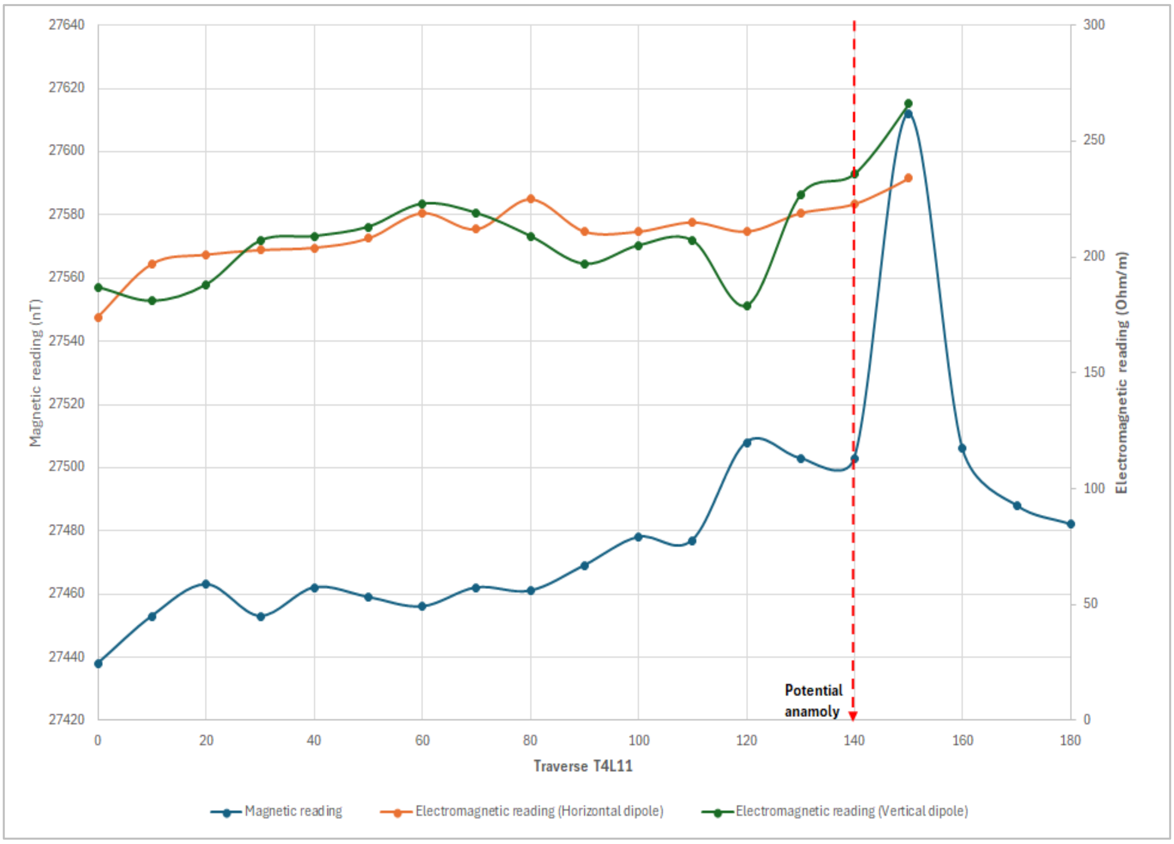
Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
HV Powerline
Potential anamoly
Traverse T4L07
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)

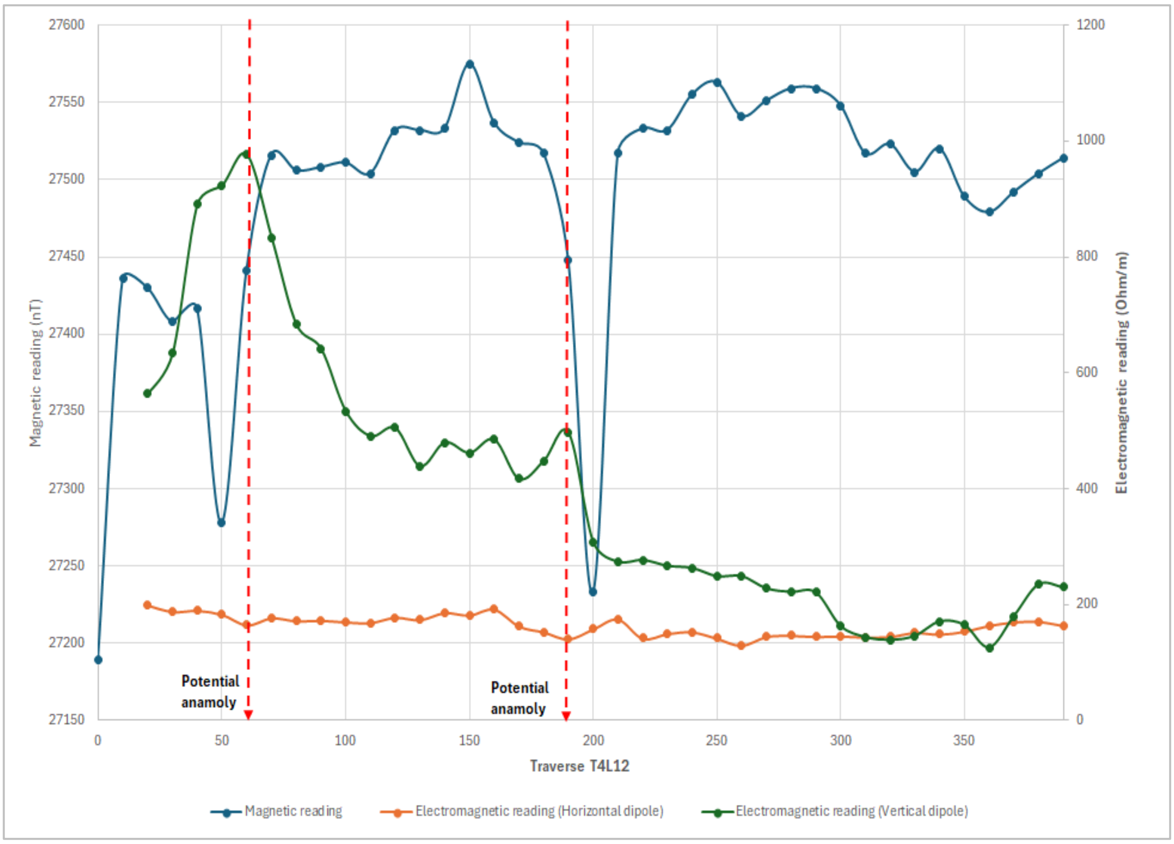


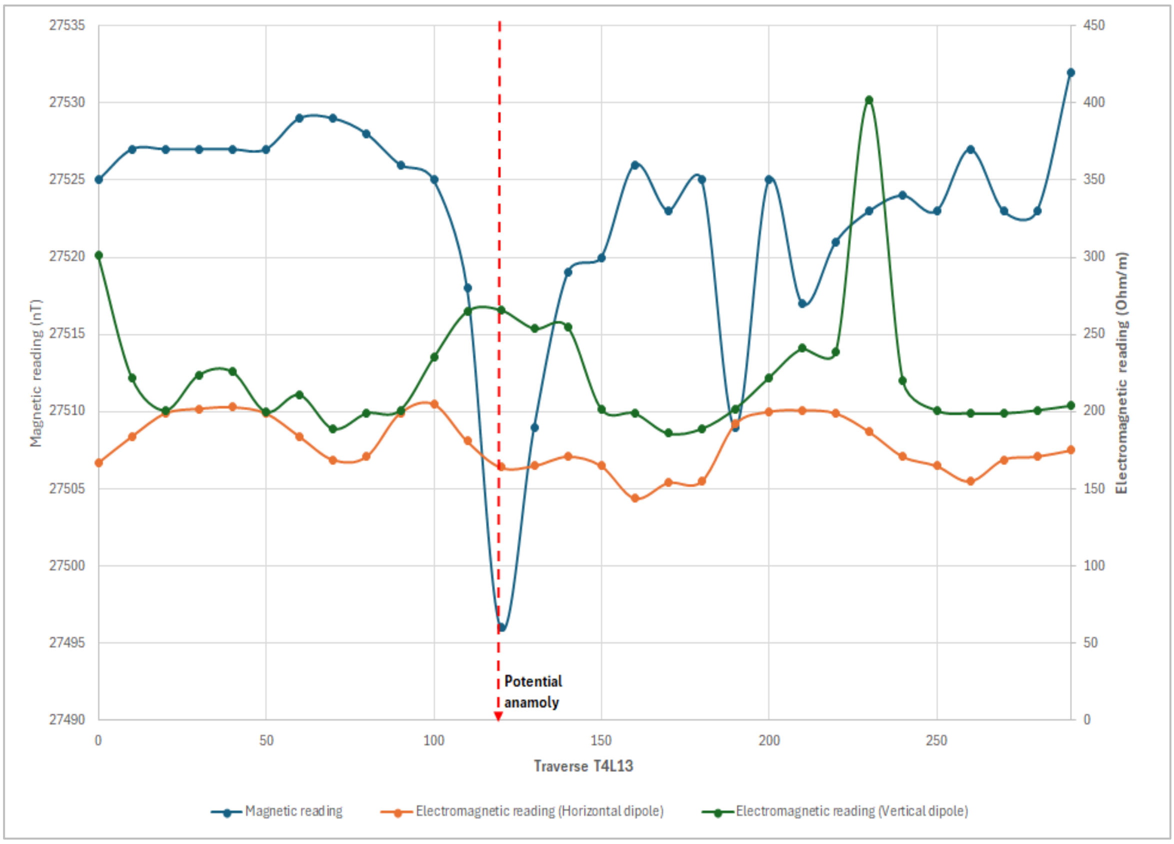
Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
HV Powerline
Traverse T4L08
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)

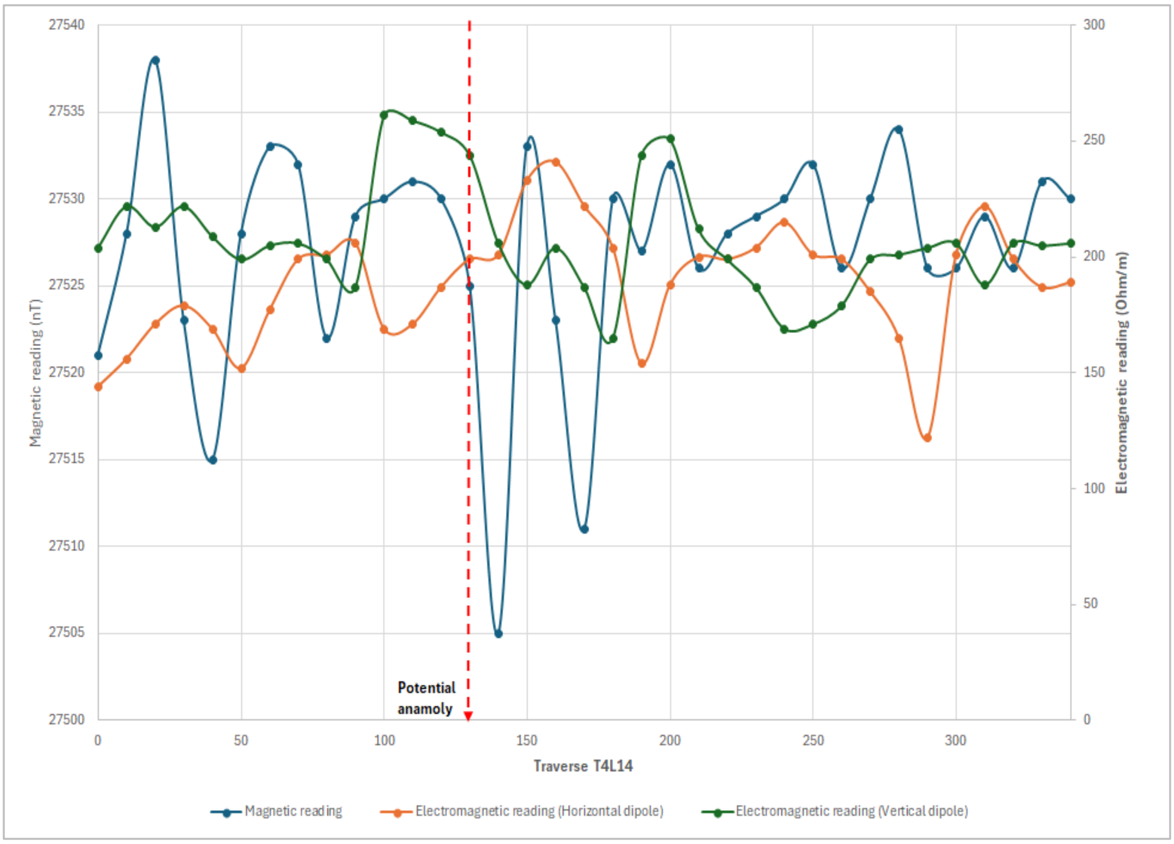


Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
Possible sub-surface stormwater structure
Traverse T4L10
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)


Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
Potential anamoly
Traverse T4L11
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)


Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
Potential anamoly
Potential anamoly
Traverse T4L12
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)


27535
27530
27525
27520
27515
27510
27505
27500
27495
27490
450
400
350
300
250
200
150
100
50
0
Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
0
50
100
150
200
250
Traverse T4L13
Potential anamoly
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)


27540
27535
27530
27525
27520
27515
27510
27505
27500
300
250
200
150
100
50
0
Magnetic reading (nT)
Electromagnetic reading (Ohm/m)
0
50
100
150
200
250
300
Traverse T4L14
Potential anamoly
Magnetic reading
Electromagnetic reading (Horizontal dipole)
Electromagnetic reading (Vertical dipole)

25. APPENDIX C: BOREHOLE GEOLOGICAL LOGS AND CONSTRUCTION

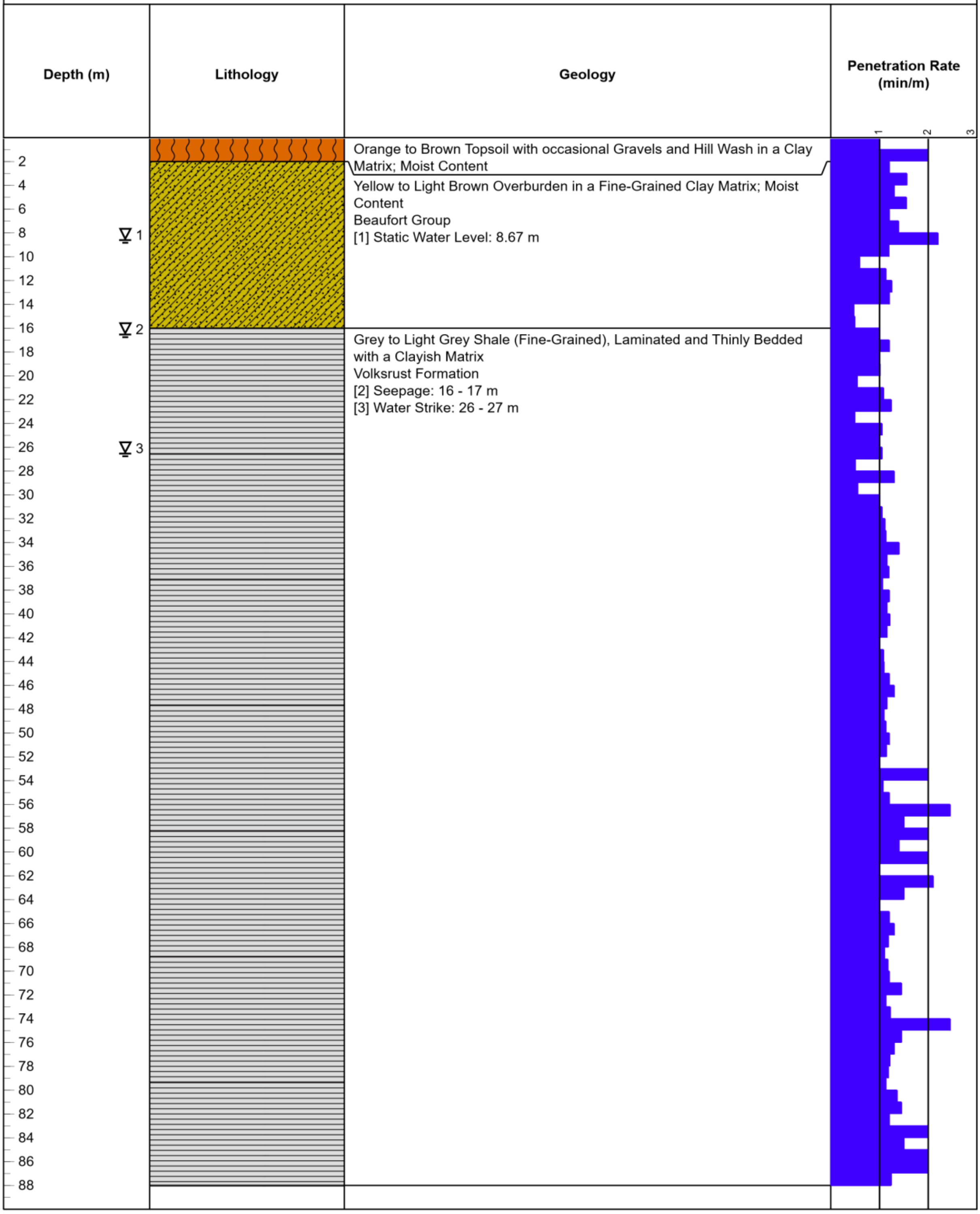
BOREHOLE: RTBH 01

COMPANY NAME: Gradient Consulting (Pty) Ltd
PROJECT NAME: Renegen Tetra 4

DRILLING METHOD: Air Percussion
TOTAL DEPTH: 88 m
STARTER CASING: 0 to 24 m (177 mm)
uPVC CASING: None
BLOW YIELD (V-NOTCH): 0.13 L/s at 27 m

COORDINATES: -28.212736; 26.718075
COORDINATE SYSTEM: WGS94

COMMENTS

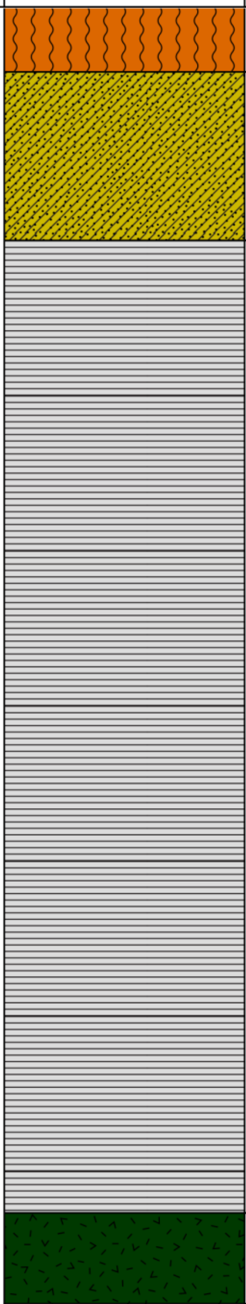
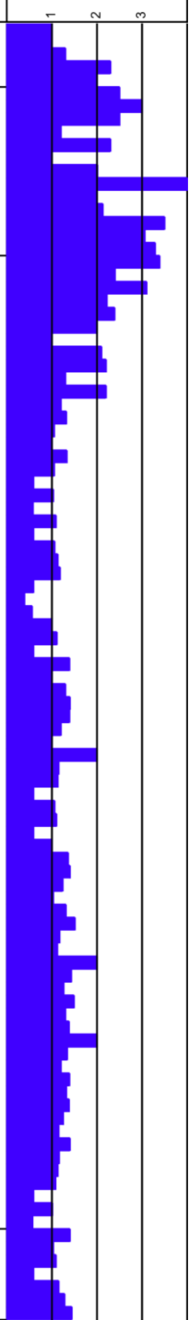


gradient
Groundwater Consulting

BOREHOLE: RTBH 04

COMPANY NAME: Gradient Consulting (Pty) Ltd	**DRILLING METHOD:** Air Percussion	**COORDINATES:** -28.120242; 26.647642
PROJECT NAME: Renegen Tetra 4	**TOTAL DEPTH:** 100 m	**COORDINATE SYSTEM:** WGS94
	STARTER CASING: 0 to 24 m (177 mm)	
	uPVC CASING: None	
	BLOW YIELD (V-NOTCH): None	

COMMENTS

Depth (m)	Lithology	Geology	Penetration Rate (min/m)
2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100		Orange to Brown Topsoil with occasional Gravels and Hill Wash in a Clay Matrix; Moist Content Yellow to Light Brown Overburden in a Fine-Grained Clay Matrix; Moist Content Beaufort Group [1] Static Water Level: 7 m [2] Seepage: 13 - 14 m (not enough for blow yield) Grey to Light Grey Shale (Fine-Grained), Laminated and Thinly Bedded with a Clayish Matrix Volksrust Formation Dolerite (Dyke/Sill); Dark Green to Blackish	

BOREHOLE: RTBH 05

COMPANY NAME: Gradient Consulting (Pty) Ltd
PROJECT NAME: Renegen Tetra 4

DRILLING METHOD: Air Percussion
TOTAL DEPTH: 100 m
STARTER CASING: 0 to 24 m (177 mm)
uPVC CASING: None
BLOW YIELD (V-NOTCH): 0.55 L/s at 92 m

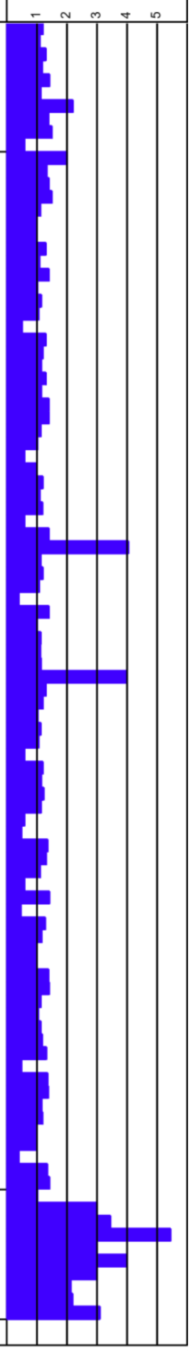
COORDINATES: -28.167142; 26.629660
COORDINATE SYSTEM: WGS94

COMMENTS

Depth (m)	Lithology	Geology
0 – 10 (▽1 at ~9 m)		Yellow to Light Brown Overburden in a Fine-Grained Clay Matrix; Moist Content Beaufort Group [1] Static Water Level: 8.93 m
10 – 90 (▽2 at ~15 m)		Grey to Light Grey Shale (Fine-Grained), Laminated and Thinly Bedded with a Clayish Matrix Volksrust Formation [2] Seepage: 15 - 16 m (not enough for blow yield)
90 – 100 (▽3 at ~92 m)		Dolerite (Dyke/Sill); Dark Green to Blackish [3] Water Strike: 92 - 93 m

Depth scale: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100

Penetration Rate (min/m)



gradient
Groundwater Consulting

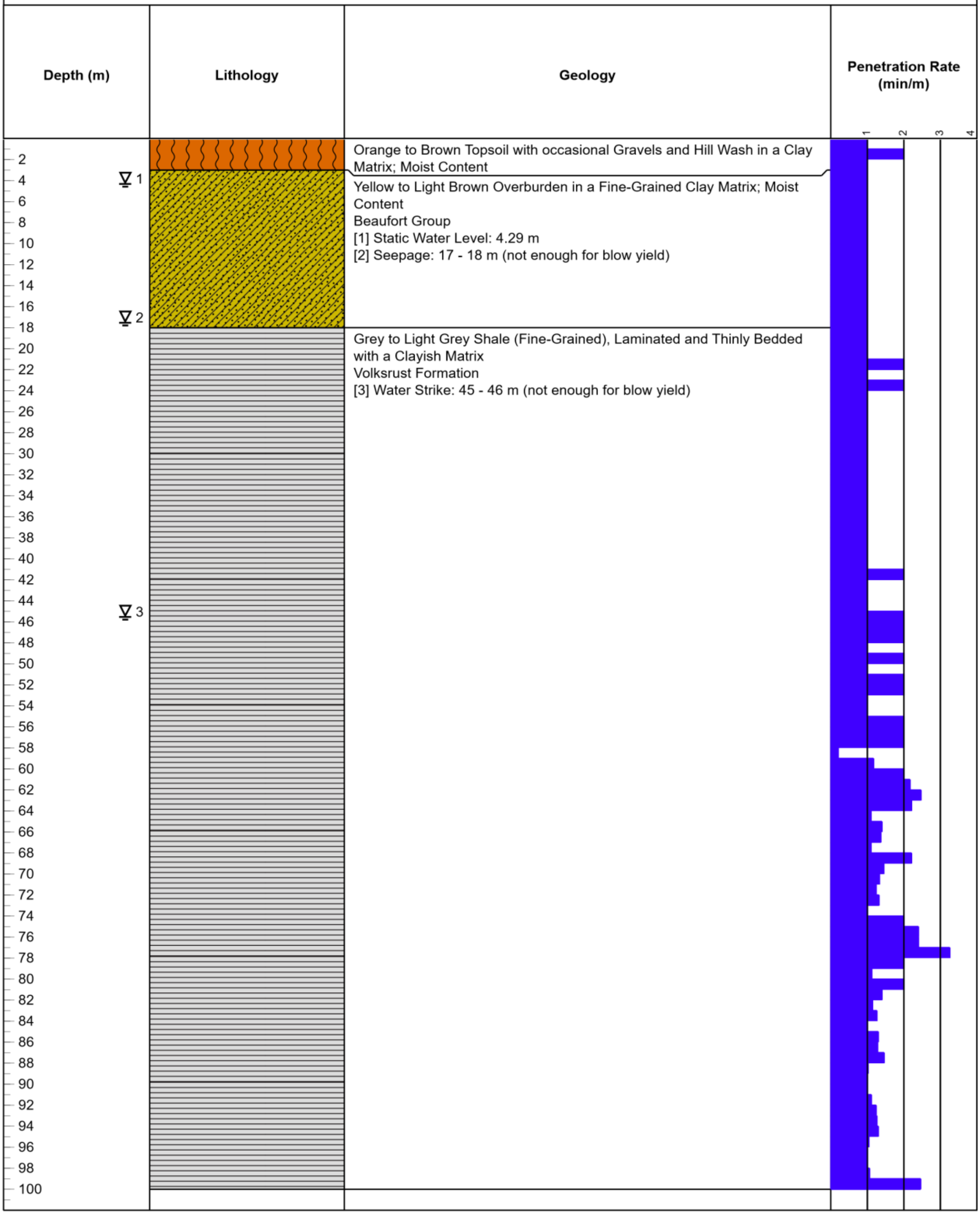
BOREHOLE: RTBH 08

COMPANY NAME: Gradient Consulting (Pty) Ltd
PROJECT NAME: Renegen Tetra 4

DRILLING METHOD: Air Percussion
TOTAL DEPTH: 100 m
STARTER CASING: 0 to 24 m (177 mm)
uPVC CASING: None
BLOW YIELD (V-NOTCH): None

COORDINATES: -28.207812; 26.782083
COORDINATE SYSTEM: WGS94

COMMENTS



gradient
Groundwater Consulting

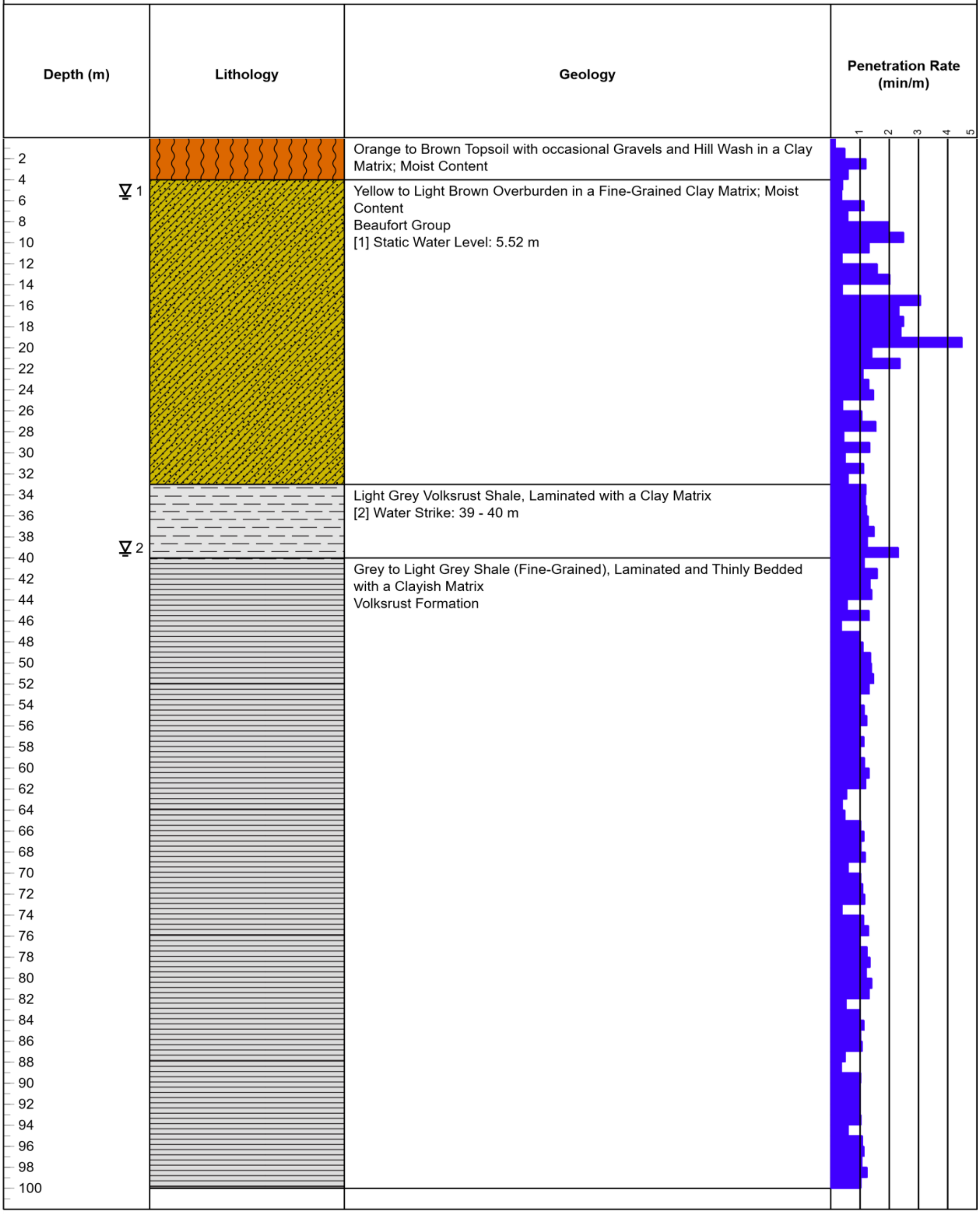
BOREHOLE: RTBH 10

COMPANY NAME: Gradient Consulting (Pty) Ltd
PROJECT NAME: Renegen Tetra 4

DRILLING METHOD: Air Percussion
TOTAL DEPTH: 100 m
STARTER CASING: 0 to 24 m (177 mm)
uPVC CASING: None
BLOW YIELD (V-NOTCH): 0.55 - 1.38 L/s at 40 m

COORDINATES: -28.177746; 26.764675
COORDINATE SYSTEM: WGS94

COMMENTS



26. APPENDIX D: AQUIFER TESTING DATASHEETS

Date started	28/02/2025	Borehole Depth	78.60	Borehole Nr	RTBH01	Coordinates S	
Time started	20:00	WL Depth	8.57	Alternative Nr		Coordinates E	
Existing Pump equipment	none	Casing Depth	-				

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
15:46	1	9.46	0.18		1	11.59	0.26	12:01	1	26.11
15:47	2				2	11.73		12:02	2	26.61
15:48	3	9.82			3	11.72		12:03	3	21.86
15:50	5	10.26			5	12.07		12:05	5	22.86
15:52	7				7	12.27		12:07	7	17.35
15:55	10	10.66			10	12.55		12:10	10	16.34
16:00	15	10.93			15	13.01		12:15	15	15.44
16:05	20	11.20			20	13.61		12:20	20	14.81
16:15	30	11.43	0.18		30	14.58	0.26	12:30	30	13.95
16:25	40				40			12:40	40	13.52
16:35	50				50			13:00	60	12.82
16:45	60				60			13:30	90	12.67
16:55	70				70			14:00	120	12.58
17:05	80				80			14:30	150	
17:15	90				90			15:00	180	
17:25	100				100			15:30	210	
17:35	110				110			16:00	240	
17:45	120				120			16:30	270	
									360	

Step 3					Step 4				Recovery	
									420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1	14.87	0.37		1	24.09	0.5		600	
	2	15.71			2	26.40			1200	
	3	15.46			3	27.90			840	
	5	16.14			5	28.51			960	
	7	17.09			7	30.10			1080	
	10	17.70			10	31.20			1200	
	15	19.65			15	32.95			1320	
	20	21.87			20	34.94			1440	
	30	23.99	0.37		30	43.32	0.5		1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
20:01	1	11.42	0.26	4:01	1		1		1	
20:02	2			4:02	2		2		2	
20:03	3	11.29		4:03	3	32.76	3		3	
20:05	5	11.75		4:05	5	28.63	5		5	
20:07	7	11.90		4:07	7	25.44	7		7	
20:10	10	12.19		4:10	10	23.13	10		10	
20:15	15	12.52		4:15	15	22.64	15		15	
20:20	20	13.09		4:20	20	21.95	20		20	
20:30	30	14.16		4:30	30	20.44	30		30	
20:40	40	15.70		4:40	40	18.98	40		40	
21:00	60	19.04		5:00	60	14.12	60		60	
21:30	90	23.26		5:30	90		90		90	
22:00	120	25.03		6:00	120	9.88	120		120	
22:30	150	26.93		6:30	150	9.77	150		150	
23:00	180	29.05		7:00	180	9.58	180		180	
23:30	210	30.17		7:30	210	9.44	210		210	
0:00	240	31.18		8:00	240	9.35	240		240	
1:00	300	33.17		9:00	300	9.26	300		300	
2:00	360	34.96		10:00	360	9.14	360		360	
3:00	420	36.66		11:00	420	9.07	420		420	
4:00	480	38.16		12:00	480	8.98	480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	01/03/2025	Borehole Depth	80.00	Borehole Nr	RTBH04	Coordinates S	
Time started	17:55	WL Depth	7.00	Alternative Nr		Coordinates E	
Existing Pump equipment	none	Casing Depth	-				

STEP TEST & RECOVERY

Step 1					Step 2			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time
17:56	1	8.55	0.15	9.63	1			
17:57	2	8.61		9.6	2			
17:58	3	8.92		9.57	3			
18:00	5	9.56		9.57	5			
18:02	7	10.02		9.54	7			
18:05	10	Switch off at 18:02		9.53	10			
18:10	15				15			
18:15	20				20			
18:25	30				30			
18:35	40				40			
18:45	50				50			
18:55	60			9.05	60			
19:05	70				70			
19:15	80				80			
19:25	90				90			
19:35	100				100			
19:45	110				110			
19:55	120				120			

Step 3					Step 4			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			

Recovery	
Time (min)	Waterlevel (m)
1	
2	
3	
5	
7	
10	
15	
20	
30	
40	
60	
90	
120	
150	
180	
210	
240	
270	
360	
420	
480	
540	
600	
1200	
840	
960	
1080	
1200	
1320	
1440	
1800	
2280	
2880	
3480	
3900	
4320	
4920	
5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
	1				1		1		1	
	2				2		2		2	
	3				3		3		3	
	5				5		5		5	
	7				7		7		7	
	10				10		10		10	
	15				15		15		15	
	20				20		20		20	
	30				30		30		30	
	40				40		40		40	
	60				60		60		60	
	90				90		90		90	
	120				120		120		120	
	150				150		150		150	
	180				180		180		180	
	210				210		210		210	
	240				240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	04/03/2025	Borehole Depth	100.00	Borehole Nr	RTBH05	Coordinates S	
Time started		WL Depth	8.93	Alternative Nr		Coordinates E	
Existing Pump equipment	none	Casing Depth	-		10, 11 before start		

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
13:51	1	9.61	0.18		1	11.51	0.22		1	21.30
13:52	2	9.85			2	11.78			2	20.19
13:53	3	10.13			3	11.81			3	19.10
13:55	5	10.29			5	11.87			5	18.40
13:57	7	10.48			7	11.94			7	16.01
14:00	10	10.65			10	12.06			10	14.97
14:05	15	10.93			15	12.28			15	13.76
14:10	20	11.16			20	12.37			20	12.93
14:20	30	11.38	0.18		30	12.59	0.22		30	12.22
14:30	40				40				40	11.61
14:40	50				50				60	10.92
14:50	60				60				90	10.39
15:00	70				70				120	10.16
15:10	80				80				150	
15:20	90				90				180	
15:30	100				100				210	
15:40	110				110				240	
15:50	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1	12.84	0.30		1		0.75		600	
	2	12.87			2				1200	
	3	12.99			3	14.9			840	
	5	13.24			5				960	
	7	13.51			7	16.48			1080	
	10	13.59			10	17.71			1200	
	15	13.76			15	20.85			1320	
	20	13.93			20	22.26			1440	
	30	14.23	0.30		30	24.18	0.75		1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
18:01	1	10.65	0.26	2:01	1	23.34	1		1	
18:02	2	11.76		2:02	2	22.50	2		2	
18:03	3	12.48		2:03	3	21.61	3		3	
18:05	5	12.84		2:05	5	20.64	5		5	
18:07	7	14.64		2:07	7	19.65	7		7	
18:10	10	15.94		2:10	10	18.73	10		10	
18:15	15	17.01		2:15	15	17.63	15		15	
18:20	20	18.06		2:20	20	17.03	20		20	
18:30	30	19.32		2:30	30	15.97	30		30	
18:40	40	20.09		2:40	40	15.27	40		40	
19:00	60	21.04		3:00	60	14.24	60		60	
19:30	90	22.06		3:30	90		90		90	
20:00	120	22.22		4:00	120	12.77	120		120	
20:30	150	23.47		4:30	150	12.35	150		150	
21:00	180	23.89		5:00	180	12.09	180		180	
21:30	210	24.21		5:30	210	11.83	210		210	
22:00	240	24.49		6:00	240	11.64	240		240	
23:00	300	23.09		7:00	300	11.35	300		300	
0:00	360	25.40		8:00	360	11.19	360		360	
1:00	420	25.69		9:00	420	10.99	420		420	
2:00	480	25.96		10:00	480	10.79	480		480	
	540			11:00	540		540		540	
	600			12:00	600		600		600	
	720			14:00	720		720		720	
	840			16:00	840		840		840	
	960			18:00	960		960		960	
	1080			20:00	1080		1080		1080	
	1200			22:00	1200		1200		1200	
	1320			4:10	1320		1320		1320	
	1440			2:00	1440		1440		1440	
	1800			8:00	1800		1800		1800	
	2280			16:00	2280		2280		2280	
	2880			2:00	2880		2880		2880	
	3600			14:00	3600		3600		3600	
	4320			2:00	4320		4320		4320	

Date started	02/03/2025	Borehole Depth	95.00		Borehole Nr	RTBH08	Coordinates S	
Time started	12:40	WL Depth	4.29	(2,05 before stash)	Alternative Nr		Coordinates E	
Existing Pump equipment	none	Casing Depth	-					

Pump on 85m

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
	1				1				1	
	2				2				2	
	3				3				3	
	5				5				5	
	7				7				7	
	10				10				10	
	15				15				15	
	20				20				20	
	30				30				30	
	40				40				40	
	50				50				60	
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
12:41	1	3.78	0.26	14:41	1	77.34	1		1	
12:42	2	4.69		14:42	2	76.69	2		2	
12:43	3	5.12		14:43	3	76.67	3		3	
12:45	5	5.99		14:45	5	76.62	5		5	
12:47	7	7.54		14:47	7	76.60	7		7	
12:50	10	9.74		14:50	10	76.59	10		10	
12:55	15	12.47		14:55	15	76.55	15		15	
13:00	20	15.39		15:00	20	76.53	20		20	
13:10	30	21.93		15:10	30	76.50	30		30	
13:20	40	28.65		15:20	40	76.36	40		40	
13:40	60	41.88		15:40	60	76.27	60		60	
14:10	90	61.69		16:10	90	76.12	90		90	
14:40	120	79.54	0.26	16:40	120	76.00	120		120	
	150			17:10	150	75.90	150		150	
	180				180		180		180	
	210				210		210		210	
	240				240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	03/03/2025	Borehole Depth	96m
Time started	13:00	WL Depth	5.52
Existing Pump equipment	none	Casing Depth	-

Borehole Nr	RTBH10	Coordinates S	
Alternative Nr		Coordinates E	

* Obstruction on 27m (pump cannot pass)

STEP TEST & RECOVERY

Step 1					Step 2			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time
11:01	1	6.26	0.28		1	8.10	0.50	
11:02	2	6.83			2	8.44		
11:03	3	6.98			3	8.57		
11:05	5	7.23			5	8.79		
11:07	7	7.37			7	9.00		
11:10	10	7.51			10	9.14		
11:15	15	7.67			15	9.24		
11:20	20	7.77			20	9.42		
11:30	30	7.97	0.28		30	9.43		
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			
	110				110			
	120				120			

Step 3					Step 4			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)
10:01	1	9.52	0.75		1	13.25	1.30	
10:02	2	9.89			2	13.77		
10:03	3	10.00			3	15.49		
10:05	5	10.44			5	15.28		
10:07	7	11.04			7	16.11		
10:10	10	11.38			10	17.02		
10:15	15	12.22			15	18.51		
10:20	20	12.57			20	19.16		
10:30	30	12.87	0.75		30	20.00	1.30	
10:40	40				40			
10:50	50				50			
11:00	60				60			
11:10	70				70			
11:20	80				80			
11:30	90				90			
13:20	100				100			

Recovery	
Time (min)	Waterlevel (m)
1	15.95
2	14.31
3	13.31
5	11.67
7	10.50
10	9.34
15	8.22
20	7.64
30	7.09
40	6.83
60	6.57
90	6.25
120	6.12
150	
180	
210	
240	
270	
360	
420	
480	
540	
600	
1200	
840	
960	
1080	
1200	
1320	
1440	
1800	
2280	
2880	
3480	
3900	
4320	
4920	
5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
15:01	1	7.11	0.56	0:01	1	10.18	1		1	
15:02	2	7.68		0:02	2	9.17	2		2	
15:03	3	8.21		0:03	3	9.00	3		3	
15:05	5	8.92		0:05	5	8.73	5		5	
15:07	7	9.31		0:07	7	8.38	7		7	
15:10	10	9.76		0:10	10	8.08	10		10	
15:15	15	10.36		0:15	15	7.82	15		15	
15:20	20	10.40		0:20	20	7.63	20		20	
15:30	30	10.62		0:30	30	7.32	30		30	
15:40	40	10.78		0:40	40	7.19	40		40	
16:00	60	10.99		1:00	60	7.00	60		60	
16:30	90	11.11		1:30	90	6.69	90		90	
17:00	120	11.26		2:00	120	6.52	120		120	
17:30	150	11.29		2:30	150	6.42	150		150	
18:00	180	11.36		3:00	180	6.29	180		180	
18:30	210	11.52		3:30	210	6.22	210		210	
19:00	240	11.76		4:00	240	6.13	240		240	
20:00	300	11.99		5:00	300	6.02	300		300	
21:00	360	12.08		6:00	360	5.94	360		360	
22:00	420	12.12		7:00	420	5.89	420		420	
23:00	480	12.15		8:00	480	5.83	480		480	
	540			9:00	540		540		540	
	600			10:00	600		600		600	
	720			12:00	720		720		720	
	840			14:00	840		840		840	
	960			16:00	960		960		960	
	1080			18:00	1080		1080		1080	
	1200			20:00	1200		1200		1200	
	1320			2:10	1320		1320		1320	
	1440			0:00	1440		1440		1440	
	1800			6:00	1800		1800		1800	
	2280			14:00	2280		2280		2280	
	2880			0:00	2880		2880		2880	
	3600			12:00	3600		3600		3600	
	4320			0:00	4320		4320		4320	

Date started	22/10/2024	Borehole Depth		Borehole Nr	7B	Coordinates S	
Time started	14:00	WL Depth	12.12	Alternative Nr		Coordinates E	
Existing Pump equipment	1,1 kW/sub	Casing Depth		TETRA 4 // Annex Glen Ross, No 562 // Doors Lourens			

STEP TEST & RECOVERY

Step 1					Step 2			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			
	110				110			
	120				120			

Step 3					Step 4			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			

Recovery	
Time (min)	Waterlevel (m)
1	
2	
3	
5	
7	
10	
15	
20	
30	
40	
60	
90	
120	
150	
180	
210	
240	
270	
360	
420	
480	
540	
600	
1200	
840	
960	
1080	
1200	
1320	
1440	
1800	
2280	
2880	
3480	
3900	
4320	
4920	
5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
14:01	1	14.98	1.76	18:01	1	26.52	1		1	
14:02	2	16.36	1.76	18:02	2	25.25	2		2	
14:03	3	17.83	1.76	18:03	3	23.77	3		3	
14:05	5	19.62	1.76	18:05	5	20.75	5		5	
14:07	7	20.74	1.76	18:07	7	19.75	7		7	
14:10	10	22.30	1.76	18:10	10	17.87	10		10	
14:15	15	25.51	1.76	18:15	15	14.82	15		15	
14:20	20	27.61	1.76	18:20	20	13.49	20		20	
14:30	30	28.58	1.43	18:30	30	12.91	30		30	
14:40	40	28.58	1.43	18:40	40	12.74	40		40	
15:00	60	28.58	1.43	19:00	60	12.61	60		60	
15:30	90	28.58	1.43	19:30	90	12.54	90	13.59	90	
16:00	120	28.58	1.43	20:00	120	12.46	120	13.65	120	
16:30	150	28.58	1.43	20:30	150	12.42	150	13.72	150	
17:00	180	28.58	1.43	21:00	180	12.40	180	13.74	180	
17:30	210	28.58	1.43	21:30	210	12.38	210	13.75	210	
18:00	240	28.58	1.43	22:00	240	12.36	240	13.75	240	
	300	4.00			300		300		300	
	360	16.46			360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	22/10/2024	Borehole Depth	60m
Time started	14:53	WL Depth	12.24
Existing Pump equipment	2,2kW	Casing Depth	-

Borehole Nr	17C	Coordinates S	
Alternative Nr	-	Coordinates E	

TETRA 4 // Helpmekaar No 47, Portion 1 // Annatjie van der Merwe

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
	1				1				1	
	2				2				2	
	3				3				3	
	5				5				5	
	7				7				7	
	10				10				10	
	15				15				15	
	20				20				20	
	30				30				30	
	40				40				40	
	50				50				60	
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (m	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
14:54	1	20.70	2.22	17:28	1	24.06	1		1	
14:55	2	21.21	2.22	17:29	2	23.02	2		2	
14:56	3	21.54	2.22	17:30	3	22.41	3		3	
14:58	5	21.87	2.22	17:32	5	21.20	5		5	
15:00	7	22.20	2.22	17:34	7	21.24	7		7	
15:03	10	22.57	2.22	17:37	10	20.95	10		10	
15:08	15	22.94	2.22	17:42	15	20.53	15		15	
15:13	20	23.27	2.22	17:47	20	20.30	20		20	
15:23	30	23.61	2.22	17:57	30	19.89	30		30	
15:33	40	24.64	2.22	18:07	40	19.54	40		40	
15:53	60	25.37	2.22	18:27	60	19.03	60		60	
16:23	90	25.96	2.22	18:57	90	18.53	90		90	
16:53	120	26.20	2.22	19:27	120	18.25	120		120	
17:23	150	25.95	2.22	19:57	150	67.07	150		150	
17:53	180	Power failure		20:27	180		180		180	
18:23	210	13.71		20:57	210		210		210	
18:53	240			21:27	240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Power went off 16:59.
Tired to restart but at 17:27 saw that the volts were too high and pump couldn't maintain yield.
Switched off at 17:27,

Date started	23/10/2024	Borehole Depth	
Time started	07:30	WL Depth	8.00
Existing Pump equipment	0,75 kW/sub	Casing Depth	

Borehole Nr	24A	Coordinates S	
Alternative Nr		Coordinates E	

TETRA 4 // Annex Glen Ross No 562, Portion 6 // Theuns Strauss

STEP TEST & RECOVERY

Step 1					Step 2			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			
	110				110			
	120				120			

Step 3					Step 4			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			

Recovery	
Time (min)	Waterlevel (m)
1	
2	
3	
5	
7	
10	
15	
20	
30	
40	
60	
90	Pump inlet→
120	
150	
180	
210	
240	
270	
360	
420	
480	
540	
600	
1200	
840	
960	
1080	
1200	
1320	
1440	
1800	
2280	
2880	
3480	
3900	
4320	
4920	
5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
7:31	1	9.97	0.92	8:31	1	37.22	1		1	
7:32	2	11.52	0.92	8:32	2	35.00	2		2	
7:33	3	14.48	0.92	8:33	3	33.21	3		3	
7:35	5	17.74	0.92	8:35	5	31.12	5		5	
7:37	7	21.41	0.92	8:37	7	28.75	7		7	
7:40	10	29.41	0.92	8:40	10	24.51	10		10	
7:45	15	34.40	0.92	8:45	15	17.43	15		15	
7:50	20	39.36	0.92	8:50	20	12.47	20		20	
8:00	30	41.91	0.92	9:00	30	10.16	30		30	
8:10	40	41.91	0.92	9:10	40	8.77	40		40	
8:30	60	41.91	0.92	9:30	60	8.26	60		60	
9:00	90	33.91		10:00	90	8.17	90		90	
9:30	120			10:30	120	8.09	120		120	
10:00	150			11:00	150	8.07	150		150	
10:30	180			11:30	180	8.04	180		180	
11:00	210			12:00	210	8.03	210		210	
11:30	240			12:30	240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	23/10/2024	Borehole Depth	18.91	Borehole Nr	N4	Coordinates S	-28.1434842
Time started	03:50	WL Depth	4.80	Alternative Nr		Coordinates E	26.713263
Existing Pump equipment	0.75	Casing Depth	-	TETRA 4 // Helpmekaar // Anton van der Veen			

STEP TEST & RECOVERY

Step 1					Step 2			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			
	110				110			
	120				120			

Step 3					Step 4			
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)
	1				1			
	2				2			
	3				3			
	5				5			
	7				7			
	10				10			
	15				15			
	20				20			
	30				30			
	40				40			
	50				50			
	60				60			
	70				70			
	80				80			
	90				90			
	100				100			

Recovery	
Time (min)	Waterlevel (m)
1	
2	
3	
5	
7	
10	
15	
20	
30	
40	
60	
90	
120	
150	
180	
210	
240	
270	
360	
420	
480	
540	
600	
1200	
840	
960	
1080	
1200	
1320	
1440	
1800	
2280	
2880	
3480	
3900	
4320	
4920	
5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (min)	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
8:51	1	6.51	0.90	12:51	1	7.56	1		1	
8:52	2	7.09	0.90	12:52	2	5.95	2		2	
8:53	3	7.35	0.90	12:53	3	5.51	3		3	
8:55	5	7.62	0.90	12:55	5	5.34	5		5	
8:57	7	8.07	0.90	12:57	7	5.26	7		7	
9:00	10	8.18	0.90	13:00	10	5.19	10		10	
9:05	15	8.20	0.90	13:05	15	5.12	15		15	
9:10	20	8.25	0.90	13:10	20	5.08	20		20	
9:20	30	8.37	0.90	13:20	30	5.02	30		30	
9:30	40	8.45	0.90	13:30	40	5.00	40		40	
9:50	60	8.51	0.90	13:50	60	4.98	60		60	
10:20	90	8.61	0.70	14:20	90	4.93	90		90	
10:50	120	8.61	0.70	14:50	120	4.90	120		120	
11:20	150	8.63	0.70	15:20	150	4.88	150		150	
11:50	180	8.70	0.90	15:50	180	4.88	180		180	
12:20	210	8.76	0.90	16:20	210		210		210	
12:50	240	8.85	0.90	16:50	240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	24/10/2024	Borehole Depth		Borehole Nr	15 D	Coordinates S	-28.277757
Time started	09:30	WL Depth	5.71	Alternative Nr		Coordinates E	26.641567
Existing Pump equipment		Casing Depth			Bertie van Jaarsveld		

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
6:31	1	5.88	0.50		1	6.30	3.28	08:01	1	6.18
6:32	2	5.98	1.85		2	6.36	3.28	08:02	2	6.15
6:33	3	6.03	1.85		3	6.38	3.28	08:03	3	6.07
6:35	5	6.07	1.85		5	6.40	3.28	08:05	5	6.02
6:37	7	6.11	1.85		7	6.45	3.28	08:07	7	5.98
6:40	10	6.12	1.85		10	6.53	3.28	08:10	10	5.95
6:45	15	6.13	1.85		15	6.53	3.28	08:15	15	5.91
6:50	20	6.16	1.85		20	6.53	3.28	08:20	20	5.89
7:00	30	6.17	1.85		30	6.53	3.28	08:30	30	5.85
	40				40			08:40	40	5.85
	50				50			10:40	60	5.84
	60				60			09:30	90	5.83
	70				70			10:00	120	5.83
	80				80			10:30	150	5.80
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	

Step 3					Step 4				Recovery (cont.)	
									420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
7:31	1	6.77	4		1				600	
7:32	2	6.8	4		2				1200	
7:33	3	6.83	4		3				840	
7:35	5	6.83	4		5				960	
7:37	7	6.83	4		7				1080	
7:40	10	6.83	4		10				1200	
7:45	15	6.83	4		15				1320	
7:50	20	6.83	4		20				1440	
8:00	30	6.83	4		30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
9:31	1	5.96	4.60	13:31	1	6.54	1		1	
9:32	2	6.09	4.60	13:32	2	6.47	2		2	
9:33	3	6.27	4.60	13:33	3	6.43	3		3	
9:35	5	6.38	4.60	13:35	5	6.35	5		5	
9:37	7	6.59	4.60	13:37	7	6.33	7		7	
9:40	10	6.69	4.60	13:40	10	6.33	10		10	
9:45	15	6.87	4.60	13:45	15	6.26	15		15	
9:50	20	6.89	4.60	13:50	20	6.24	20		20	
10:00	30	6.93	4.60	14:00	30	6.18	30		30	
10:10	40	6.93	4.60	14:10	40	6.16	40		40	
10:30	60	6.93	4.60	14:30	60	6.14	60		60	
11:00	90	6.93	4.60	15:00	90	6.09	90		90	
11:30	120	6.94	4.60	15:30	120	6.02	120		120	
12:00	150	6.94	4.60	16:00	150	6.00	150		150	
12:30	180	6.95	4.60	16:30	180	6.00	180		180	
13:00	210	6.95	4.60	17:00	210	5.97	210		210	
13:30	240	6.96	4.60	17:30	240	5.96	240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	25/10/2024	Borehole Depth	-	Borehole Nr	12A	Coordinates S	
Time started	11:00	WL Depth	9.89	Alternative Nr	-	Coordinates E	
Existing Pump equipment		Casing Depth	-	TETRA 4 // Lecia Viljoen // Exceslion No 147 // Biltong Place			

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
9:01	1	9.97	2.00		1	12.77	2.00	10:01	1	10.91
9:02	2	10.11	2.00		2	13.06	2.00	10:02	2	10.43
9:03	3	10.20	2.00		3	13.22	2.00	10:03	3	10.22
9:05	5	10.36	2.00		5	13.27	2.00	10:05	5	10.12
9:07	7	10.65	2.00		7	13.29	2.00	10:07	7	10.09
9:10	10	10.71	2.00		10	13.35	2.00	10:10	10	10.07
9:15	15	11.06	2.00		15	13.41	2.00	10:15	15	10.03
9:20	20	11.62	2.00		20	13.45	2.00	10:20	20	10.03
9:30	30	11.70	2.00		30	13.49	2.00	10:30	30	10.02
	40				40			10:40	40	10.02
	50				50			11:00	60	10.00
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
11:01	1	11.19	2.50	15:01	1	11.79	1		1	
11:02	2	12.00	2.50	15:02	2	10.80	2		2	
11:03	3	12.22	2.50	15:03	3	10.56	3		3	
11:05	5	12.32	2.50	15:05	5	10.45	5		5	
11:07	7	12.47	2.50	15:07	7	10.39	7		7	
11:10	10	12.52	2.50	15:10	10	10.33	10		10	
11:15	15	12.60	2.50	15:15	15	10.28	15		15	
11:20	20	12.84	2.50	15:20	20	10.24	20		20	
11:30	30	13.10	2.50	15:30	30	10.20	30		30	
11:40	40	13.36	2.50	15:40	40	10.17	40		40	
12:00	60	13.51	2.50	16:00	60	10.12	60		60	
12:30	90	13.77	2.50	16:30	90	10.08	90		90	
13:00	120	13.79	2.50	17:00	120	10.06	120		120	
13:30	150	13.84	2.50	17:30	150	10.03	150		150	
14:00	180	13.87	2.50	18:00	180	10.02	180		180	
14:30	210	13.90	2.50	18:30	210	10.01	210		210	
15:00	240	13.95	2.50	19:00	240	10.00	240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	26-10-2024	Borehole Depth	20m	Borehole Nr	Jubeny	Coordinates S	-28.100128
Time started	14:00	WL Depth	18.00	Alternative Nr		Coordinates E	26.751961
Existing Pump equipment	1,5 kW/sub	Casing Depth		TETRA 4 // Jonkers Rust No 72, Portion 0			

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Waterlevel (m)
10:31	1	18.21	0.20		1	18.00	0.25	11:11	1	19.39
10:32	2	18.35	0.20		2	19.02	0.25	11:12	2	19.18
10:33	3	18.55	0.20		3	19.07	0.25	11:13	3	19.06
10:35	5	18.72	0.20		5	19.24	0.25	11:15	5	18.92
10:37	7	18.81	0.20		7	19.44	0.25	11:17	7	18.76
10:40	10	18.85	0.20	Pump inlet →	10	19.59	0.25	11:20	10	18.40
10:45	15	18.88	0.20		15			11:25	15	18.25
10:50	20	18.95	0.20		20			11:30	20	18.15
11:00	30	18.97	0.20		30			11:40	30	18.09
	40				40			11:50	40	18.07
	50				50			12:10	60	18.04
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
14:01	1	18.17	0.10	18:01	1	18.48	1		1	
14:02	2	18.22	0.10	18:02	2	18.33	2		2	
14:03	3	18.26	0.10	18:03	3	18.25	3		3	
14:05	5	18.31	0.10	18:05	5	18.19	5		5	
14:07	7	18.37	0.10	18:07	7	18.16	7		7	
14:10	10	18.41	0.10	18:10	10	18.14	10		10	
14:15	15	18.42	0.10	18:15	15	18.11	15		15	
14:20	20	18.43	0.10	18:20	20	18.09	20		20	
14:30	30	18.47	0.10	18:30	30	18.07	30		30	
14:40	40	18.51	0.10	18:40	40	18.05	40		40	
15:00	60	18.57	0.10	19:00	60	18.04	60		60	
15:30	90	18.64	0.10	19:30	90	18.03	90		90	
16:00	120	18.69	0.10	20:00	120	18.02	120		120	
16:30	150	18.73	0.10	20:30	150	18.02	150		150	
17:00	180	18.76	0.10	21:00	180	18.01	180		180	
17:30	210	18.77	0.10	21:30	210	18.00	210		210	
18:00	240	18.78	0.10	22:00	240	18.00	240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	28/10/2024	Borehole Depth	-	Borehole Nr	KAL 2.1	Coordinates S	
Time started	13:00	WL Depth	7.70	Alternative Nr		Coordinates E	
Existing Pump equipment	0,75 kW	Casing Depth	-	TETRA 4 // Kalkoenrkans No 225, Porion 2 // Willem du Plessis			

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
9:31	1	8.21	0.20		1	12.16	0.30	11:01	1	26.92
9:32	2	8.58	0.20		2	12.28	0.30	11:02	2	25.94
9:33	3	8.97	0.20		3	12.42	0.30	11:03	3	25.29
9:35	5	9.26	0.20		5	12.87	0.30	11:05	5	24.32
9:37	7	9.92	0.20		7	13.19	0.30	11:07	7	23.35
9:40	10	10.50	0.20		10	13.57	0.30	11:10	10	20.93
9:45	15	11.11	0.20		15	14.49	0.30	11:15	15	10.08
9:50	20	11.48	0.20		20	15.52	0.30	11:20	20	16.60
10:00	30	12.03	0.20		30	16.39	0.30	11:30	30	13.91
	40				40			11:40	40	11.12
	50				50			12:00	60	8.48
	60				60			12:30	90	7.96
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
10:31	1	16.63	0.40		1				600	
10:32	2	16.88	0.40		2				1200	
10:33	3	17.24	0.40		3				840	
10:35	5	17.66	0.40		5				960	
10:37	7	18.33	0.40		7				1080	
10:40	10	18.98	0.40		10				1200	
10:45	15	21.14	0.40		15				1320	
10:50	20	23.42	0.40		20				1440	
11:00	30	27.32	0.40		30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
13:01	1	8.19	0.20	17:01	1	26.62	1		1	
13:02	2	8.41	0.20	17:02	2	26.08	2		2	
13:03	3	8.75	0.20	17:03	3	25.42	3		3	
13:05	5	9.12	0.20	17:05	5	24.43	5		5	
13:07	7	9.70	0.20	17:07	7	23.21	7		7	
13:10	10	10.17	0.20	17:10	10	21.00	10		10	
13:15	15	10.72	0.20	17:15	15	18.50	15		15	
13:20	20	11.28	0.20	17:20	20	17.00	20		20	
13:30	30	12.15	0.20	17:30	30	14.12	30		30	
13:40	40	12.78	0.20	17:40	40	11.54	40		40	
14:00	60	14.09	0.20	18:00	60	8.76	60		60	
14:30	90	15.75	0.20	18:30	90	8.09	90		90	
15:00	120	17.12	0.20	19:00	120	8.00	120		120	
15:30	150	19.00	0.20	19:30	150	7.92	150		150	
16:00	180	21.81	0.20	20:00	180	7.89	180		180	
16:30	210	24.80	0.20	20:30	210	7.87	210		210	
17:00	240	27.19	0.20	21:00	240	7.85	240		240	
	300	19.49			300		300		300	
	360	4.00			360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	29/10/2024	Borehole Depth	
Time started	09:00	WL Depth	7.45
Existing Pump equipment		Casing Depth	

Borehole Nr	8A	Coordinates S	
Alternative Nr		Coordinates E	

TETRA 4 // Kalkoenkrans No 225, Portion 2 // Willem du Plessis

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
7:01	1	7.54	0.20		1	7.88	0.40	08:01	1	8.19
7:02	2	7.60	0.20		2	7.96	0.40	08:02	2	7.83
7:03	3	7.66	0.20		3	8.06	0.40	08:03	3	7.71
7:05	5	7.42	0.20		5	8.12	0.40	08:05	5	7.62
7:07	7	7.74	0.20		7	8.16	0.40	08:07	7	7.58
7:10	10	7.76	0.20		10	8.20	0.40	08:10	10	7.54
7:15	15	7.76	0.20		15	8.26	0.40	08:15	15	7.53
7:20	20	7.77	0.20		20	8.29	0.40	08:20	20	7.52
7:30	30	7.79	0.20		30	8.31	0.40	08:30	30	7.50
	40				40			08:40	40	7.49
	50				50			09:00	60	7.48
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
									420	
									480	
									540	

Step 3					Step 4				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Waterlevel (m)
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
9:01	1	7.62	0.40	13:01	1	8.00	1		1	
9:02	2	7.80	0.40	13:02	2	7.81	2		2	
9:03	3	7.92	0.40	13:03	3	7.67	3		3	
9:05	5	7.95	0.40	13:05	5	7.72	5		5	
9:07	7	8.00	0.40	13:07	7	7.67	7		7	
9:10	10	8.05	0.40	13:10	10	7.66	10		10	
9:15	15	8.11	0.40	13:15	15	7.64	15		15	
9:20	20	8.14	0.40	13:20	20	7.62	20		20	
9:30	30	8.19	0.40	13:30	30	7.60	30		30	
9:40	40	8.25	0.40	13:40	40	7.59	40		40	
10:00	60	8.30	0.40	14:00	60	7.58	60		60	
10:30	90	5.37	0.40	14:30	90	7.57	90		90	
11:00	120	8.39	0.40	15:00	120	7.56	120		120	
11:30	150	8.41	0.40	15:30	150	7.55	150		150	
12:00	180	8.42	0.40	16:00	180	7.54	180		180	
12:30	210	8.43	0.40	16:30	210	7.54	210		210	
13:00	240	8.44	0.40	17:00	240	7.53	240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

Date started	30/10/2024	Borehole Depth		Borehole Nr	16B	Coordinates S	
Time started	09:00	WL Depth	13.89	Alternative Nr	10	Coordinates E	
Existing Pump equipment		Casing Depth		TETRA 4 // Annex Glen Ross No 562 / Gert Prinsloo			

STEP TEST & RECOVERY

Step 1					Step 2				Recovery	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Time (min)	Waterlevel (m)
	1				1				1	
	2				2				2	
	3				3				3	
	5				5				5	
	7				7				7	
	10				10				10	
	15				15				15	
	20				20				20	
	30				30				30	
	40				40				40	
	50				50				60	
	60				60				90	
	70				70				120	
	80				80				150	
	90				90				180	
	100				100				210	
	110				110				240	
	120				120				270	
									360	
Step 3					Step 4				420	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	Time (min)	Draw-down (m)	Yield (ℓ/s)	Recovery (m)	480	
									540	
	1				1				600	
	2				2				1200	
	3				3				840	
	5				5				960	
	7				7				1080	
	10				10				1200	
	15				15				1320	
	20				20				1440	
	30				30				1800	
	40				40				2280	
	50				50				2880	
	60				60				3480	
	70				70				3900	
	80				80				4320	
	90				90				4920	
	100				100				5760	

CONSTANT DISCHARGE TEST

Constant Discharge Test							Observation BH		Observation BH	
Pump Cycle of pumped borehole				Recovery Cycle of pumped borehole			BH #		BH #	
							Distance:		Distance:	
							Waterlevel:		Waterlevel:	
Actual Time	Time (min)	Draw-down (m)	Yield (ℓ/s)	Actual Time	Rec Time (n	Recovery (m)	Time (min)	Draw-down (m)	Time (min)	Draw-down (m)
9:01	1	15.55	1.44	11:01	1	17.92	1		1	
9:02	2	16.73	1.44	11:02	2	17.60	2		2	
9:03	3	17.36	1.44	11:03	3	17.06	3		3	
9:05	5	17.81	1.44	11:05	5	16.37	5		5	
9:07	7	18.17	1.44	11:07	7	16.00	7		7	
9:10	10	18.44	1.44	11:10	10	15.83	10		10	
9:15	15	18.68	1.44	11:15	15	15.67	15		15	
9:20	20	18.83	1.44	11:20	20	15.59	20		20	
9:30	30	19.00	1.44	11:30	30	15.56	30		30	
9:40	40	19.17	1.44	11:40	40	15.42	40		40	
10:00	60	19.61	1.44	12:00	60	15.38	60		60	
10:30	90	19.62	1.44	12:30	90	15.33	90		90	
11:00	120	19.88	1.44	13:00	120	15.29	120		120	
	150	5.99			150		150		150	
	180				180		180		180	
	210				210		210		210	
	240				240		240		240	
	300				300		300		300	
	360				360		360		360	
	420				420		420		420	
	480				480		480		480	
	540				540		540		540	
	600				600		600		600	
	720				720		720		720	
	840				840		840		840	
	960				960		960		960	
	1080				1080		1080		1080	
	1200				1200		1200		1200	
	1320				1320		1320		1320	
	1440				1440		1440		1440	
	1800				1800		1800		1800	
	2280				2280		2280		2280	
	2880				2880		2880		2880	
	3600				3600		3600		3600	
	4320				4320		4320		4320	

27. APPENDIX E: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

28. APPENDIX F: GEOCHEMICAL ANALYSIS LABORATORY CERTIFICATES

ANALYTICAL REPORT: Acid / Base Accounting (ABA)

To:	Gradient Consulting (Pty) Ltd (C.O.D)	Date of Request: 05/11/2024	UIS Analytical Services
Attention:	Ferdinand Mostert		Analytical Chemistry Laboratories 4, 6
Ref No:			
Site Location:			
Order No:	Q-GEO-24/04340/PAID		Fax: (012) 665 4294

analytical servic

Certificate of analysis: 62983

Note: No unauthorised copies may be made of this report.
Note: Samples analysed after drying

Lims ID	Sample ID	Paste pH	Total Sulphur	Acid Potential (AP)	Neutralization Potential (NP)	Nett Neutralization Potential (NNP)	Neutralising Potential Ratio (NPR) (NP : AP)
	ABA						
			%	kg CaCO3/t	kg CaCO3/t	kg CaCO3/t	NP:AP
		Ratio 1:1					
984264	Tillite	10.4	0.017	0.519	11.1	10.6	21.4
984264 QC	Duplicate	10.4	0.017	0.516	10.9	10.4	21.1
984265	Shale	10.1	0.023	0.709	0.00	-0.71	0.00
984266	Quaritize	9.84	0.098	3.069	16.0	12.9	5.20
984267	Sandstone	10.1	0.023	0.728	36.3	35.6	49.9
984268	Dolorite	10.5	0.057	1.769	11.7	9.97	6.64
984269	Lava	10.1	0.027	0.838	18.4	17.6	22.0

Lims ID	Forms Of Sulphur	S (total)	S (Sulphide)
		%	%
984264	Tillite	0.017	0.004
984264 QC	Duplicate	0.017	0.004
984265	Shale	0.023	0.012
984266	Quaritize	0.098	0.018
984267	Sandstone	0.023	0.007
984268	Dolorite	0.057	0.015
984269	Lava	0.027	0.009

Note: Negative NP values are obtained when the volume of NaOH(0.1N) titrated (pH:8.3) is greater than the volume of HCl(1N) to reduce the pH of the sample to 2.0-2.5. Any negative NP values are corrected to 0.00

Chemical elements:	ABA, NAG, S
Instrument:	Methohm Titrino, LECO CS 230
Method:	Carbon & Sulphur in Soil/Ore samples by combustion and infrared detection EPA 600 Modified Sobek, Single addition NAG test

29. APPENDIX G: SPECIALIST CURICULUM VITAE