Document Number
HG-R-25-010-V1

KELVIN POWER STATION WATER USE LICENCE HYDROGEOLOGICAL BASELINE INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

October 2025

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

Compiled by:
JFW Mostert (M.Sc. Hydrogeology, *Pr.Sci.Nat.*)

Gradient Consulting Pty Ltd Reg No: 2018/053781/07
Director: JFW Mostert (MSc. Hydrogeology)
13 Barnstable Road, Lynnwood Manor, Pretoria, 0081
www.gradient.co.za

REPORT DISTRIBUTION LIST

Name	Institution
Monica Niehof	Environmental Impact Management Services (Pty) Ltd
John Von Mayer	Environmental Impact Management Services (Pty) Ltd
Lavhe Nelwamondo	Kelvin Power (Pty) Ltd

DOCUMENT HISTORY

Report no	Date	Version	Status
HG-R-25-010-V1	September 2025	1.0	Draft
HG-R-25-010-V1	October 2025	1.0	Final

REPORT REVIEW AND SIGN OFF

Report undertaken by:	JFW Mostert
Signature:	
Designation:	Hydrogeologist (Pr.Sci.Nat.40057/14 – Water Resource Science)
Reference Number:	HG-R-25-010-V1
Date:	22 October 2025

INDEMNITY AND SPECIALIST DECLARATION

The findings, results, observations, conclusions and recommendations given in this report are based on the author's best scientific and professional knowledge as well as available information. The report is based on assessment techniques, which are limited by information available, time and budgetary constraints relevant to the type and level of investigation undertaken and Gradient Consulting (Pty) Ltd reserve the right to modify aspects of the report including the recommendations if and when new information may become available from ongoing research, monitoring, further work in this field, or pertaining to the investigation.

Although Gradient Consulting (Pty) Ltd exercises due care and diligence in rendering services and preparing documents, Gradient Consulting (Pty) Ltd accepts no liability, and the client, by receiving this document, indemnified Gradient Consulting (Pty) Ltd against all actions, claims, demands, losses, liabilities, costs, damages and expenses arising from or in connection with the services rendered, directly or indirectly by Gradient Consulting (Pty) Ltd and by the use of the information contained in this document.

This report has been drafted as per the latest requirements for specialist reports as set by the Department of Environmental Affairs and listed in Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07 April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA). We realise that a false declaration is an offence in terms of regulation 48 of the Environmental Impact Assessment Regulations, 2014 (as amended) promulgated in terms of the National Environmental Management Act, 107 of 1998 (NEMA) and is punishable in terms of section 49B of the NEMA.

I, JFW Mostert, hereby declare that:

- I act as the independent specialist in this 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)

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

Executive summary

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment to support a Water Use Licence (WUL) amendment application process to be followed. Kelvin Power Station has an Environmental Management Plan (EMP) in terms of NEMA Section 28, dated 2009 and plans to update the EMP and align its operation activities with legislative requirements.

The investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts from the power generation operation on sensitive environmental receptors. This report summarises the main conclusions and recommendations derived from the study.

Kelvin Power Station falls within the Ekurhuleni Metropolitan Municipality, Gauteng Province, South Africa. The existing development is situated approximately 4.0km southwest of Kempton Park and approximately 8.0km northwest of Benoni covering a total footprint of ~149.0ha .

The topography of the greater study area are characteristically an undulating highveld plateau with gentle rises and dips. The relief of the area varies between 0.0 – 130.0m towards the eastern segment and between 30.0 – 210.0m towards the western perimeter. The landscape gradually flattens out towards the lower laying drainage system towards the northwest (approximate elevation low of 1430.0mamsl), while the southern and southwestern perimeters are shaped by ridges also forming the catchment water divide (approximate elevation high of 1787.0mamsl). The lowest topographical elevation on-site is recorded as 1620.0mamsl which is situated towards the western perimeter forming part of the local drainage system while the highest topographical point recorded on site is approximately 1671.0mamsl towards the east.

The greater study is situated in primary catchment (A) of the Crocodile and Juksei River drainage systems which covers a total area of approximately 48 000km^2. The resource management falls under the Limpopo Water Management Area and is situated within quaternary catchment A21C. The hydrology of the region is characterised by predominately perennial watercourses with the main rivers draining the greater study area in a general north-westerly direction being the Jukskei River. Locally a tributary of the Jukskei River, Modderfonteinspruit, flows just west of the project area forming a confluence with the Jukskei River approximately 11.0km northwest of the site.

The calculated mean annual precipitation for this rainfall zone is 675.69mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 467.09mm/a and the 95th percentile (representing a 1:20 flood period) 939.30mm/a. The catchment area is categorised under evaporation zone 3A which has a mean annual evaporation (s-pan) ranging between 1700mm/a, more than double the annual precipitation.

The surficial geology of the study area comprises of felsic, intermediate rocks of the Halfway House Dome situated on the central Kaapvaal Craton formed through a series of magmatic events during the mid-Archaean age. The Ventersdorp Supergroup comprising of mafic and ultramafic volcanic rocks of the Klipriviersberg Group striking in a southwest northeast direction and dipping at approximately 50° in a southeastern orientation occurs

just southwest of the project area. Following the Ventersdorp Group are siliciclastic rocks of the West Rand Group (Hospital Hill, Jeppestown as well as Government Subgroups) of the Witwatersrand Supergroup which also dips approximately 45° in a general south to southwestern orientation. The Dwyka Group of the Karoo Supergroup flanks the West Rand Group towards the eastern perimeter of the greater study area while carbonate rocks of the Malmani Subgroup (Chuniespoort Group) occur towards the north and northeast.

Structural analysis indicates the presence of various SW-NE as well as N-S trending fault zones traversing the greater study area. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

The study area is predominantly underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0L/s), it should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones. The host aquifers consist of primarily intermediate or alkaline intrusive. Most hard-rock aquifers are secondary in nature with groundwater associated with fracturing, fault zones as well as contact zones. For the purposes of this investigation, three main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone:

i. **A shallow Quaternary (perched and unconfined) aquifer:** These aquifers consist of recent types of sediments and are characteristically primary porosity aquifers, such that groundwater flow occurs in the pore spaces between soil and sediment particles. These aquifers are formed by alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth. Clay lenses in the soil and unsaturated zones may cause local, perched water tables which occur above the regional water table.

ii. **A shallow, intergranular aquifer within the Halfway House Granites:** These aquifers occur in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually, these aquifers can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. In secondary porosity aquifers, groundwater flow occurs along fractures, while water is stored within the rock matrix. Due to higher effective porosity (n) this aquifer is more susceptible to impacts from contaminant sources compared to confined aquifers.

iii. **A deeper, fractured aquifer within the Halfway House Granites:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured granite as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

Under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. Regional drainages can be generally classified as influent or gaining stream systems as the groundwater head elevation of the water table in the vicinity of the stream is higher than the altitude of the stream bed and, accordingly, there definitely exists groundwater discharge as baseflow to local drainages.

An approximation of recharge for the study area is estimated at ~4.23% of MAP i.e. ~28.82 mm/a.

A hydrocensus user survey within the greater study area was conducted during July 2025 where relevant hydrogeological baseline information was gathered. A total of 25 geosites were visited as part of the hydrocensus user survey.

The unsaturated zone within the study area is in the order of 1.50 to 15.0m with a mean thickness of approximately ~5.0m. Due to clay/silt lenses throughout the study area, the shallow vadose zone can also be indicative of perched aquifer conditions which may be associated with seepage zones/ spring localities observed throughout the study area.

The minimum water level recorded is 1.52mbgl (KPS-BH02), while the deepest water level was measured at borehole locality KPS-MON01 (13.90mbgl). It is noted that the latter corresponds to the topographical setting of the borehole locality. The average water level is calculated at 5.49mbgl, while the regional average water level is recorded as ~15.0mbgl. It can thus be concluded that the study area is characterised by a shallow water table or piezometric head. It can be noted that Coefficient of Variation (CV) calculated for the water level database is relatively low, indicating that the regional groundwater system is in quasi-steady state conditions.

Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation and even with dynamic water levels taken into consideration, the correlation is calculated at R^2 >0.98. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system and will flow in a general western to south-western direction.

The average groundwater gradient of the shallow, weathered aquifer in the vicinity of the study area is relatively flat and calculated at a mean of 0.015, with a maximum of 0.022 in a southwestern to northeastern orientation.

The expected seepage rate from contamination originating at surface pollution sources is estimated at an average of approximately 5.56 metres per annum (m/a), with a maximum distance of ~12.0m/a in a southwestern to northeastern orientation.

The hydrochemical analysis results suggest the overall ambient groundwater quality is moderate good with the majority of macro and micro determinants of most samples below the SANS 241:2015 limits. Groundwater can be described as neutral to alkaline, saline to very saline and hard to very hard. The majority of samples analysed indicate enriched calcium and magnesium which can be attributed to the igneous formation host aquifer and are probably of geological origin. It should however be noted that, monitoring boreholes in close proximity to existing waste body footprints indicate an impacted groundwater environment with high salt load (TDS and conductivity) and sulphate being the main diver of the salt content. Neutral conditions as well as below limit metal concentrations suggest that Acid Rock Drainage (ARD) is currently not occurring.

The water quality of surface water localities analysed is poor and can be described as neutral, very saline and very hard. Nitrate concentration for both surface water samples analysed is highly elevated. It should be noted that only contact water samples were analysed and thus, the water quality discussed does not necessarily represent the ambient surface water quality.

Three distinct categories can be observed: the following samples analysed suggest a recently recharged and unimpacted groundwater environment i.e., KPS MON7, KPS MON09, KPS MON10, KPS MON11, KPS BH04, KPS BH05, KPS BH07 as well as KPS NB03 (Category A: Magnesium-Bi-carbonate dominance) while geosites KPS BH01, KPS BH02, KPS MON02, KPS MON03, KPS MON04, KPS MON12, KPS MON13, KPS MON14, KPS MON16, KPS NB01 and KPS NB02 suggest an area of static and disordinate environments (Category B: Calcium-Sulphate dominance). Borehole localities KPS MON01, KPS MON05 and KPS MON06 including both surface water features analysed (RD2 and DC) suggest an area of sodium and chloride enrichment (brine environment) (Category C: Sodium-Chloride dominance).

According to the aquifer classification map of South Africa the project area is underlain by a "**Minor aquifer**". The groundwater Quality Management (GQM) Index of 4 was calculated for the local aquifer system and according to this estimate, and a "**Medium**" level groundwater protection is required for this aquifer system.

According to the DRASTIC index methodology applied, the activities and associated infrastructure's risk to groundwater pollution of the host aquifer system, is rated as "**Moderate**".

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

The following potential sources have been identified:

i. Seepage of poor-quality water originating from wastewater management infrastructure.

ii. Leachate of elements from ash dumps and coal stockpiles causing poor-quality water entering local resources and host aquifers.:

iii. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.

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.

The following receptors were identified:

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

ii. Down-gradient drainages and streams including associated riparian zone aquifer system(s) and baseflow contribution.

iii. Private or neighbouring boreholes associated with relevant fracture zones and/or structures(s)if intercepted by the pollution plume migration footprint

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

A scenario simulated a TDS pollution plume for the existing ash dumps for the operational phase(s) without implementation of mitigation and/or management measures. The simulated pollution plume extent covers a total area of approximately 1.05km^2 reaching a maximum distance of ~650.0m migrating in a general southwestern direction from where it propagates northwest following the lower laying drainage system of the Modderfonteinspruit. Potential receptors include monitoring boreholes situated down-gradient from the source as well as the Modderfonteinspruit and associated riparian zone. It is noted that no private owned boreholes are impacted on. It can be observed that the TDS mass load contribution to all the observation boreholes breaks through the SANS 241:2015 threshold after a simulation period of approximately 5-10 years increasing steadily to a maximum concentration of between ~1100.0 to 1550.0mg/l.

A post-closure scenario was simulated to evaluate the TDS pollution plume migration within the intergranular aquifer host after discontinuing of mining activities. The 50-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.25km^2, reaching a maximum distance of ~750.0m in a general northwestern direction towards the lower laying drainage systems. The 100-year simulation period indicate that the pollution plume extent covers a total footprint of approximately 1.35km^2, reaching a maximum distance of ~950.0m in a general northwestern direction towards the lower laying drainage systems. Potential receptors include monitoring boreholes situated down-gradient from the source as well as the Modderfonteinspruit and associated riparian zone.

Two alternative management and mitigation scenarios which include active as well as passive water management strategies were simulated to evaluate the remedial options available.

An active management scenario evaluating the mitigating effect of establishment of a series of seepage capturing or scavenger boreholes situated down-gradient of the existing waste body footprints simulated. Due to the negative hydraulic gradient formed locally at each seepage capturing borehole, the gradient curtain constrains the propagation of the pollution plume and effectively reduce the footprint by ~35.0% to ~0.65km^2.

An active management scenario evaluating the mitigating effect of a sub-surface cut-off trench/fracturing curtain on the plume migration was simulated as depicted in Figure 12-33. Due to shallow groundwater levels i.e., relatively thin vadose zone, this mitigation alternative will intercept adequate water to create a negative gradient within these zones, effectively constraining the plume migration reducing it's footprint by ~25.0% to ~0.75km^2.

Based on the constraining effects of these mitigation scenarios on the pollution plume migration, both alternatives can be viewed as the remedial options for implementation. It can be noted that a collective approach can also be evaluated combining these alternatives for a cumulative impact.

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

The main operational activities include disposal of waste material, wastewater management and associated infrastructure as well as discharging of wastewater to the local drainage system.

During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as **insignificant** as no groundwater will be removed from storage via dewatering or abstraction. Groundwater quality impacts from existing waste body footprints and associated infrastructure are rated as **high** negative without implementation of remedial measures and **medium** to **low** negative with implementation of mitigation measures.

The main post-closure activities include rehabilitation and decommissioning of related infrastructure. During the post-closure phase, the environmental significance rating of groundwater quantity impacts on down-gradient receptors remains **insignificant** as not water will be removed from storage**.** Groundwater quality impacts from mining footprints are rated as **high** negative without implementation of remedial measures and **medium** to **low** negative with implementation of mitigation measures.

The following recommendations are proposed following this investigation:

i. It is recommended that the management and mitigation measures be implemented as part of the integrated groundwater management plan (Section 14 of this Report). The Licensee shall appoint a suitably qualified and responsible person and make all of the necessary and reasonable financial, human and equipment resources available to him/her" to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.

ii. It is recommended that the revised monitoring network and program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

iii. Additional monitoring boreholes, as recommended, should be established to replace demolished boreholes down-gradient of existing waste infrastructure in order to evaluate the groundwater drawdown as well as mass load contribution to environmental and sensitive groundwater receptors. Drilling localities should be determined by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.

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

v. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial (once every two years) basis as newly gathered site characterisation data and monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.

List of Abbreviations

ABA	**Acid Base Accounting**
ASTM	**American Society for Testing Materials**
Avg	**Average**
BH	**Borehole**
CMB	**Chloride Mass Balance**
CV	**Coefficient of Variation**
b	**Saturated Thickness**
DMR	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs**
EC	**Electrical Conductivity (mS/m)**
EA	**Environmental Authorisation**
EIA	**Environmental Impact Assessment**
E.N.	**Electro Neutrality**
EPA	**United States Environmental Protection Agency**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN	**Government Notice**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
IWULA	**Integrated Water Use License Application**
ISP	**Internal Strategic Perspective**
K	**Hydraulic Conductivity (m/d)**
KPS	**Kelvin Power Station**
l/s	**Litre per second**
LoM	**Life of Mine**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute Error**
mamsl	**Metres Above Mean Sea Level**
MAP	**Mean Annual Precipitation**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
mcm	**Million Cubic Metres**
ME	**Mean Error**
meq/L	**Mili-equivalents per litre**
mg/l	**Milligrams per litre**
mm/a	**Millimetre per annum**
MPRDA	**Minerals and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
NAWL	**No Access to Water Level**
NGA	**National Groundwater Archive**
NGDB	**National Groundwater Database**

NRMSD	**Normalised Root Mean Square Deviation**
NWA	**National Water Act (Act 36 of 1998)**
REV	**Representative Elementary Value**
RMSE	**Root Mean Square Error**
S	**Storage coefficient**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
Sc	**Specific Storage**
SoW	**Scope of Work**
SRTM	**Shuttle Radar Topography Mission**
T	**Transmissivity (m2/d)**
TDS	**Total Dissolved Solids**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
USGS	**United States Geological Survey**
WGS	**World Geodetic System**
WM	**With Mitigation**
WOM	**Without Mitigation**
WRC	**Water Research Commission**
WUL	**Water Use Licence**

Table of contents

List of figures

List of tables

List of equations

1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment to support a Water Use Licence (WUL) amendment application process to be followed. Kelvin Power Station has an Environmental Management Plan (EMP) in terms of NEMA Section 28, dated 2009 and plans to update the EMP and align its operation activities with legislative requirements.

Kelvin Power Station has two separate power stations: A-station (currently in the process of being decommissioned and demolished – subject to receipt of the relevant environmental authorisation) and B-station (currently operational). 'B' Station has an installed capacity of 420 MW comprising seven 60 MW turbo-alternators and seven 250 tons/hr boilers (four Babcock and Wilcox and three Mitchell-made boiler units). The steam conditions at the turbine stop valve are 482°C and 62 bar. The first unit on the A–Station was commissioned and went commercial on the 27th of March 1957. The power station makes use of coal and water for the generation of electricity (ENVASS, 2025).

The investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts from the power generation operation on sensitive environmental receptors. This report summarises the main conclusions and recommendations derived from the study.

1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors.
ii. Determine the current status quo of the regional groundwater system including aquifer classification, aquifer
iii. Development of a numerical groundwater flow and pollution plume migration model.
iv. Hydrogeological impact assessment and risk matrix.
v. Recommendations on best practise mitigation and management measures to be implemented.
vi. Compilation of an integrated groundwater monitoring network and protocol.

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-24-046-V1, submitted in November 2024. This project plan and scope of work was compiled based on the following guidelines and regulations:

i. Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications.
ii. Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07

April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA).

iii. Best Practice Guidelines (G4 – Impact Prediction) as published by the former Department of Water Affairs and Sanitation (DWS, 2004).

1.3.1. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

i. Information gathering and data acquisition.

ii. Desk study and review of historical groundwater baseline information, existing specialist reports as well as DWS supported groundwater databases i.e. national groundwater archive (NGA).

iii. Fatal flaw and gap analysis.

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

Phase B will entail the following activities:

i. Hydrocensus user survey 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 associated infrastructure footprints.

ii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of sixteen (16) water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

iii. Assess the structural geology and geometry of the aquifer systems with respect to hydraulic interactions and compartmentalisation.

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

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

1.3.3. Phase C: Development of a numerical groundwater flow and mass transport model

Phase C 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 existing and proposed infrastructure footprints 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. Potential water level drawdown and groundwater zone of depression created from abstraction activities.

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

d. Water management alternatives and best practice mitigation measures.

1.3.4. Phase D: Hydrogeological impact assessment and reporting

Phase D will entail the following activities:

i. Compilation of a detailed hydrogeological specialist investigation report with conclusions and recommendations on the following aspects:

a. Fatal flaw and gap analyses.

b. Site baseline characterisation.

c. Aquifer classification and vulnerability.

d. Field work summary, aquifer characterisation and data interpretation.

e. Numerical groundwater flow and pollution plume migration model.

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

g. Recommendation of best practice mitigation and management measures to be implemented.

1.4. Details and expertise of the author

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

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. Aquatico, 2024. Kelvin Power Station Quarterly Water Quality Report December 2024. Report Number: KPS/QWR4/2024/PWB.
ii. Aquiworx software. 2016. Version 2.5.2.0. Centre for Water Sciences and Management at the North-West University.
iii. Barnard, H. C., 2000. An explanation of the 1:500 000 Hydrogeological Map. Johannesburg 2526.
iv. Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2628AA and 2628AB [Map]. Edition 9. Scale 1:50,000. Mowbray, South Africa: Chief Directorate of Surveys and Mapping.
v. Council of Geoscience geological map sheet 2628: Johannesburg (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: Crocodile West Marico Water Management Area. Prepared by Golder Associates (Pty) Ltd on behalf of the Directorate National Water Resources Planning. Report no. P WMA 03/000/00/0303.
x. ESRI basemaps, 2025.
xi. Google Earth, 2025. 6.0.12032 Beta.
xii. Groundwater Complete, 2025. Kelvin Power Station Report On Groundwater Monitoring Results For Quarter 4 Of 2024.
xiii. JR Vegter, DWS and WRC, 1995. Groundwater Resources of the Republic of South Africa.
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.
xv. Parsons, R, 1995. A South African Aquifer System Management Classification, Water Research Commission, WRC Report No KV 77/95.
xvi. van Tonder and Xu, 2000. Program to estimate groundwater recharge and the Groundwater Reserve.
xvii. Water Research Commission (WRC), 2012. Water Resources of South Africa.

1.6. Project assumptions and limitations

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

i. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic and spatial data, a lower resolution of 1:250 000 scale for geological data and a 1: 500 000 scale resolution for hydrogeological information.
ii. The Digital Elevation Model (DEM) data was interpolated with a USGS grid spacing of 25.0m intervals.
iii. Rainfall data and other climatic data was sourced from the WR2012 database.

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

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

vi. No site characterisation boreholes were drilled and/or tested as part of this investigation and aquifer parameters as well as hydrostratigraphic units were assumed based on similar groundwater environments and studies conducted.

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

viii. 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.

ix. The geological structures (fault zones and dyke contact zones) were modelled as permeable linear zones.

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

xi. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly[1].

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

2. METHODOLOGY

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

2.1. Desk study and review

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

2.2. Evaluation of potential environmental receptors

A hydrocensus user survey was conducted in July 2025 in which high-risk environmental receptors have been identified. The hydrocensus user survey evaluated and verified 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 mining development.

2.3. Hydrochemical analysis

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

2.4. Formulation of a conceptual hydrogeological model

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

2.5. Development of a numerical groundwater flow and mass transport model

A numerical groundwater flow and mass transport model was developed based on the defined groundwater conceptual model including gathered site characterisation information. The latter will serve as a tool to evaluate various water management options and different scenarios will be applied to quantify and qualify potential groundwater impacts.

2.6. Groundwater impact assessment

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

3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS

The following water management legislation should be adhered to:

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

The purpose of the National Water Act, 36 of 1998 ("NWA") as set out in Section 2, is to ensure that the country's water resources are protected, used, developed, conserved, managed, and controlled, in a way which inter alia considers the reduction, prevention and degradation of water resources. The NWA states in Section 3 that the National Government is the public trustee of the Nation's water resources. The National Government must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons and in accordance with its constitutional mandate. Section 22 of the NWA states that a person may only use water without a license if such water use is: permissible under Schedule 1, if that water use constitutes as a continuation of an existing lawful water use, or if that water use is permissible in terms of a general authorization issued under Section 39. Permissible water use furthermore includes water use authorised by a license issued in terms of the NWA or alternatively without a license if the responsible authority dispensed with a license requirement under subsection 3. Kelvin Power (Pty) Ltd operates under an approved water use license (WUL) (Reference Number: 03/A21C/FGH/1110) which was issued on 24 June 2011 and is valid for a period of fifteen (15). Section 21 of the National Water Act indicates that water use includes the following:

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

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

The National Environmental Management Act 107 of 1998 intends:

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

ii. to provide for matters connected therewith.

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

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

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

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

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

The classification and definitions herein considered the following documents[2]:

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

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

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

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

Kelvin Power Station falls within the Ekurhuleni Metropolitan Municipality, Gauteng Province, South Africa. The existing development is situated approximately 4.0km southwest of Kempton Park and approximately 8.0km northwest of Benoni covering a total footprint of ~149.0ha .

The site is accessible via secondary route R25 situated to the northwest. 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 5-1 with the project boundary and topo-cadastral map depicted in Figure 5-2.

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

Latitude	26° 6'56.29"S
Longitude	28°11'42.24"

4.2. Project description and existing infrastructure

Kelvin Power comprises of two stations; Station A and Station B. Coal is burnt inside the boiler to produce super-heated steam (SHS). The SHS is transported via pipes to the turbines. Here, the SHS drives the blades of the turbine, spinning the rotor at high speed (mechanical energy). The rotor then turns the generator, which generates electricity. The slurry (containing fine and coarse ash) from the burnt coal is hydraulically routed to Ash Dam A for deposition.

For steam production in the boilers, demineralised water is added as make-up water to recycled condensate. The steam is condensed by cooling it with water circulated through the hyperbolic cooling towers. Kelvin receives approximately 3 681 m^3/d of water from Rand Water and about 13 955 m^3/d of treated effluent.

Station A operations ceased, and this station is currently under extended care and maintenance. Station A has an installed capacity of 180 megawatts comprising six (6) turbo-alternators of 30 megawatts each and 11 boilers which consume approximately 85 tonnes of coal per hour. The furnaces at this station are chain grate types as opposed to the pulverised fuel type in Station B.

Station A, which utilised a larger coal fraction for heat generation, produced coarse ash, most of which was previously discarded on an open dumping area to the west of the power station (Golder, 2021). The power station makes use of coal and water for the generation of electricity. Relatively small quantities of chemicals are also utilised for the treatment of water for the boilers in the demineralisation plant.

Kelvin consumes approximately 1.5 million tonnes of coal per annum, which is transported by road to Kelvin from various mines in the Mpumalanga Province. Station B uses 0.85 to 1.0 million tonnes per annum. These quantities will increase in proportion to production rate.

Kelvin receives water from the Rand Water Board (RWB) and treated effluent from the Northern Wastewater Treatment Works (NWTW) which is situated in Diepsloot. Roughly 15 000 m^3/d of water from NWTW is utilised at the Kelvin Power Station.

Station B has an installed capacity of 420 megawatts comprising seven (7) turbo-alternators of 60 megawatts each, and seven (7) boilers, which consume 250 tonnes of coal per hour. The steam is delivered at 62 bar and 482°C. The station turbo-alternators are not operated at full capacity to safeguard against failure (Golder, 2021). The turbine shaft is coupled to the alternator rotor, rotating at 3 000 revolutions per minute. This large electro-magnet produces electricity by inducing voltage, which causes current to flow in the alternator stator. The electricity is transformed up to the grid voltage by the generator transformer and supplied to the grid via the switch yard.

For steam production in the boilers, demineralised water is added as make-up water to recycled condensate. The steam is condensed by cooling it with water circulated through the hyperbolic cooling towers (five towers for Station B) to the south of the power station buildings.

Station B uses a pulverised fine-coal fraction for heat generation, which results in a fine ash by-product. Previously, all the ash was pumped in slurry form to Ash Dam A. Presently, approximately 10% of the ash is being collected by a cement manufacturer as raw material, thereby facilitating waste minimisation (both in terms of ash and water use) at the power station. In addition, this practice is increasing the life of the Ash Dam's operational phase. The remainder of the ash is still slurried and disposed of on Ash Dam A.

The final waste product from Kelvin is in the form of a wastewater effluent, consisting of cooling tower blow-down, effluent from miscellaneous cooling water uses, ash-quenching effluent and washings. These effluents are discharged to the Modderfonteinspruit after de-siltation. Refer to Figure 5-3 for a simplified layout map of the above-mentioned processes (ENVASS, 2025).

5. PHYSIOGRAPHY

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

5.1. Topography

The topography of the greater study area are characteristically an undulating highveld plateau with gentle rises and dips. The relief of the area varies between 0.0 – 130.0m towards the eastern segment and between 30.0 – 210.0m towards the western perimeter. The landscape gradually flattens out towards the lower laying drainage system towards the northwest (approximate elevation low of 1430.0mamsl), while the southern and southwestern perimeters are shaped by ridges also forming the catchment water divide (approximate elevation high of 1787.0mamsl). The lowest topographical elevation on-site is recorded as 1620.0mamsl which is situated towards the western perimeter forming part of the local drainage system while the highest topographical point recorded on site is approximately 1671.0mamsl towards the east. Due to the presence of artificial ash dumps, on-site gradients are highly variable, especially towards the southwestern zone of the study area, however the gradient are generally moderate to gentle. The average slope is calculated at ~3.0% with an elevation loss of approximately 74.0m over a lateral distance of 2.0km in a general northwestern orientation. Figure 5-4 depicts a topographical cross-section (east-west aspect) of the greater study area while Figure 5-5 shows the regional topographical contours and setting.

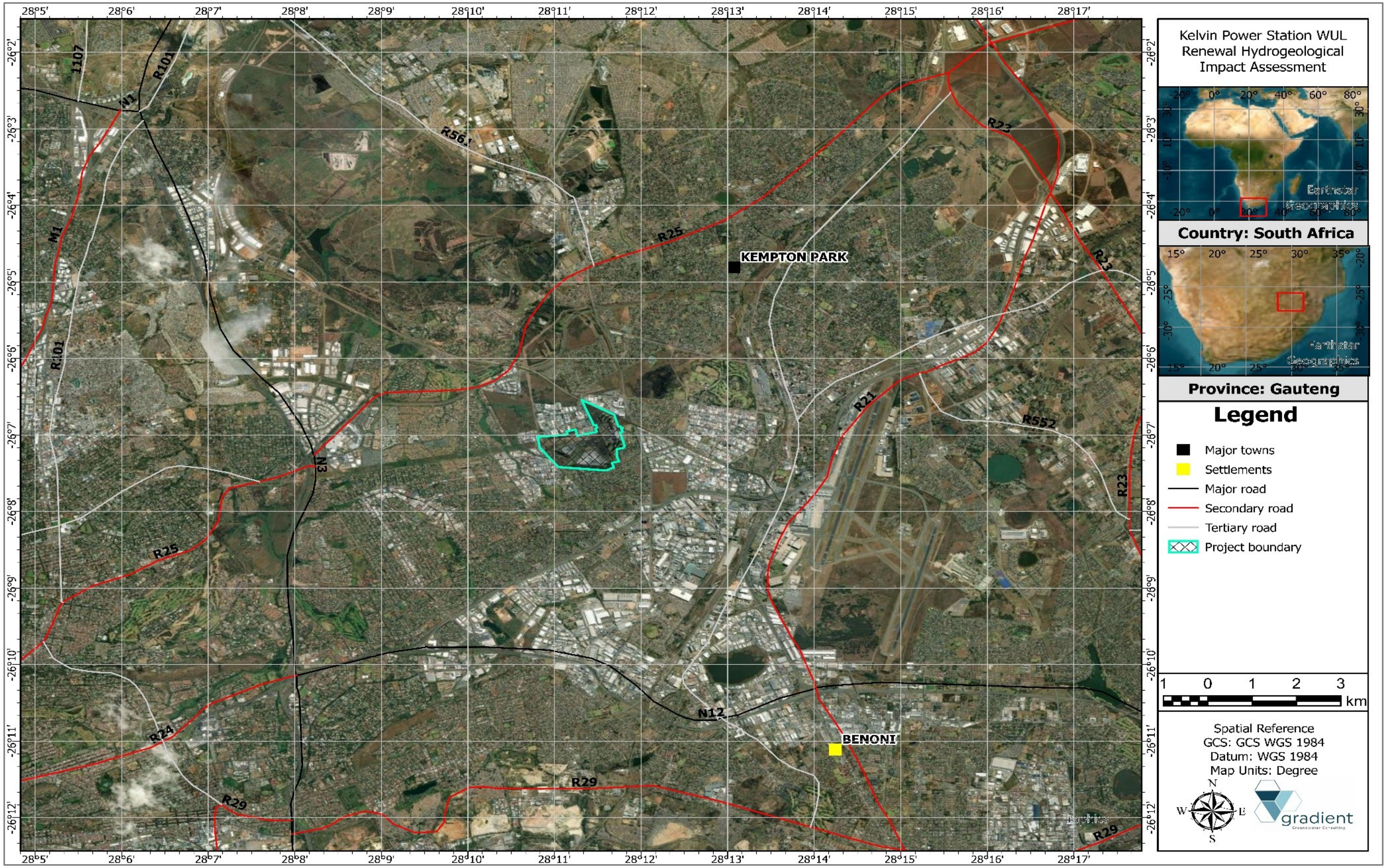


Figure 5-1 **Aerial extent and greater study area.**

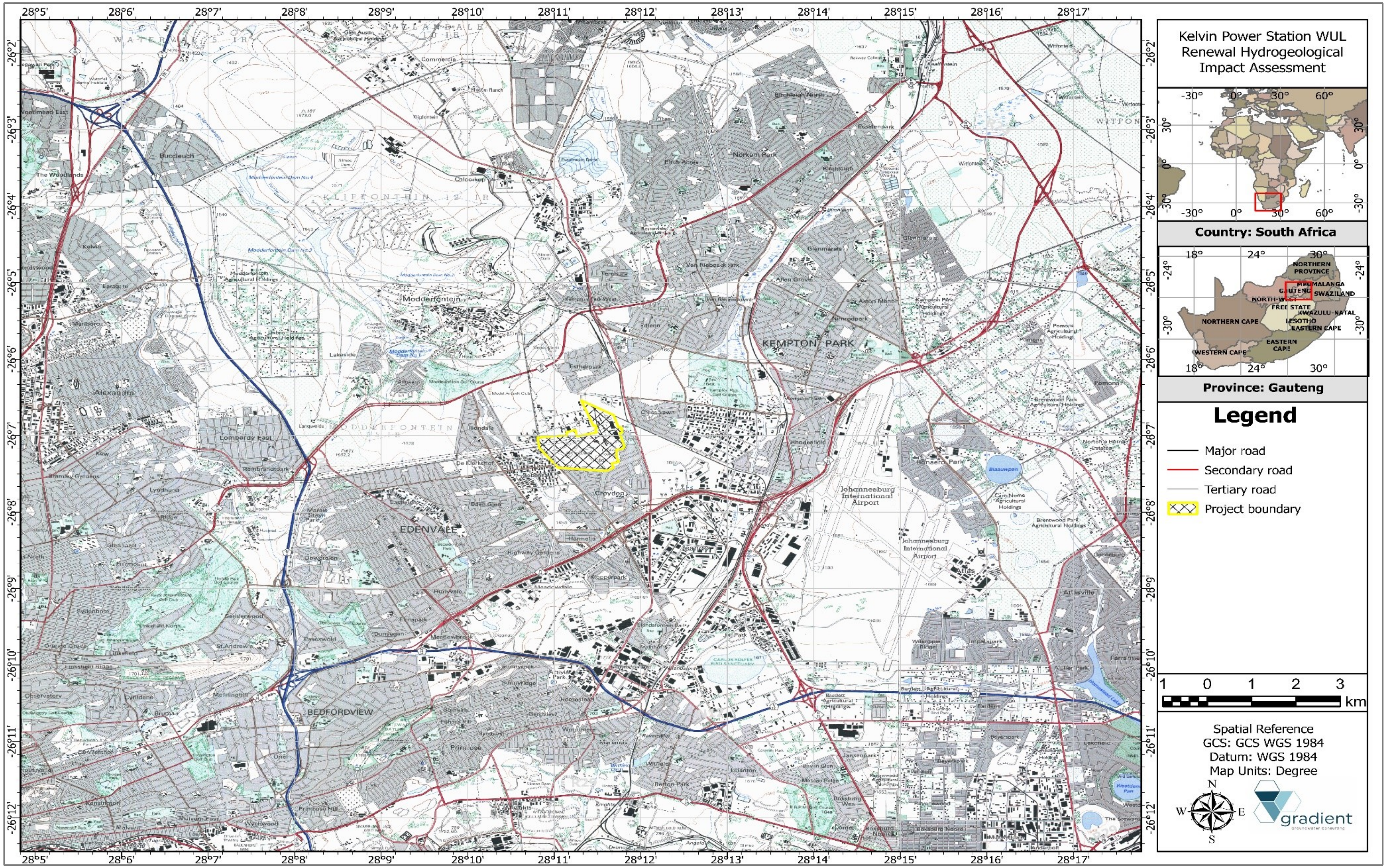


Figure 5-2 Greater study area (1:50 000 topographical mapsheet 2628AA and 2628AB).

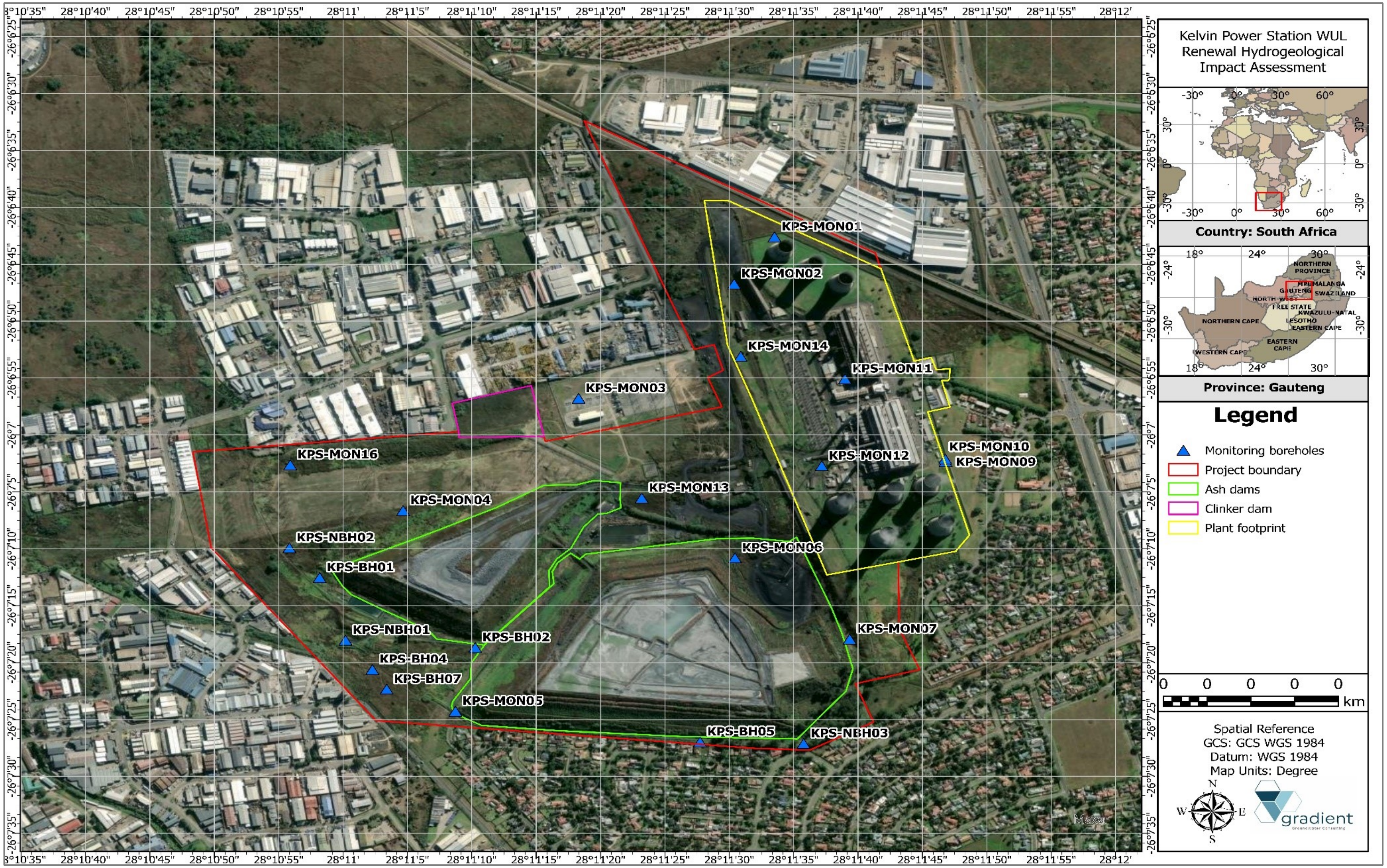


Figure 5-3 **General site layout and infrastructrure map.**

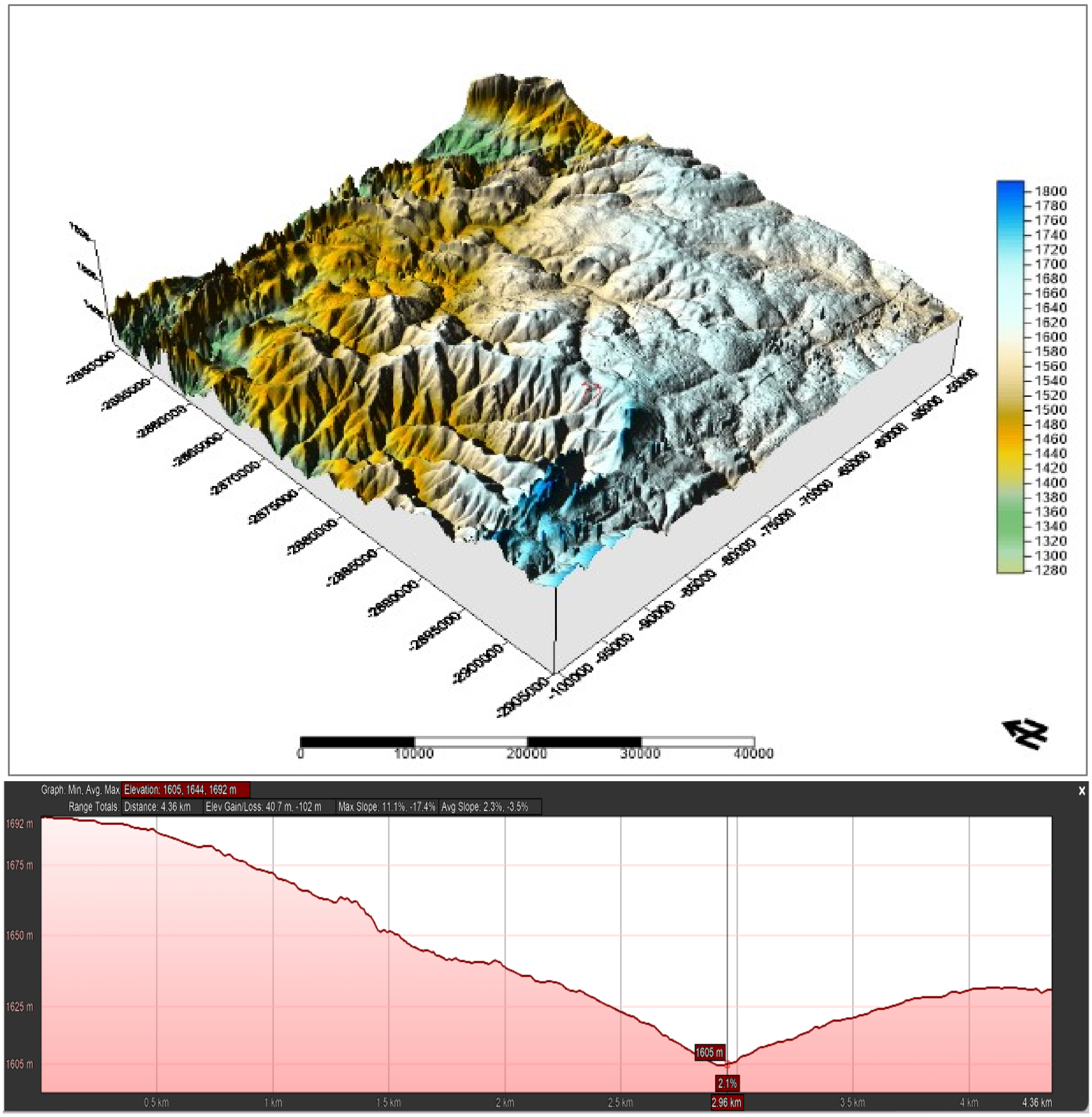


Figure 5-4 **Topographical cross-sections of the greater project area.**

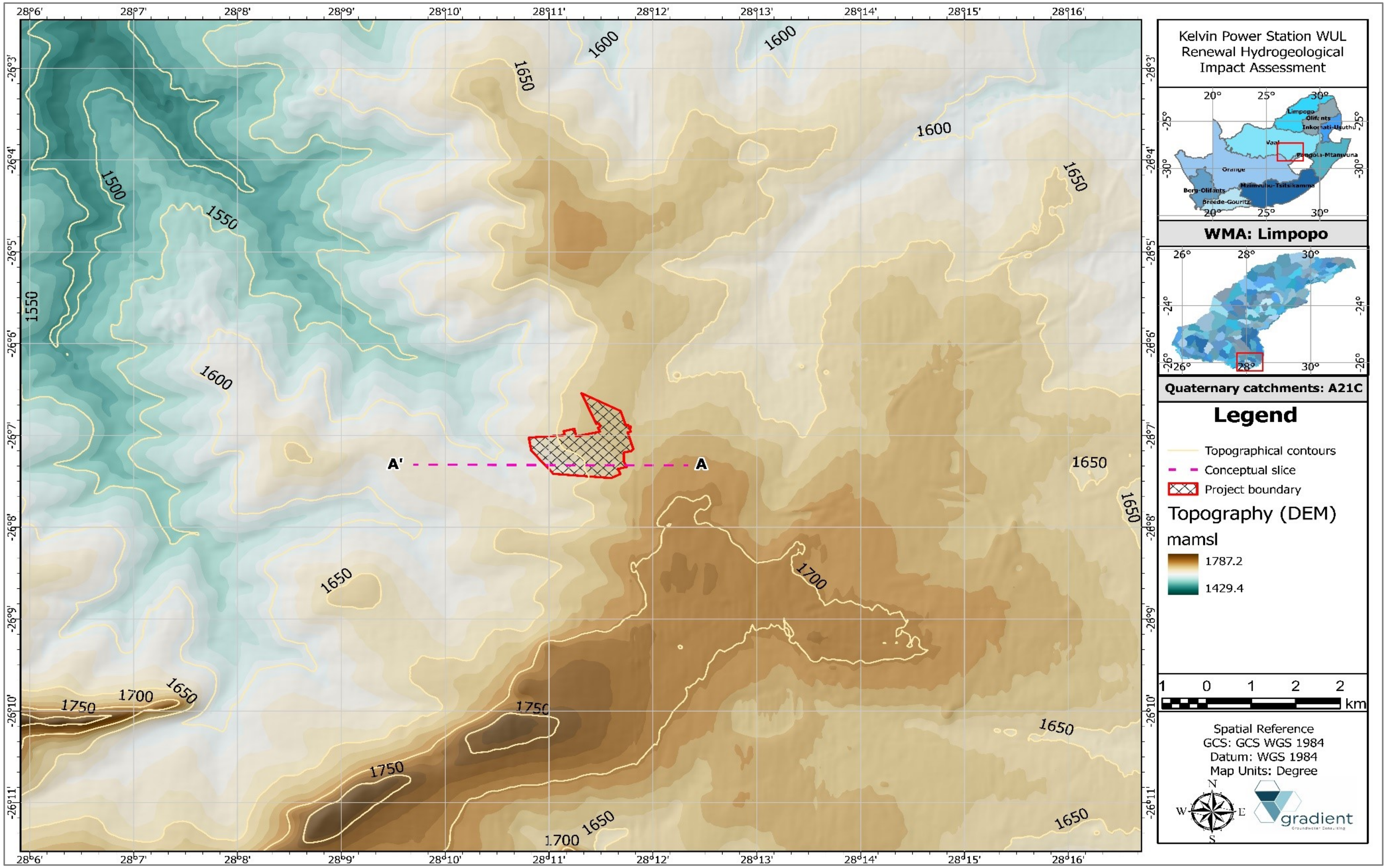


Figure 5-5 **Regional topography and conceptual slice.**

5.2. Drainage and catchment

The greater study is situated in primary catchment (A) of the Crocodile and Juksei River drainage systems which covers a total area of approximately 48 000km^2. The resource management falls under the Limpopo Water Management Area (WMA3)(previously Crocodile (West) and Marico WMA[3]) which spans portions of the North West Province, northern Gauteng as well as Limpopo Province.

The study area is situated within quaternary catchment A21C (761.0km^2) which falls within hydrological zone F and the estimated mean annual runoff (MAR) being 49.0mm (WR 2012, Aquiworx 2016). The hydrology of the region is characterised by predominately perennial watercourses with the main rivers draining the greater study area in a general north-westerly direction being the Jukskei River.

Locally a tributary of the Jukskei River, Modderfonteinspruit, flows just west of the project area forming a confluence with the Jukskei River approximately 11.0km northwest of the site as depicted in Figure 5-6. Various dams i.e. Modderfontein dam 01 – dam 04 as well as associated wetland system can be observed towards the northwest of the study area. It will be imperative to include this wetland system as a sensitive receptor for potential contamination originating from related activities. Table 5-1provides a summary of relevant climatological and hydrogeological information for the relevant quaternary catchments.

Table 5-1 Quaternary catchment information.

Attribute	Quaternary catchment A21C
Water Management Area (WMA)	Limpopo
Primary catchment	A
Secondary catchment	A2
Tertiary catchment	A21
Quaternary catchment	A21C
Major rivers	Jukskei, Krokodil
Hydro-zone	F
Rainfall zone	A2B
Area (km^2)	761.0
Mean annual rainfall (mm)	682.2
Mean annual evaporation (mm)	1700.0
Mean annual runoff (mm)	49.0
Baseflow (mm)	20.3
Population	545 170.0
Total groundwater use (l/s)	45.3
Present Eco Status Category	Category C
Recharge (mm)	50.0 - 75.0
Average water level (mbgl)	15.0
Soil type	LmSa - SaLm 20 SaClLm - 70
Groundwater General Authorization	0 m^3/ha/a

Note: Catchment based information sourced from Aquiworx 2016

[3] It should be noted that the Department of Water Affairs (DWA), now the Department of Water and Sanitation (DWS), replaced the original 19 WMAs established in 2004 by 9 new WMAs as defined in Government Gazette No. 35517, July 2012. This resulted in the grouping of the Crocodile (West) and Marico and Limpopo WMAs into the single Limpopo WMA.

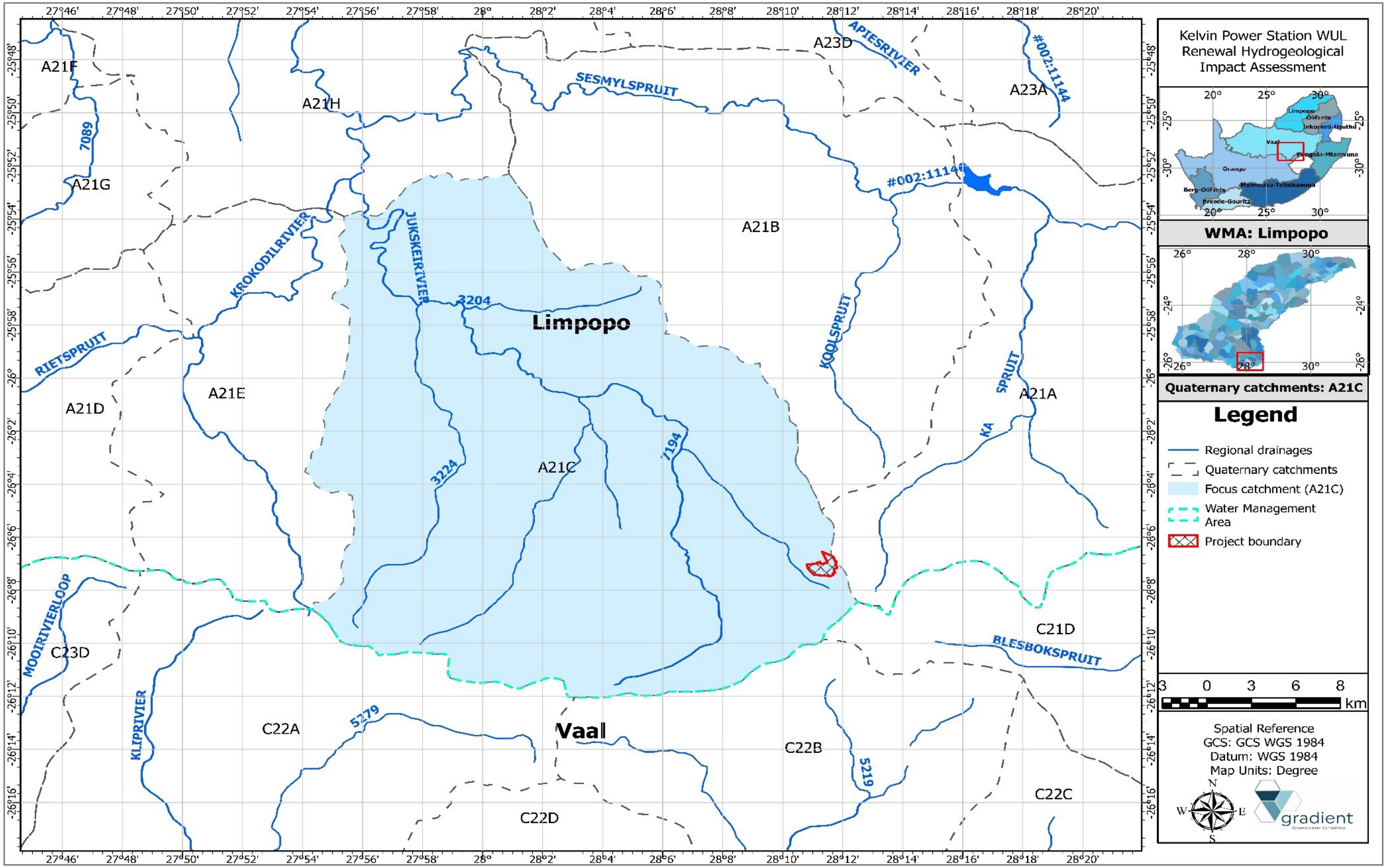


Figure 5-6 **Quaternary catchments and water management area.**

5.2.1. Climate

According to the Koppen-Geiger climate classification system, the climate of the study area is classified as Cwb (Climate Change & Infectious Diseases Group, 2023). This classification indicates that the study area has a warm, semi-arid climate characterized by cold, dry winters and warm summers. The average temperature in the study area ranges between 4.0 °C in the winter (July) and 26.0 °C in the summer (January). Refer to Figure 5-7 for the Mean Yearly Temperature and rainfall distribution of the greater study area.

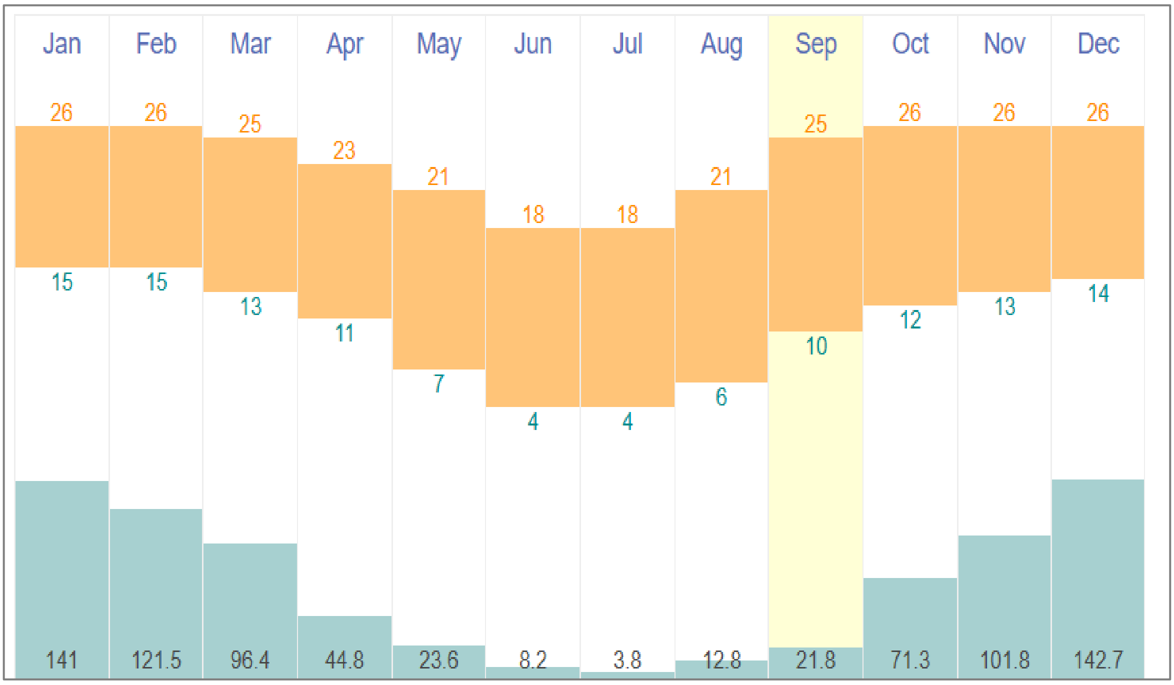


Figure 5-7 Mean Yearly Temperature and rainfall distribution of the greater study area, 1992 – 2021 (Climate-Data, 2021).

The study area's weather pattern reflects a typical summer rainfall region, with > 85% of precipitation occurring as high-intensity thunderstorms from October to March. Patched rainfall and evaporation data were sourced from the WR2012 database (Rainfall zone A2B) and span a period of some 90 years (1920 – 2009). Time-series rainfall data tables are listed in Appendix A.

The calculated mean annual precipitation (MAP) for this rainfall zone is 675.69mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 467.09mm/a and the 95th percentile (representing a 1:20 flood period) 939.30mm/a. The highest MAP for the 90 years of rainfall data was recorded as of 1034.40mm (1996) while the lowest MAP of 409.50mm was recorded during 1991. The catchment area is categorised under evaporation zone 3A which has a mean annual evaporation (s-pan) ranging between 1700mm/a, more than double the annual precipitation (WRC, 2016). Figure 5-8 depicts a bar chart of the monthly rainfall patterns of the greater study area while Figure 5-9 indicate the yearly rainfall distributions. Figure 5-10 shows a comparison graph of the monthly precipitation vs monthly evaporation figures.

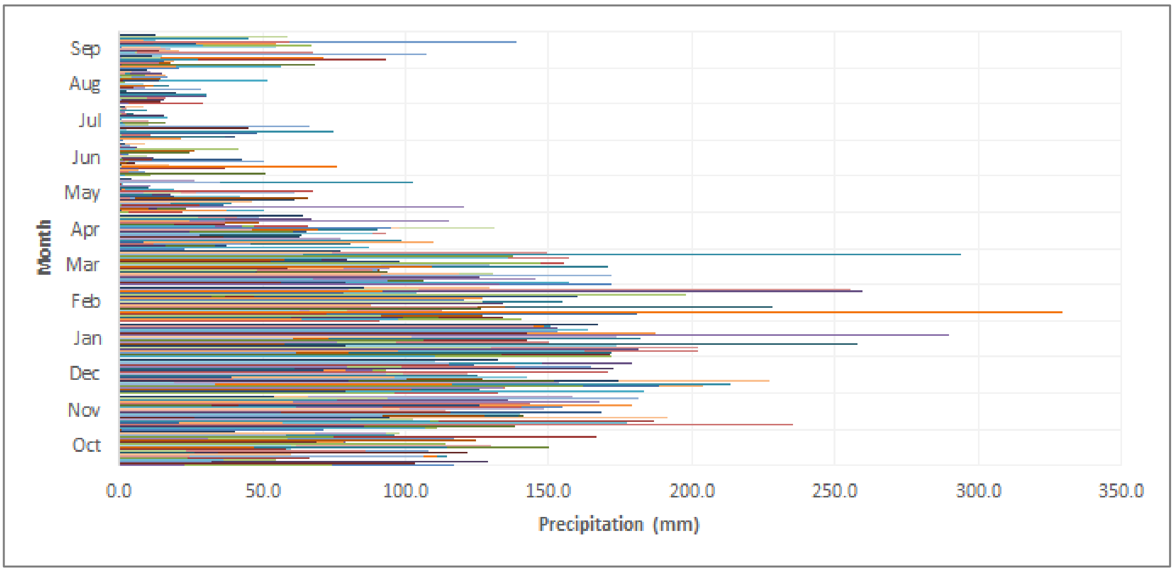


Figure 5-8 **Monthly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

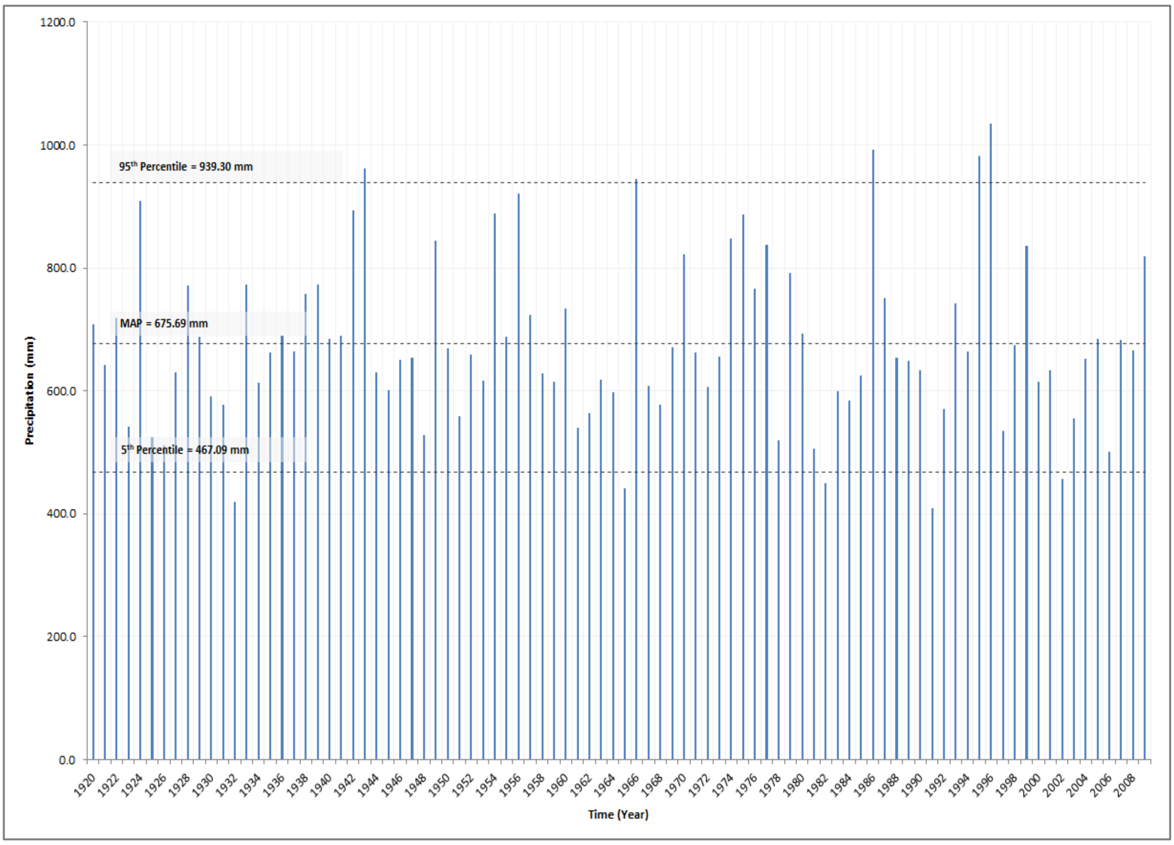


Figure 5-9 **Yearly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

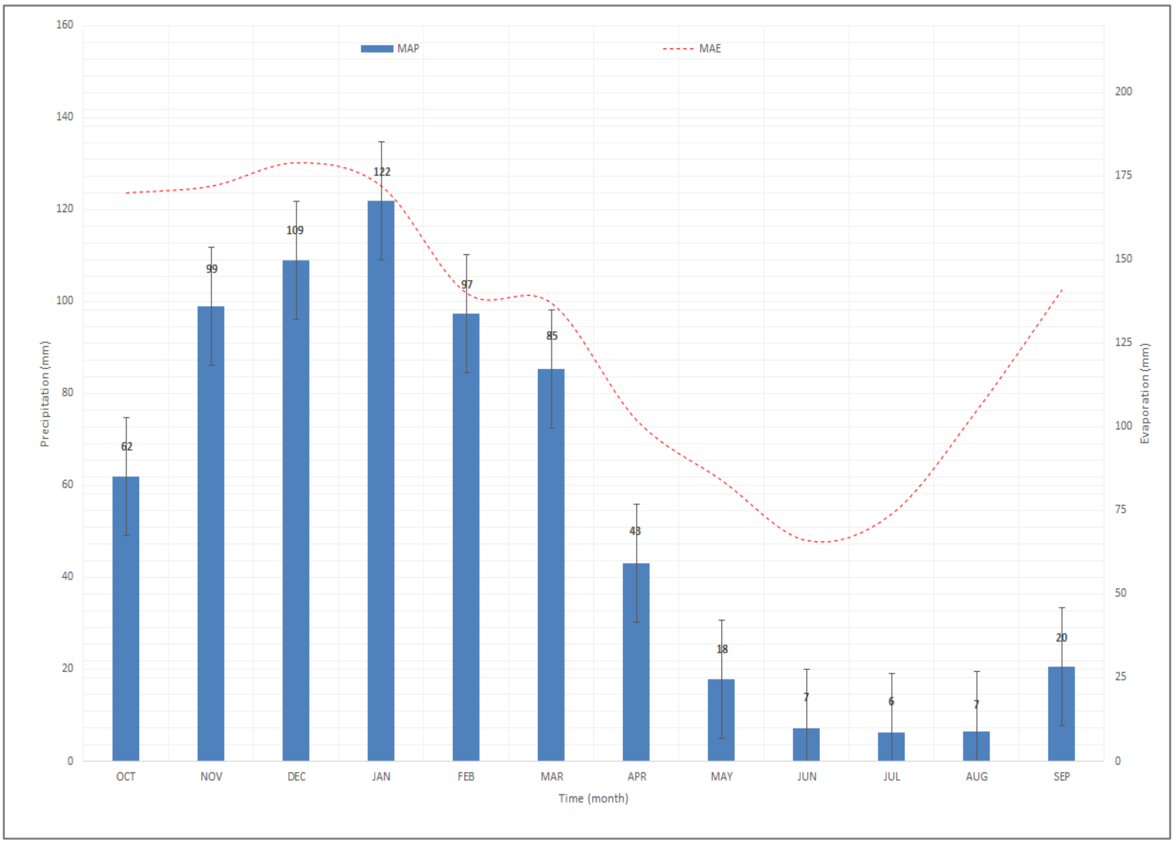


Figure 5-10 Comparison of monthly precipitation vs monthly evaporation (WRC, 2016).

5.3. Geological setting

The following sections summarises the regional and local geology.

5.3.1. Regional geology

According to the Council for Geoscience (CGS) 1:250 000 geological maps (Geological Map Sheet 2628 Johannesburg the surficial geology of the study area comprises of felsic, intermediate rocks of the Halfway House Dome situated on the central Kaapvaal Craton formed through a series of magmatic events during the mid-Archaean age.

The Ventersdorp Supergroup comprising of mafic and ultramafic volcanic rocks of the Klipriviersberg Group striking in a southwest northeast direction and dipping at approximately 50° in a southeastern orientation occurs just southwest of the project area. Following the Ventersdorp Group are siliciclastic rocks of the West Rand Group (Hospital Hill, Jeppestown as well as Government Subgroups) of the Witwatersrand Supergroup which also dips approximately 45° in a general south to southwestern orientation.

The Dwyka Group of the Karoo Supergroup flanks the West Rand Group towards the eastern perimeter of the greater study area while carbonate rocks of the Malmani Subgroup (Chuniespoort Group) occur towards the north and northeast.

5.3.2. Structural geology

The Karoo Basin, situated toward the east of the project area, 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). Such dolerite dykes associated with the Karoo Dolerite Suite occur toward the south and southeast of the study area which may be relatively thin, usually not wider than 5.0m while sills may be as thick as 100.0m. Structural analysis indicate the presence of various SW-NE as well as N-S trending fault zones traversing the greater study area. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

5.3.3. Soils

Soils in the study area were identified using GIS data obtained from WR2012 (WRC, 2016). The data indicates that soils toward the western zone of the study area is classified as Sandy-Loam to Sandy-Clay-Loam (SaLm-SaClLm) while the eastern segment is classified as Sandy-Clay-Loam (SaClLm).

Figure 5-11 **Regional geology and stratigraphy (Geological map sheet 2628: Johannesburg (1:250 000 scale).**

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

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

6.1. Regional hydrogeology

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

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

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2526 (Johannesburg) the study area is predominantly underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0L/s), it should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. (Barnard, 2000). The host aquifers consist of primarily intermediate or alkaline intrusive. Most hard-rock aquifers are secondary in nature with groundwater associated with fracturing, fault zones as well as contact zones.

According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the Central Highveld Region (Region 17). The maximum aquifer thickness i.e., shallow, intergranular aquifer system is <20m with water stored mainly in fractures principally restricted to a shallow zone below groundwater level. Figure 6-1 depicts a conceptualised cross section of the greater study area. Refer to Figure 6-2 for a map illustrating the typical groundwater occurrence for the greater study area while Figure 6-3 depicts the hydrogeological map of the greater study area.

6.2. Local hydrostratigraphic units

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

i. **A shallow Quaternary (perched and unconfined) aquifer:** These aquifers consist of recent types of sediments and are characteristically primary porosity aquifers, such that groundwater flow occurs in the pore spaces between soil and sediment particles. These aquifers are formed by alluvial material along the riparian zone of local drainages and are limited to a zone of variable width and depth. Clay lenses in the soil and unsaturated zones may cause local, perched water tables which occur above the regional water table.

ii. **A shallow, intergranular aquifer within the Halfway House Granites:** These aquifers occur in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Groundwater flow patterns usually follow the topography, discharging as natural springs at topographic low-lying areas. Usually, these aquifers can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. In secondary porosity aquifers, groundwater flow occurs along fractures, while water is stored within the rock matrix. Due to higher effective porosity (n) this aquifer is more susceptible to impacts from contaminant sources compared to confined aquifers.

iii. **A deeper, fractured aquifer within the Halfway House Granites:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured granite as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

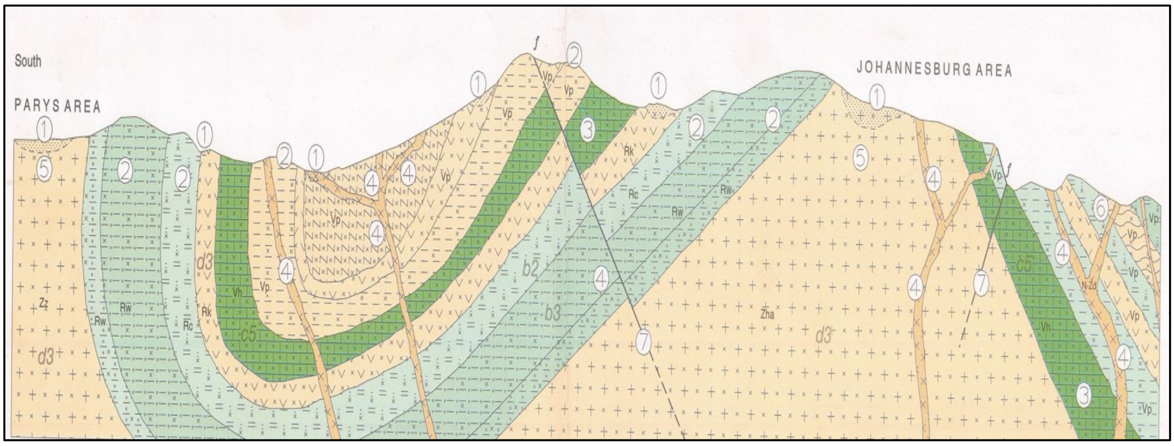


Figure 6-1 Schematic cross section to illustrate typical groundwater occurance in the Johannesburg area (Barnard, 1999)..

[4] Refer to project assumptions and limitations, it should be noted that no site characterisation boreholes have been drilled to confirm this statement.

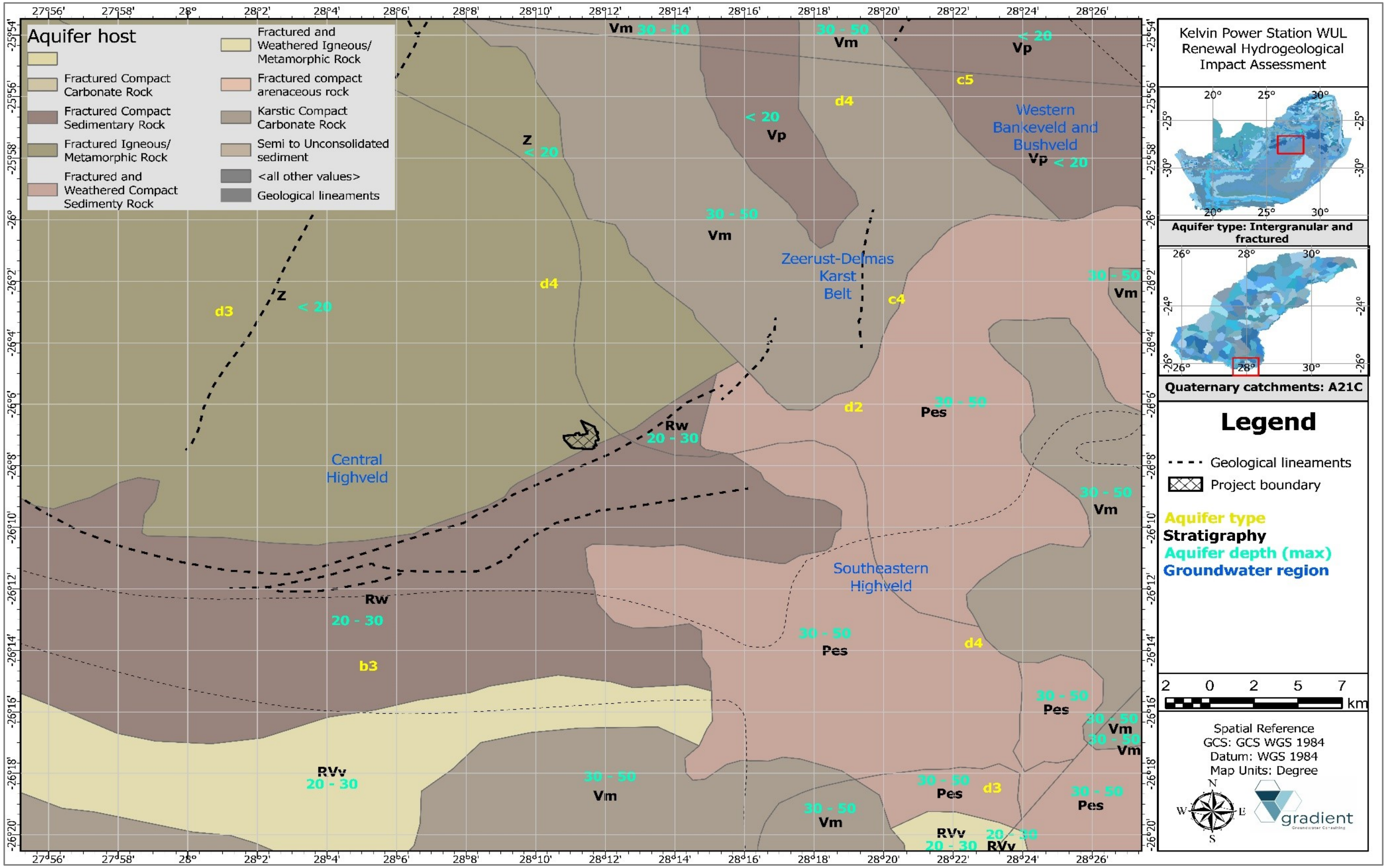


Figure 6-2 **Typical aquifer hosts and groundwater occurrence for the study region (2526 Johanesburg).**

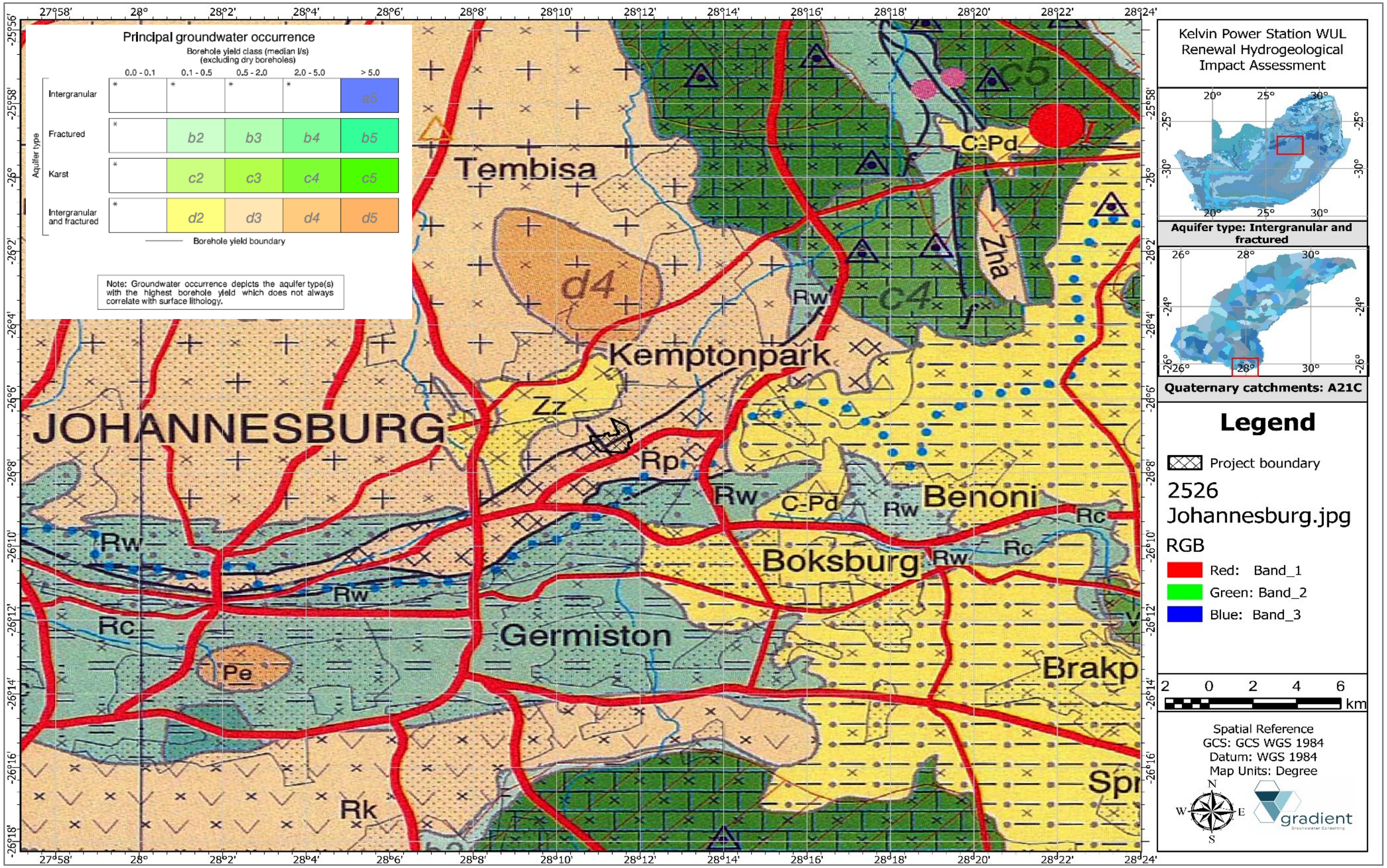


Figure 6-3 **Hydrogeological map of the greater study region (2526 Johannesburg).**

6.3. 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) as shown in Figure 6-4. According to records documented by Van Tonder and Dennis (2003), under natural conditions this area exhibits certain regions where there is pronounced interaction between surface and groundwater. The two regimes are therefore well-linked and should be integrated to manage any water-related issues in these catchments. Regional drainages can be generally classified as influent or gaining stream systems. Groundwater head elevation compared to topographical elevation confirms that there exists groundwater discharge as baseflow to local drainages.

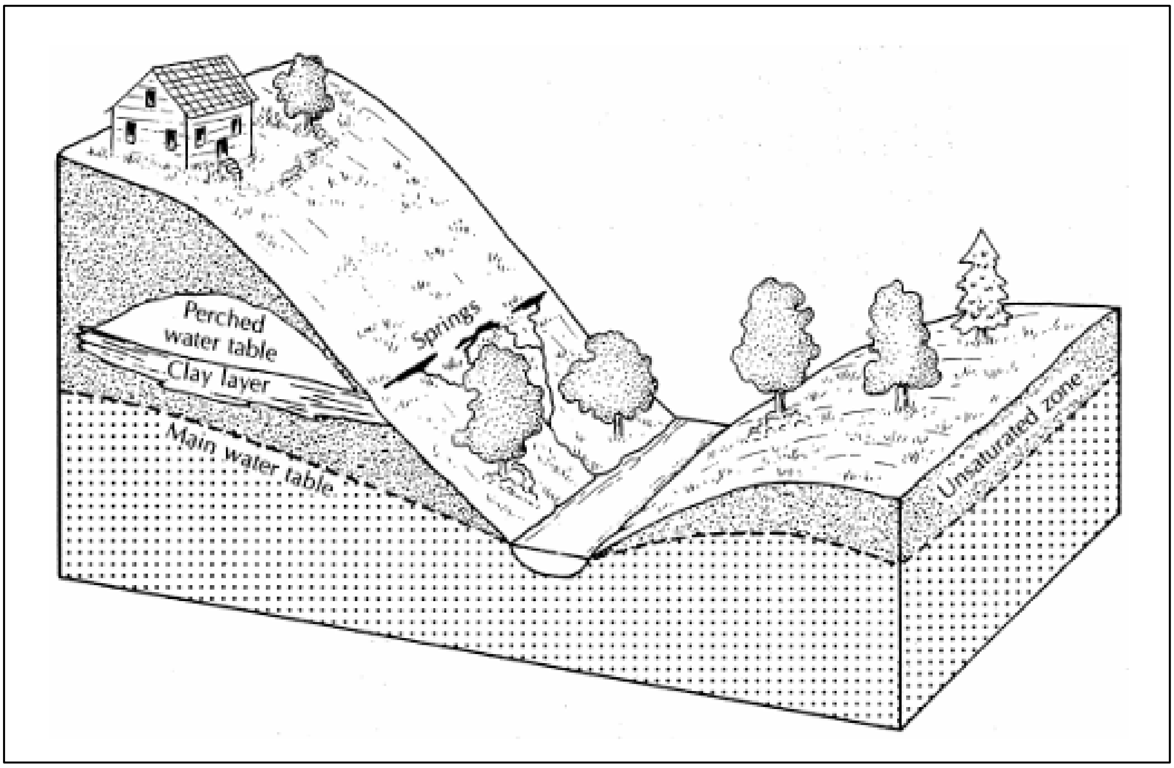


Figure 6-4 Illustration of the Unsaturated Zone (Fetter and Kreamer, 2023).

6.4. Hydraulic parameters

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

6.4.1. Hydraulic conductivity and Transmissivity

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

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

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

where:

K = Hydraulic Conductivity (m/d).

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

dh/dl = Hydraulic gradient.

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

The hydraulic conductivity of igneous formations such as evident on site can range from $10E^{-05}$ – $10E^{-02}$ m/d. The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10E^{-06}$ – $10E^{-01}$m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10E^{-09}$ – $10E^{-06}$ m/d.

It should be noted that the hydraulic conductivity of fault zones traversing the greater study area may be orders of magnitude higher than the matrix formations and will act as preferred pathways for groundwater flow and contaminant transport. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e., riverbed aquifers can be orders higher and can vary between $10E^{-02}$ – $10E^{+01}$ m/d as depicted in Figure 6-5 (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.

Data interpretation from recent constant discharge pump tests conducted indicate average transmissivity values ranging between 0.50 to 1.50m^2/d (Groundwater Complete, 2025).

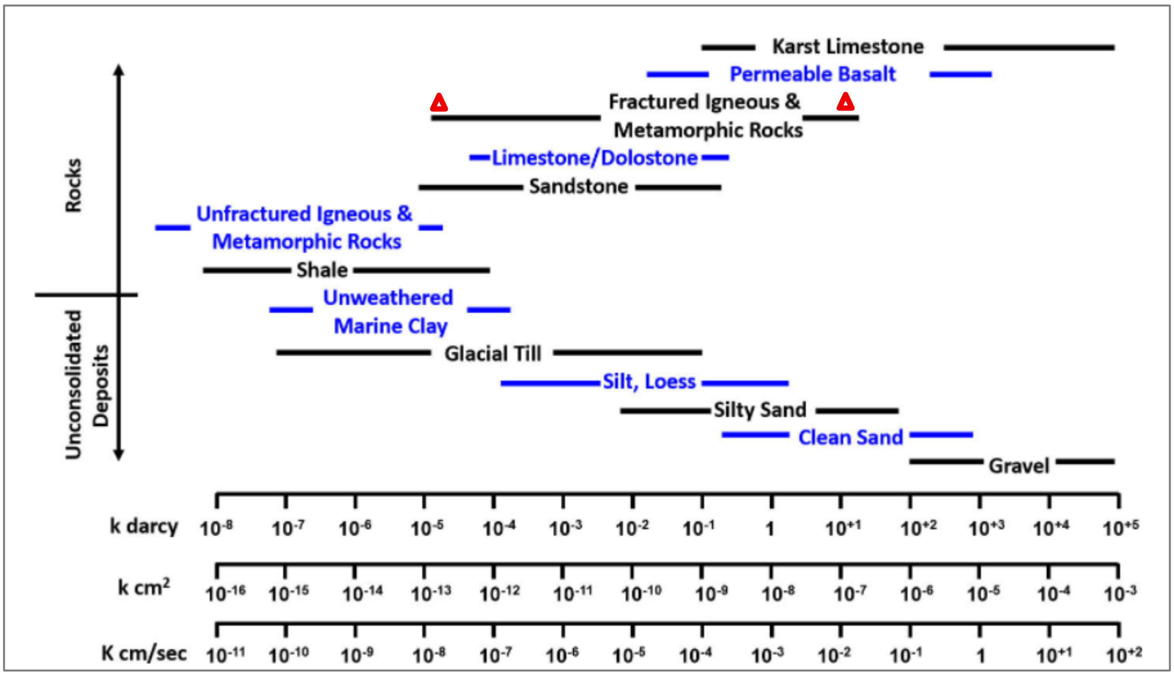


Figure 6-5 **Typical hydraulic conductivity values for on-site hydrostratigraphical units.**

6.4.2. Storativity

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

6.4.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. Porosity is an intrinsic value of seepage velocity and hence contamination migration. The porosity of fractured igneous formations ranges between 0.1% – 1%, while porosity of weathered formations can range between 3% to 10% depending on the nature and state of weathering. The intrinsic porosity of primary aquifers i.e., alluvial deposits can be as high as 15% depending on the nature of sorting (Freeze and Cherry, 1979).

6.4.4. Recharge

An approximation of recharge for the study area is estimated at ~4.23% of MAP i.e. ~28.82 mm/a as summarised in Table 6-1. Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride Mass Balance (CMB) methodology (refer to Figure 6-6) (ii) Geology (iii) Vegter Groundwater Recharge Map (Figure 6-7) (iv) Harvest Potential (Figure 6-8) (v) Baseflow as a minimum of recharge and, (vi) Published literature.

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

Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Chloride	25.58	3.75	4.00
Geology	34.10	5.00	1.00
Vegter	45.00	6.60	2.00
ACRU	30.00	4.40	3.00
Baseflow	25.00	3.67	4.00
Published literature	24.50	3.59	3.00
Weighted average	**28.82**	**4.23**	**17.00**

Notes: Recharge per annum were calculated using a MAP of 682.0mm/a.

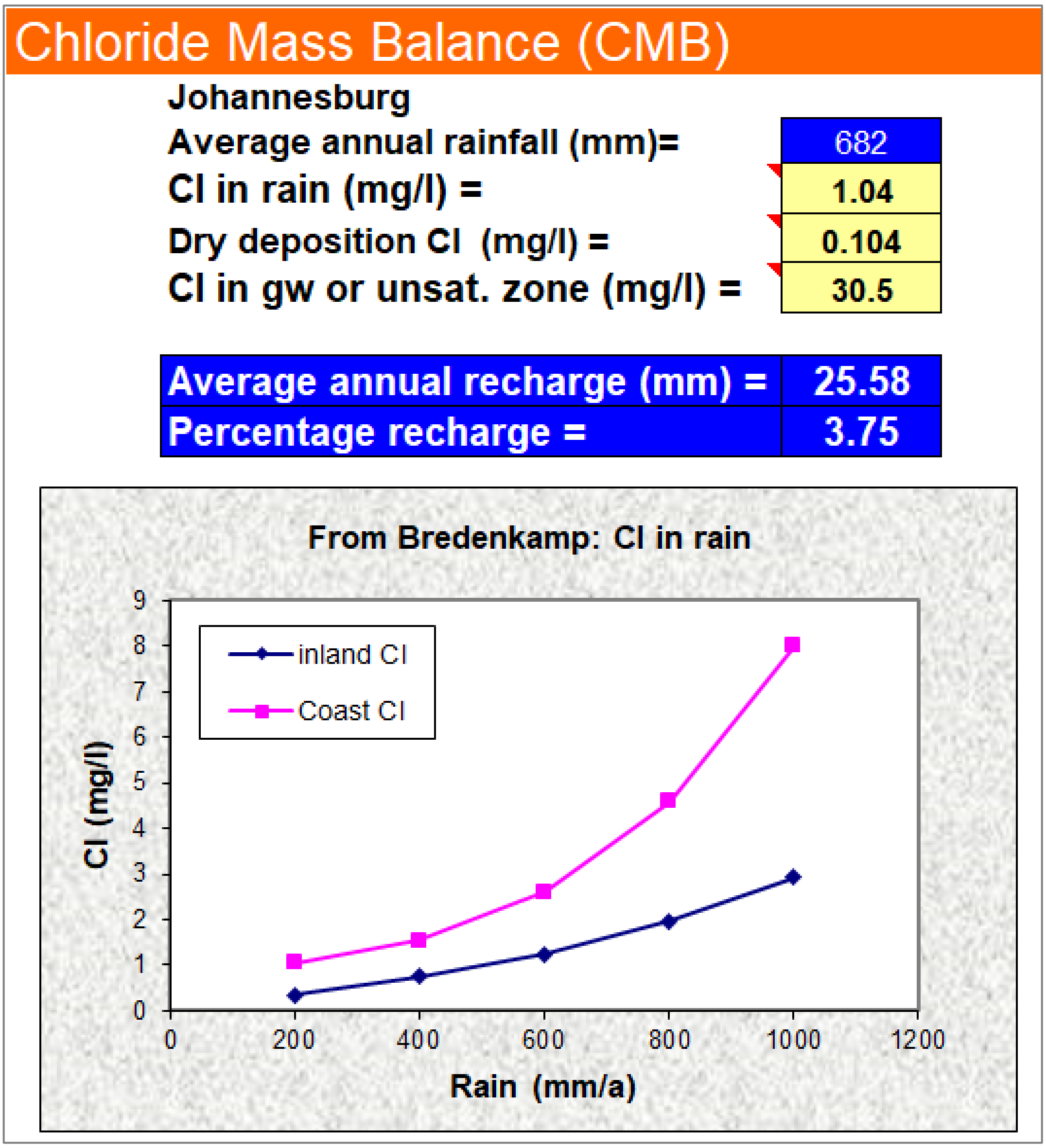


Figure 6-6 Chloride Mass Balance (CMB) method summary.

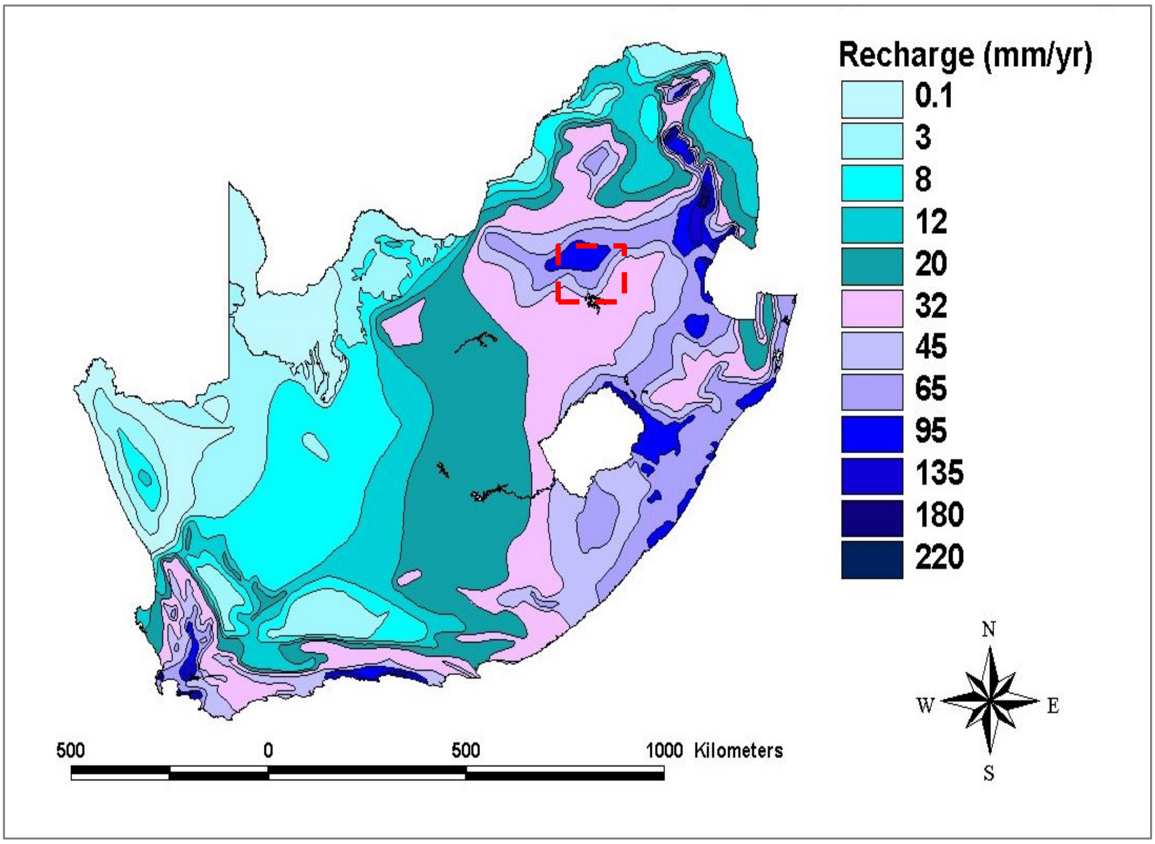


Figure 6-7 Groundwater recharge distribution in South Africa (After Vegter, 1995).

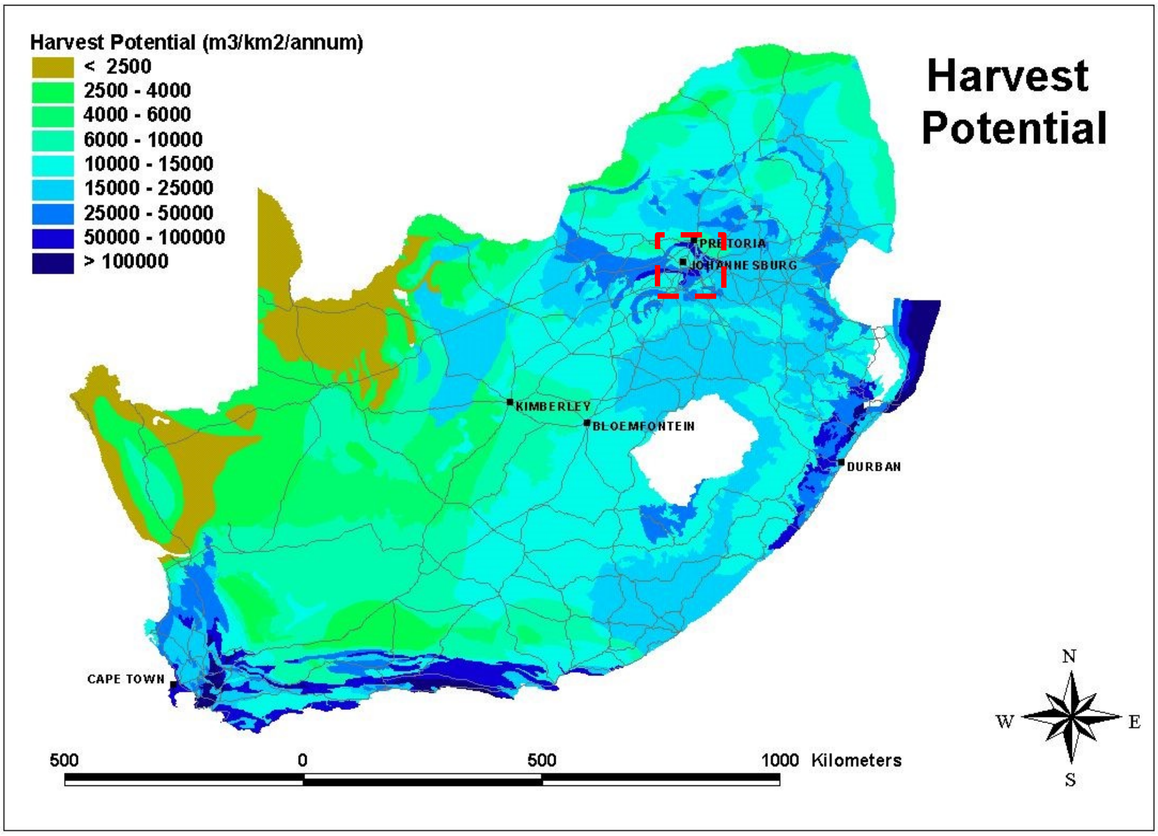


Figure 6-8 Harvest potential distribution in South Africa (DWS, 2013).

7. SITE INVESTIGATION

7.1. Hydrocensus user survey

A hydrocensus user survey within the greater study area was conducted during July 2025[5] where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater and surface water conditions including applications and to identify potential sensitive environmental receptors i.e., groundwater and surface water users including wetlands or spring localities in close vicinity to the existing power generation operations. A total of 25 geosites were visited as part of the hydrocensus user survey. Relevant information is summarised in Table 7-2 with a spatial distribution map of geosites shown in Figure 7-1. Table 7-1 tabulates local landowners visited, however no boreholes or other receptors could be identified.

7.1.1. Geosite type

A total of 25 geosites or potential receptors were visited and recorded consisting of 22 boreholes (~88.0%) and 5 surface water features (12.0%).

7.1.2. Groundwater status

All the boreholes recorded are in use and being applied for monitoring purposes.

7.1.3. Borehole equipment

None of the boreholes visited are equipped as they are being applied for monitoring purposes.

Table 7-1 Hydrocensus user survey: relevant visited outside of the project boundary.

Site ID	Latitude	Longitude	Owner	Field notes
n/a	-26.11603	28.19807	Kelvin Estate	No boreholes, appointment only, spoke with security
n/a	-26.12456	28.19072	Host Hub Guest House	No borehole, spoke with owner
n/a	-26.12748	28.18546	Rolop CC	No borehole, spoke with owner
n/a	-26.12308	28.18255	Trouw Nutrition	No borehole, spoke with facilities manager
n/a	-26.12720	28.18536	Sondor Performance Foams	No borehole, spoke with facilities manager
n/a	-26.12504	28.18381	Coprechem	No boreholes, appointment only, spoke with security
n/a	-26.12156	28.20029	Eco Motel	No borehole, spoke with receptionist
n/a	-26.11960	28.20166	GlenChem	No borehole, spoke with receptionist
n/a	-26.11677	28.20056	Berry & Donaldson	No borehole, spoke with receptionist
n/a	-26.11828	28.20008	Sasol Fill station	No borehole, spoke with manager
n/a	-26.11222	28.19755	Engen Fill station	No borehole, spoke with manager
n/a	-26.10827	28.19580	Steel Mate	No borehole, spoke with owner
n/a	-26.10941	28.19257	Air Liquide	No borehole, spoke with security
n/a	-26.11149	28.18766	Value Chemical Logistics	No borehole, spoke with receptionist

Notes: N/A: Not applicable

Notes: Due to the POPIA act (Act 4 of 2013) no personal contact details were reflected in this table

[5] Relevant site information gathered will thus be representative of dry-season contribution.

Table 7-2 Hydrocensus user survey: relevant geosite information.

Site ID	Latitude	Longitude	Geosite type	Site status	Water level status	Depth (mbgl)**	Water level (mbgl)	Equipment type	Water application	Owner	Field notes
KPS-BH01	-26.12013	28.18283	Borehole	In use	Static	6.50	3.00	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-BH02	-26.12184	28.18618	Borehole	In use	Static	11.81	1.27	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-BH04	-26.12237	28.18397	Borehole	In use	Static	12.00	1.62	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-BH05	-26.12414	28.19104	Borehole	In use	Static	17.00	2.84	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-BH07	-26.12285	28.18427	Borehole	In use	Static	15.00	3.47	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON01	-26.11181	28.19264	Borehole	In use	Static	35.00	8.77	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON02	-26.11296	28.19177	Borehole	In use	Static	30.00	5.98	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON03	-26.11576	28.18842	Borehole	In use	Static	30.00	5.70	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON04	-26.11849	28.18463	Borehole	In use	Static	30.00	2.39	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON05	-26.12339	28.18576	Borehole	In use	Static	30.00	2.43	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON06	-26.11965	28.19179	Borehole	In use	Static	30.00	2.04	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON07	-26.12163	28.19426	Borehole	In use	Static	20.00	1.90	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON09	-26.11730	28.19633	Borehole	In use	Static	35.00	4.99	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON10	-26.11724	28.19632	Borehole	In use	Static	15.00	4.95	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON11	-26.11528	28.19416	Borehole	In use	Static	25.00	4.79	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON12	-26.11740	28.19366	Borehole	In use	Static	25.00	6.17	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON13	-26.11819	28.18978	Borehole	In use	Static	16.00	4.78	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON14	-26.11473	28.19191	Borehole	In use	Static	20.00	5.46	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-MON16	-26.11738	28.18219	Borehole	In use	Static	20.00	3.97	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-NBH01	-26.12166	28.18339	Borehole	In use	Static	47.00	1.68	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-NBH02	-26.11940	28.18218	Borehole	In use	Static	50.00	1.78	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
KPS-NBH03	-26.12418	28.19327	Borehole	In use	Static	27.00	3.41	Not Equipped	Monitoring	Kelvin Power Station	Sample taken
DC	-26.12157	28.18394	Decant	In use	Flowing	n/a	n/a	n/a	Water management	Kelvin Power Station	Decant only if dams are full.
RD1	-26.12109	28.18415	Return Water Dam	In use	Flowing	n/a	n/a	n/a	Water management	Kelvin Power Station	Process water, reused.
RD2	-26.11901	28.18887	Return Water Dam	In use	Flowing	n/a	n/a	n/a	Water management	Kelvin Power Station	Process water, reused.

Notes: N/A: Not applicable

****Borehole depth reflected is approximate depths and should be confirmed**

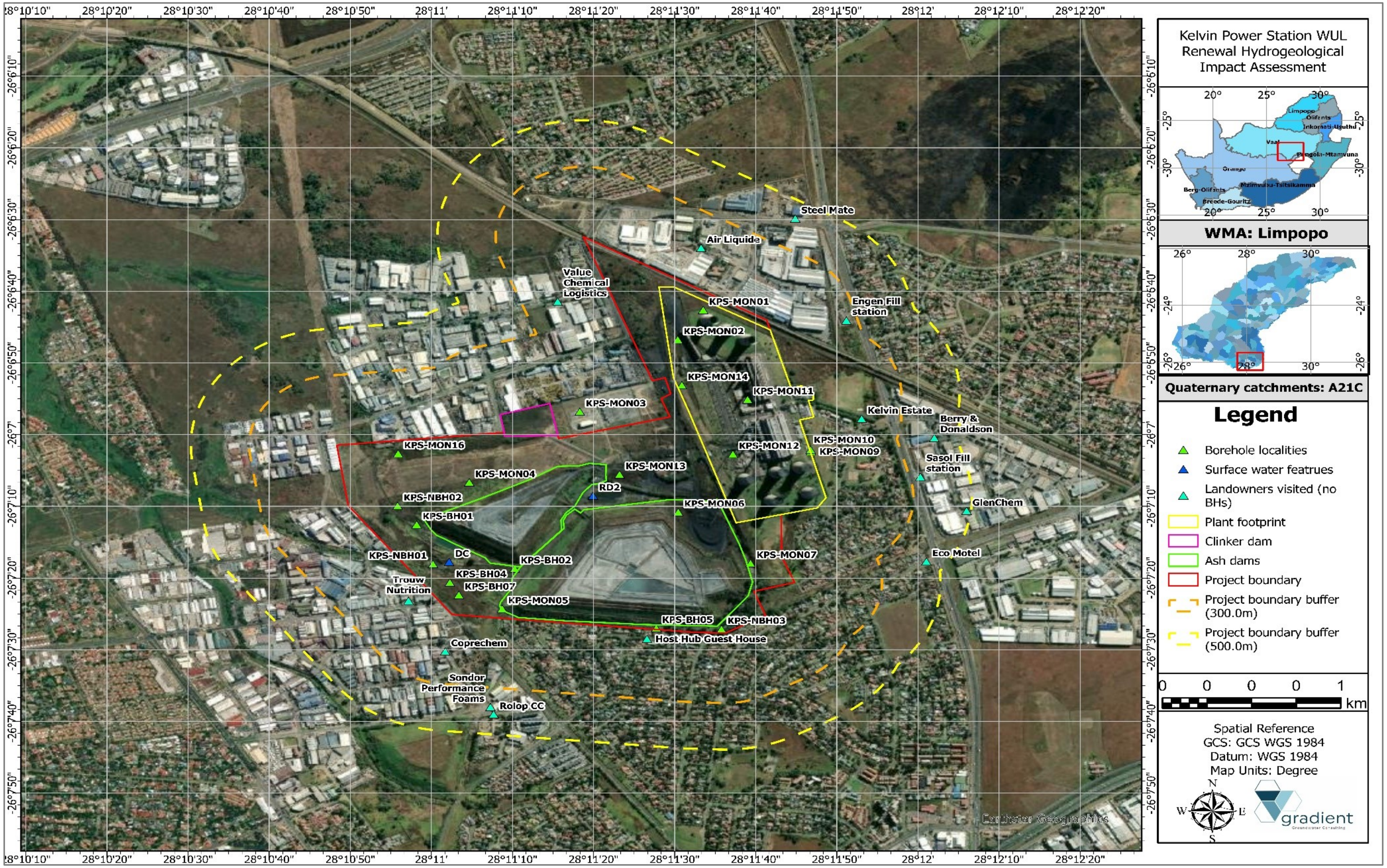


Figure 7-1 **Spatial distribution of hydrocensus user survey geosites.**

8. GROUNDWATER FLOW EVALUATION

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

8.1. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water level elevation from corresponding surface topography. The latter will govern the infiltration rate, as well as effective recharge of rainfall to the aquifer. Furthermore, the nature of the formation(s) forming the unsaturated zone will significantly influence the mass transport of surface contamination to the underlying aquifer(s). The unsaturated zone within the study area is in the order of 1.50 to 15.0m with a mean thickness of approximately ~5.0m. Due to clay/silt lenses throughout the study area, the shallow vadose zone can also be indicative of perched aquifer conditions which may be associated with seepage zones/ spring localities observed throughout the study area.

8.2. Depth to groundwater

A distribution of borehole water levels recorded as part of the hydrocensus user survey conducted were considered and used to interpolate local groundwater elevation and hydraulic head contours as summarised in Table 8-1 and depicted in Figure 8-1. The minimum water level recorded is 1.52mbgl (KPS-BH02), while the deepest water level was measured at borehole locality KPS-MON01 (13.90mbgl). It is noted that the latter corresponds to the topographical setting of the borehole locality. The average water level is calculated at 5.49mbgl, while the regional average water level is recorded as ~15.0mbgl (Aquiworx, 2016). It can thus be concluded that the study area is characterised by a shallow water table or piezometric head. Table 8-2 tabulates water levels statistics as calculated from the last three monitoring periods. It can be noted that Coefficient of Variation (CV) calculated for the water level database is relatively low, indicating that the regional groundwater system is in quasi-steady state conditions.

8.3. Groundwater flow direction and hydraulic gradients

Bayesian interpolation was used to interpolate the groundwater levels throughout the study area. Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation and even with dynamic water levels taken into consideration, the correlation is calculated at R^2 >0.98 as depicted in Figure 8-2. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system and will flow in a general western to south-western direction as depicted in Figure 8-3.

Table 8-1 Regional water level summary.

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
KPS-BH01	1630.65	5.51	1625.14
KPS-BH02	1634.41	1.52	1632.89
KPS-BH04	1624.12	2.28	1621.84
KPS-BH05	1654.98	3.07	1651.91
KPS-BH07	1629.03	4.05	1624.98
KPS-MON01	1668.92	13.90	1655.02
KPS-MON02	1668.17	12.56	1655.61
KPS-MON03	1663.90	10.88	1653.02
KPS-MON04	1647.20	5.62	1641.58
KPS-MON05	1636.56	2.30	1634.26
KPS-MON06	1656.29	2.29	1654.00
KPS-MON07	1660.51	2.28	1658.23
KPS-MON09	1666.95	5.26	1661.69
KPS-MON10	1666.89	5.18	1661.71
KPS-MON11	1669.42	5.73	1663.69
KPS-MON12	1668.44	7.75	1660.69
KPS-MON13	1659.66	7.15	1652.51
KPS-MON14	1668.44	10.61	1657.83
KPS-MON16	1639.52	5.88	1633.64
KPS-NBH01	1621.64	1.68	1619.96
KPS-NBH02	1631.45	1.78	1629.67
KPS-NBH03	1662.89	3.41	1659.48
Average	**1651.20**	**5.49**	**1645.75**
Minimum	**1621.64**	**1.52**	**1619.96**
Maximum	**1669.42**	**13.90**	**1663.69**
Standard deviation	**16.62**	**3.58**	**14.69**
Correlation		**0.98**	

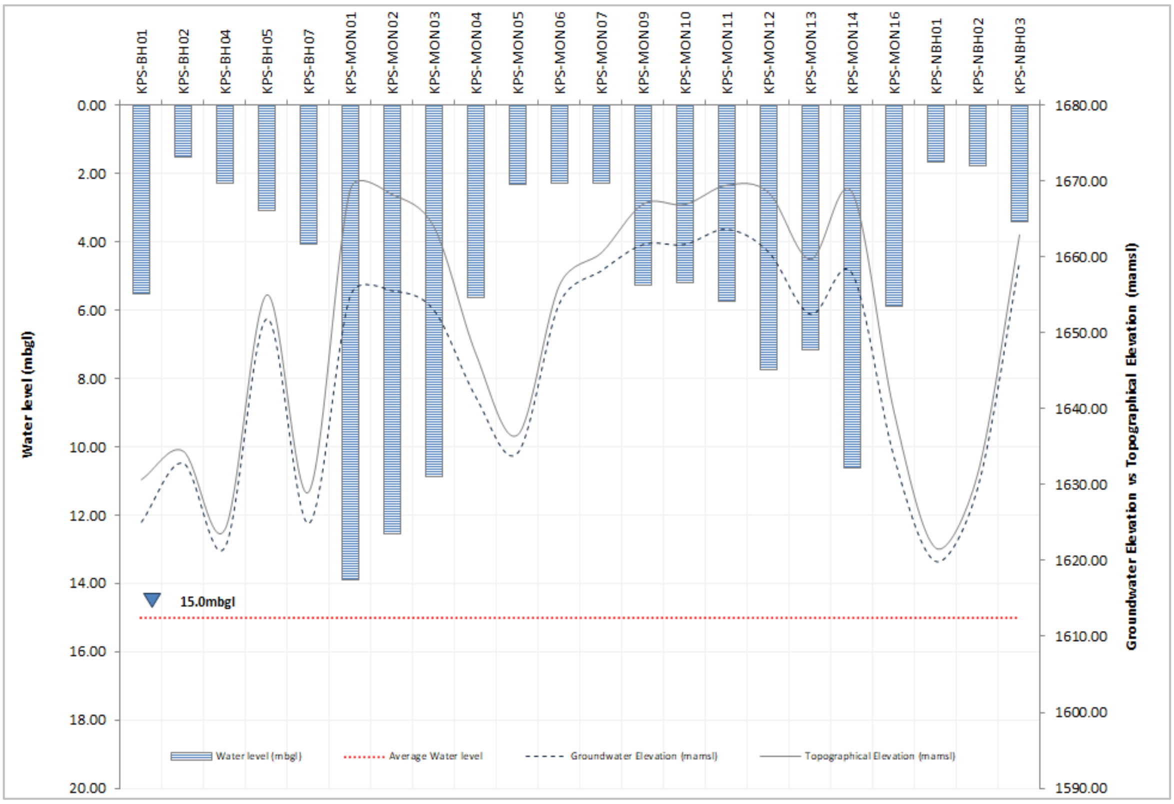


Figure 8-1 Bar chart indicating regional water level summary.

Table 8-2 Water level statistics.

Monitoring BH	Water level (mbgl): Sept 2024	Water level (mbgl): Dec 2024	Water level (mbgl): Jul 2025	Geometric Mean	Standard deviation	Coefficient of Variation (CV)
KPS BH01	5.51	5.20	5.51	5.40	0.15	2.70
KPS BH02	1.52	1.45	1.52	1.50	0.03	2.21
KPS BH04	2.28	2.11	2.28	2.22	0.08	3.61
KPS BH05	3.07	3.15	3.07	3.10	0.04	1.22
KPS BH07	4.05	4.10	4.05	4.07	0.02	0.58
KPS MON01	13.90	13.35	13.90	13.71	0.26	1.89
KPS MON02	12.56	11.83	12.56	12.31	0.34	2.80
KPS MON03	10.88	10.22	10.88	10.66	0.31	2.92
KPS MON04	5.62	5.16	5.62	5.46	0.22	3.97
KPS MON05	2.30	2.54	2.30	2.38	0.11	4.76
KPS MON06	2.29	2.18	2.29	2.25	0.05	2.30
KPS MON07	2.28	2.30	2.28	2.29	0.01	0.41
KPS-MON09	5.26	5.26	5.26	5.26	0.00	0.00
KPS-MON10	5.18	5.25	5.18	5.20	0.03	0.63
KPS-MON11	5.73	6.08	5.73	5.84	0.16	2.82
KPS-MON12	7.75	7.68	7.75	7.73	0.03	0.43
KPS-MON13	7.15	6.70	7.15	7.00	0.21	3.03
KPS-MON14	10.61	10.19	10.61	10.47	0.20	1.89
KPS-MON16	5.88	5.75	5.88	5.84	0.06	1.05

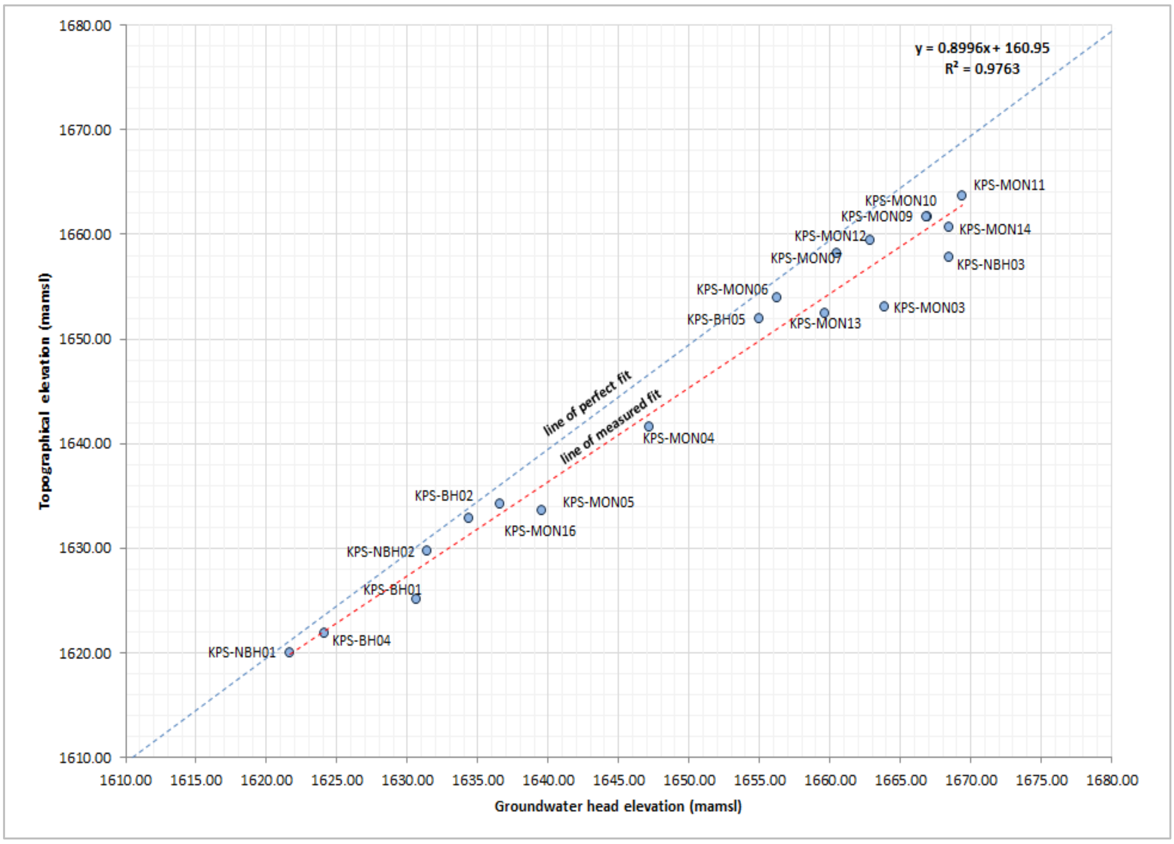


Figure 8-2 Topographical elevation vs. groundwater elevation correlation graph.

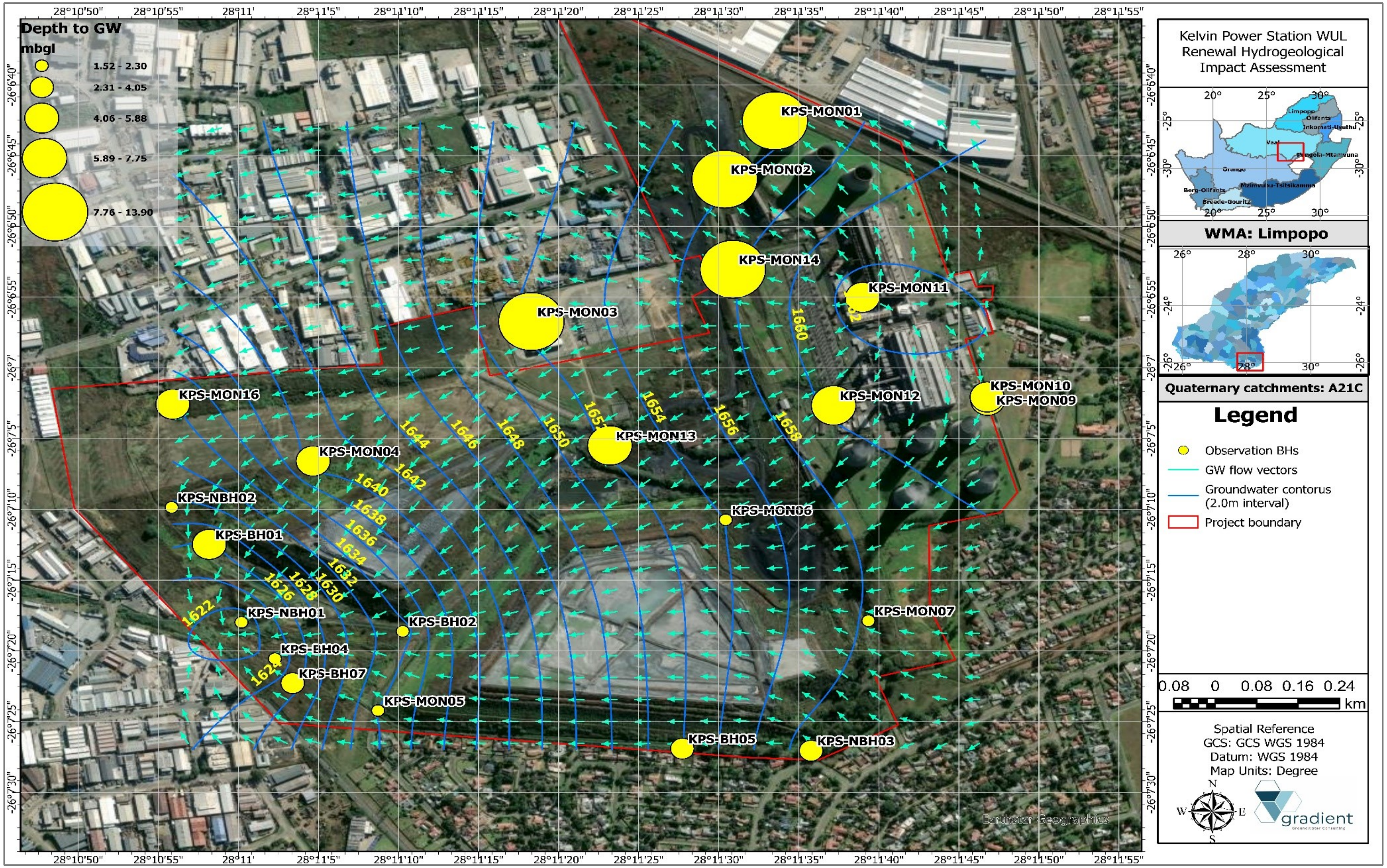


Figure 8-3 **Regional groundwater flow direction and depth to groundwater.**

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

Equation 8-1 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 the study area is relatively flat and calculated at a mean of 0.015, with a maximum of 0.022 in a southwestern to northeastern orientation as summarised in Table 8-3.

Table 8-3 Inferred groundwater gradient and seepage direction.

Inferred seepage direction	Hydraulic gradient (i)
S to N	0.002
E to W	0.019
SW to NE	0.022
SE to NW	0.017
Minimum	**0.002**
Maximum	**0.022**
Standard deviation	**0.008**
Geometric Mean	**0.015**

8.4. Darcy flux and groundwater flow velocity

The Darcy flux (or velocity) is a function of the hydraulic conductivity (K) and the hydraulic gradient as suggested by Equation 8-2 whereas the seepage velocity can be defined as the Darcy flux divided by the effective porosity[6] (Equation 8-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

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

Equation 8-2 Darcy flux.

$$v = Ki$$

Equation 8-3 Seepage velocity.

$$v = \frac{Ki}{ø}$$

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

The expected seepage rate from contamination originating at surface pollution sources is estimated at an average of approximately 5.56 metres per annum (m/a), with a maximum distance of ~12.0m/a in a southwestern to northeastern orientation as summarised in Table 8-4.

Table 8-4 Darcy flux and seepage rates[7].

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	0.002	0.188	0.0003	0.125	0.002	0.826
E to W	0.019	0.188	0.004	0.125	0.028	10.241
SW to NE	0.022	0.188	0.004	0.125	0.033	12.125
SE to NW	0.017	0.188	0.003	0.125	0.026	9.362
Minimum	**0.002**	**0.188**	**0.000**	**0.125**	**0.002**	**0.826**
Maximum	**0.022**	**0.188**	**0.004**	**0.125**	**0.033**	**12.125**
Standard deviation	**0.008**	**0.000**	**0.001**	**0.000**	**0.012**	**4.338**
Geometric Mean	**0.010**	**0.188**	**0.002**	**0.125**	**0.015**	**5.567**

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

9. HYDROCHEMISTRY

In order to assess future impacts of the existing power generation activities on the groundwater regime, it is necessary to develop a baseline/background to be applied as benchmark. The following section serves to characterise ambient groundwater conditions and develop a relevant baseline for future reference. Refer to Appendix B for the water quality certificate..

9.1. Water quality analysis

The South African National Standards (SANS 241: 2015) have been applied to assess the water quality within the project area. The standards are relevant to treated drinking water and specify a maximum limit based on associated risks for constituents (Refer to Table 9-1). Water samples were submitted for analysis at a SANAS accredited laboratory for inorganic analysis. These standards were selected for use as the current and future water uses in the area are primarily domestic application and/or industrial purposes.

Table 9-1 SANS 241:2015 risks associated with constituents occurring in water.

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

Table 9-2 SANS 241:2015 physical aesthetic, operational and chemical parameters.

Parameter	Risk	Unit	Standard limits [a]
Physical and aesthetic determinants			
Electrical conductivity (EC)	Aesthetic	mS/m	≤170
Total Dissolved Solids (TDS)	Aesthetic	mg/l	≤1200
Turbidity [b]	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH [c]	Operational	pH units	≥5 to ≤9,7
Chemical determinants – macro			
Nitrate as N[d]	Acute health	mg/l	≤11
Sulphate as SO_4^{-2}	Acute health	mg/l	≤500
	Aesthetic	mg/l	≤250
Fluoride as F	Chronic health	mg/l	≤1.5
Ammonia as N	Aesthetic	mg/l	≤1.5
Chloride as Cl^-	Aesthetic	mg/l	≤300
Sodium as Na	Aesthetic	mg/l	≤200
Zinc as Zn	Aesthetic	mg/l	≤5
Chemical determinants – micro			
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^-.

9.2. 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 samples analysed indicate good plausibility and data can be considered as accurate and correct (Table 9-3).

Equation 9-1 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 9-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
KPS BH 1	33.049	33.906	-1.28%
KPS BH 2	12.773	12.460	1.24%
KPS BH 4	12.649	12.679	-0.12%
KPS BH 5	9.881	10.123	-1.21%
KPS BH 7	4.901	5.131	-2.29%
KPS NBH 1	10.830	11.068	-1.09%
KPS NBH 2	15.532	15.012	1.70%
KPS MON 1	9.600	9.653	-0.27%
KPS MON 2	2.401	2.545	-2.90%
KPS MON 3	3.214	3.070	2.29%
KPS MON 4	9.254	9.487	-1.25%
KPS MON 5	15.126	14.814	1.04%
KPS MON 6	14.649	14.834	-0.63%
KPS MON 7	6.549	6.948	-2.95%
KPS MON 9	4.557	4.385	1.93%
KPS MON 11	1.163	1.154	0.37%
KPS MON 12	26.945	25.658	2.45%
KPS MON 13	31.119	32.157	-1.64%
KPS MON 14	10.734	11.100	-1.68%
KPS MON 16	24.915	25.713	-1.58%
KPS MON 105	4.804	4.982	-1.82%
RD 2	18.368	18.195	0.47%
KPS NB 03	7.367	7.768	-2.65%
DC	18.523	17.815	1.95%

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

Table 9-4, Table 9-5 as well as Table 9-6 below classify water quality according to pH, salinity as well as hardness.

Table 9-4 Hydrochemical classification according to pH-values.

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

Table 9-5 Hydrochemical classification according to salinity.

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

Table 9-6 Hydrochemical classification according to hardness.

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

9.3. Groundwater quality

The hydrochemical analysis results suggest the overall ambient groundwater quality is moderate good with the majority of macro and micro determinants of most samples below the SANS 241:2015 limits. Groundwater can be described as neutral to alkaline, saline to very saline and hard to very hard. The majority of samples analysed indicate enriched calcium and magnesium which can be attributed to the igneous formation host aquifer and are probably of geological origin. It should however be noted that, monitoring boreholes in close proximity to existing waste body footprints indicate an impacted groundwater environment with high salt load (TDS and conductivity) and sulphate being the main diver of the salt content. Neutral conditions as well as below limit metal concentrations suggest that Acid Rock Drainage (ARD) is currently not occurring.

The water quality of surface water localities analysed is poor and can be described as neutral, very saline and very hard. Nitrate concentration for both surface water samples analysed is highly elevated. It should be noted that only contact water samples were analysed and thus, the water quality discussed does not necessarily represent the ambient surface water quality.

Refer to Table 9-7 for a summary of the surface water samples analysed, while Table 9-8 and Table 9-9 tabulates groundwater samples analysed. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health). Figure 9-1 depicts a bar-chart of the major anion and cation composition with Figure 9-2 indicating a spatial distribution map of the hydrochemistry. Below is a short summary of water quality per sampling locality.

9.3.1. Borehole locality KPS BH01

This geosite is situated on western perimeter - toe of Ash Dam B. Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.33.
- TDS of 1988.63mg/l.
- Total Hardness ($CaCO_3$/l) of 1314.89mg/l.

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

- Electrical Conductivity (EC) of 237.0mS/m.
- TDS of 1988.63mg/l.
- Calcium of 205.0mg/l.
- Magnesium of 195.0mg/l.
- Boron of 3.69mg/l.

9.3.2. Borehole locality KPS BH02

This geosite is situated on the southern toe of Ash Dam B. Water quality can be described as neutral, saline and very hard:

- pH of 7.69.
- TDS of 651.47mg/l.
- Total Hardness ($CaCO_3$/l) of 597.04mg/l.

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

- Magnesium of 118.0mg/l.

9.3.3. Borehole locality KPS BH04

This geosite is situated on western perimeter of the project boundary. Water quality can be described as neutral, saline and very hard:

- pH of 7.68.
- TDS of 654.22mg/l.
- Total Hardness ($CaCO_3$/l) of 586.69mg/l.

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

- Magnesium of 111.0mg/l.

9.3.4. Borehole locality KPS BH05

This geosite is situated on the southern perimeter - south of Ash Dam A. Water quality can be described as neutral, saline and very hard:

- pH of 7.82.
- TDS of 497.32mg/l.
- Total Hardness ($CaCO_3$/l) of 467.10mg/l.

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

- Magnesium of 95.30mg/l.

9.3.5. Borehole locality KPS BH07

This geosite is situated on the south western perimeter of the project boundary. Water quality can be described as neutral, non-saline and hard:

- pH of 7.88.
- TDS of 268.90mg/l.
- Total Hardness ($CaCO_3$/l) of 213.99mg/l.

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

9.3.6. Borehole locality KPS NBH01

This geosite is situated down-gradient of Ash Dam B. Water quality can be described as neutral, saline and very hard:

- pH of 7.66.
- TDS of 563.42mg/l.
- Total Hardness ($CaCO_3$/l) of 513.04mg/l.

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

- Magnesium of 103.0mg/l.

9.3.7. Borehole locality KPS NBH02

This geosite is situated down-gradient of Ash Dam B. Water quality can be described as neutral, saline and extremely hard:

- pH of 8.01.
- TDS of 820.68mg/l.
- Total Hardness ($CaCO_3$/l) of 736.92mg/l.

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

- Magnesium of 155.0mg/l.

9.3.8. Borehole locality KPS NBH03

This geosite is situated down-gradient of Ash Dam A. Water quality can be described as alkaline, non-saline and very hard:

- pH of 8.96.
- TDS of 372.40mg/l.
- Total Hardness ($CaCO_3$/l) of 330.01mg/l.

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

- Magnesium of 72.50mg/l.

9.3.9. Borehole locality KPS MON01

This geosite is situated on northern perimeter next to the coal stockpile. Water quality can be described as neutral, saline and hard:

- pH of 8.09.
- TDS of 554.96mg/l.
- Total Hardness ($CaCO_3$/l) of 223.81mg/l.

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

9.3.10. Borehole locality KPS MON02

This geosite is situated on the northern perimeter south of the coal stockpile. Water quality can be described as alkaline, non-saline and moderately soft:

- pH of 8.68.
- TDS of 137.46mg/l.
- Total Hardness ($CaCO_3$/l) of 80.14mg/l.

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

9.3.11. Borehole locality KPS MON03

This geosite is situated north of the ash dump on the northwestern perimeter. Water quality can be described as alkaline, non-saline and slightly hard:

- pH of 9.18.
- TDS of 157.86mg/l.
- Total Hardness ($CaCO_3$/l) of 141.04mg/l.

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

9.3.12. Borehole locality KPS MON04

This geosite is situated on the western perimeter between the Ash Dump and Ash Dam B. Water quality can be described as alkaline, saline and very hard:

- pH of 8.96.
- TDS of 511.89mg/l.
- Total Hardness ($CaCO_3$/l) of 430.19mg/l.

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

- Magnesium of 98.90mg/l.

9.3.13. Borehole locality KPS MON05

This geosite is situated on the southern perimeter on the southern toe of the Ash Dam A. Water quality can be described as alkaline, saline and hard:

- pH of 8.51.
- TDS of 970.22mg/l.
- Total Hardness ($CaCO_3$/l) of 241.94mg/l.

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

- Sodium of 213.0mg/l.

9.3.14. Spring locality KPS MON06

This geosite is situated between Ash Dam A and the southern Coal Stockpile. Water quality can be described as neutral, saline and moderately soft:

- pH of 8.18.
- TDS of 959.52mg/l.
- Total Hardness ($CaCO_3$/l) of 51.33mg/l.

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

- Sodium of 283.0mg/l.

- Potassium of 51.30mg/l.

9.3.15. Spring locality KPS MON07

This geosite is situated south east of the southern Coal Stockpile. Water quality can be described as neutral, non-saline and hard:

- pH of 8.46.
- TDS of 331.97mg/l.
- Total Hardness ($CaCO_3$/l) of 281.86mg/l.

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

9.3.16. Borehole locality KPS MON09

This geosite serves as a background monitoring boreholes representative of the shallow aquifer. Water quality can be described as neutral, non-saline and hard:

- pH of 8.01.
- TDS of 211.377mg/l.
- Total Hardness ($CaCO_3$/l) of 211.85mg/l.

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

9.3.17. Borehole locality KPS MON10

This geosite serves as a background monitoring boreholes representative of the deep aquifer. Water quality can be described as neutral, non-saline and hard:

- pH of 7.54.
- TDS of 246.04mg/l.
- Total Hardness ($CaCO_3$/l) of 222.25mg/l.

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

9.3.18. Borehole locality KPS MON11

This geosite is situated in the fuel storage area. Water quality can be described as neutral, non-saline and soft:

- pH of 7.91.
- TDS of 62.58mg/l.
- Total Hardness ($CaCO_3$/l) of 45.35mg/l.

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

9.3.19. Monitoring borehole KPS MON12

This geosite is situated in the HFO storage area. Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.06.
- TDS of 1448.18mg/l.
- Total Hardness ($CaCO_3$/l) of 1154.60mg/l.

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

- Electrical Conductivity (EC) of 201.0mS/m.
- TDS of 1448.18mg/l.
- SO_4 of 547.80mg/l.

- NO_3 of 12.21mg/l.
- Calcium of 154.0mg/l.
- Magnesium of 187.0mg/l.

9.3.20. Monitoring borehole KPS MON13

This geosite is situated in the brick yard. Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.26.
- TDS of 1830.49mg/l.
- Total Hardness ($CaCO_3$/l) of 1438.23mg/l.

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

- Electrical Conductivity (EC) of 237.0mS/m.
- TDS of 1830.49mg/l.
- SO_4 of 1159.0mg/l.
- Magnesium of 325.0mg/l.

9.3.21. Monitoring borehole KPS MON14

This geosite is situated in the switch yard. Water quality can be described as neutral, saline and very hard:

- pH of 8.21.
- TDS of 628.64mg/l.
- Total Hardness ($CaCO_3$/l) of 496.66mg/l.

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

- Magnesium of 114.0mg/l.

9.3.22. Monitoring borehole KPS MON16

This geosite is situated at the clinker dump. Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.32.
- TDS of 1493.61mg/l.
- Total Hardness ($CaCO_3$/l) of 1213.83mg/l.

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

- Electrical Conductivity (EC) of 197.0mS/m.
- TDS of 1493.61mg/l.
- SO_4 of 942.0mg/l.
- Magnesium of 222.0mg/l.

9.3.23. Surface water locality RD2

This geosite is a return water dam and part of the waste water management infrastructure situated downstream of the ash dumps. Water quality can be described as neutral, very saline and very hard:

- pH of 6.94.
- TDS of 1217.26mg/l.
- Total Hardness ($CaCO_3$/l) of 438.18mg/l.

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

- Electrical Conductivity (EC) of 177.0mS/m.
- TDS of 1217.26mg/l.
- NO_3 of 40.90mg/l.
- Magnesium of 222.0mg/l.

9.3.24. Surface water locality DC

This geosite is representative of decant or leachate water flowing from the ash dumps. Water quality can be described as neutral, very saline and very hard:

- pH of 8.02.
- TDS of 1196.44mg/l.
- Total Hardness ($CaCO_3$/l) of 377.67mg/l.

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

- NO_3 of 27.60mg/l.
- Sodium of 226.0mg/l.

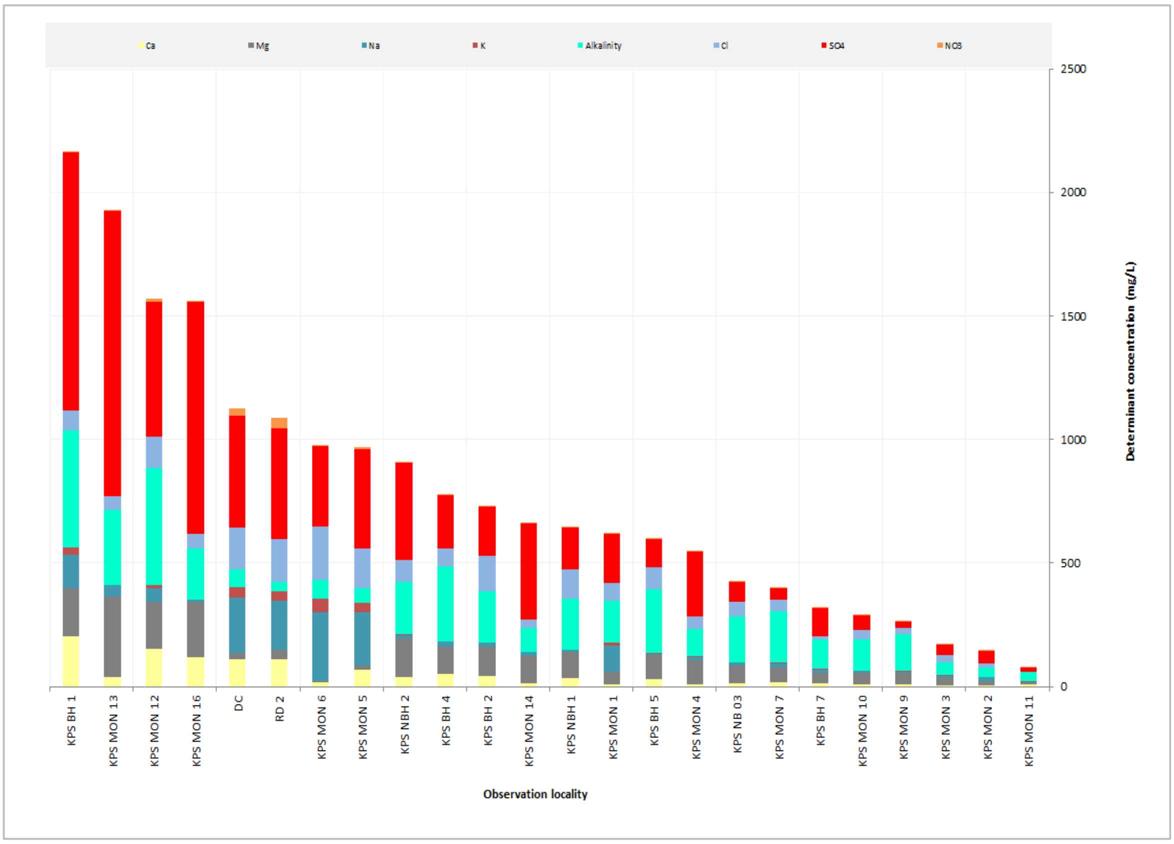


Figure 9-1 **Hydrochemistry: Composite bar-chart indicating major anion cation composition of water samples analysed.**

Table 9-7 Hydrochemistry: Surface water quality evaluation of hydrocensus samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	RD 2	DC
Physical determinands					
Colour	-	-	-	Yellowish	Grey
Temperature	°C	-	-	25.00	25.00
General parameters					
pH	-	Operational	≥5.0 ≤ 9.5	6.94	8.02
EC	mS/m	Aesthetic	≤170.0	**177.00**	167.00
TDS		Aesthetic	≤ 1 200.0	**1217.27**	1196.45
Total Alkalinity	CaCO3/l	-	-	41.20	70.10
Total Hardness	mg/l	-	-	438.18	377.67
Anions					
Cl	mg/l	Aesthetic	≤300.0	172.00	171.00
SO_4	mg/l	Acute health	≤500.0	448.00	452.00
F	mg/l	Acute health	≤1.50	0.20	0.14
NO_3< N	mg/l	Acute health	≤12.0	**40.90**	**27.60**
Cations and metals					
Na	mg/l	Aesthetic	≤200.0	197.00	**226.00**
K	mg/l	Aesthetic	≤50.0	36.50	41.50
Ca	mg/l	Aesthetic	≤150.0	111.00	112.00
Mg	mg/l	Operational	70.0	39.10	23.80
Al	mg/l	Operational	0.3	0.06	0.26
Fe	mg/l	Acute health	2.0	0.15	0.38
Mn	mg/l	Operational	0.4	0.09	<0.01
Ba	mg/l	Chronic health	0.7	0.02	0.07
B	mg/l	Chronic health	2.4	0.50	0.86
Cd	mg/l	Chronic health	0.003	<0.002	<0.002
Cr (VI+)	mg/l	Chronic health	0.05	<0.02	<0.02
U	mg/l	Chronic health	0.03	<0.01	<0.01
Hg	mg/l	Chronic health	0.006	<0.003	<0.003
As	mg/l	Acute health	0.01	<0.009	<0.009
Cu	mg/l	Acute health	2.0	<0.01	<0.01
CN	mg/l	Acute health	0.2	<0.01	<0.01
Cd	mg/l	Chronic health	0.003	<0.002	<0.002
Pb	mg/l	Chronic health	0.01	<0.01	<0.01
Zn	mg/l	Aesthetic	5.0	<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 9-8 Hydrochemistry: Groundwater quality evaluation of KPS and NB borehole samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	KPS BH 1	KPS BH 2	KPS BH 4	KPS BH 5	KPS BH 7	KPS NBH 1	KPS NBH 2	KPS NB 03
Physical determinands											
Colour	-	-	-	Clear	Clear	Clear	Clear	Clear	Rusty	Rusty	Brownish
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	7.33	7.69	7.68	7.82	7.88	7.66	8.01	8.96
EC	mS/m	Aesthetic	≤170.0	237.00	108.00	102.00	86.80	46.40	95.80	117.00	66.10
TDS		Aesthetic	≤ 1 200.0	1988.63	651.47	654.22	497.33	268.91	563.43	820.68	372.41
Total Alkalinity	CaCO3/l	-	-	472.00	204.00	305.00	256.00	120.00	205.00	214.00	222.00
Total Hardness	mg/l	-	-	1314.90	597.04	586.69	467.11	213.99	513.05	736.92	330.02
Anions											
Cl	mg/l	Aesthetic	≤300.0	80.90	144.00	71.60	90.90	13.50	118.00	87.80	56.60
SO_4	mg/l	Acute health	≤500.0	1047.00	201.00	217.00	114.00	112.00	172.00	394.00	80.20
F	mg/l	Acute health	≤1.50	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.37
NO_3< N	mg/l	Acute health	≤12.0	<0.35	0.92	<0.35	0.37	<0.35	<0.35	<0.35	<0.35
Cations and metals											
Na	mg/l	Aesthetic	≤200.0	133.00	15.70	17.40	7.95	12.70	9.80	13.80	10.40
K	mg/l	Aesthetic	≤50.0	29.90	1.24	1.85	3.84	0.99	1.34	1.51	2.39
Ca	mg/l	Aesthetic	≤150.0	205.00	44.50	51.90	29.90	13.30	35.60	39.50	12.60
Mg	mg/l	Operational	70.0	195.00	118.00	111.00	95.30	43.90	103.00	155.00	72.50
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	0.06	<0.01	<0.01
Mn	mg/l	Operational	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	0.04	<0.01
Ba	mg/l	Chronic health	0.7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
B	mg/l	Chronic health	2.4	3.69	0.14	0.08	0.05	0.13	0.14	0.16	0.22
Cd	mg/l	Chronic health	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
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
Hg	mg/l	Chronic health	0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Cu	mg/l	Acute health	2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd	mg/l	Chronic health	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Pb	mg/l	Chronic health	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Aesthetic	5.0	<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 9-9 Hydrochemistry: Groundwater quality evaluation of KPS MON borehole samples analysed.

Determinant	Unit	Risk	SANS 241:2015 limits	KPS MON 1	KPS MON 2	KPS MON 3	KPS MON 4	KPS MON 5	KPS MON 6	KPS MON 7	KPS MON 9	KPS MON 10	KPS MON 11	KPS MON 12	KPS MON 13	KPS MON 14	KPS MON 16
Physical determinands																	
Colour	-	-	-	Clear	Clear	Brownish	Brownish	Brownish	Brownish	Brownish	Greyish	Clear	Clear	Greyish	Clear	Clear	Clear
Temperature	°C	-	-	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
General parameters																	
pH	-	Operational	≥5.0 ≤ 9.5	8.09	8.68	9.18	8.96	8.51	8.18	8.46	8.01	7.54	7.91	7.06	7.26	8.21	7.32
EC	mS/m	Aesthetic	≤170.0	85.20	22.70	28.40	76.40	143.00	145.00	59.90	39.30	44.40	10.90	201.00	237.00	86.70	197.00
TDS		Aesthetic	≤ 1 200.0	554.97	137.46	157.86	511.90	970.23	959.52	331.98	211.38	246.04	62.58	1448.18	1830.49	628.65	1493.61
Total Alkalinity	CaCO3/l	-	-	171.00	50.80	65.10	130.00	67.70	78.30	222.00	148.00	128.00	36.50	473.00	302.00	95.80	205.00
Total Hardness	mg/l	-	-	223.82	80.15	141.04	430.19	241.95	51.34	281.87	211.85	222.26	45.36	1154.60	1438.23	496.67	1213.84
Anions																	
Cl	mg/l	Aesthetic	≤300.0	70.20	17.50	30.60	48.40	161.00	214.00	45.30	26.00	36.10	1.58	127.41	54.00	32.00	59.50
SO_4	mg/l	Acute health	≤500.0	200.00	49.30	42.90	264.00	401.00	329.00	47.50	25.50	60.30	17.70	547.80	1159.00	393.00	942.00
F	mg/l	Acute health	≤1.50	<0.09	<0.09	<0.09	<0.09	<0.09	0.12	<0.09	<0.09	<0.09	0.16	<0.09	0.09	<0.09	<0.09
NO_3< N	mg/l	Acute health	≤12.0	0.65	<0.35	<0.35	<0.35	5.95	2.10	0.35	1.93	1.85	<0.35	12.21	4.23	1.02	3.59
Cations and metals																	
Na	mg/l	Aesthetic	≤200.0	109.00	14.80	6.70	12.00	213.00	283.00	18.00	5.34	6.42	4.63	58.50	46.20	15.10	9.11
K	mg/l	Aesthetic	≤50.0	11.40	2.51	2.76	1.22	39.20	51.30	2.80	1.67	1.21	1.78	10.40	1.07	1.25	0.75
Ca	mg/l	Aesthetic	≤150.0	8.00	5.05	4.04	9.18	68.20	18.30	16.90	9.31	7.54	9.26	154.00	40.00	10.90	120.00
Mg	mg/l	Operational	70.0	49.50	16.40	31.80	98.90	17.40	1.37	58.20	45.80	49.40	5.40	187.00	325.00	114.00	222.00
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	<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	<0.01	<0.01	<0.01
Mn	mg/l	Operational	0.4	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Ba	mg/l	Chronic health	0.7	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
B	mg/l	Chronic health	2.4	0.10	0.02	<0.01	0.05	0.87	1.55	2.15	0.01	0.02	0.02	1.15	1.31	0.10	0.34
Cd	mg/l	Chronic health	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr (VI+)	mg/l	Chronic health	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<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	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	Chronic health	0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
As	mg/l	Acute health	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Cu	mg/l	Acute health	2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CN	mg/l	Acute health	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd	mg/l	Chronic health	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Pb	mg/l	Chronic health	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	mg/l	Aesthetic	5.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	<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.

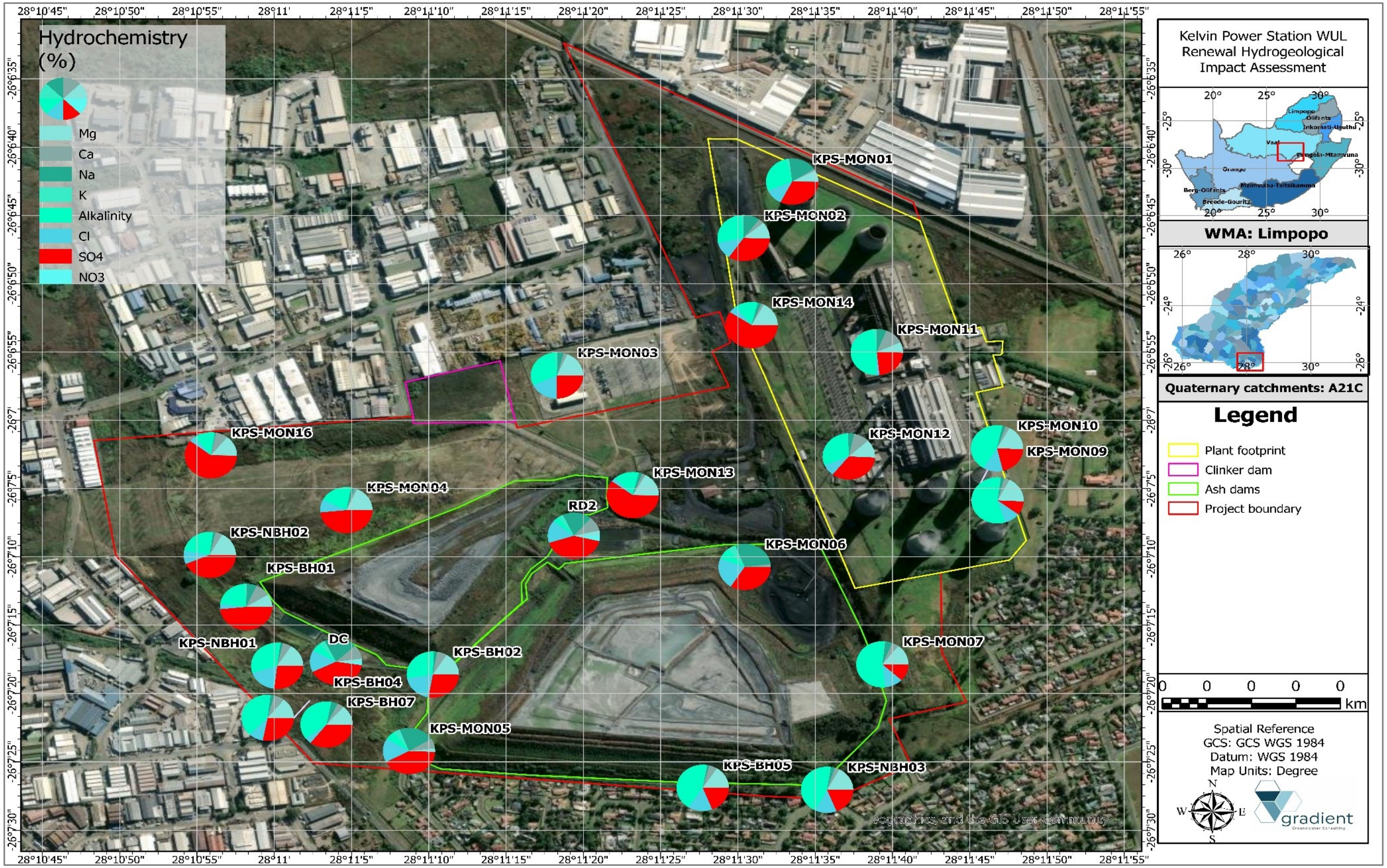


Figure 9-2 **Hydrochemical analysis spatial distribution (mg/l).**

9.4. 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.

9.4.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 9-3). Different water types derived from different environments plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area generally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and coordinated regimes. Figure 9-4 depicts a piper diagram developed from the water quality analysis results. Three distinct categories can be observed: the following samples analysed suggest a recently recharged and unimpacted groundwater environment i.e., KPS MON7, KPS MON09, KPS MON10, KPS MON11, KPS BH04, KPS BH05, KPS BH07 as well as KPS NB03 (Category A: Magnesium-Bi-carbonate dominance) while geosites KPS BH01, KPS BH02, KPS MON02, KPS MON03, KPS MON04, KPS MON12, KPS MON13, KPS MON14, KPS MON16, KPS NB01 and KPS NB02 suggest an area of static and disordinate environments (Category B: Calcium-Sulphate dominance). Borehole localities KPS MON01, KPS MON05 and KPS MON06 including both surface water features analysed (RD2 and DC) suggest an area of sodium and chloride enrichment (brine environment) (Category C: Sodium-Chloride dominance).

9.4.2. 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 9-5 depict Stiff diagrams representing KPS as well as KPS NBH borehole localities while Figure 9-6 shows Stiff diagrams representing KPS MON boreholes as well as surface water samples analysed. It is evident that the boreholes situated down-gradient of existing waste body footprints indicate sulphate-calcium/ magnesium dominance suggesting an impacted aquifer system. When evaluating the hydrochemical signature of the background borehole targeting the shallow, intergranular aquifer (KPS MON09) and comparing it to the background borehole targeting the deeper, fractured aquifer (KPS MON10) the correlation is very good. Accordingly, it can be concluded that there is a distinct hydraulic interconnectivity between these aquifer units.

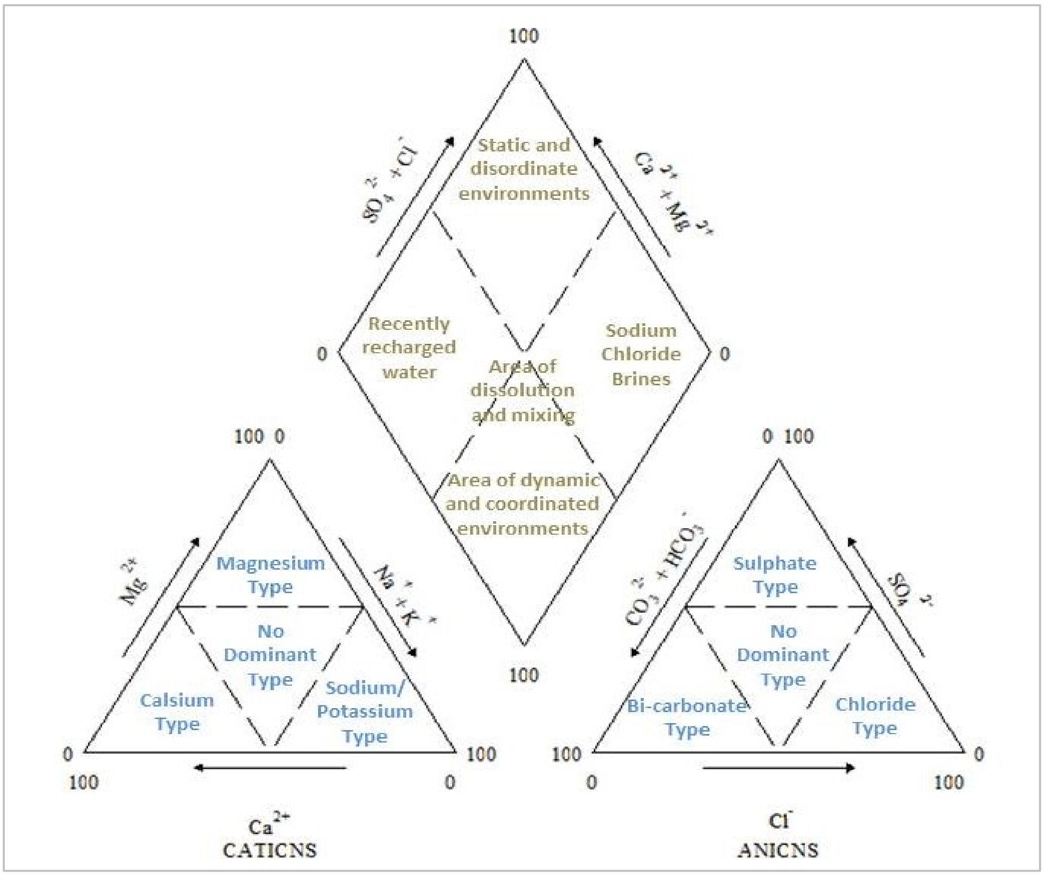


Figure 9-3 **Piper diagram indicating classification for anion and cation facies in terms of ion percentages.**

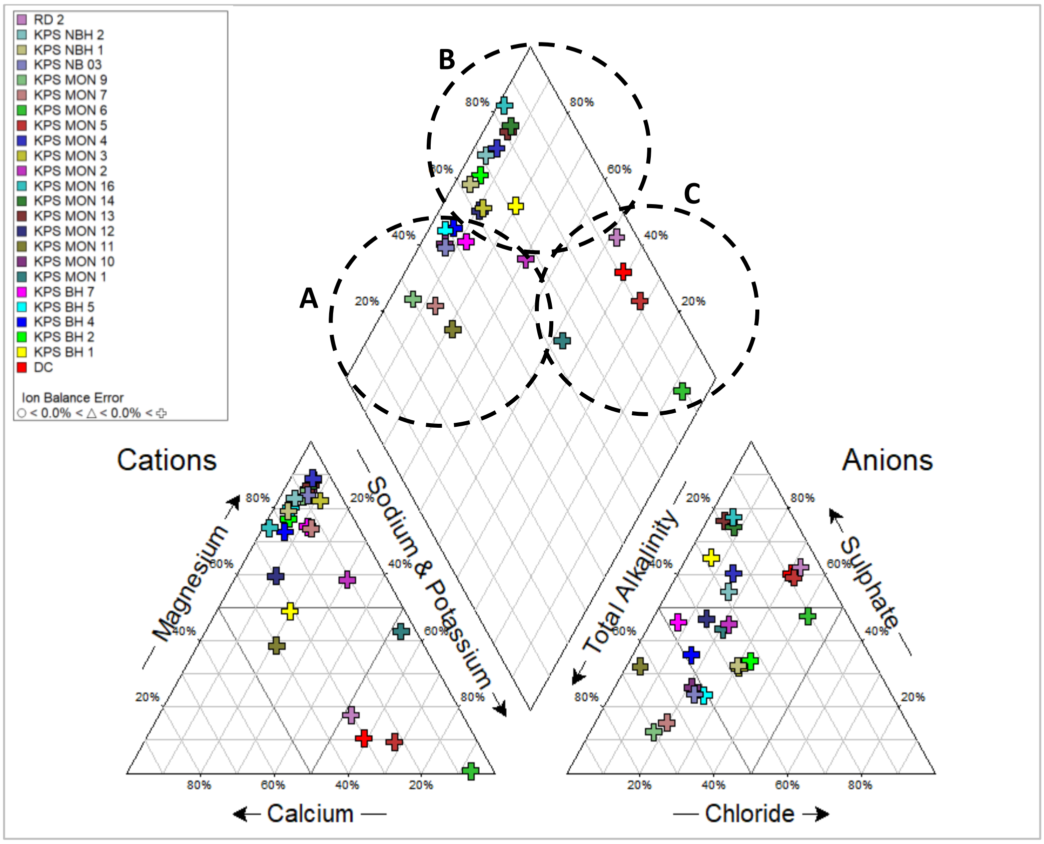


Figure 9-4 **Piper diagram indicating major anions and cations of water samples analysed.**

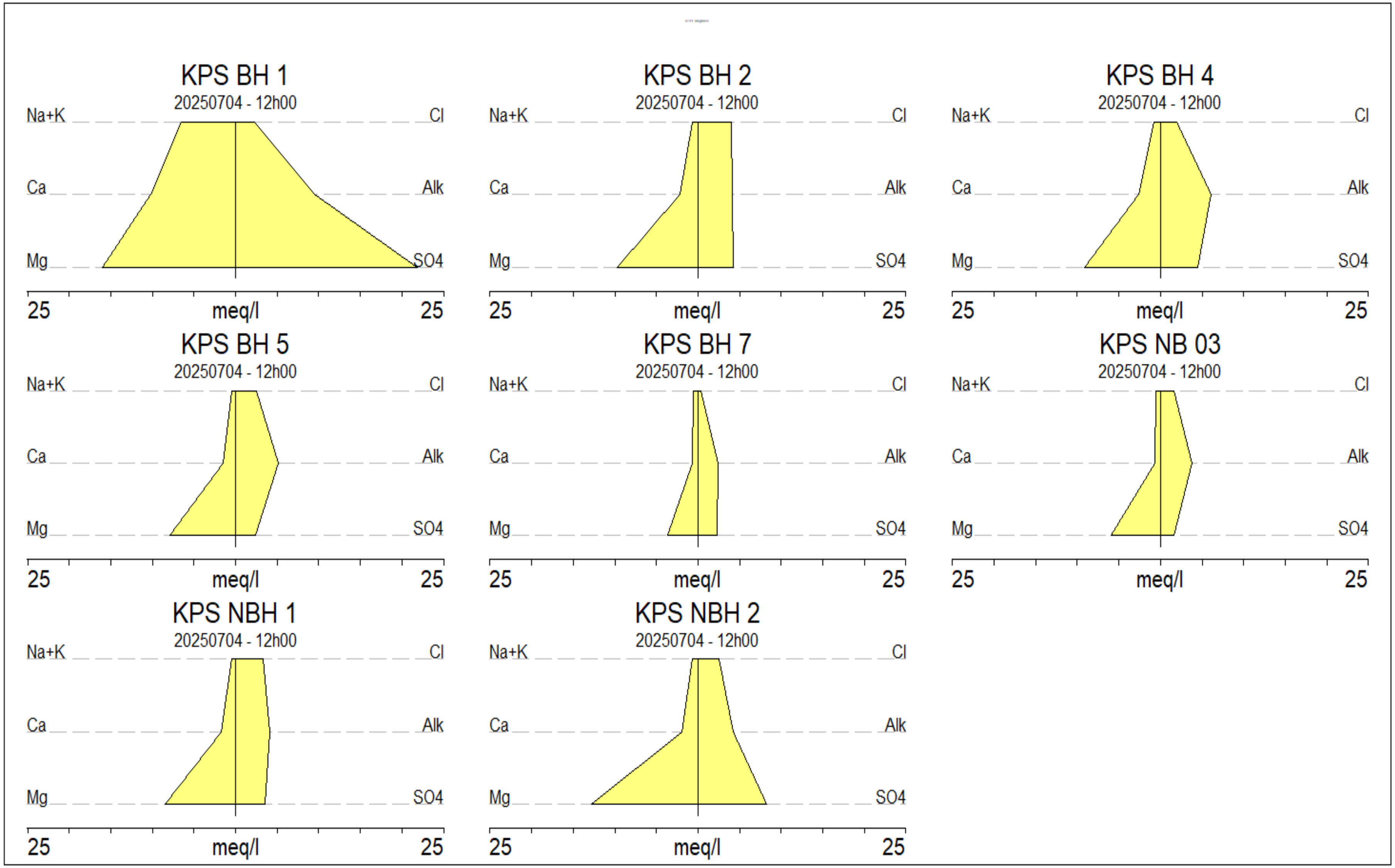


Figure 9-5 **Stiff diagrams representing KPS as well as KPS NBH borehole localities.**

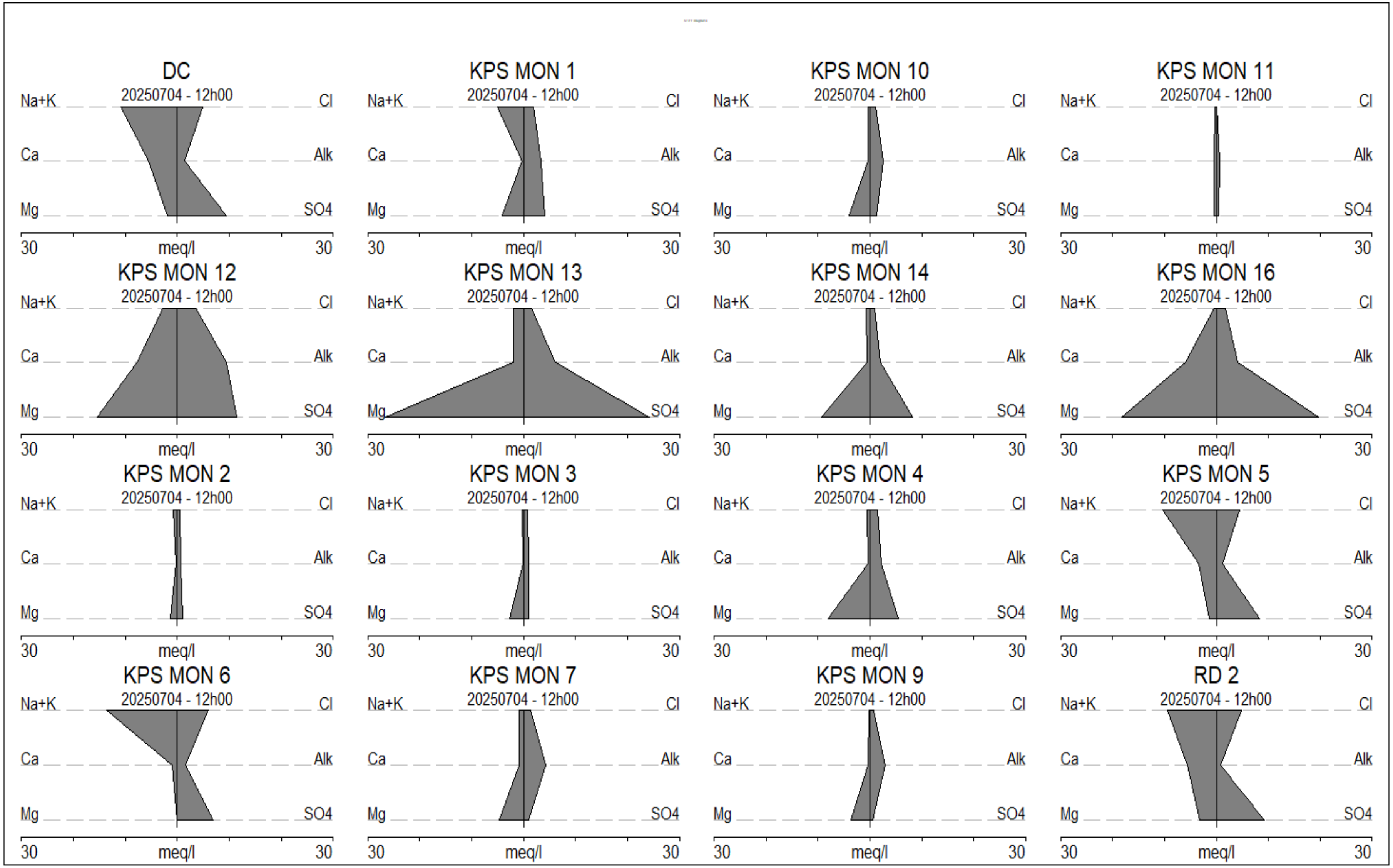


Figure 9-6 **Stiff diagrams representing KPS MON boreholes as well as surface water samples analysed.**

9.4.3. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems as depicted in Figure 9-7. Different fields of the diagram are 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.

Groundwater localities situated up-gradient of existing waste body footprints can be classified as Field 02 i.e., mostly fresh, clean and relatively young with HCO3- and CO3 dominance evident indicative of an unimpacted groundwater environment while monitoring localities situated down-gradient, or in close proximity to waste body footprints can be classified as Field05 or Filed06, indicative of groundwater that is a mix of different types and has undergone SO4 and NaCl mixing/contamination or old stagnant NaCl dominated water. The latter suggests an impacted groundwater system (Refer to Figure 9-8).

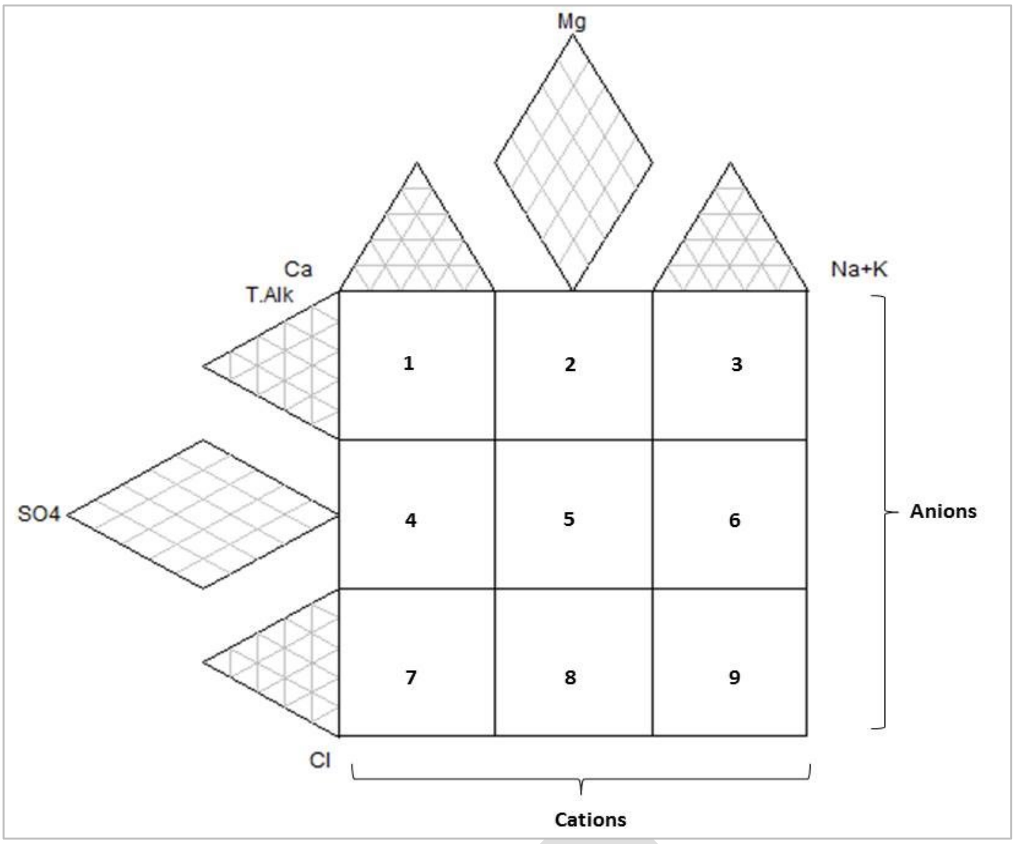


Figure 9-7 **Extended Durov diagramindicating major anions and cations.**

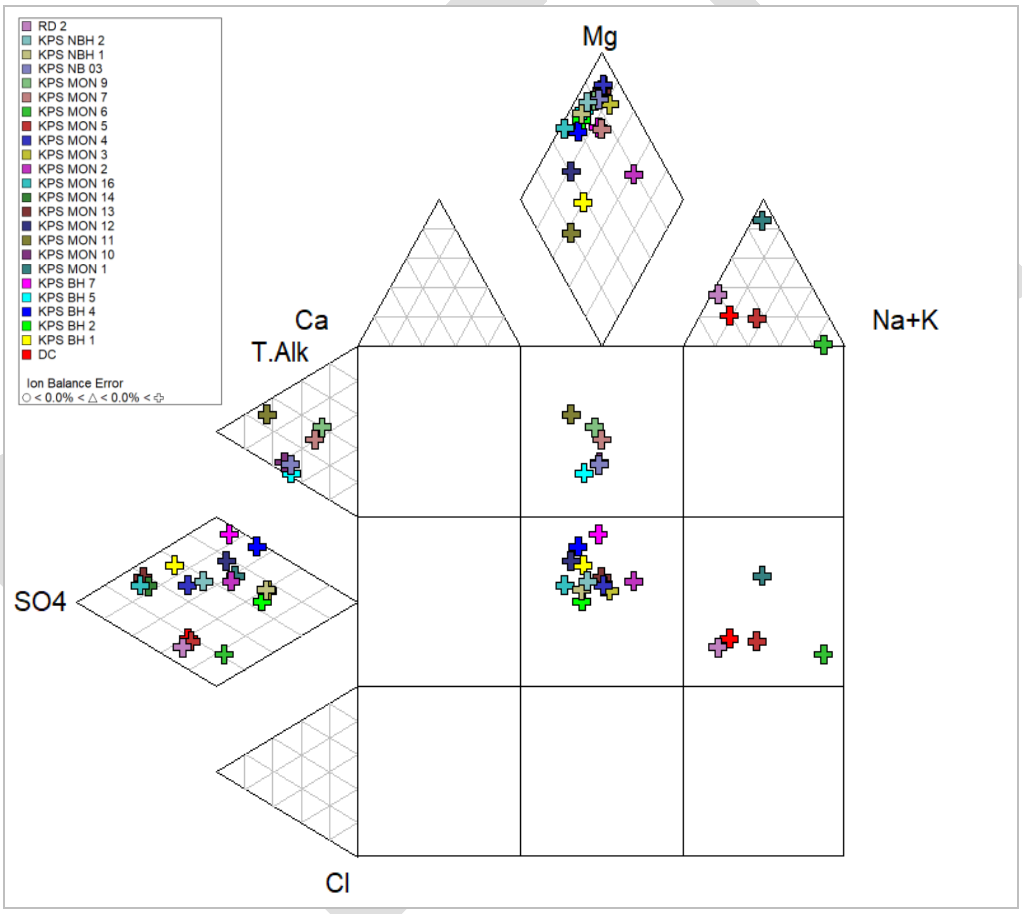


Figure 9-8 **Extended Durov diagram of water samples analysed.**

10. AQUIFER CLASSIFICATION AND GROUNDWATER MANAGEMENT INDEX

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

Equation 10-1 GMQ Index.

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

10.1. Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). Aquifer classification forms a very useful planning tool which can be applied to guide the management of groundwater systems. According to the aquifer classification map of South Africa the project area is underlain by a "**Minor aquifer**". Refer to Figure 10-1 (DWS, 2013). The classifications and definitions for each aquifer system are summarised in Table 10-1.

Table 10-1 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.

10.2. Aquifer vulnerability

Aquifer vulnerability can be defined as the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a "**Moderate**" vulnerability rating. Refer to Figure 10-2 (DWS, 2013).

10.3. Aquifer susceptibility

Aquifer susceptibility is a qualitative measure of relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities. According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a "**Medium**" susceptibility rating. Refer to Figure 10-3 (DWS, 2013).

Table 10-2 Groundwater Quality Management Index.

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

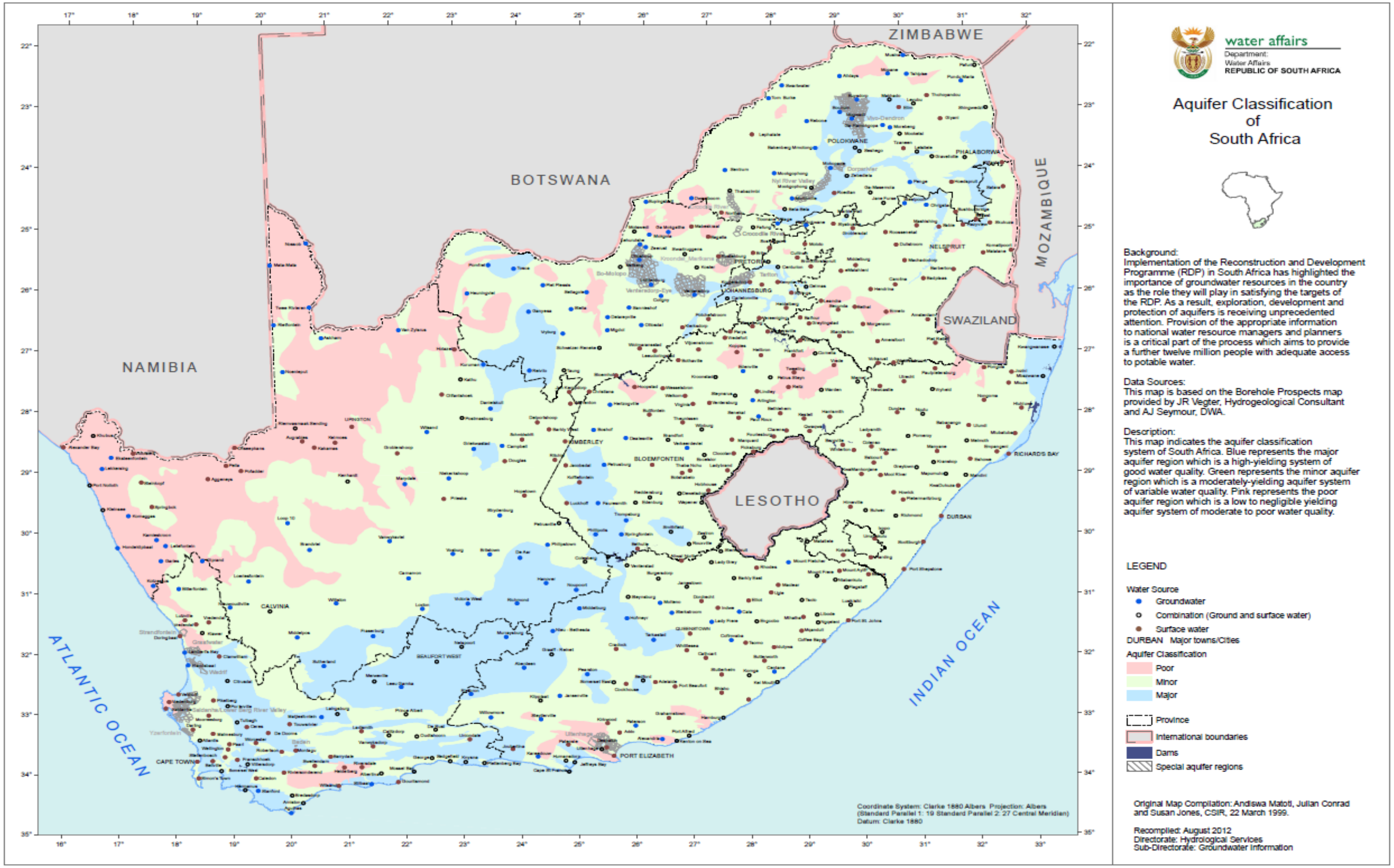


Figure 10-1 **Aquifer classification of South Africa (DWS, 2013).**

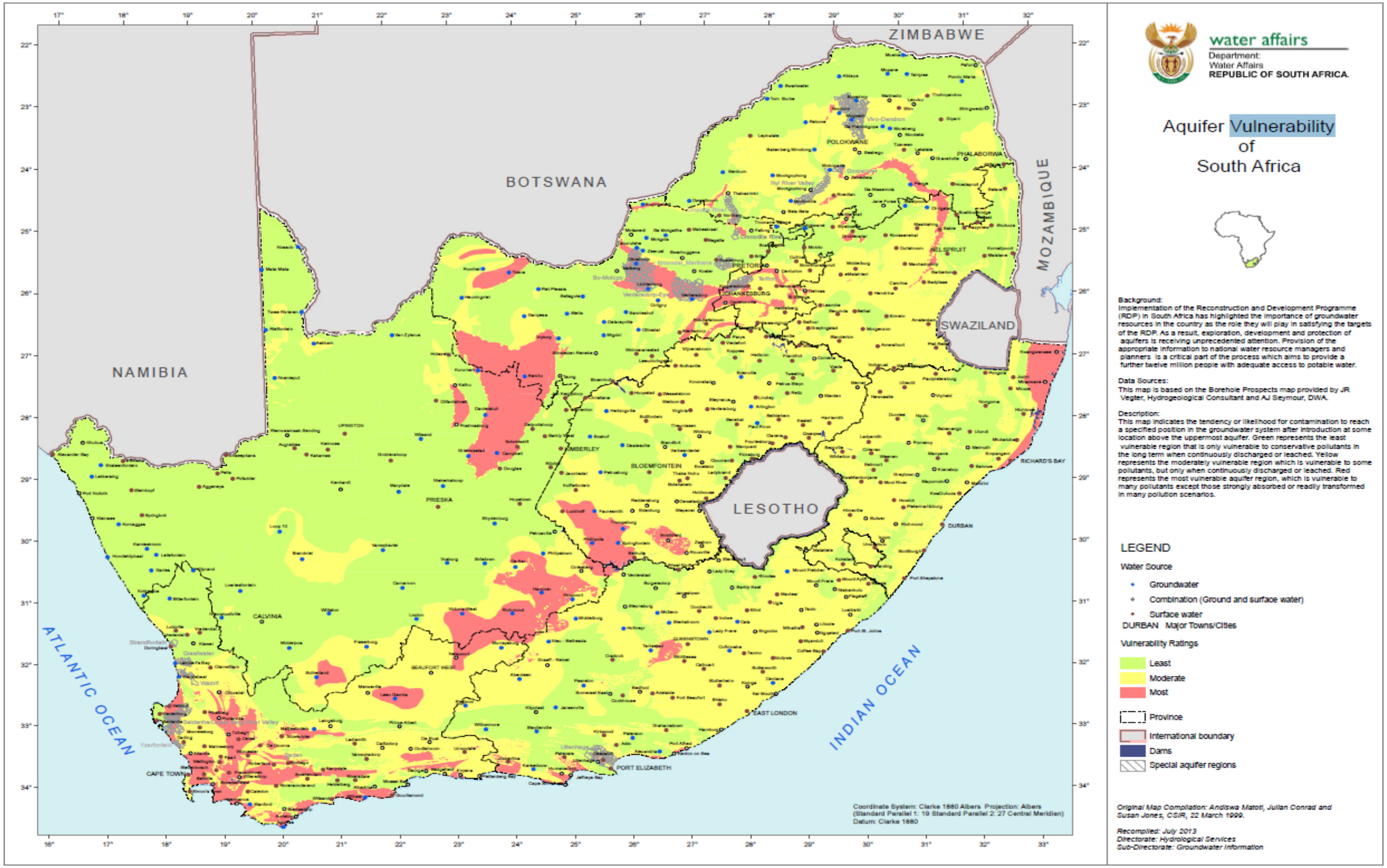


Figure 10-2 **Aquifer vulnerability of South Africa (DWS, 2013).**

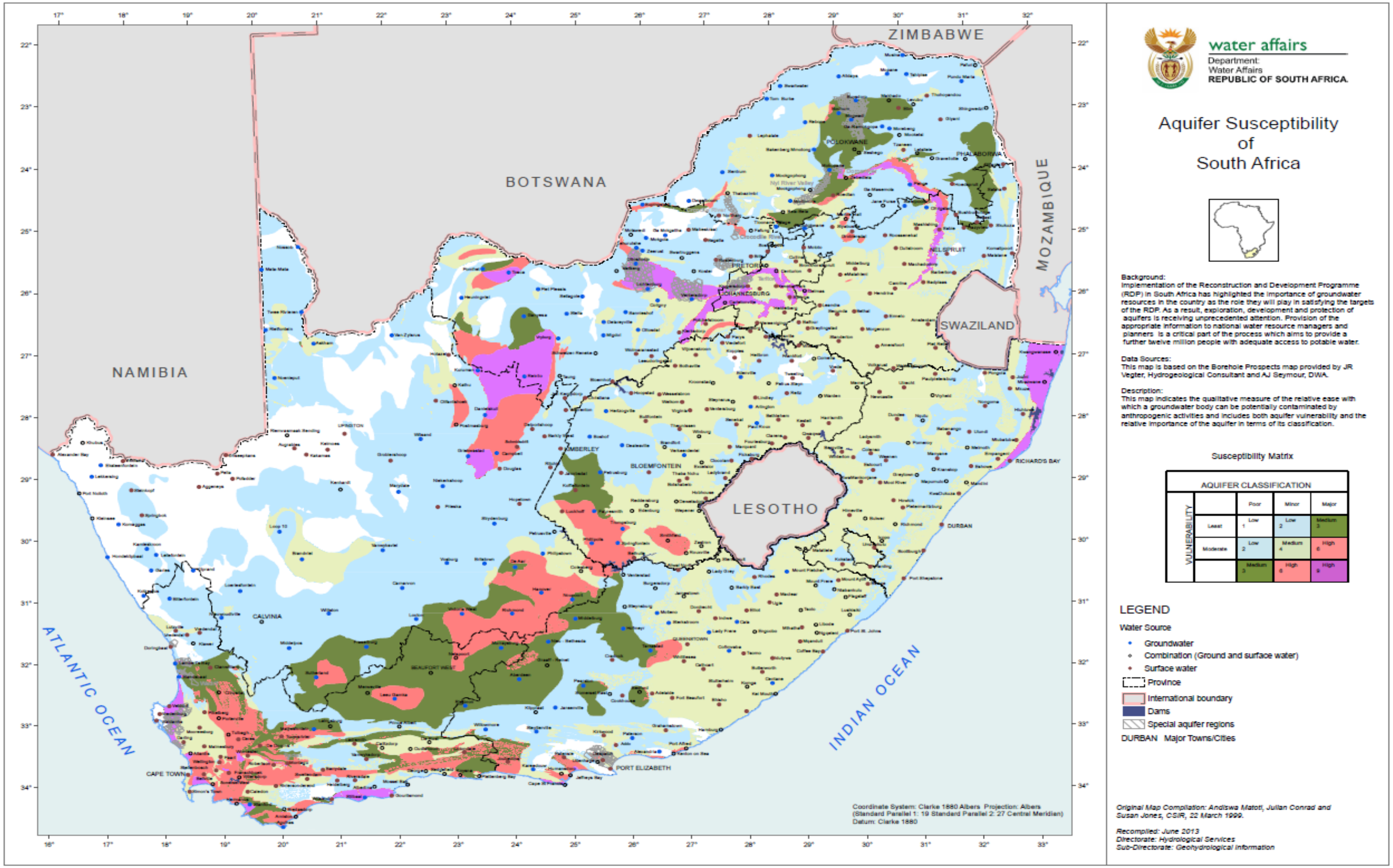


Figure 10-3 **Aquifer Susceptibility of South Africa (DWS, 2013).**

10.4. Groundwater contamination risk assessment

The concept of groundwater vulnerability to contamination by applying the DRASTIC methodology was introduced by Aller et al. (1987) and refined by the US EPA (United States Environmental Protection Agency). DRASTIC is an acronym for a set of parameters that characterise the hydrogeological setting and combined evaluated vulnerability: Depth to water level, Nett Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and Hydraulic Conductivity. This method provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeological parameters. Lynch et al (1994) suggests a considerable variation in terms of hydraulic conductivity in hard rock aquifers and revised this methodology to accommodate local aquifer conditions accordingly. Parameters used as part of the index are summarised in Table 10-3. The DRASTIC index (DI) can be computed by applying Equation 10-2. According to the DRASTIC index methodology applied, the activities and associated infrastructure's risk to groundwater pollution of the host aquifer system, is rated as "**Moderate**", Di = 100 (refer to Table 10-5).

Equation 10-2 DRASTIC Index (Di).

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

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 10-3 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 10-4 below (Lynch et al, 1994).

Table 10-4 Ratings assigned to groundwater vulnerability parameters (Lynch et al, 1994).

Depth to groundwater (D_R)

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

Net Recharge (R_R)

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

Aquifer Media (A_R)

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

Soil Media (S_R)

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

Topography (T_R)

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

Impact of the vadose zone (I_R)

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

Table 10-5 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) = 100				

10.5. Source-pathway-receptor evaluation

In order to evaluate the risk of groundwater contamination, potential sources of contamination should be identified, as well as potential pathways and receptors. The pollution linkage concept relies on the identification of a potential pollutant (i.e. source) on-site which is likely to have the potential to cause harm to a receptor by means of a pathway by which the receptor may be exposed to the contaminant (Figure 10-4).

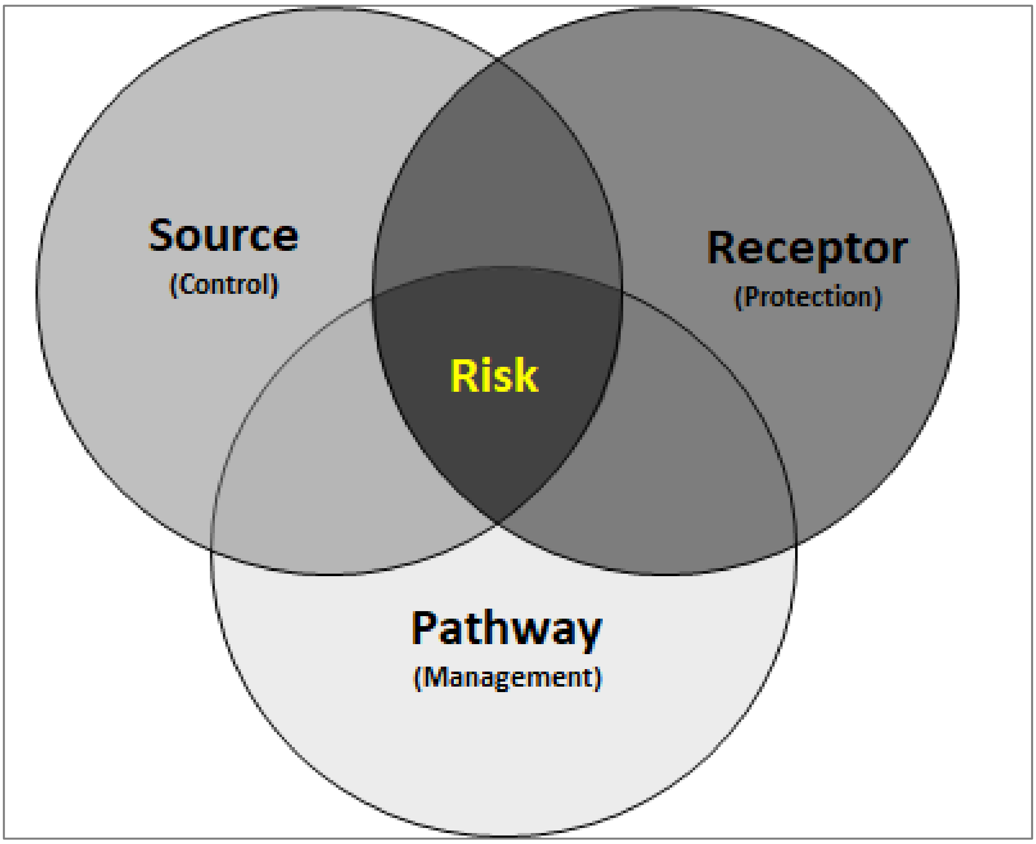


Figure 10-4 **Source pathway receptor principle.**

10.5.1. Potential sources

The following potential sources have been identified:

i. Seepage of poor-quality water originating from wastewater management infrastructure.

ii. Leachate of elements from ash dumps and coal stockpiles causing poor-quality water entering local resources and host aquifers.:

iii. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.

10.5.2. 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.

10.5.3. Potential receptors

The following receptors were identified:

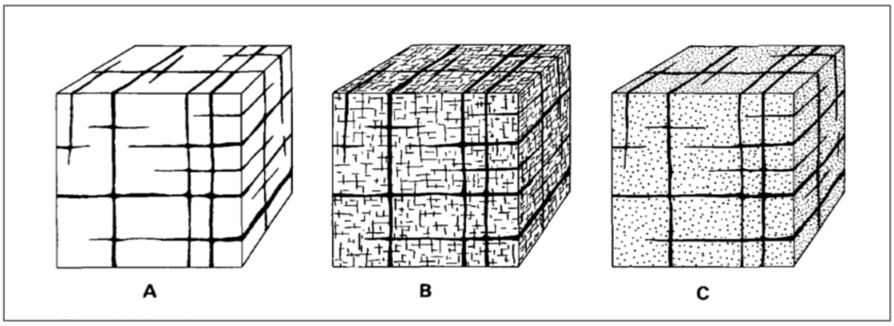
i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.

ii. Down-gradient drainages and streams including associated riparian zone aquifer system(s) and baseflow contribution.

iii. Private or neighbouring boreholes associated with relevant fracture zones and/or structures(s)if intercepted by the pollution plume migration footprint

11. 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 11-1 depicts a generalised hydrogeological conceptual model for similar environments and illustrates the concept of primary porous media aquifers and secondary fractured rock media aquifers. In porous aquifers, flow occurs through voids between unconsolidated rock particles whereas in double porosity aquifers, the host rock is partially consolidated, and flow occurs through the pores as well as fractures in the rock. In secondary aquifers the host rock is consolidated, and porosity is generally restricted to fractures that have formed after consolidation of the rock. Figure 11-2 depicts the formulated hydrogeological conceptual model for the pre-mitigation scenarios while Figure 11-3 show the hydrogeological conceptual model for the mitigates scenario with relevant data and information included (refer to Figure 12-2 for spatial reference).



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

Figure 11-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

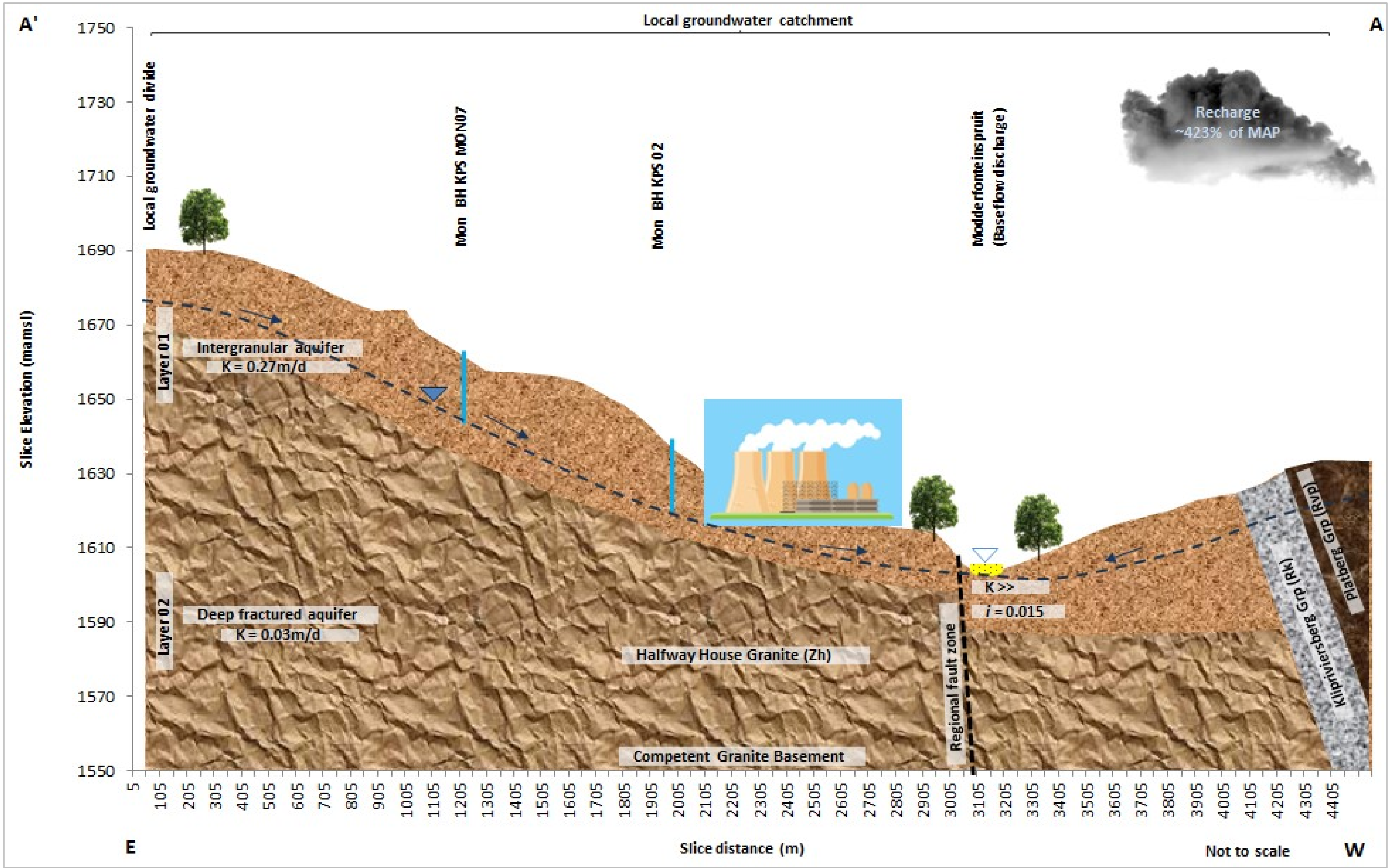


Figure 11-2 **Hydrogeological conceptual model (Pre-mitigation): East-West cross section (A'-A) (Refer to Figure 12-2).**

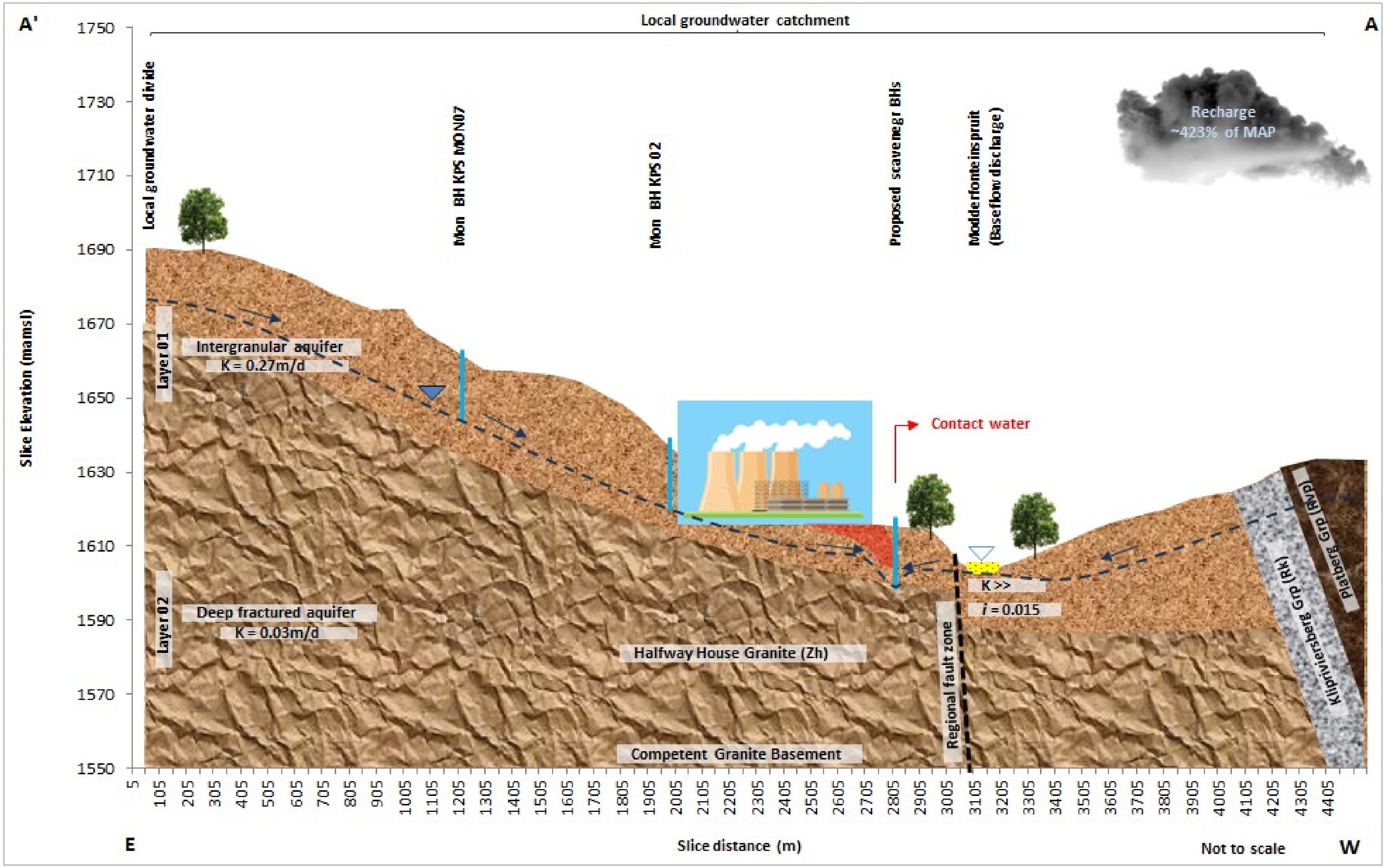


Figure 11-3 **Hydrogeological conceptual model (Post-mitigation): East-West cross section (A'-A) (Refer to Figure 12-2).**

12. 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.

12.1. Approach to modeling

The typical workflow and modelling approach employed is summarised in Figure 12-1 below and encompass a conceptualisation phase, calibration phase as well as a prediction phase.

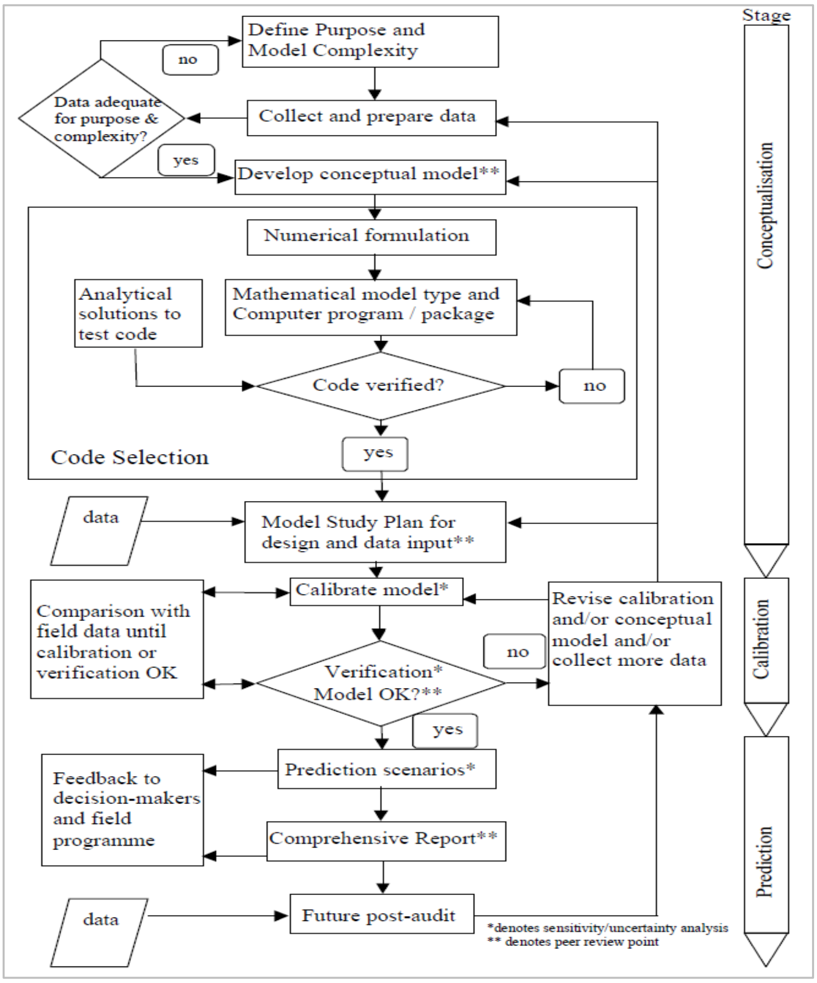


Figure 12-1 **Workflow numerical groundwater flow model development.**

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 12-1 **Simplified groundwater balance.**

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

where:

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

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

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

The piezometric gradient, which can be measured from site characterization and monitoring boreholes are known and the boreholes can be pump tested to determine the transmissivity and hydraulic conductivity. The outflow per unit length (L) of aquifer are given by Darcy's law as, q=K dh/dL where q is the Darcy flux in m/d (or $m^3/m^2/d$) and K is the hydraulic conductivity, D the aquifer thickness and dh/dl the piezometric gradient. Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small error (usually <10.0 % of the aquifer thickness).

12.2. 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.

12.3. Model development

12.3.1. Model domain

A model grid was created with global origin X: 81178.98[m] and Y: -2890528.51[m] using triangular prism type of elements. The model has a width of 28 645.6[m], height of 19 788.0[m], depth of 565.48[m] and spans an area of $4.30e^{+08}m^2$ with a volume of $\sim 7.31e^{+10}m^3$. The model domain was delineated based on regional drainages as well as topographical highs i.e., discharge zones and no-flow zones (Figure 12-2). Figure 12-3 indicates the model supermesh view from which the finite element mesh was generated while Figure 12-4 and Figure 12-5 shows the model finite element mesh (FEM) construction.

12.3.2. Model construction

The model was constructed from FEM and consist of two layers i.e., three slices, 474 232 triangular prism elements per layer, a total of 948 464 elements for the model domain, with 237 340 nodes per slice a total of 712 020 nodes for the model domain. The mesh quality is acceptable and summarised below:

- Delaunay violating triangle: 0.40%.
- Interior holes: 0.
- Obtuse angled triangles: 0.10% > 120°, 3.70% > 90°.

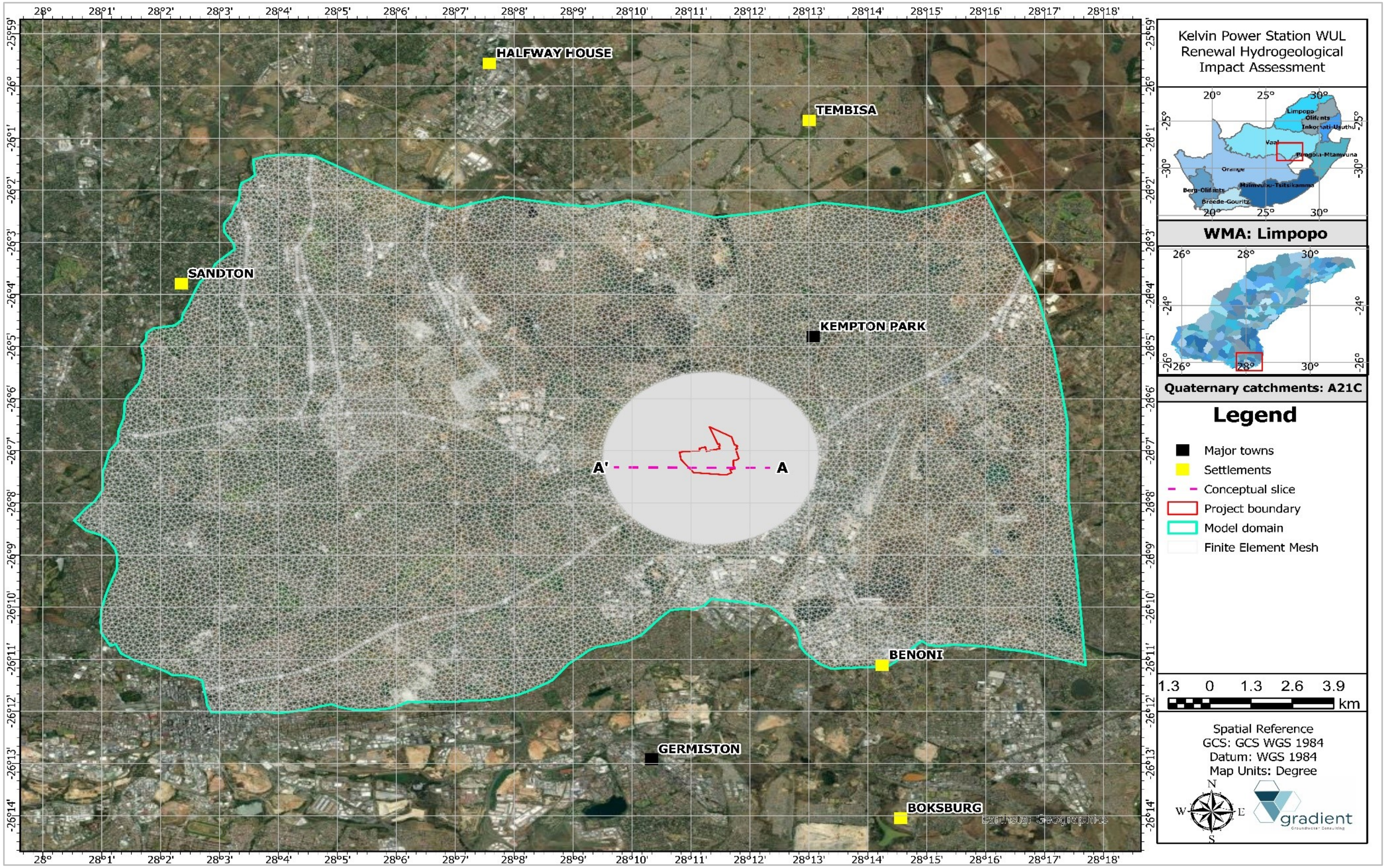


Figure 12-2 **Model domain: Aerial extent.**

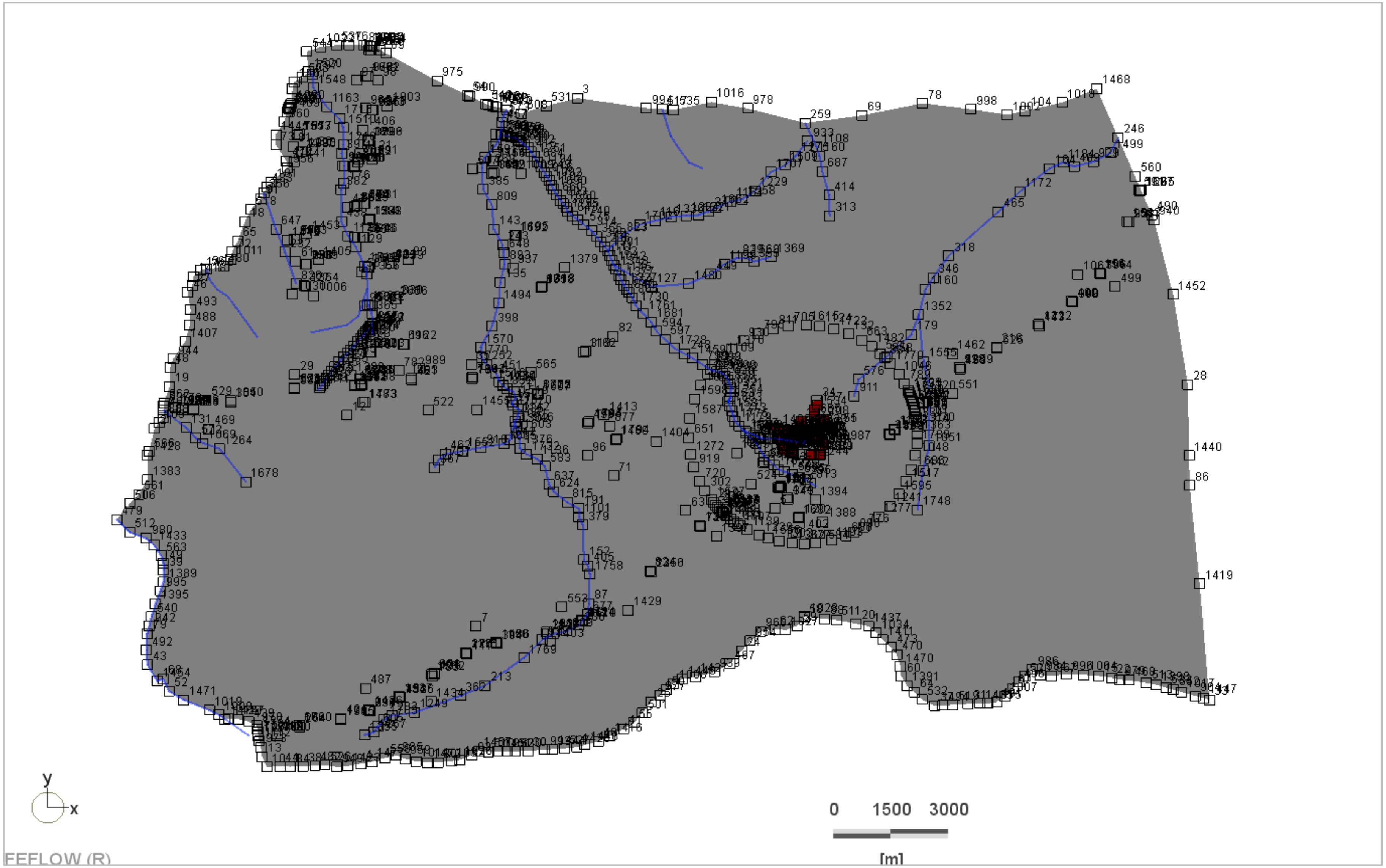


Figure 12-3 Model domain: Supermesh view.

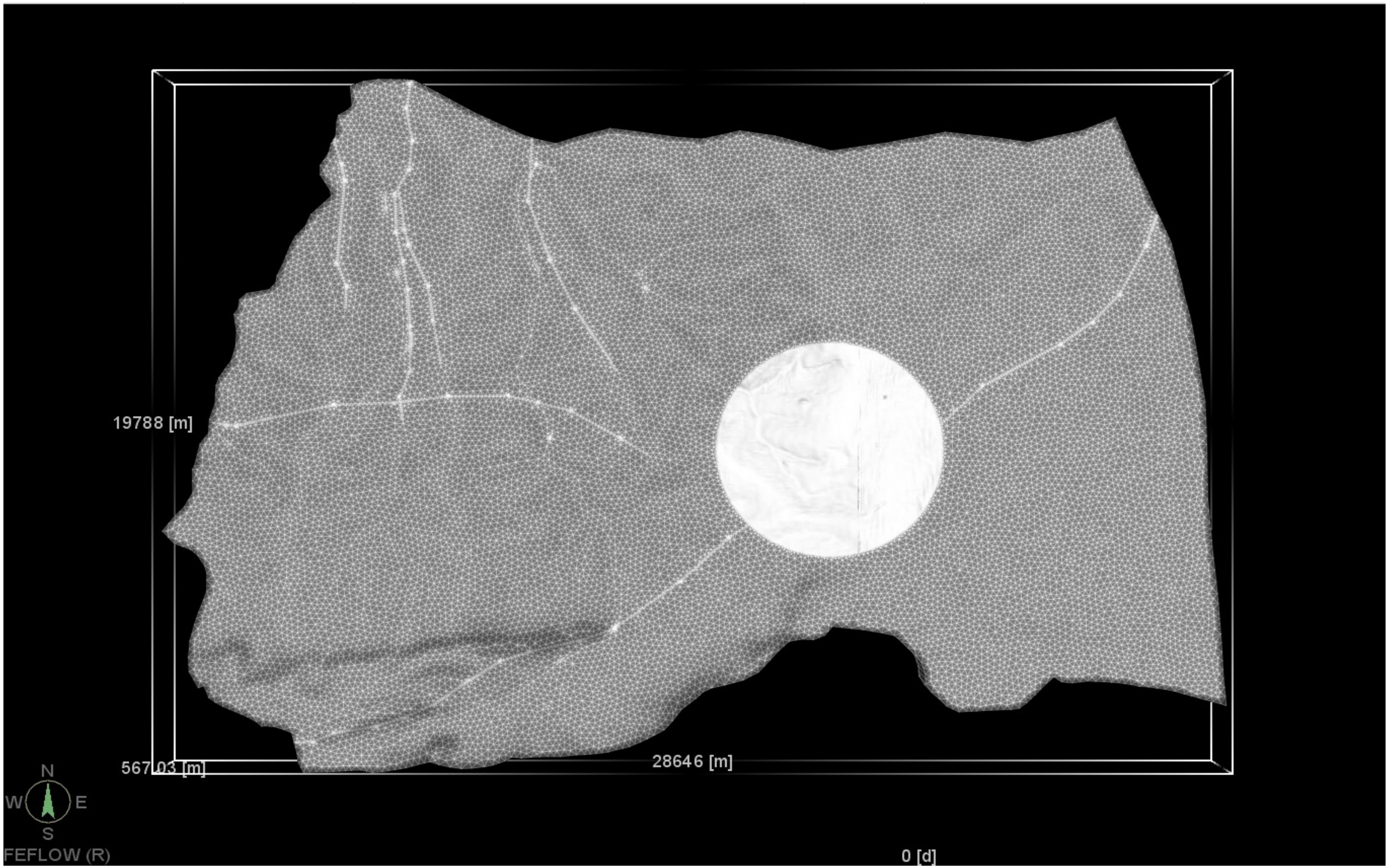


Figure 12-4 **Model domain 3-D FEM mesh view depicting a plan-view south-northern orientation.**

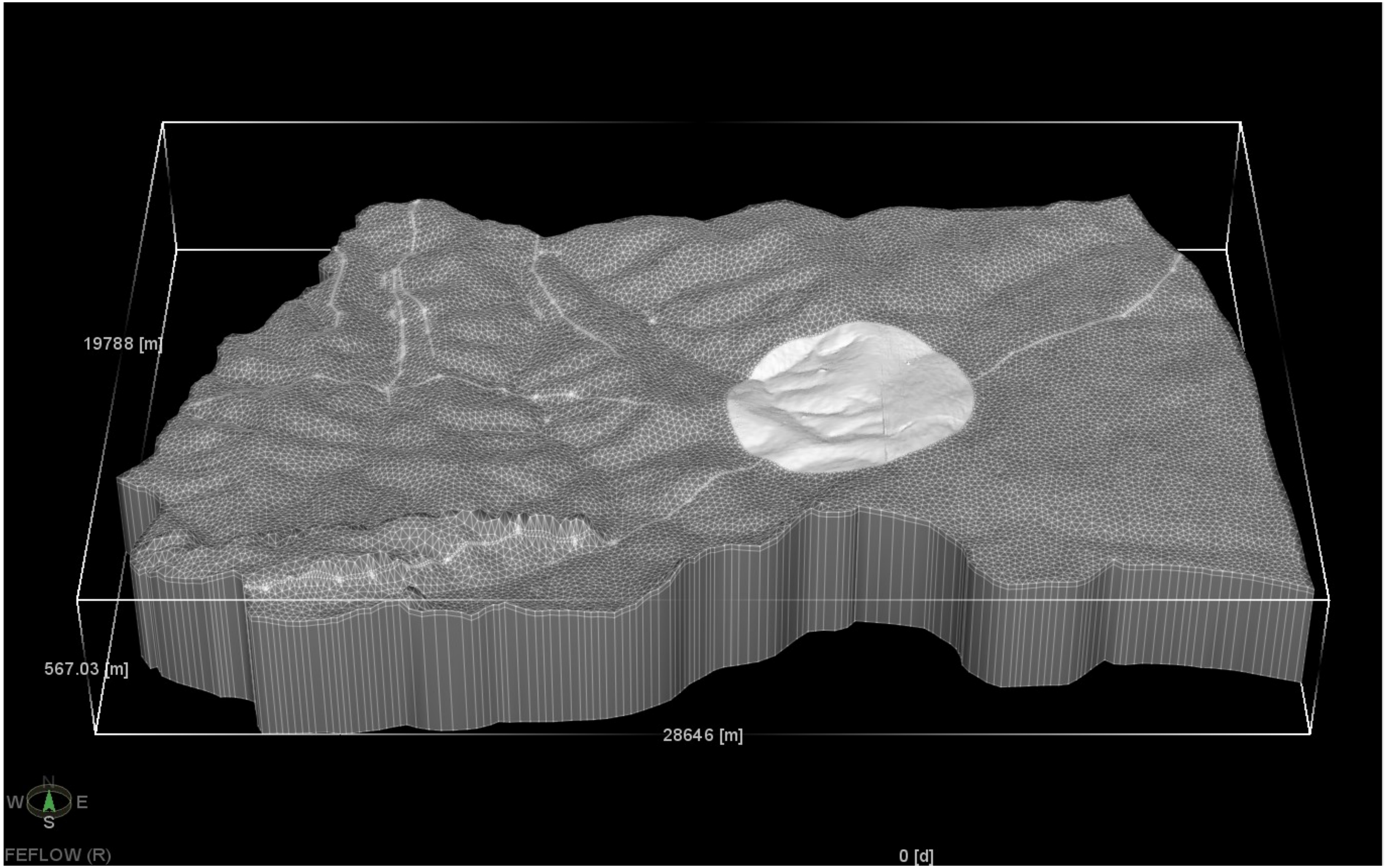


Figure 12-5 **Model domain 3-D FEM mesh view depicting a cross sectional view in a south-northern orientation.**

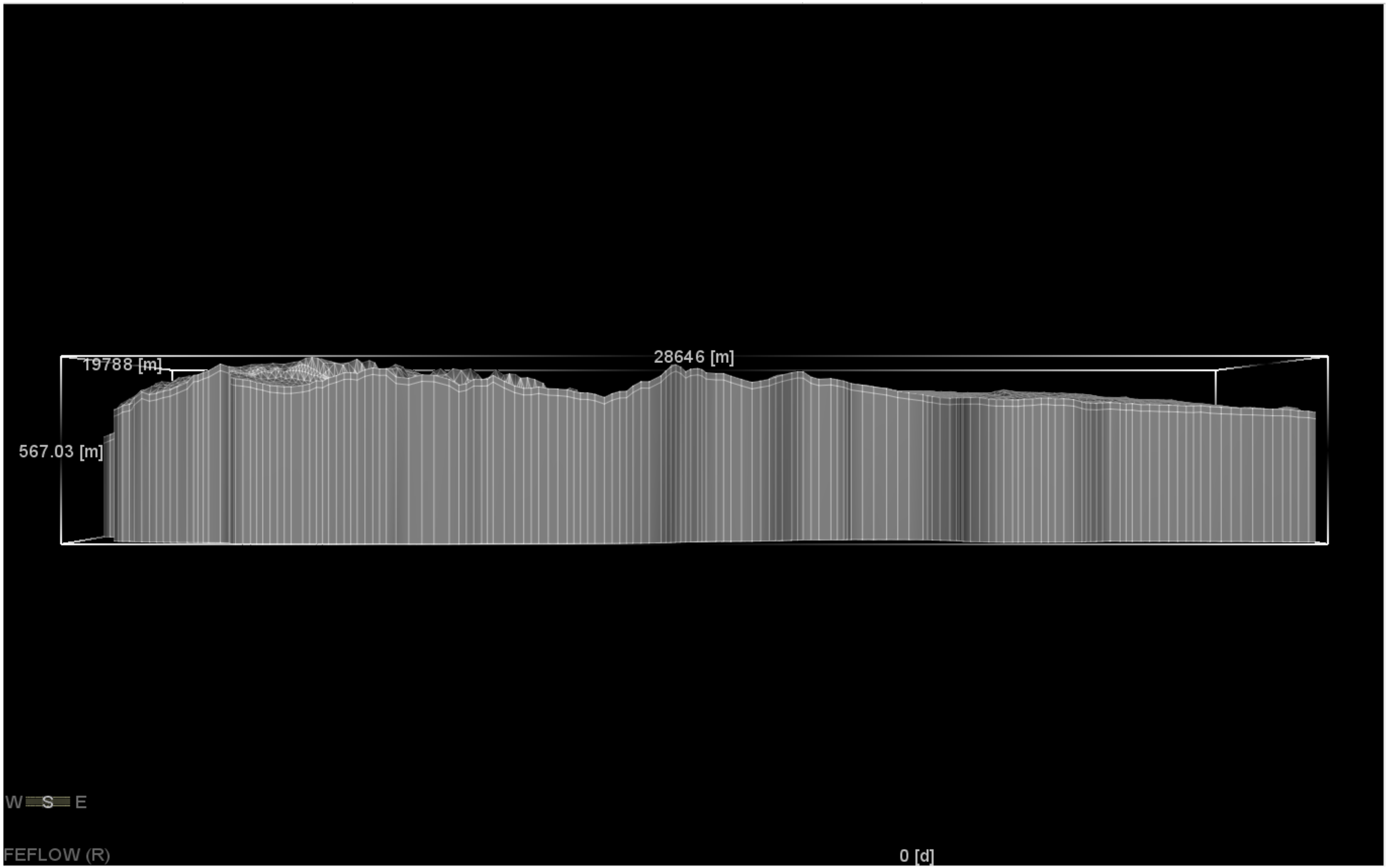


Figure 12-6 **Model domain 3-D FEM mesh view depicting a cross sectional view in a south-northern orientation.**

12.3.3. Model layers

The groundwater model consists of two layers, representing identified hydrostratigraphical units. The top layer was based on surface topography with succeeding layers developed horizontally parallel to this layer[8]. Layer sequence and average thickness are listed below (refer to Table 12-1):

i. Layer 01: A shallow, intergranular zone aquifer occurring in the transitional soil and weathered bedrock formations (Average thickness = 30.0m).

ii. Layer 02: A deep fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock (Average thickness = ~150.0m).

12.3.4. Boundary conditions

For the purposes of this model, it is assumed that the lower perimeter of the model domain i.e., competent granite basement which is generally impermeable and serves to isolate the fractured aquifer from potential 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., Jukskei River as well as associated drainage system were assigned as specific head boundary conditions (Dirichlet Type I) with a maximum constraint set where baseflow discharge from the model domain[9]. Figure 12-7 indicates different boundary conditions assigned within the model domain.

12.4. 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 guided by the site characterisation and aquifer tests phase performed.

12.4.1. Hydraulic Conductivity

Hydraulic conductivity (K) values were sourced from historical aquifer characterisation data as well as literature values published for similar hydrogeological environments. The model calibration was also used to guide refinement of aquifer parameter values[10.] The average hydraulic conductivity values assigned for the shallow, intergranular aquifer is 0.27m/d, ranging from 0.028m/d for the denser Swazian granite formations to 0.45m/d for the Malmani doloite formations. The average hydraulic conductivity values assigned for the deeper, fractured aquifer is 0.03m/d. Regional fault zones have been assigned a higher hydraulic conductivity of 0.56m/d and will act as conduits for groundwater flow and contaminant transport. Hydraulic conductivity values were assigned to all major hydrostratigraphic units within the model domain as depicted in Figure 12-8 and Figure 12-9. A ratio of 1:1 for hydraulic conductivity (K) in x and y directions have been assigned, with a 1:10 ratio in the z direction i.e., anisotropic aquifer with exception of the alluvial zone which have a

[8] Zones where relevant coal seam contours were available i.e., within the Mining Right area, floor elevations were assigned as such.
[9] Refer to "gaining stream" assumption.
[10] Hydraulic parameters assigned for various hydrostratigraphical units correlate well to historical models and literature values published for similar geological environments.

ratio of 1:1 i.e., isotropic aquifer. Table 12-1provides a summary of parameter values per layer.

12.4.2. Sources and sinks

The primary source to groundwater is through recharge. The average recharge assigned to the model is estimated at ~20.0mm/a, ranging between 15.0mm/a for the denser granite formations to 30.0mm/a for the dolomitic formations. Figure 12-10 depicts a spatial distribution of recharge volumes assigned as listed in Table 12-1. Sinks in the model domain include groundwater abstraction from privately owned and community boreholes as well as groundwater discharge to baseflow.

12.4.3. Storativity and specific storage

Specific storage values were assigned per layer and ranges between $1.00E^{-06}$ for the denser granite formations to $1.00E^{-04}$ for regional fault zones depending on which hydrostratigraphic unit is targeted as listed in Table 12-1and indicated in Figure 12-11.

12.4.4. Porosity

A porosity value ranging from 0.01% (denser igneous formations) to 10.0-15.0%% (more porous dolomite formations and regional fault zones) was assigned per model layer as listed in Table 12-1 and indicated in Figure 12-12. It should be noted that rehabilitated opencast and other modified areas can have porosity values of >15.0% or larger.

12.4.5. 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.

Table 12-1 Model set-up: Hydraulic Parameters.

Model Layer	Hydrostratigraphic unit	Layer thickness (m)	Hydraulic Conductivity (K)		Recharge (Re)	Specific storage (Sc)	Porosity (n)
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)	In/Outflow on top/bottom (mm/a)	Sc (1/m)	%
Layer 1	Halfway House Granite	30.00	0.141	0.014	20.00	1.00E-05	2.00E-02
	Swazian Erathem		0.028	0.003	15.00	1.00E-06	1.00E-02
	Hospital Hill SbGrp, West Rand Grp		0.413	0.041	17.50	2.00E-05	2.50E-02
	Government SbGrp, West Rand Grp		0.338	0.034	19.00	3.50E-05	4.00E-02
	Klipriviersberg Grp, Ventersdorp SpGrp		0.197	0.020	18.00	3.00E-05	3.00E-02
	Platberg Grp, Ventersdorp SpGrp		0.375	0.038	18.00	4.50E-05	4.00E-02
	Dwyka Grp, Karoo SpGrp		0.300	0.030	16.00	4.50E-05	4.50E-02
	Madzaringwe Fm, Karoo SpGrp		0.356	0.036	18.00	5.00E-05	5.00E-02
	Black Reef Fm, Transvaal SpGrp		0.169	0.017	20.00	6.00E-05	5.50E-02
	Malmani SbGrp, Transvaal SpGrp		0.450	0.045	30.00	7.50E-05	1.00E-01
	Fault zones		0.562	0.056	25.00	1.00E-04	1.50E-01
Layer 2	Halfway House Granite	150.00	0.014	0.001	0.00	1.00E-06	2.00E-03
	Swazian Erathem		0.003	0.000		1.00E-07	1.00E-03
	Hospital Hill SbGrp, West Rand Grp		0.041	0.004		2.00E-06	2.50E-03
	Government SbGrp, West Rand Grp		0.034	0.003		3.50E-06	4.00E-03
	Klipriviersberg Grp, Ventersdorp SpGrp		0.020	0.002		3.00E-06	3.00E-03
	Platberg Grp, Ventersdorp SpGrp		0.038	0.004		4.50E-06	4.00E-03
	Dwyka Grp, Karoo SpGrp		0.030	0.003		4.50E-06	4.50E-03
	Madzaringwe Fm, Karoo SpGrp		0.036	0.004		5.00E-06	5.00E-03
	Black Reef Fm, Transvaal SpGrp		0.017	0.002		6.00E-06	5.50E-03
	Malmani SbGrp, Transvaal SpGrp		0.045	0.005		7.50E-06	1.00E-02
	Fault zones		0.056	0.006		1.00E-05	1.50E-02

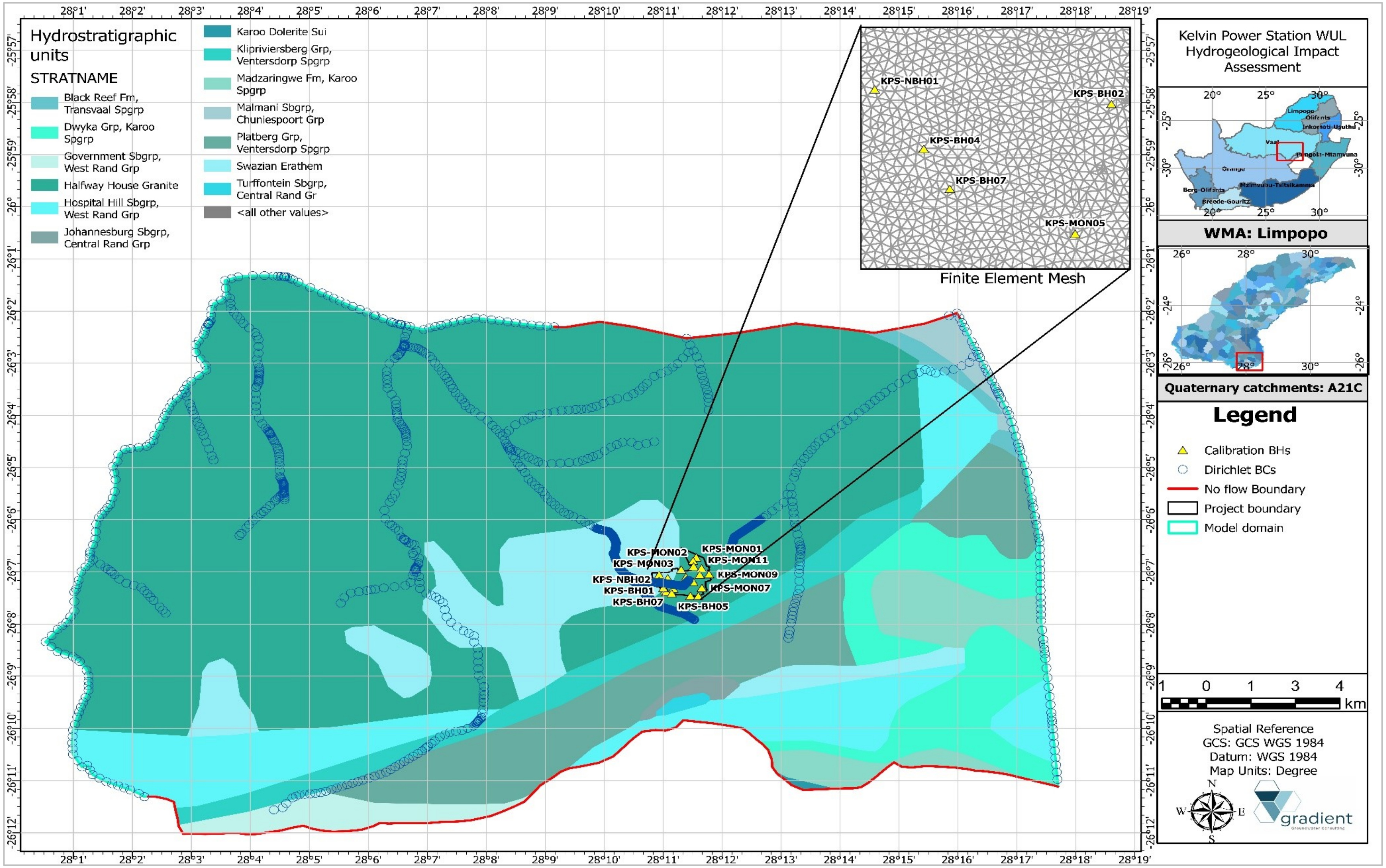


Figure 12-7 **Hydrostratigraphic units and model boundary conditions.**

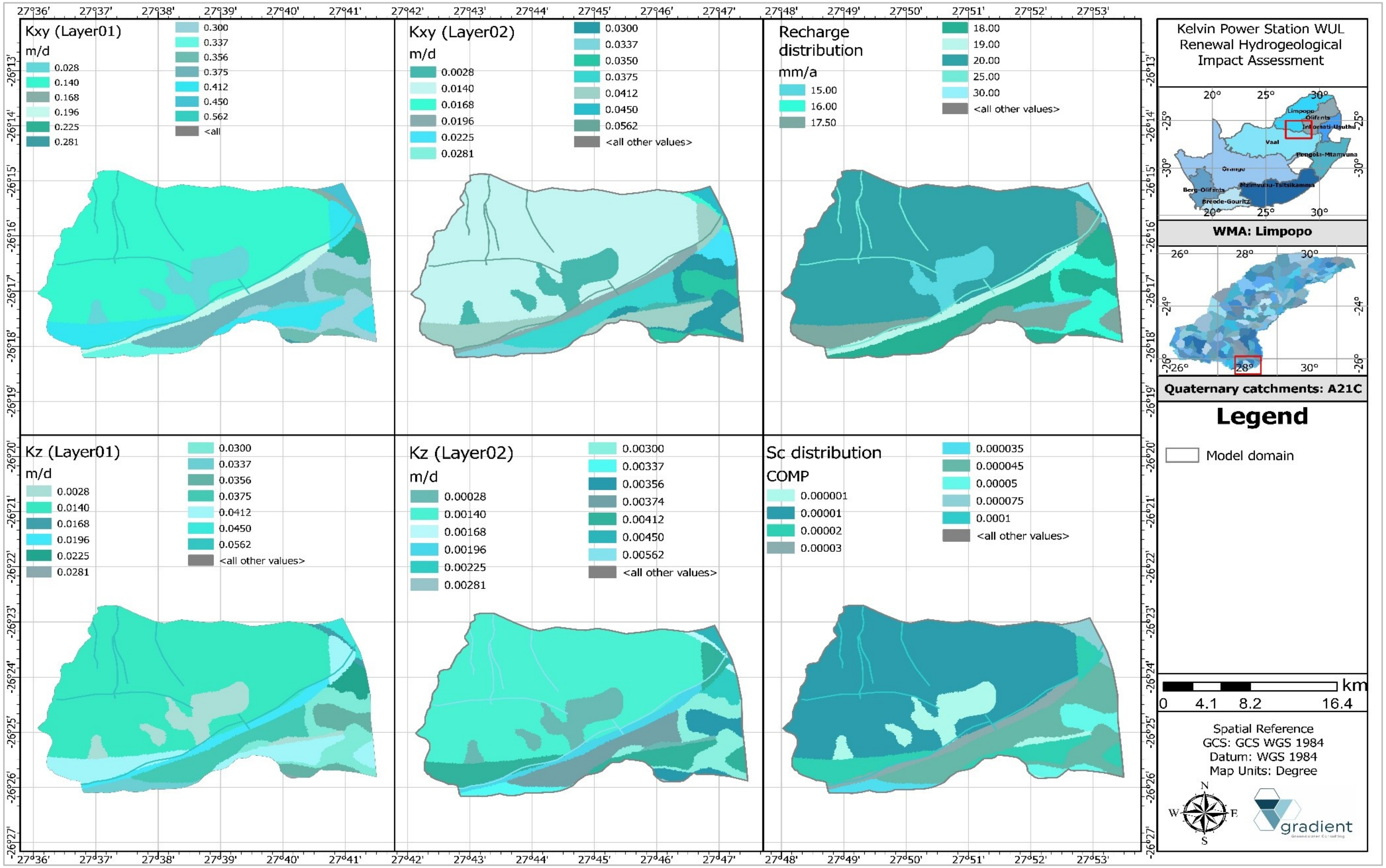


Figure 12-8 **Numerical groundwater flow model: Hydraulic properties.**

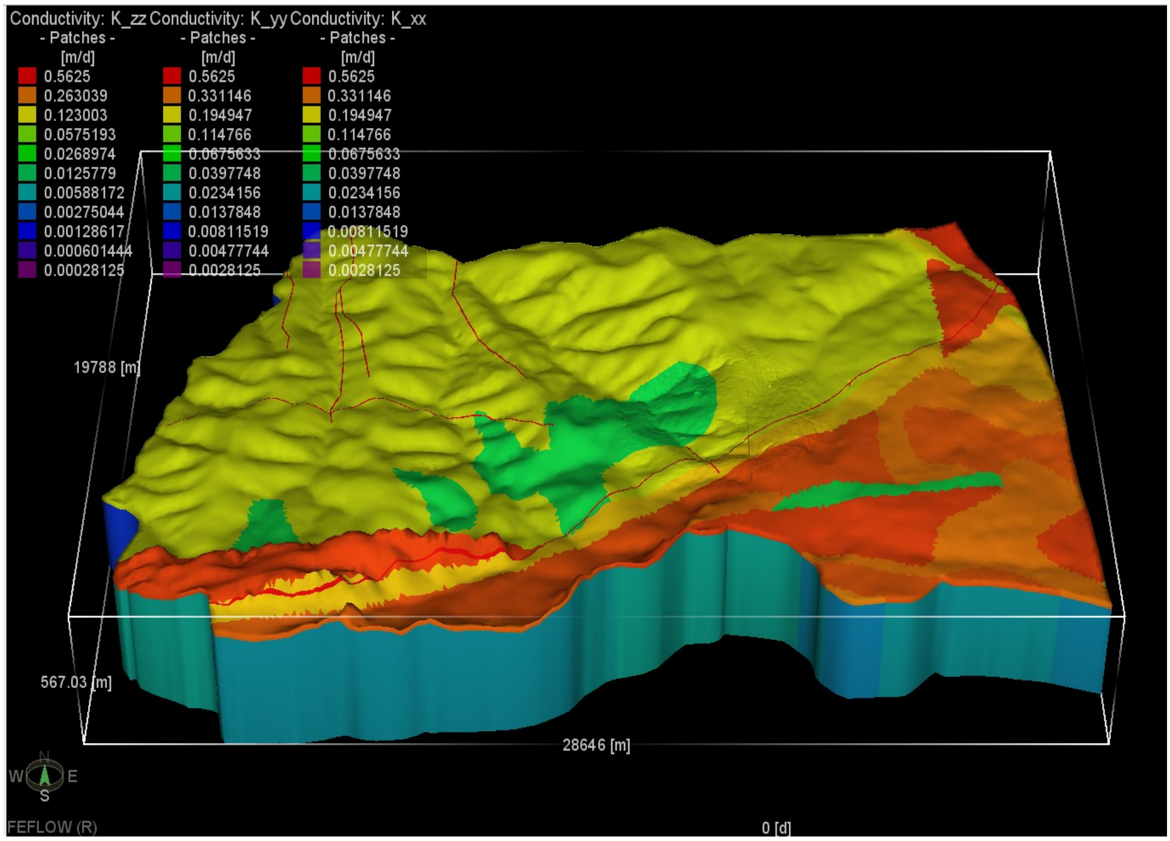


Figure 12-9 **Model development: Numerical groundwater flow model: Hydraulic conductivity distribution.**

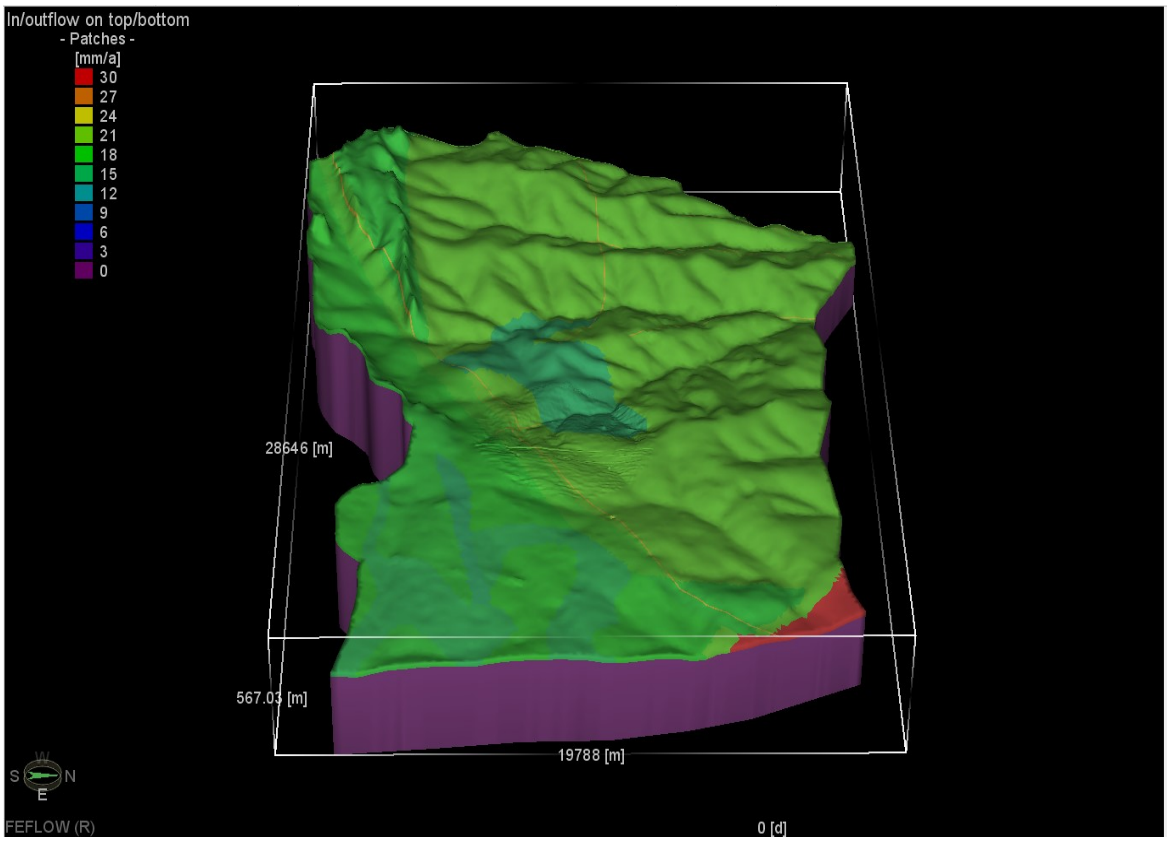


Figure 12-10 **Model development: Numerical groundwater flow model: Recharge distribution.**

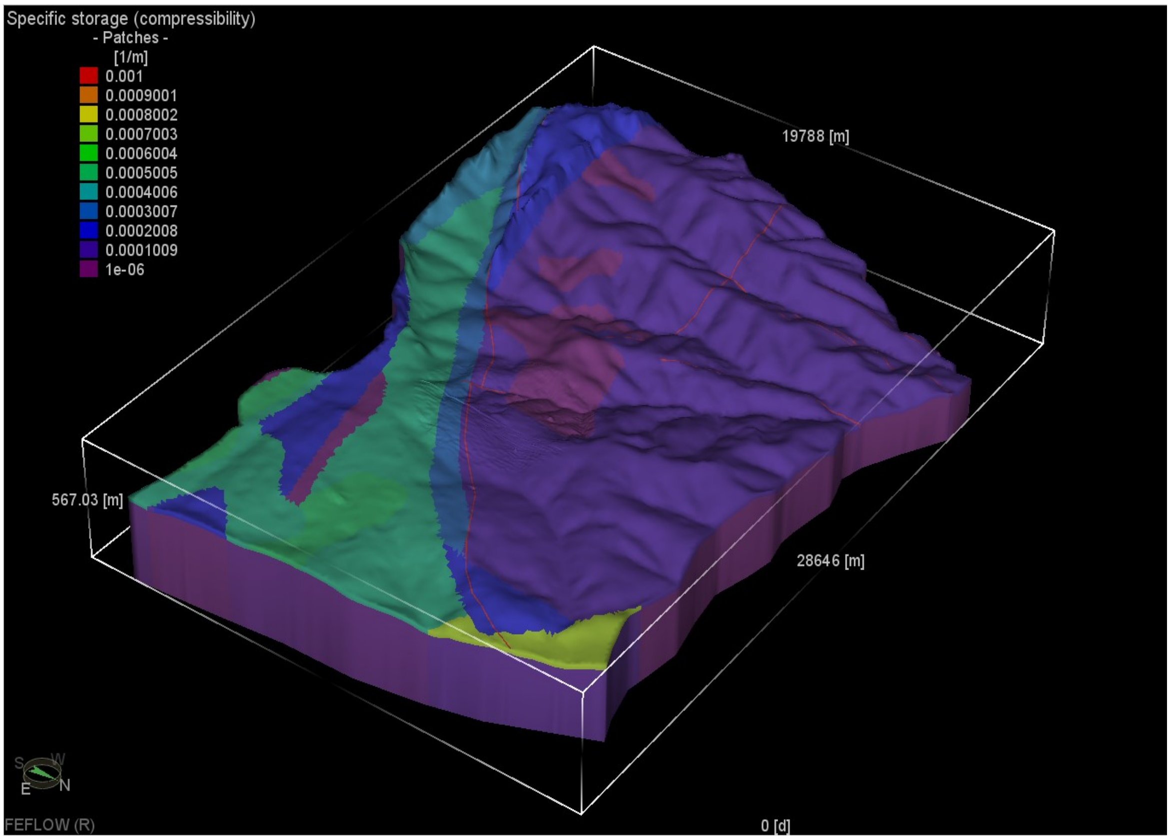


Figure 12-11 **Model development: Numerical groundwater flow model: Specific storage distribution.**

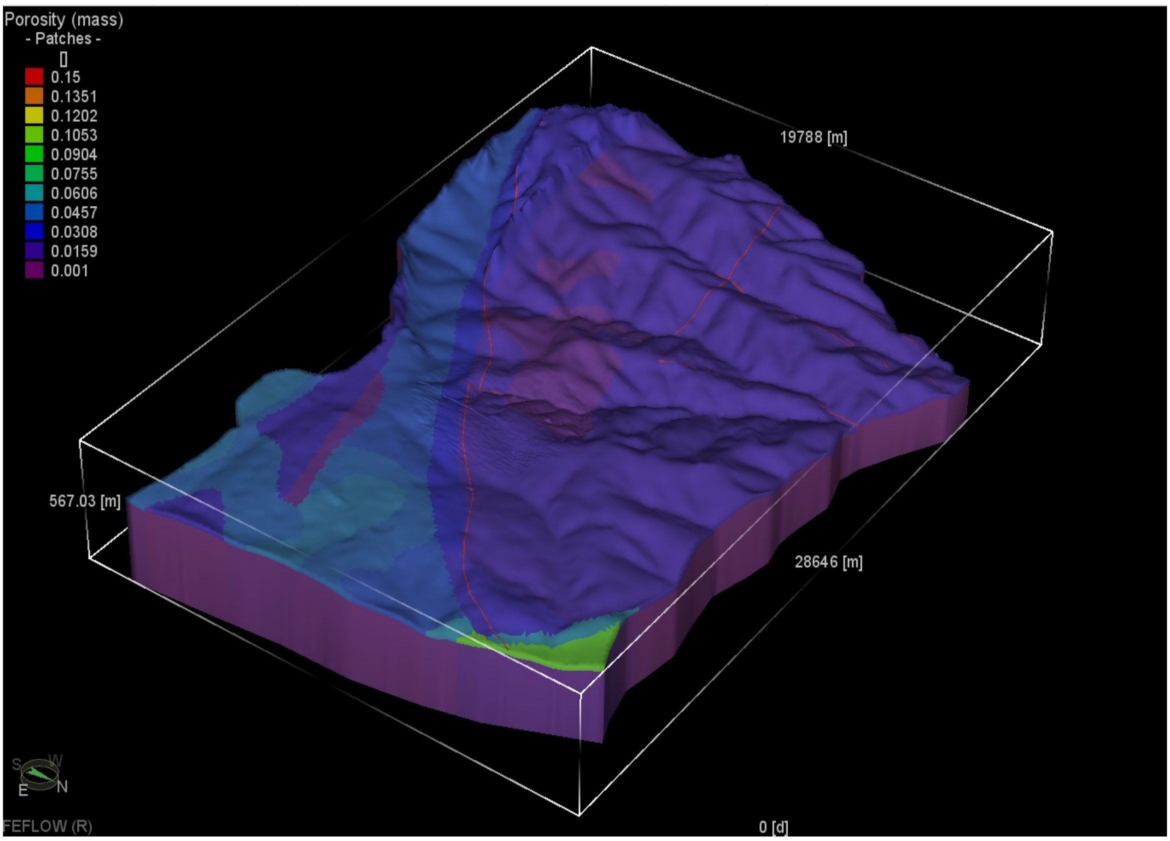


Figure 12-12 **Model development: Numerical groundwater flow model: Porosity distribution.**

12.5. Model calibration

12.5.1. Steady state calibration (∞)

A steady state groundwater flow model was developed to simulate equilibrium conditions, i.e., pre-mining conditions, which will be used as initial hydrogeological conditions for transient simulations. The model was standardised by applying the American Society for Testing Materials (ASTM) guidelines (1993), as well as methods presented in Anderson and Woesner (1992) and Spitz and Moreno (1996) case studies. Under steady state conditions, the groundwater flow equation is reduced to exclude storativity. Groundwater levels of gathered observation boreholes were simulated by varying aquifer parameters (hydraulic conductivity and recharge) until an acceptable fit between the measured and simulated hydraulic heads was obtained as summarised in Table 12-2. Observed groundwater levels were plotted against measured water levels and a correlation of ~0.98 was obtained (refer to Figure 12-13, Figure 12-14 and Figure 12-15) while Figure 12-16 indicate calibration error margin per borehole observation locality.

Figure 12-17 depicts a cross-sectional view in a east-west orientation A'-A on which the hydrogeological conceptual model is based with Figure 12-18 showing steady state hydraulic head contours and groundwater flow directions. Figure 12-19 indicate the Darcy flow vectors in the direct vicinity of the existing waste infrastructure.

A good correlation indicates that the developed groundwater model will accurately represent on-site conditions. The residual calibration error is expressed through the calculated; mean error (ME), mean absolute error (MAE) as well as the root mean squared error (RMSE) of the observed versus simulated heads. The RMSE was evaluated as a ratio of the total saturated thickness across the model domain and calculated errors are summarised below:

i. Mean Error (ME): -1.51m.

ii. Mean Absolute Error (MAE): 2.30m.

iii. Normalised Root Mean Square Deviation (NRMSD): 7.34% i.e., represents the deviation between observed and calibration water levels across the model domain.

Table 12-2 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)
KPS BH01	1630.64	3.00	1627.64	1630.65	-3.00	3.00	9.03
KPS BH05	1654.97	2.84	1652.13	1657.43	-5.30	5.30	28.10
KPS MON01	1668.91	8.77	1660.14	1661.21	-1.07	1.07	1.15
KPS MON02	1668.17	5.98	1662.19	1661.00	1.19	1.19	1.42
KPS MON03	1663.89	5.70	1658.19	1657.59	0.60	0.60	0.36
KPS MON04	1647.19	2.39	1644.80	1644.50	0.30	0.30	0.09
KPS MON06	1656.29	2.04	1654.25	1658.54	-4.29	4.29	18.37
KPS MON07	1660.51	1.90	1658.61	1663.40	-4.79	4.79	22.96
KPS-MON09	1666.95	4.99	1661.96	1664.51	-2.55	2.55	6.52
KPS-MON10	1666.89	4.95	1661.94	1664.48	-2.54	2.54	6.45
KPS-MON11	1669.41	4.79	1664.62	1662.36	2.26	2.26	5.13
KPS-MON12	1668.44	6.17	1662.27	1662.00	0.27	0.27	0.07
KPS-MON13	1659.65	4.78	1654.87	1656.12	-1.25	1.25	1.57
KPS-MON14	1668.43	5.46	1662.97	1660.85	2.12	2.12	4.48
KPS-MON16	1639.51	3.97	1635.54	1638.11	-2.57	2.57	6.60
KPS-NBH02	1631.45	1.78	1629.67	1631.68	-2.01	2.01	4.05
KPS-NBH03	1662.89	3.41	1659.48	1662.46	-2.98	2.98	8.88
Average	**1657.89**	**4.29**	**1653.60**	**1655.11**	**-1.51**	**2.30**	**7.37**
Minimum	**1630.64**	**1.78**	**1627.64**	**1630.65**	**-5.30**	**0.27**	**0.07**
Maximum	**1669.41**	**8.77**	**1664.62**	**1664.51**	**2.26**	**5.30**	**28.10**
Correlation			**0.98**				
∑					**-25.61**	**39.11**	**125.24**
1/n					**-1.51**	**2.30**	**7.37**
Root Mean Square Deviation (RMSD)					**1.23**	**1.52**	**2.71**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**7.34**

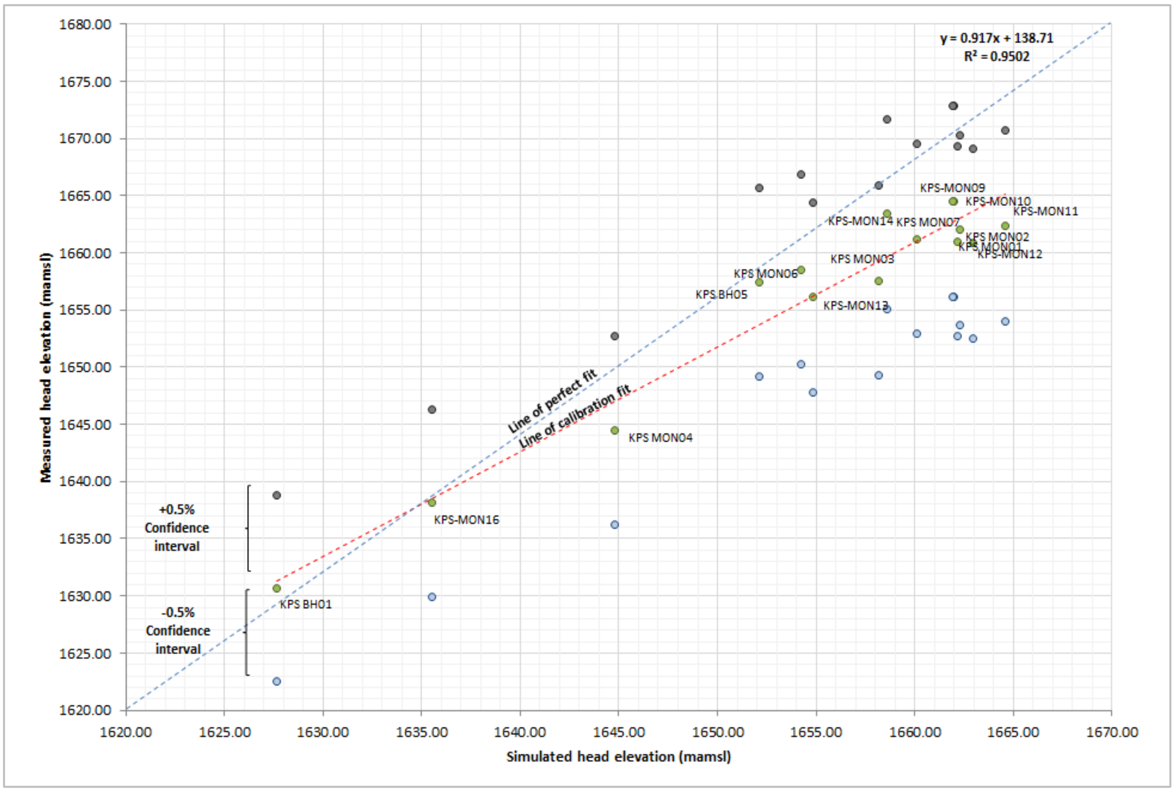


Figure 12-13 Model steady state calibration: Scatter plot of simulated vs. measured hydraulic head elevation.

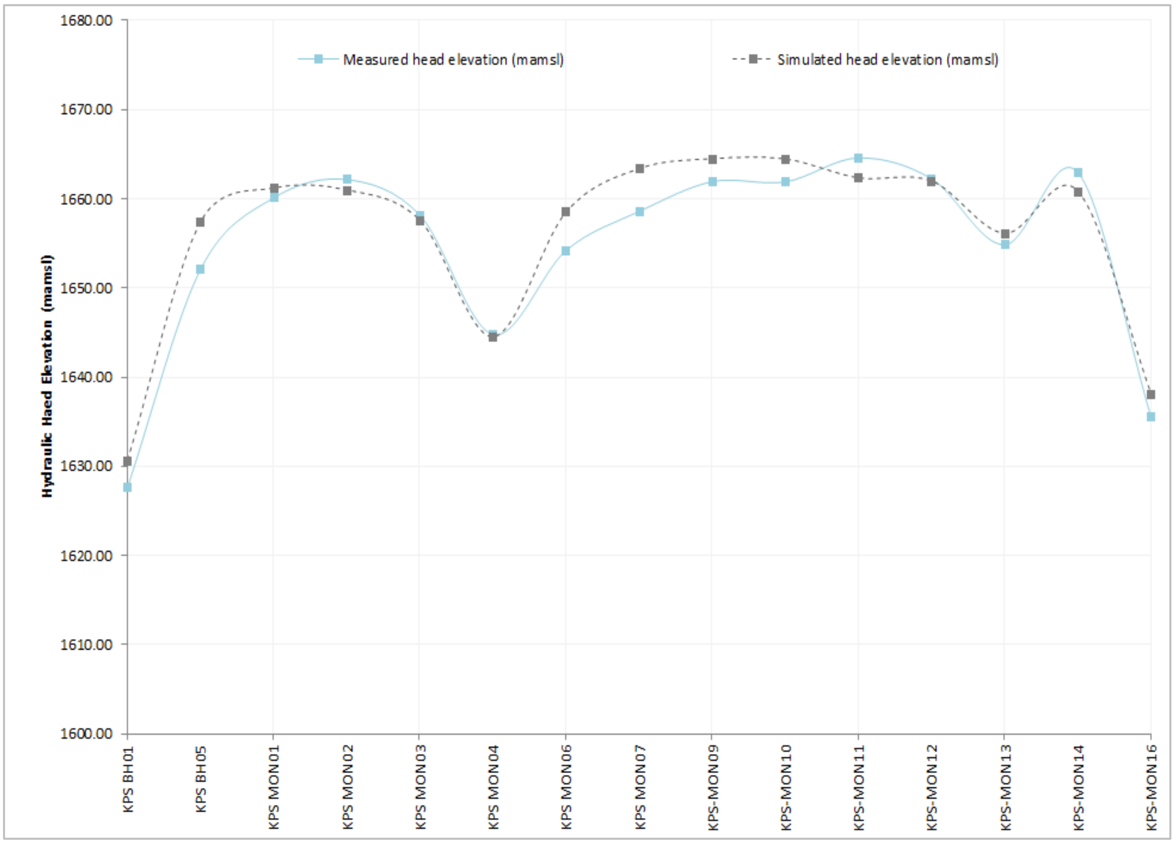


Figure 12-14 Model steady state calibration: curve of simulated vs. measured hydraulic head elevation.

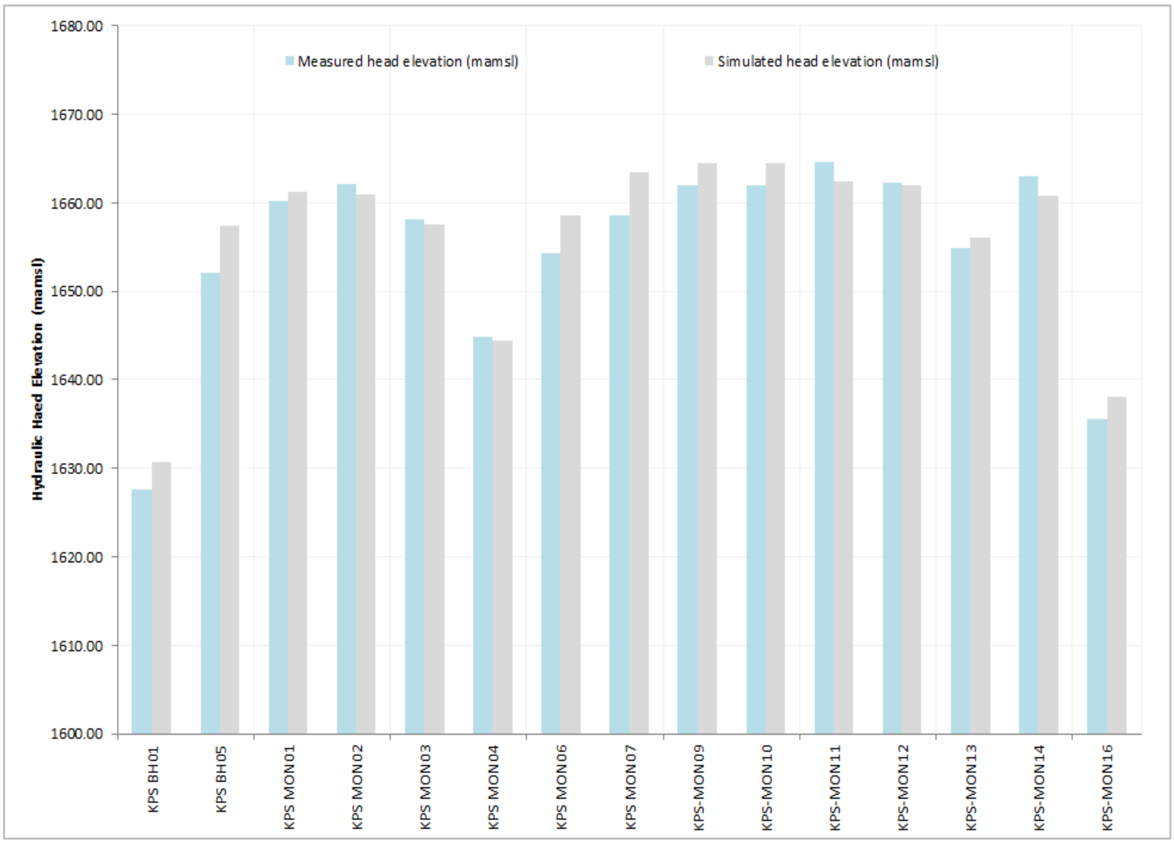


Figure 12-15 Model steady state calibration: Bar chart of simulated vs. measured hydraulic head elevation.

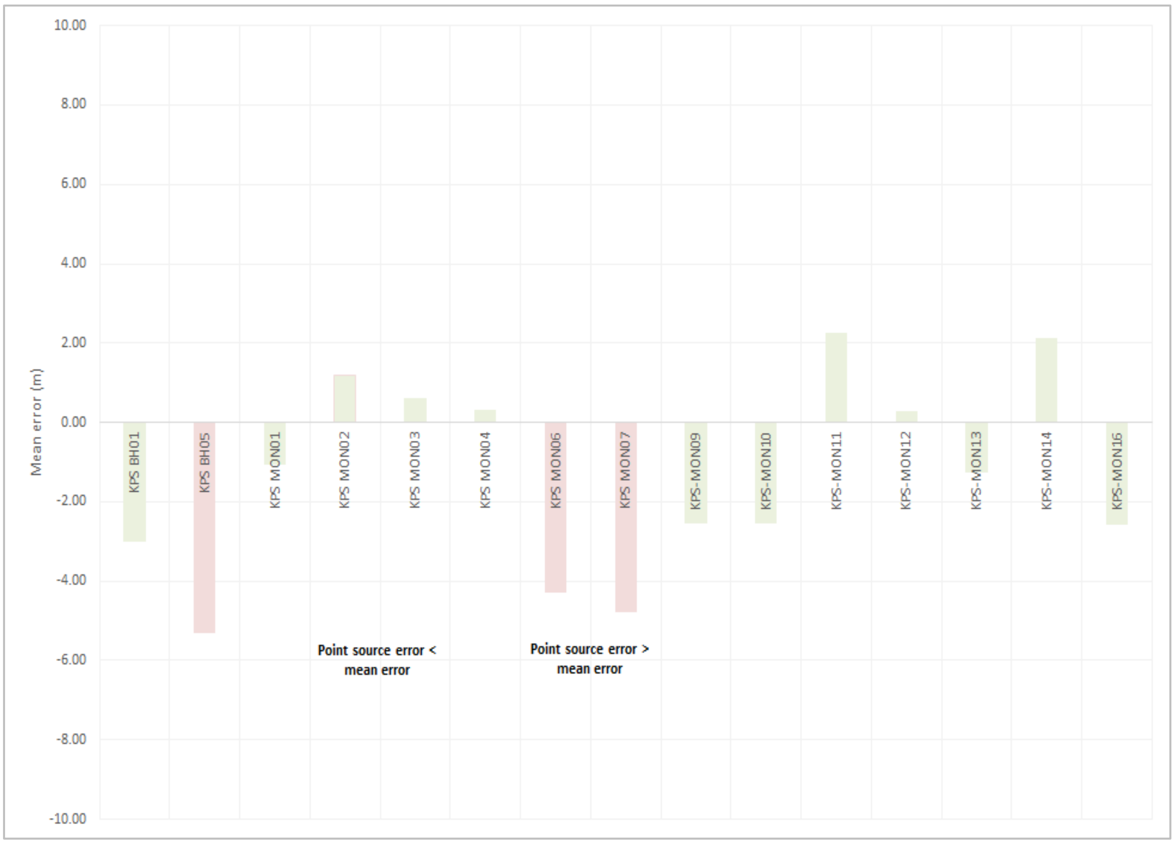


Figure 12-16 Model steady state calibration: Bar-chart of simulated vs. measured hydraulic head elevation.

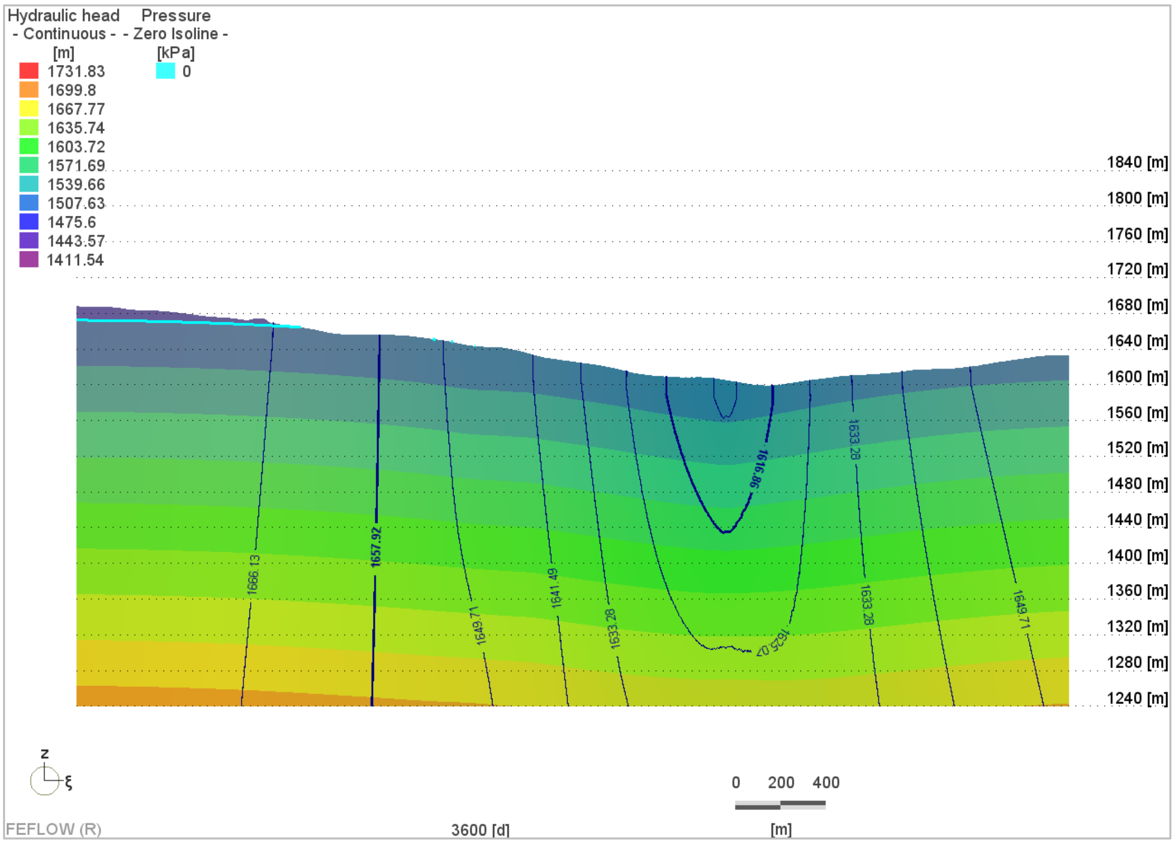


Figure 12-17 Model domain 3-D FEM mesh view (cross sectional view in a NW-SE orientation A-A'.

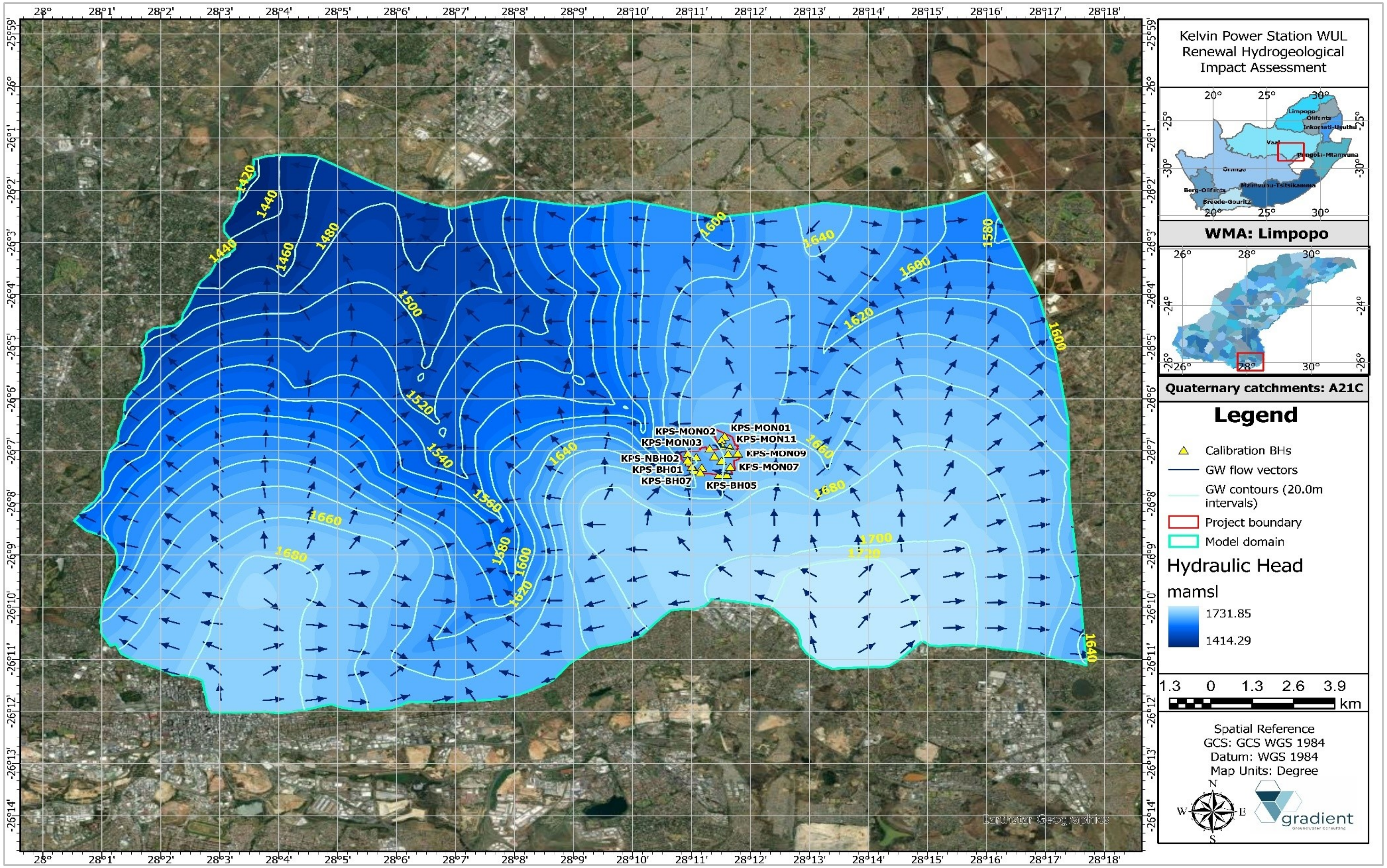


Figure 12-18 **Model calibration: steady state hydraulic heads and groundwater flow direction.**

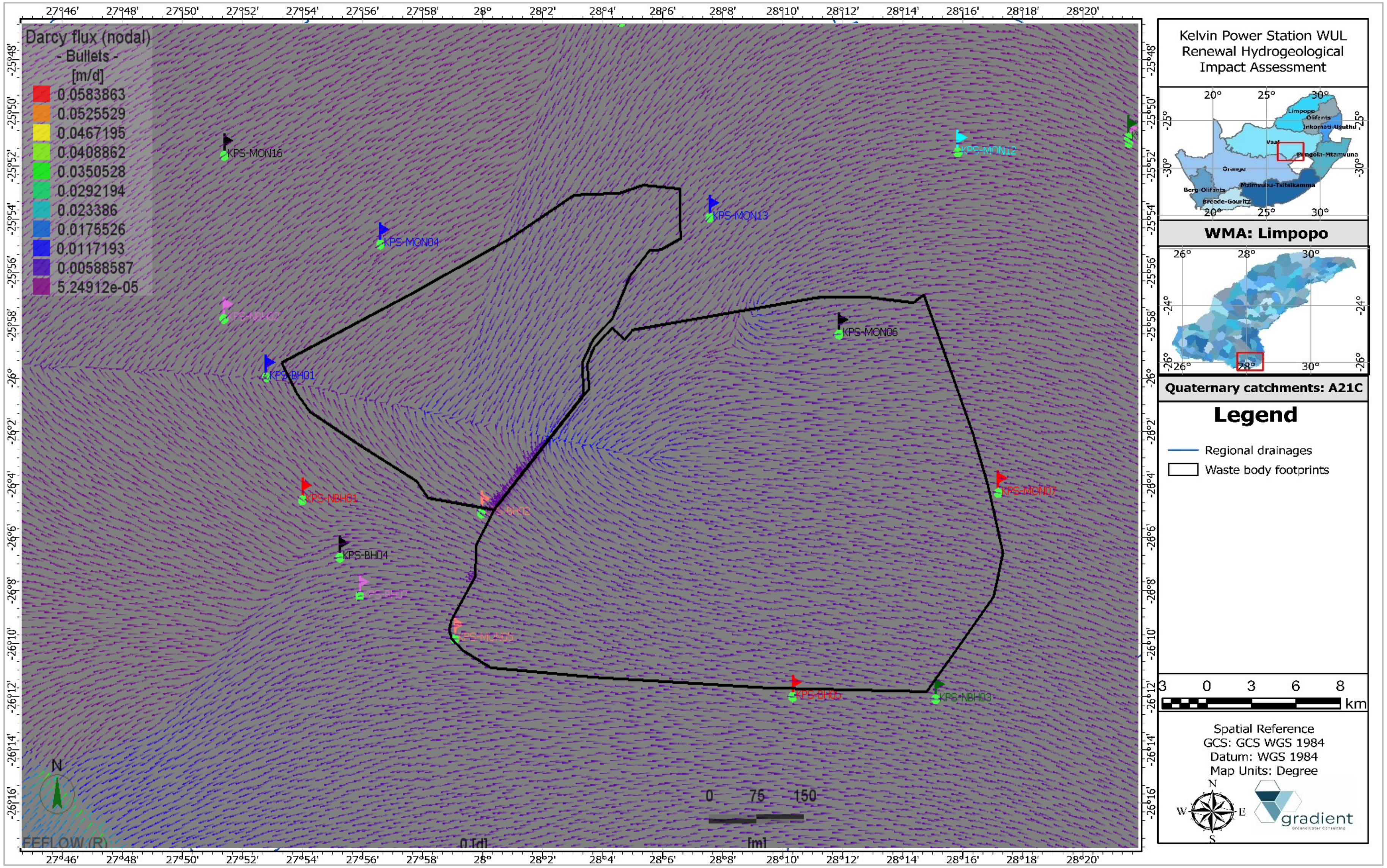


Figure 12-19 **Model calibration: Map indicating the Darcy flow-vectors in the vicinity of the waste infrastructure.**

12.5.2. Model sensitivity analysis

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs (Saltelli, 2002). The process of recalculating outcomes under alternative assumptions to determine the impact of a variable under sensitivity analysis can increase the understanding of the relationships between input and output variables in a system or model as well as reduce the model uncertainty (Pannell, 1997). In order to verify the sensitivity of the calibrated model in terms of hydraulic stresses, aquifer parameters (i.e., recharge and transmissivity) were adjusted while the impact on the hydraulic head elevation evaluated at relevant on-site borehole localities. As summarised in Table 12-2 The model tends to be more sensitive to an increase in hydraulic conductivity as well as a downward change in recharge(Figure 12-20, Figure 12-21 and Figure 12-22)[11].

Table 12-3 Steady State Model Calibration – Sensitivity analysis.

Parameter	Scenario: Base Case	Scenario: -25.0% of calibrated K-value	Scenario: -+25.0% of calibrated K-value	Scenario: -25.0% of calibrated recharge	Scenario: +25.0% of calibrated recharge
Correlation	0.98	0.98	0.96	0.96	0.98
Mean Error	-1.51	1.98	5.85	5.30	-1.61
Mean Abs Error	2.30	2.84	6.20	5.65	2.18
RMSD	2.71	3.39	7.20	6.64	3.49
NRMSD	7.34%	9.16%	19.46%	17.96%	7.73%

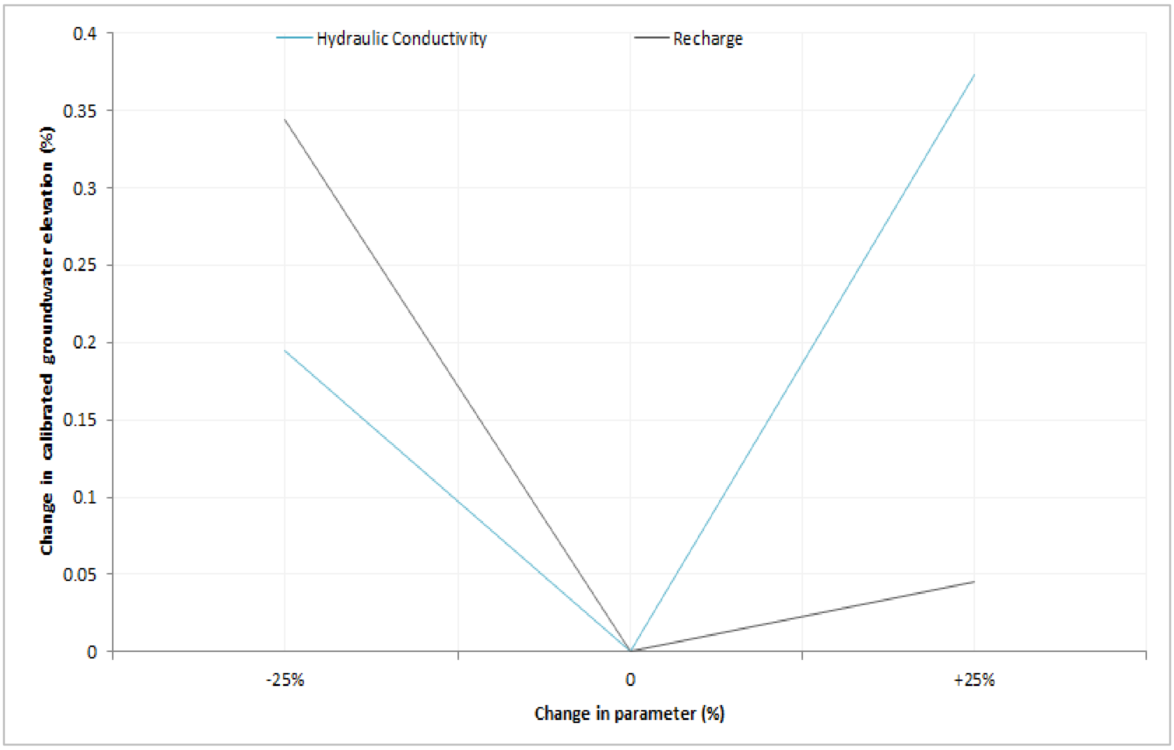


Figure 12-20 Model steady state calibration: sensitivity analysis for monitoring locality KPS BH05.

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

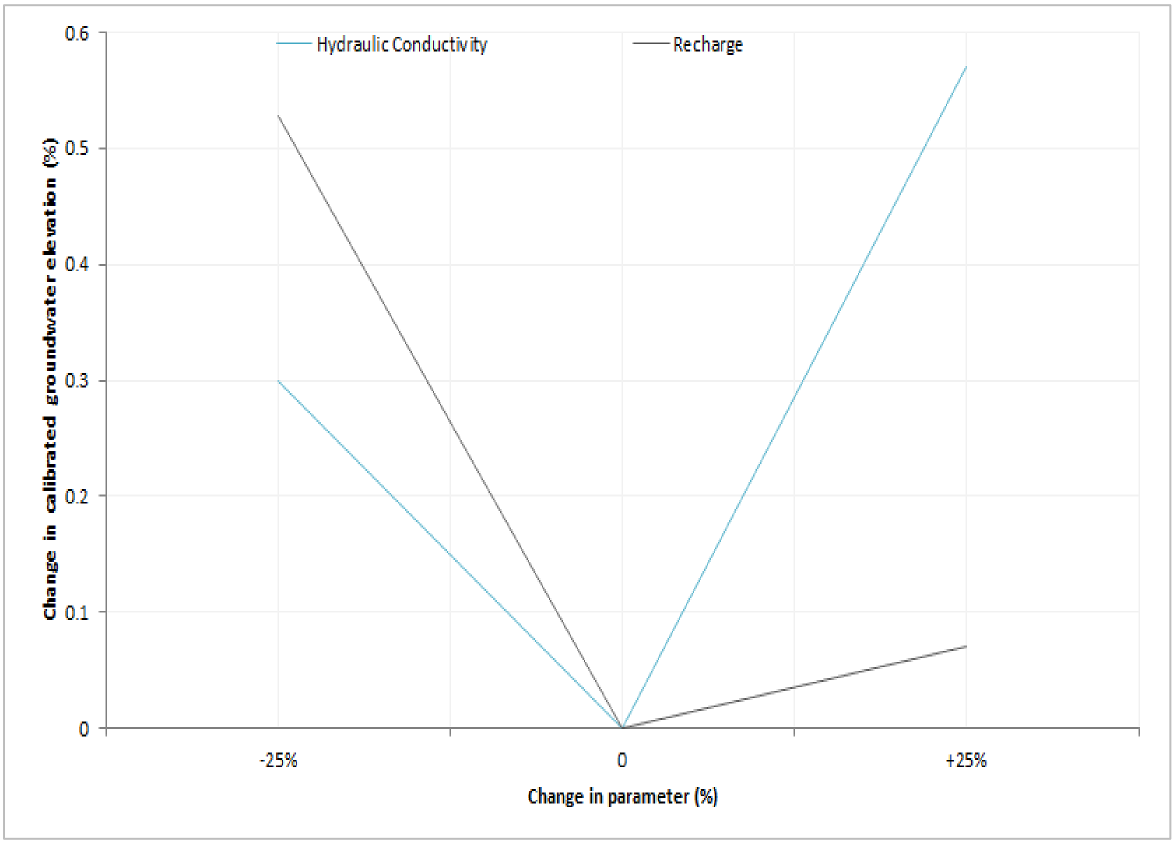


Figure 12-21 **Model steady state calibration: sensitivity analysis for monitoring locality KPS MON09.**

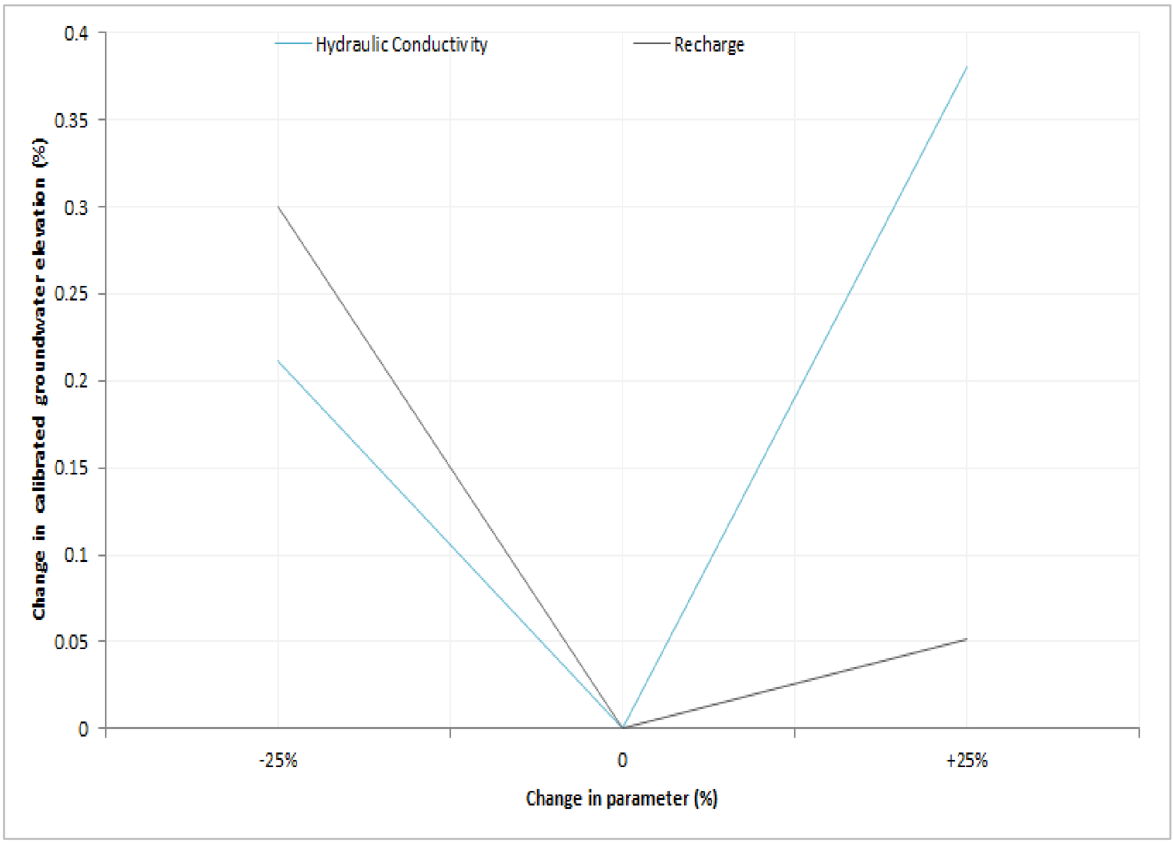


Figure 12-22 **Model steady state calibration: sensitivity analysis for monitoring locality KPS MON16.**

12.6. 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 12-2 Groundwater flow.

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

where:

h = hydraulic head [L]

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]

12.6.1. Model simulation scenarios

Various management scenarios were modelled for the purposes of planning and decision making with stress periods listed in Table 12-4:

i. **Scenario 01:** Baseline pre-development conditions.

ii. **Scenario 02:** TDS pollution plume migration within the host aquifer for the operational phase(s) without implementation of mitigation or management measures.

iii. **Scenario 03:** TDS pollution plume migration within the host aquifer for the post-closure phase(s) without implementation of mitigation or management measures.

iv. **Scenario 04a (mitigation and management):** Implementation of a cut-off/ fracturing trench down-gradient of existing waste body footprints.

v. **Scenario 04b (mitigation and management):** Establishment of a series of seepage capturing or scavenger boreholes situated down-gradient of existing waste body footprints.

Table 12-4 Summary of model stress-periods.

Stress period	Description
1966 -2025	Operational phase
2026 - 2076	50-Years Post-closure phase
2077-2126	100-Years Post-closure phase

12.6.2. Scenario 01: Baseline pre-mining conditions

Scenario 01 simulated the site baseline and pre-mining conditions. Table 12-5 summarises the groundwater catchment water balance representing steady state conditions. Recharge is assumed the only source of inflow to the system and has been simulated at $2.235E^{+04}m^3/d$, while the largest loss to the groundwater system is via baseflow, $2.234E^{+04}m^3/d$. Water removed from storage accounts to $7.819E^{+00}$ while water captured as storage accounts to $1.00E^{+00}$. Imbalance ignoring internal transfers equates to $8.20E^{+04}m^3/d$.

Table 12-5 Catchment water balance: Scenario 01 – Baseline pre-mining conditions.

Scenario 01 – Catchment water balance: Steady state baseline			
Parameter	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge (m^3/d)	2.235E+04	0.000E+00	2.235E+04
Dirichlet BC's discharging as baseflow (m^3/d)	0.000E+00	2.234E+04	-2.234E+04
Storage Capture(-)/Release(+)(m3/d)	1.000E+00	7.819E+00	-6.819E+00
Imbalance (m^3/d)	8.200E-01	0.000E+00	8.200E-01
Total (m^3/d)	**2.235E+04**	**2.235E+04**	**0.000E+00**

12.7. Numerical mass transport model

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

Equation 12-3 Advection-dispersion.

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

where:

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

n = porosity of saturated zone;

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

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

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

$n\rho\Gamma$ = mass of pollutant added to the water (or leaving it) as a result of chemical interactions among species inside the water, or by various decay phenomena[12];

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

p = density of pollutant;

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

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

Advection and hydrodynamic dispersion are the major processes controlling transport through a porous

[12] 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.

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 tools 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.

The calibrated groundwater flow model was used as basis to perform the solute/mass transport scenarios. Total Dissolved Solids (TDS) was applied as the proxy source with source term assumptions based on existing hydrochemical analysis. Monitoring boreholes situated in close proximity to the waste body footprints suggest a salt load of approximately 2000mg/l. Model domain background values were interpreted from the hydrochemical data analysis as gathered during the hydrocensus user survey and assigned as ~ 450.0 mg/l.

12.7.1. Scenario 02: TDS pollution plume migration within the host aquifer for the operational phase(s) without implementation of mitigation or management measures.

This scenario simulated a TDS pollution plume for the existing ash dumps for the operational phase(s) without implementation of mitigation and/or management measures. Figure 12-23 depicts a model cross section of the pollution plume migration within the aquifer and it is evident that the mass transport of the pollution plume is mostly limited to the shallow, intergranular aquifer, however, does migrate to the deeper, fractured aquifer as well. Figure 12-24 shows the simulated particle tracking and expected flow pathways of contaminants within the shallow, intergranular aquifer originating from potential pollution sources for the operational phase. The dominant pollution plume migration is towards the west and northwest.

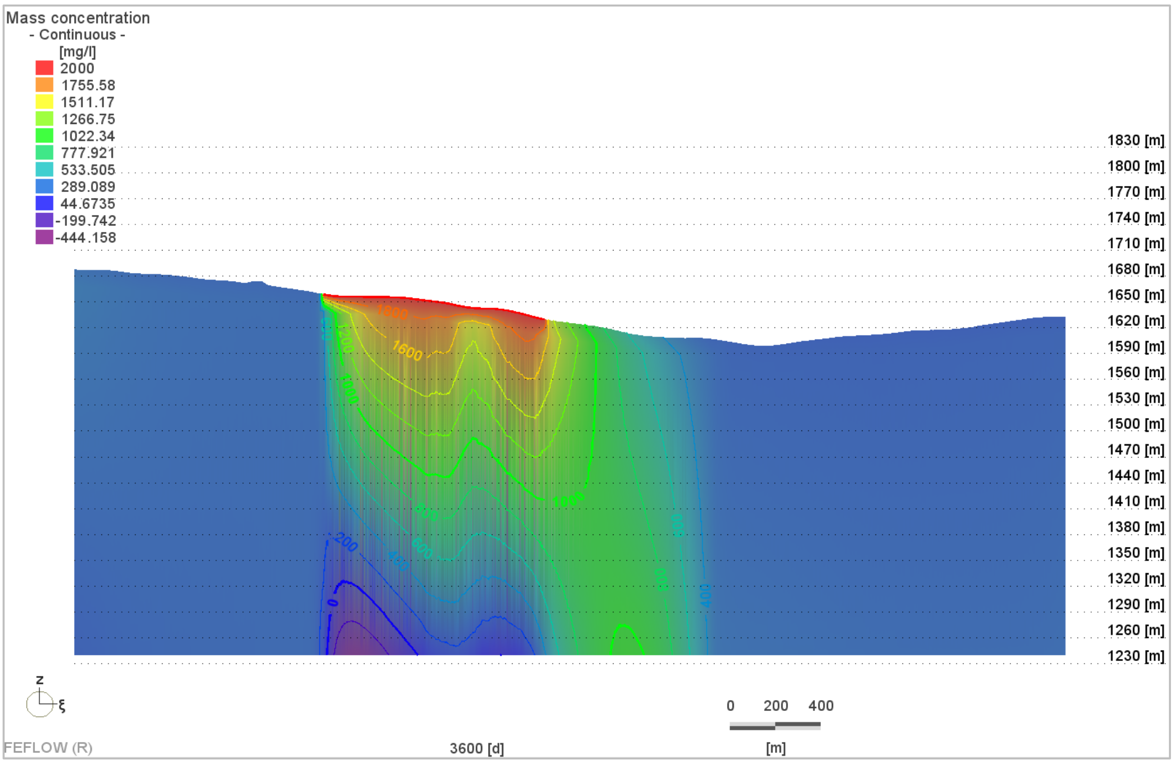


Figure 12-23 **Scenario04: Cross sectional view of the simulated sulphate pollution plume for the operational phase (A-A').**

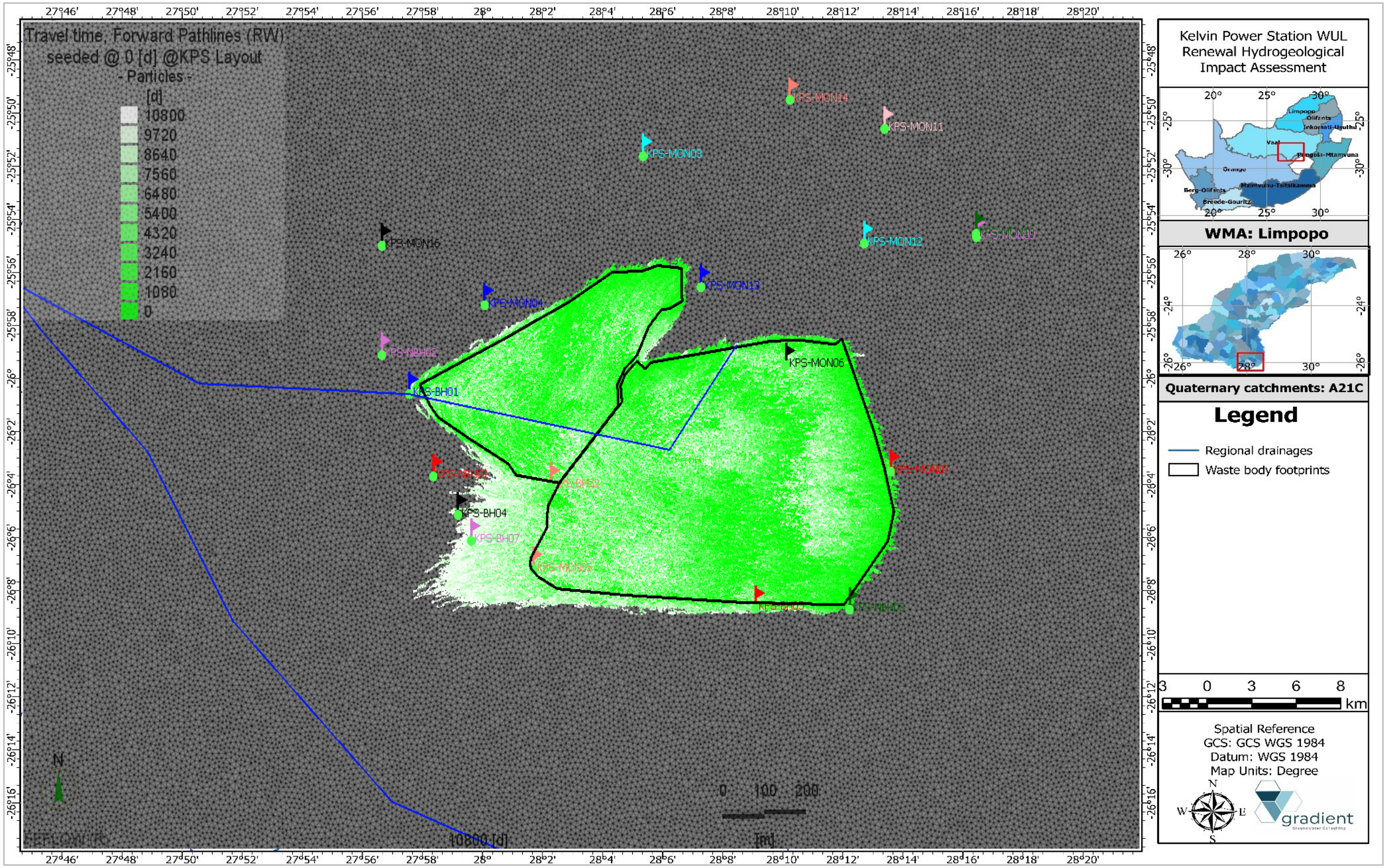


Figure 12-24 **Scenario02: Simulated particle tracking of contaminants within the shallow, intergranular aquifer originating from waste footprints for the operatinal phase.**

The simulated pollution plume extent covers a total area of approximately 1.05km^2 reaching a maximum distance of ~650.0m migrating in a general southwestern direction from where it propagates northwest following the lower laying drainage system of the Modderfonteinspruit. Potential receptors include monitoring boreholes situated down-gradient from the source as well as the Modderfonteinspruit and associated riparian zone. It is noted that no private owned boreholes are impacted on.

Figure 12-25 indicate a time-series graph of the TDS mass load contribution to down-gradient borehole receptors within the intergranular aquifer host for the operational period. It can be observed that the TDS mass load contribution to all the observation boreholes breaks through the SANS 241:2015 threshold after a simulation period of approximately 5-10 years increasing steadily to a maximum concentration of between ~1100.0 to 1550.0mg/l.

As mentioned, it is also noted that the simulated pollution plume reaches the riparian zone of the Modderfonteinspruit. Figure 12-26 summarises a time-series graph of the mass load contribution to down-gradient receptors i.e., wetland and associated drainage system. The simulated TDS mass load contribution to this receptor reaches a steady sate concentration of approximately 980.0mg/l after a simulation period of ~12 years, however remains below the SANS 241:2015 limit for the operational phase. Figure 12-27 depicts various phases of the simulated TDS pollution plume migration within the host, emanating from the exiting ash dump footprints while Figure 12-28 shows the current TDS pollution plume (2025).

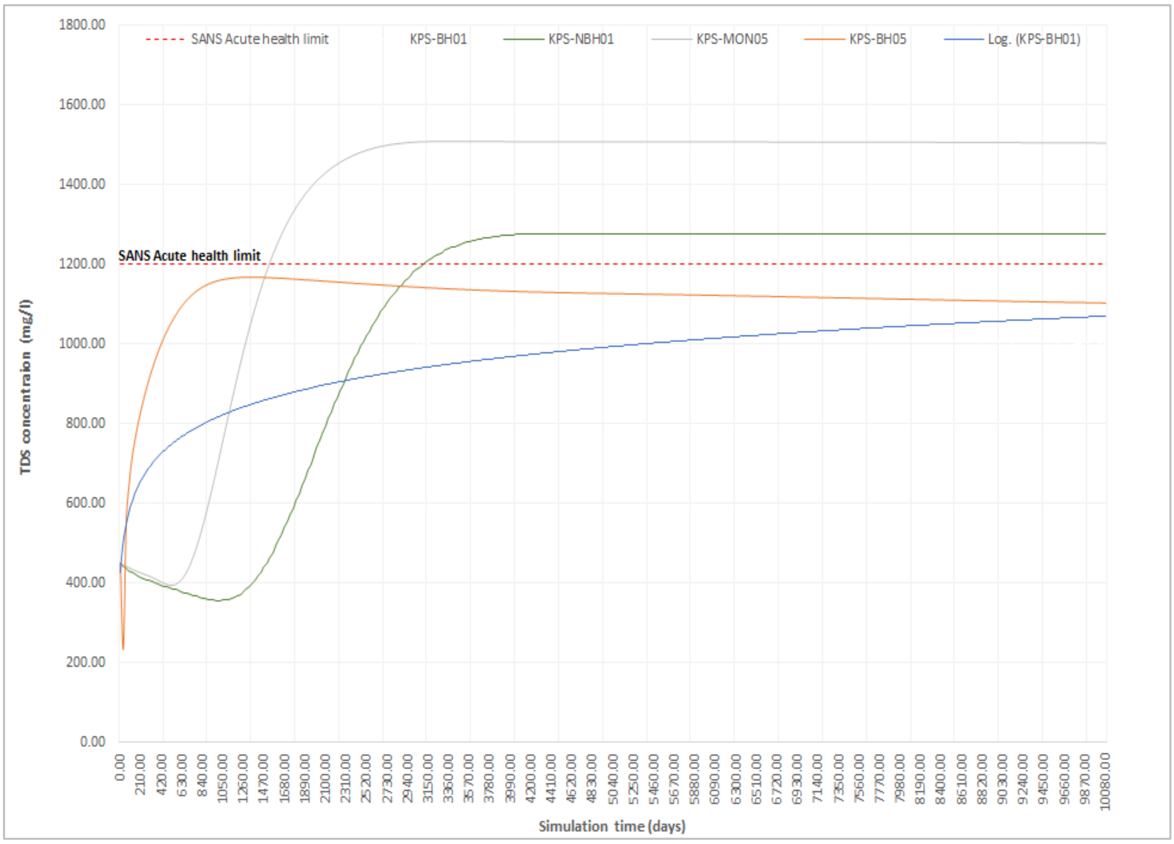


Figure 12-25 **Scenario 02: Time-series graph indicating the TDS mass load contribution to down-gradient borehole receptors within the intergranular aquifer host during the operational phase.**

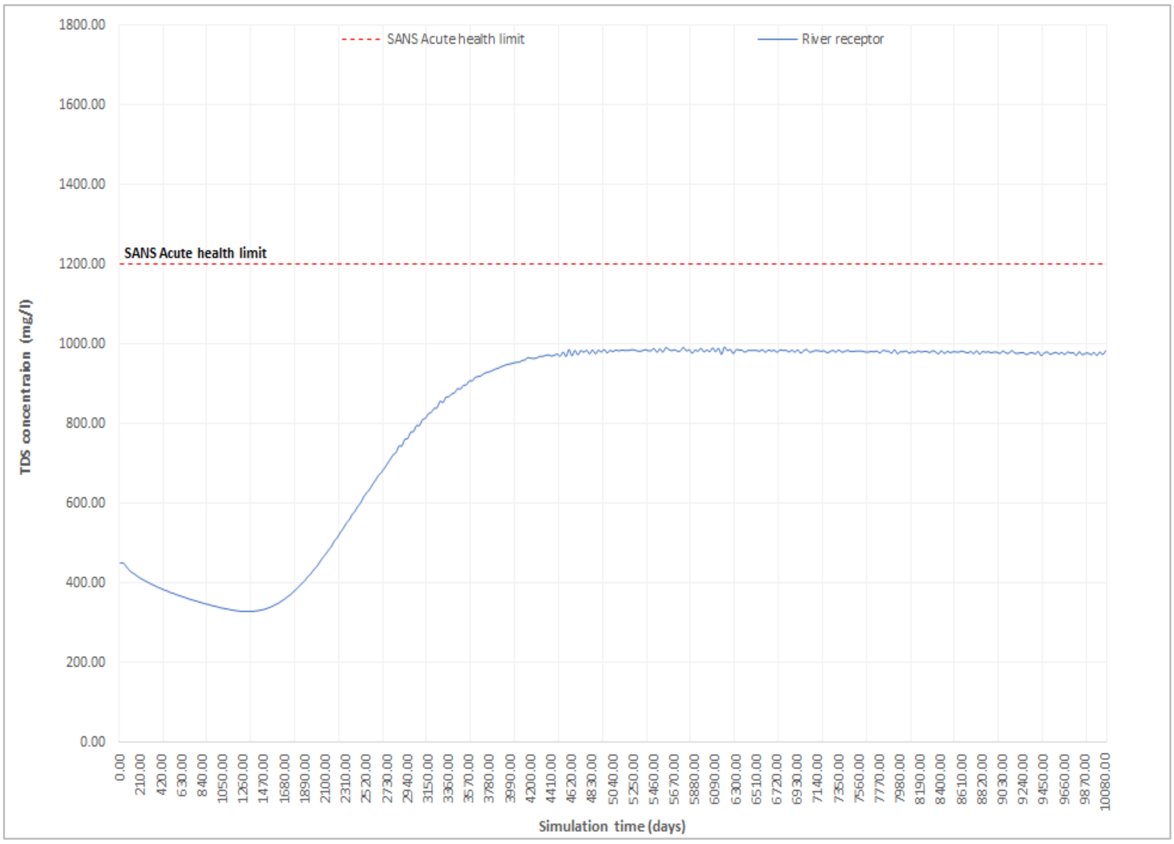


Figure 12-26 **Scenario 02: Time-series graph indicating the TDS mass load contribution of opencast footprints to down-gradient wetland receptors within the intergranular aquifer host during the operational phase.**

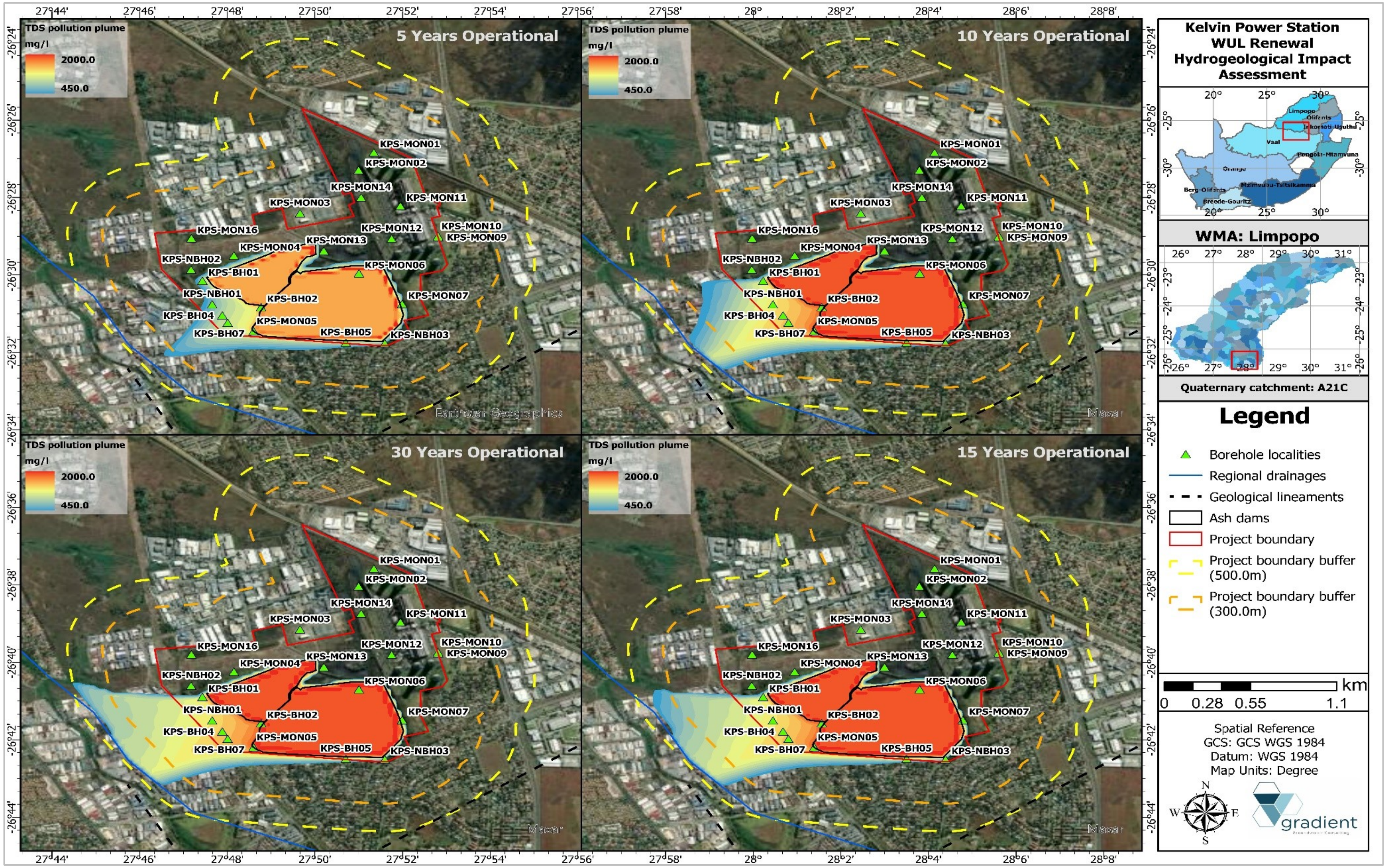


Figure 12-27 **Scenario 02: TDS pollution plume migration within the host aquifer for various stages during the operational phase.**

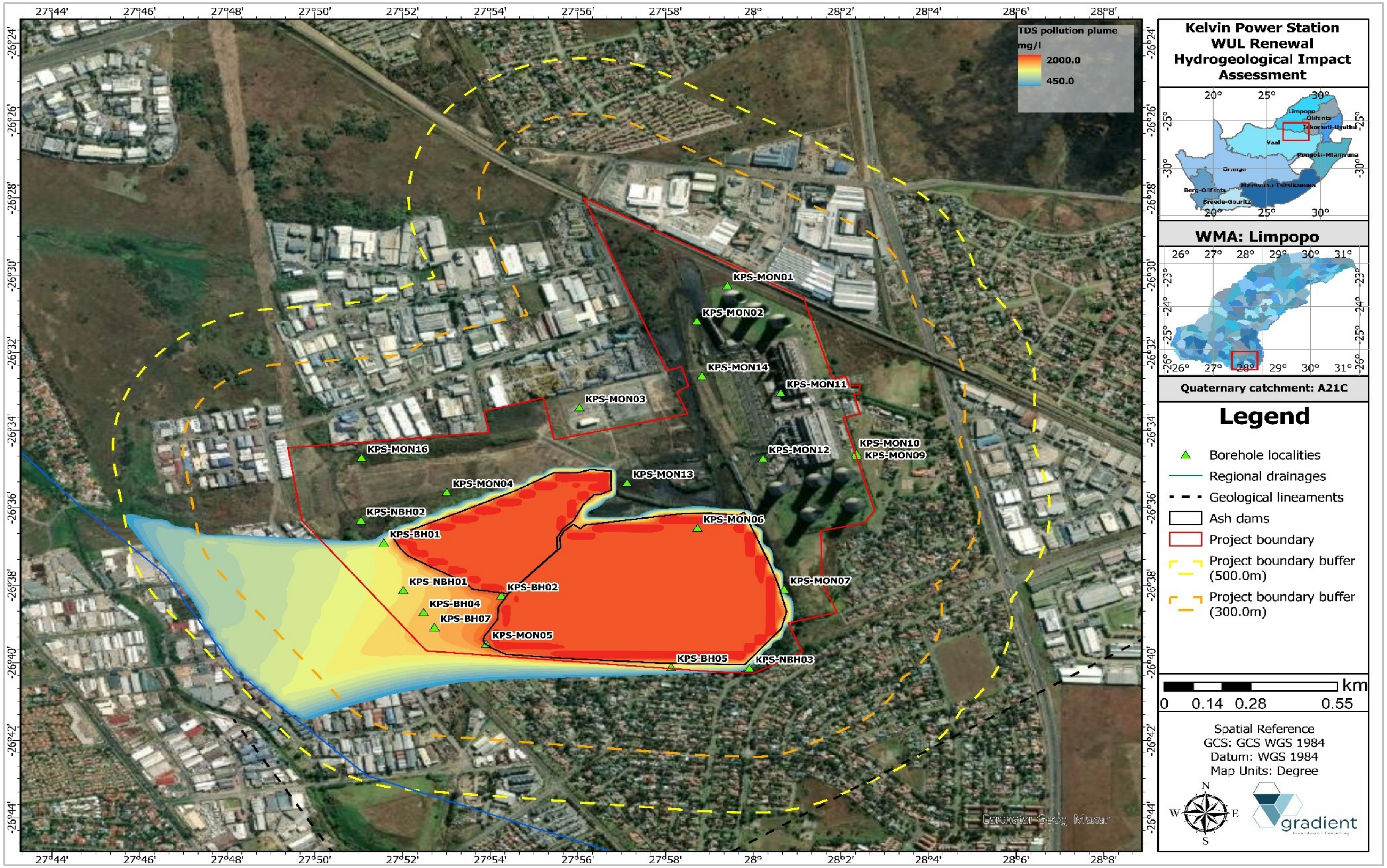


Figure 12-28 **Scenario 02: TDS pollution plume migration within the host aquifer for the operational phase (Current plume).**

12.7.2. Scenario 03: TDS pollution plume migration within the host aquifer for the post-closure phase(s) without implementation of mitigation or management measures

A post-closure scenario was simulated to evaluate the TDS pollution plume migration within the intergranular aquifer host after discontinuing of mining activities. The 50-year simulation period suggest that the pollution plume extent covers a total area of approximately 1.25km^2, reaching a maximum distance of ~750.0m in a general northwestern direction towards the lower laying drainage systems. The 100-year simulation period indicate that the pollution plume extent covers a total footprint of approximately 1.35km^2, reaching a maximum distance of ~950.0m in a general northwestern direction towards the lower laying drainage systems. Potential receptors include monitoring boreholes situated down-gradient from the source as well as the Modderfonteinspruit and associated riparian zone. It is noted that no private owned boreholes are impacted on.

Figure 12-29 indicate a time-series graph of the TDS mass load contribution to down-gradient borehole receptors within the intergranular aquifer host for the post-closure phase. It can be observed that the TDS mass load contribution to all the observation boreholes remains relatively constant at concentration of between 950.0 to 1250.0mg/l for the duration of the simulation.

Figure 12-30 shows the simulated particle tracking and expected flow pathways of contaminants within the shallow, intergranular aquifer originating from potential pollution sources for the post-closure phase. Figure 12-31 depicts various phases of the simulated TDS pollution plume migration within the host, emanating from the exiting ash dump footprints.

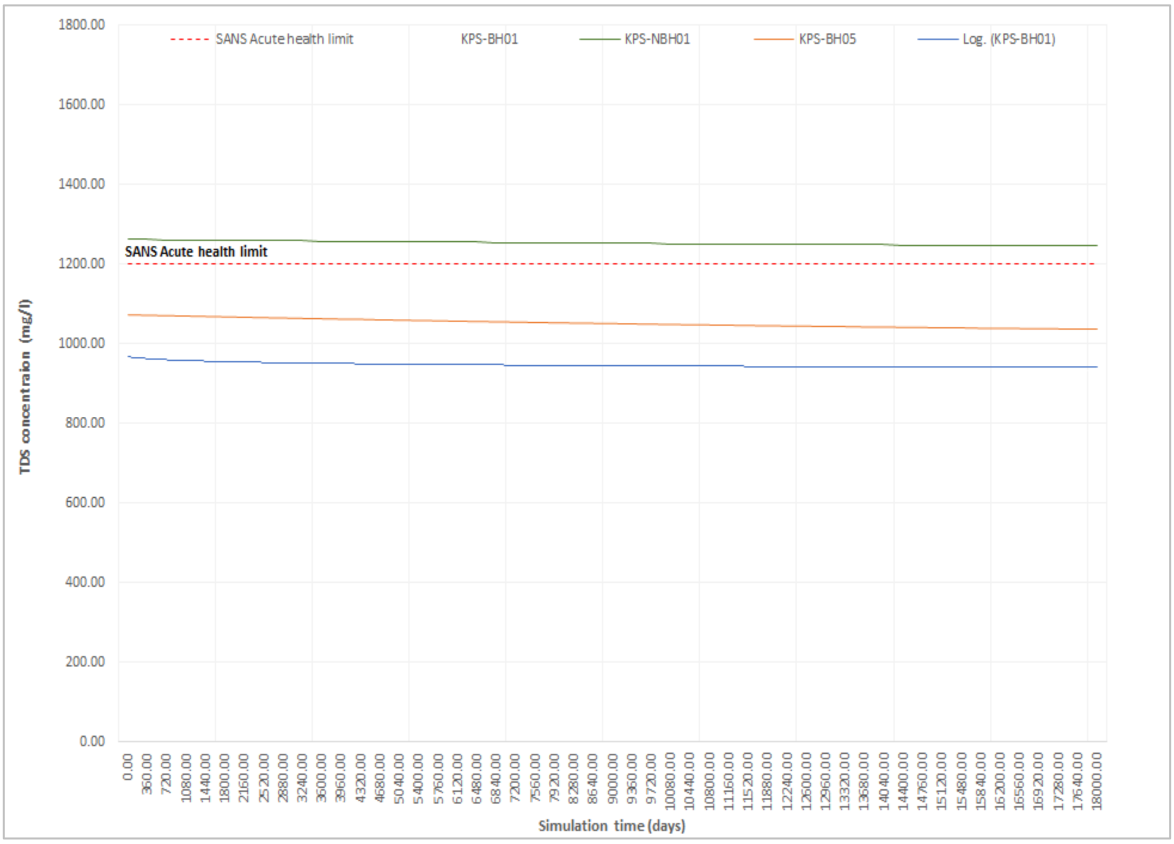


Figure 12-29 Scenario 03: Time-series graph indicating post-closure mass load contribution to borehole receptors.

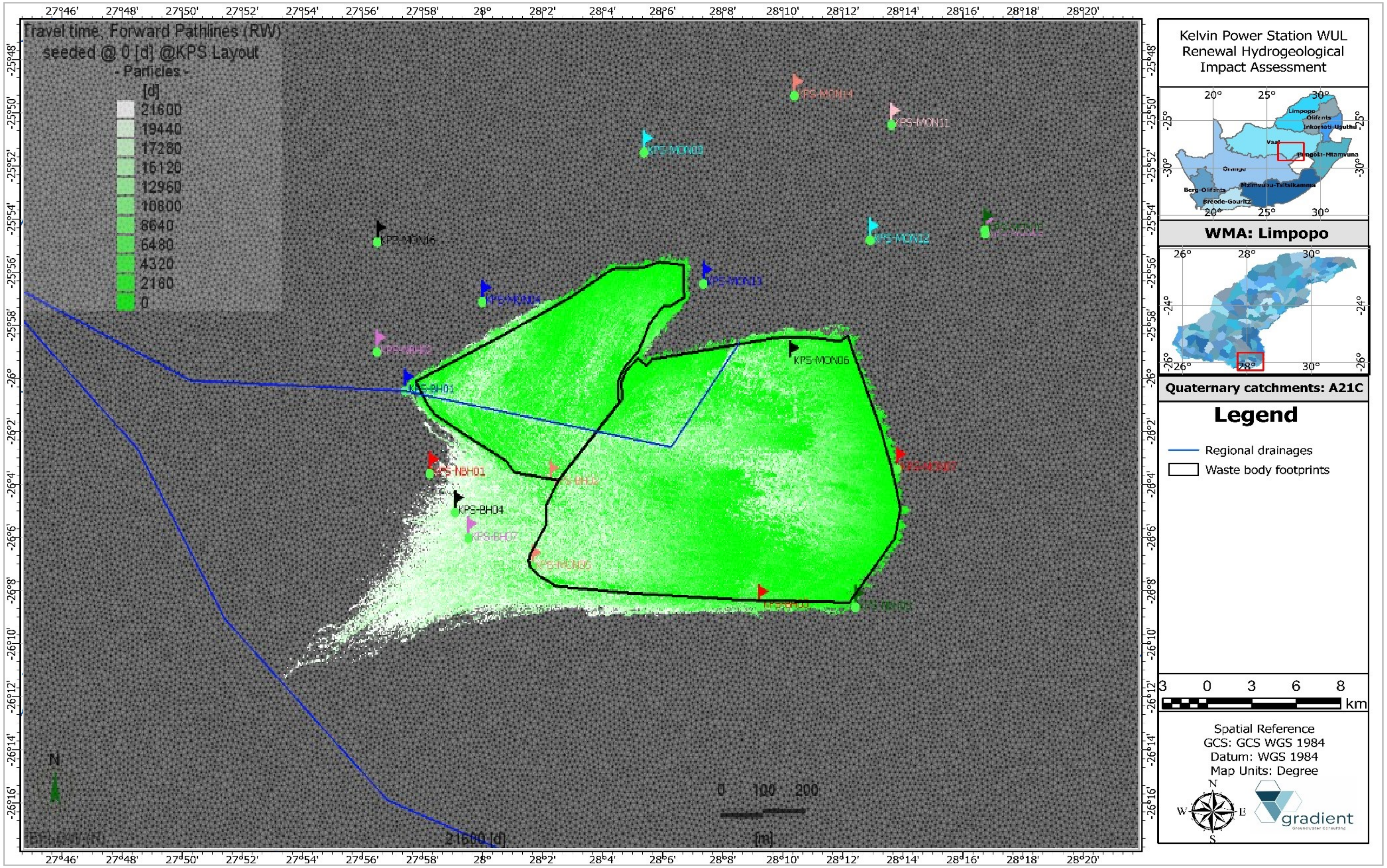


Figure 12-30 **Scenario 03: Simulated particle tracking of contaminants within the shallow, intergranular aquifer originating from waste footprints for the post-closure phase.**

Figure 12-31 **Scenario 03: TDS pollution plume migration within the intergranular aquifer for the post-closure phase(s).**

12.7.3. Scenario 04: Mitigation and management

Two alternative management and mitigation scenarios which include active as well as passive water management strategies were simulated to evaluate the remedial options available. Table 12-6 provides a summary of the mitigatory effect and effectiveness of proposed management alternatives on the pollution plume migration while Figure 12-32 shows a time-series graph indicating mass load contribution on down-gradient receptors (Pre-mitigation vs Post-mitigation scenarios).

12.7.4. Scenario 04a: Implementation of a series of seepage capturing boreholes down-gradient of existing waste body footprints

An active management scenario evaluating the mitigating effect of establishment of a series of seepage capturing or scavenger boreholes situated down-gradient of the existing waste body footprints simulated as depicted in Figure 12-33. Due to the negative hydraulic gradient formed locally at each seepage capturing borehole, the gradient curtain constrains the propagation of the pollution plume and effectively reduce the footprint by ~35.0% to ~0.65km^2. Intercepted groundwater volumes expected is approximately 151.20m^3/d and will be a function of the borehole yields. Water intercepted may be re-introduced into the contact water circuit for reuse in the mining process. It is recommended that newly established seepage capturing boreholes be subjected to constant discharge pump tests in order to determine borehole safe yields and optimal abstraction duty cycles.

12.7.5. Scenario 04b: Implementation of a cut-off/ fracturing trench down-gradient of existing waste body footprints

An active management scenario evaluating the mitigating effect of a sub-surface cut-off trench/fracturing curtain[13] on the plume migration was simulated as depicted in Figure 12-34 and Figure 12-35. Due to shallow groundwater levels i.e., relatively thin vadose zone, this mitigation alternative will intercept adequate water to create a negative gradient within these zones, effectively constraining the plume migration reducing its footprint by ~25.0% to ~0.75km^2. Intercepted groundwater volumes expected is approximately 143.81m^3/d and will be a function of the depth of the proposed cut-off trench. Water intercepted may be re-introduced into the contact water circuit for reuse in the mining process. Based on the constraining effects of these mitigation scenarios on the pollution plume migration, both alternatives can be viewed as the remedial options for implementation. It can be noted that a collective approach can also be evaluated combining these alternatives for a cumulative impact.

Table 12-6 Scenario 04: Effectiveness of mitigation and management alternatives on pollution plume areas.

Mitigation and management scenarios	Combined plume area (pre-mitigation)(km^2)	Combined plume area (post-mitigation)(km^2)	Improvement (%)	Intercepted contact water volume (m^3/d)
Scenario 04a: Implementation of a series of seepage capturing boreholes down-gradient of existing waste body footprints	1.00	0.65	35.00	151.20
Scenario 04b: Implementation of a cut-off/ fracturing trench down-gradient of existing waste body footprints	1.00	0.75	25.00	143.81

[13] A boundary condition with seepage faces equal to elevation – 5mbgl has been simulated for this scenario, however effectiveness of this mitigation measures will be dependent on the practical implementation on site.

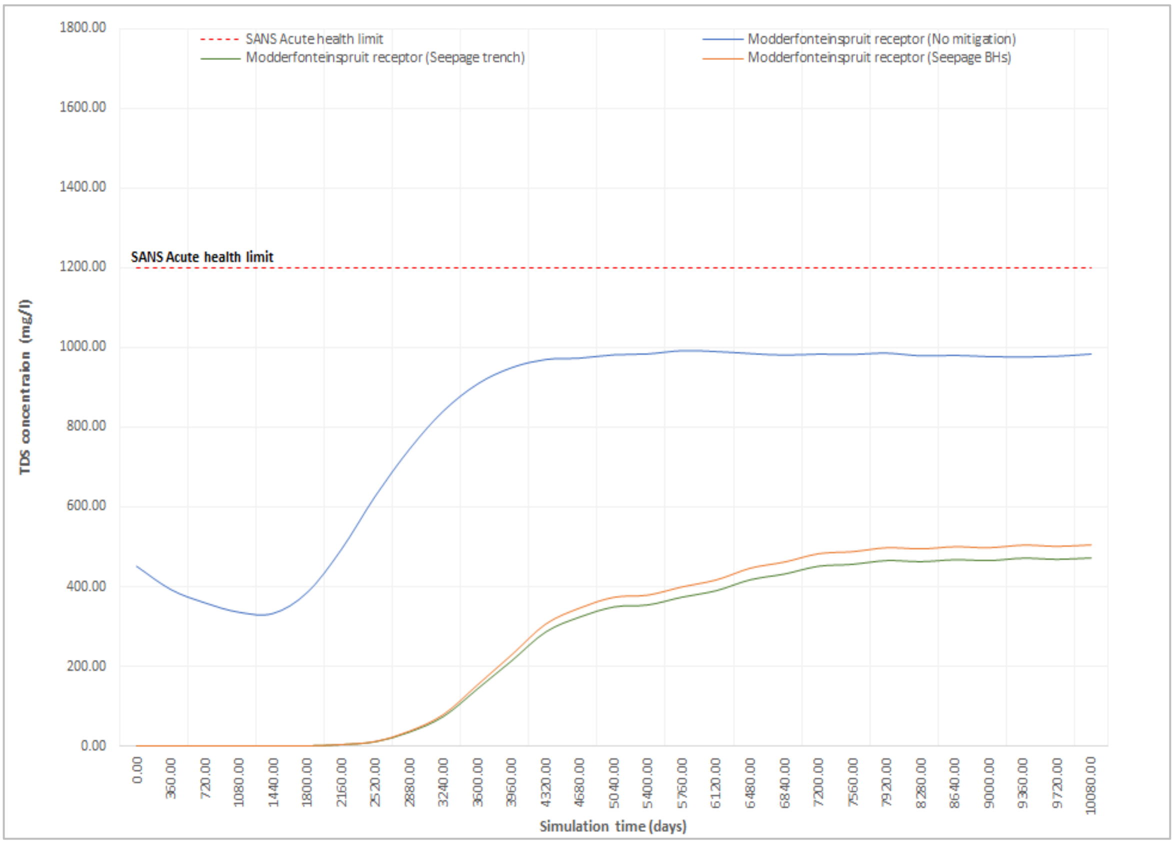


Figure 12-32 **Scenario 04: Time-series graph indicating TDS mass load contribution on down-gradient receptors (Pre-mitigation vs Post-mitigation scenarios).**

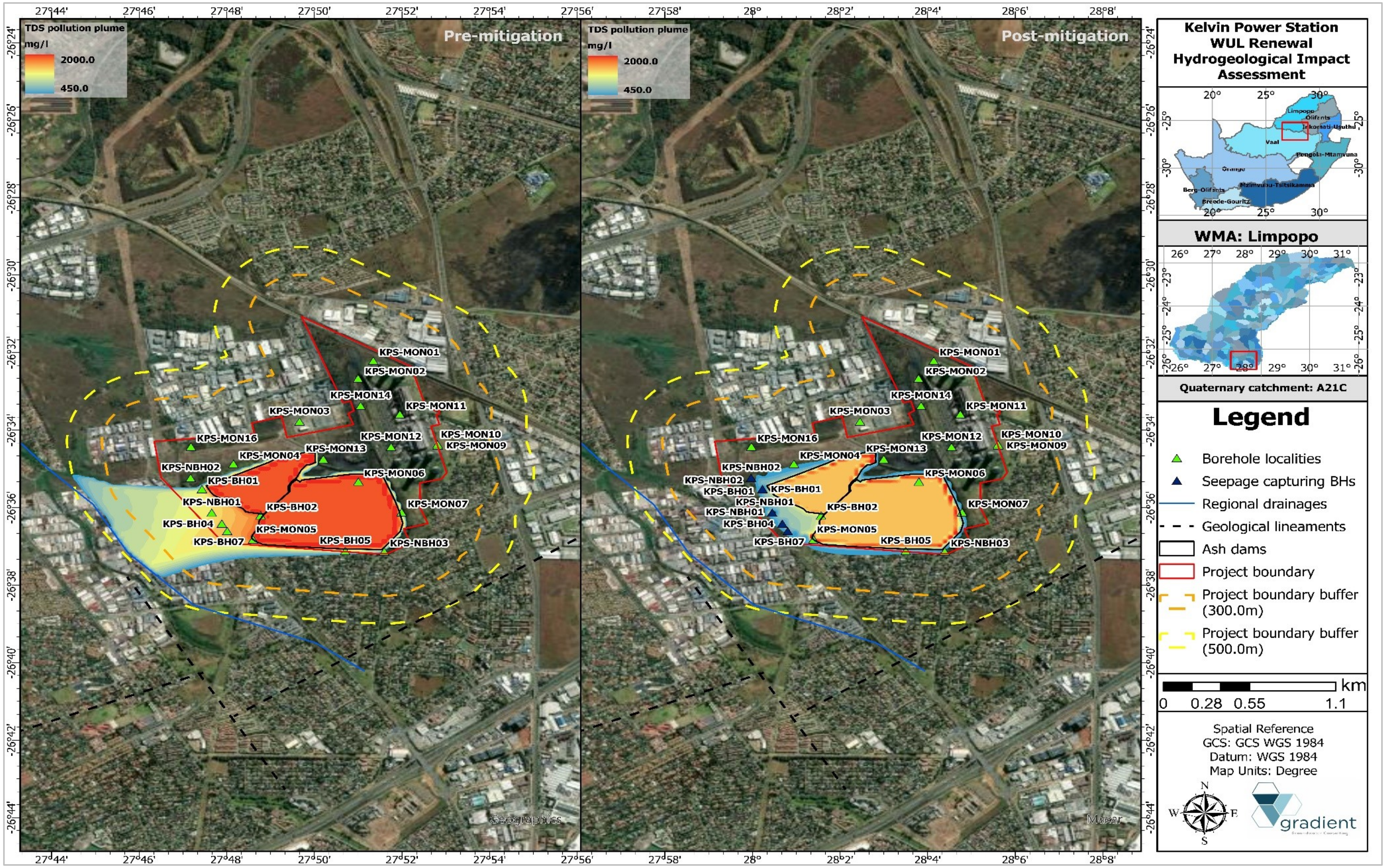


Figure 12-33 **Scenario 04a: Mitigation and management- Implementation of seepage capturing boreholes down-gradient of existing infrastructure.**

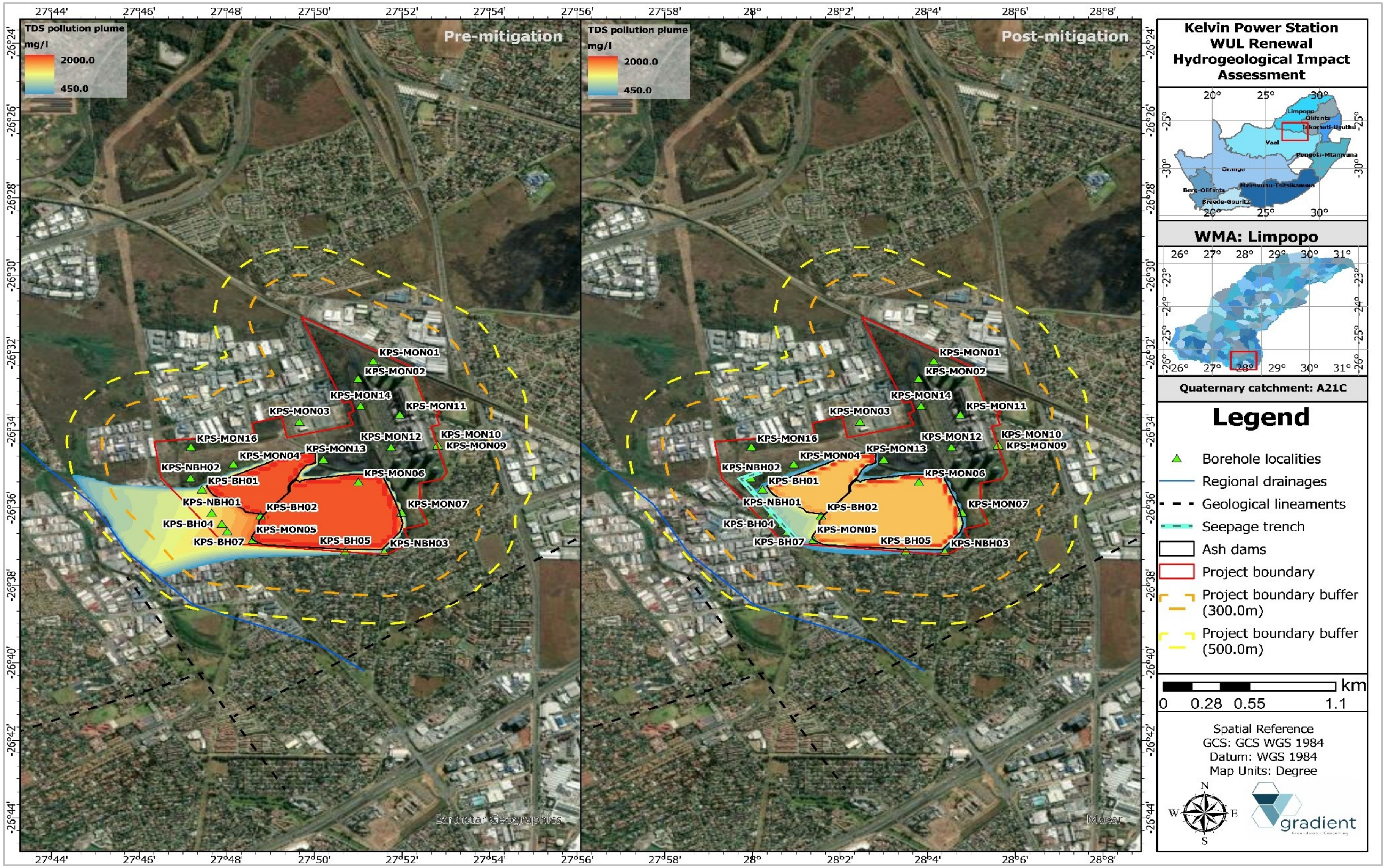


Figure 12-34 **Scenario 04b: Mitigation and management- Implementation of a cut-off/ fracturing trench down-gradient of existing infrastructure.**

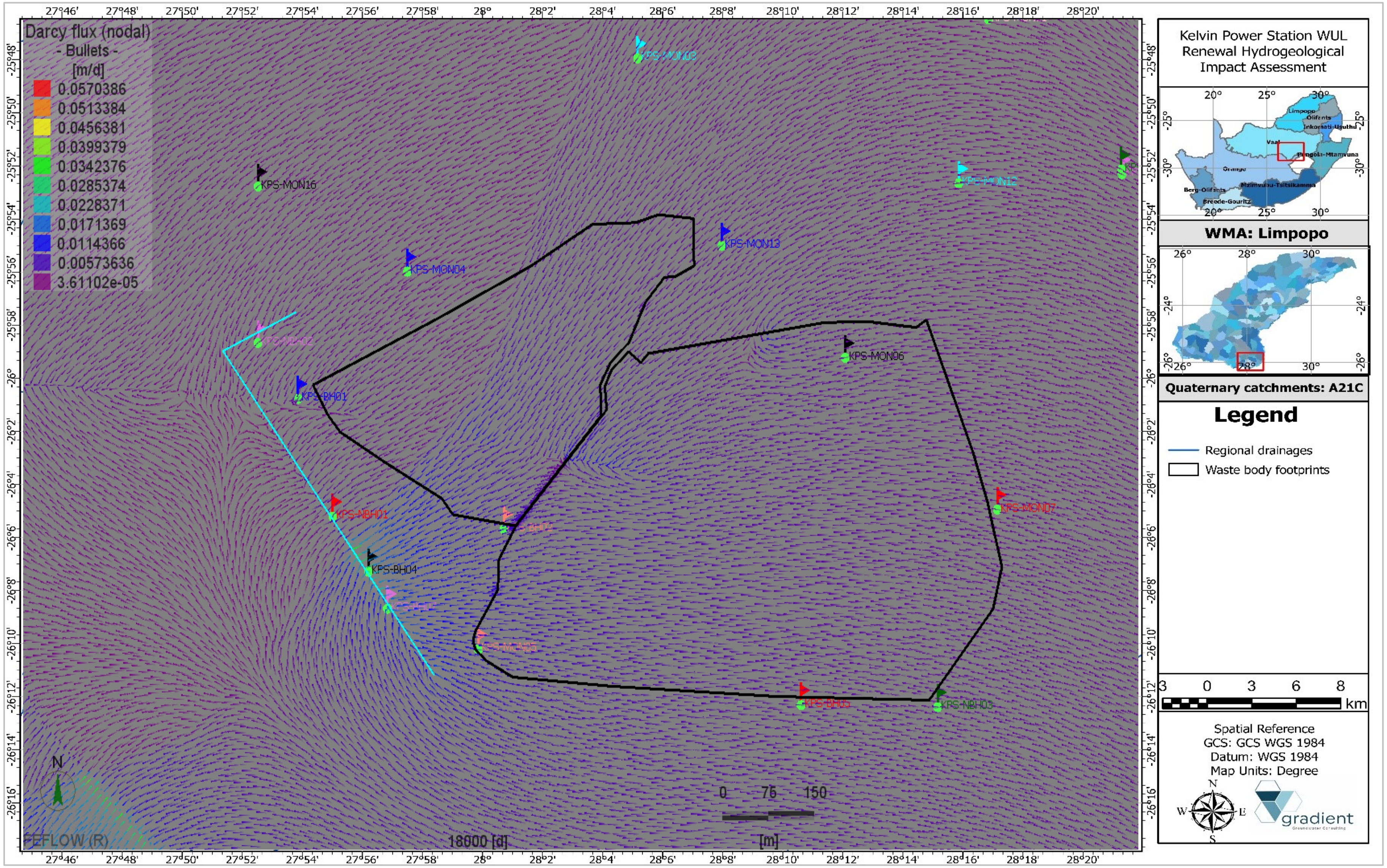


Figure 12-35 **Scenario 04b: Map indicating the Darcy flow-vectors in the vicinity of the porposed seepage trench.**

13. ENVIRONMENTAL IMPACT ASSESSMENT

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

13.1. 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.

13.2. 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 13-1 Impact Consequence.

$$\mathbf{C} = \ (\boldsymbol{E} + \boldsymbol{D} + \boldsymbol{M} + +\boldsymbol{R})(\boldsymbol{N}\mathbf{4})$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 13-1 below with Table 13-2 summarising the probability scorings.

Table 13-1 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 13-2 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 13-2 Impact Consequence.

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

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25 as summarised in Table 13-4. These **ER** scores are then grouped into respective classes as described in Table 13-4.

Table 13-3 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 13-4 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.

13.3. 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 13-5.

Table 13-5 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 13-3 Impact Consequence.

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

The result is a priority score which ranges from 3 to 9 and a consequent **PF** ranging from 1 to 2 (Refer to Table 13-6 below).

Table 13-6 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 13-7), 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 13-7 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.

13.4. Impact Identification and significance ratings

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

13.4.1. Construction phase: Associated activities and impacts

As this is an existing development with no new construction activities planned, potential impacts associated with the construction phase activities will not be discussed.

13.4.2. Operational phase: Associated activities and impacts

The main operational activities include disposal of waste material, wastewater management and associated infrastructure as well as discharging of wastewater to the local drainage system.

During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as **insignificant** as no groundwater will be removed from storage via dewatering or abstraction. Groundwater quality impacts from existing waste body footprints and associated infrastructure are rated as **high** negative without implementation of remedial measures and **medium to low** negative with implementation of mitigation measures (Refer to Table 13-8). The main impacts associated with operational phase activities include the following:

i. Poor quality leachate may emanate from existing ash dumps, waste-water management infrastructure as well as the plant area which may have a negative impact on groundwater and surface water quality.

ii. Dust suppression with poor quality water, obtained from mine dirty water containment facilities, may potentially have a detrimental impact on groundwater and surface water quality.

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

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

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

vi. Groundwater pollution as a result of wastewater spills and seepage from the de-siltation ponds and return water dams.

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

The main post-closure activities include rehabilitation and decommissioning of related infrastructure. During the post-closure phase, the environmental significance rating of groundwater quantity impacts on down-gradient receptors remains **insignificant** as not water will be removed from storage**.** Groundwater quality impacts from mining footprints are rated as **high** negative without implementation of remedial measures and **medium to low** negative with implementation of mitigation measures (refer to Table 13-9). The main impacts associated with post-operational phase activities include the following:

i. Poor quality leachate may emanate from existing ash dumps, waste-water management infrastructure as well as the plant area which may have a negative impact on groundwater and surface water quality.

ii. Rehabilitation and decommissioning of related infrastructure may have a negative impact on groundwater and surface water quality.

iii. Dust suppression with poor quality water, obtained from mine dirty water containment facilities, may potentially have a detrimental impact on groundwater and surface water quality.

iv. De-mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.

Table 13-8 Impact significance rating: Operational phase.

Impact	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance S	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
Poor quality leachate may emanate from existing ash dumps, waste-water management infrastructure as well as the plant area which may have a negative impact on groundwater and surface water quality	Operation		1	3	4	4	4	3.8	4	15	High +	1	2	3	3	3		3	8.25	Low to medium +	Medium	1	2	1.13	9.28	Medium to high +
Mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.	Operation		1	2	3	4	4	3.3	4	13	Medium to high +	1	1	3	3	3		3	7.5	Low to medium +	Medium	1	2	1.13	8.44	Medium to low +
Surface and groundwater deterioration and siltation due to contaminated stormwater run-off.	Operation		1	2	3	3	4	3	3	9	Medium to high +	1	1	2	3	3		3	6.75	Low to medium +	Medium	1	2	1.13	7.59	Medium to low +
Groundwater pollution as a result of wastewater spills and seepage from the de-siltation ponds and return water dams.	Operation		1	2	3	3	4	3	3	9	Medium to high +	1	1	3	3	3		3	7.5	Low to medium +	Medium	1	2	1.13	8.44	Medium to low +

Table 13-9 Impact significance rating: Post-closure and decommissioning phase.

Impact	Phase	Event	Pre-Nature	Pre-Extent	Pre-Duration	Pre-Magnitude	Pre-Reversibility	Consequence	Pre-Probability	Pre-Mitigation Significance S	Pre-Mitigation Significance	Post-Nature	Post-Extent	Post-Duration	Post-Magnitude	Post-Reversibility	Consequence2	Post-Probability	Post-mitigation Significance	Post-Mitigation Significance	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score	Final Significance
Poor quality leachate may emanate from existing ash dumps, waste-water management infrastructure as well as the plant area which may have a negative impact on groundwater and surface water quality	Decommissi		1	3	4	4	3	3.5	4	14	High +	1	2	3	2	3		3	7.5	Low to medium +	Medium	1	2	1.13	8.44	Medium to low +
Rehabilitation and decommissioning of related infrastructure may have a negative impact on groundwater and surface water quality.	Decommissi		1	3	4	4	3	3.5	4	14	High +	1	2	3	2	2		3	6.75	Low to medium +	Medium	1	2	1.13	7.59	Medium to low +
De-mobilisation and maintenance of heavy vehicle and machinery on-site may cause hydrocarbon contamination of surface water and groundwater resources.	Decommissi		1	2	3	3	4	3	4	12	Medium to high +	1	1	3	2	3		3	6.75	Low to medium +	Medium	1	2	1.13	7.59	Medium to low +

14. 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 operational and decommissioning/ post-closure phases of the project.

14.1. Potential impacts and associated risks

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

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

14.2. Key responsibilities

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

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

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

14.3. Mitigation and management

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

14.3.1. Construction phase: Management and mitigation measures

As this is an existing development with no new construction activities planned, potential impacts associated with the construction phase activities will not be discussed.

14.3.2. Operational phase: Management and mitigation measures

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

i. Development and implementation of an integrated groundwater monitoring program evaluating hydrochemistry as well as water levels will serve as early warning mechanism to implement mitigation measures such as down-gradient of the mining infrastructure in order to constrain the contamination plume migration as well as manage related impacts. It should be noted that the applicant do have an existing monitoring network and programme in place, however it is recommended that a revised monitoring network, as discussed under Section 15 of this report, should be implemented.

ii. Waste classification and assessment of all potential waste material handled and disposed of on-site have been determined. Accordingly, all waste material should be handled and disposed of based on the Safety Data Sheets (SDSs) for the respective waste streams with information on the potential hazards, emergency response, protective measures and correct storage methodology.

iii. Down-gradient seepage capturing alternatives i.e., establishment of seepage capturing cut-off trenches or establishment of scavenger boreholes should be implemented as active waste-water management techniques in order to constrain the migration of pollution plumes emanating from pollution sources during the post-closure phase.

iv. Intercepted contact water should be treated to acceptable water quality standards and re-introduced to the catchment water balance.

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

vi. Heavy vehicles and machinery must be serviced and maintained regularly in order to ensure that oil spillages are limited. Spill trays must be provided if refuelling of operational vehicles is done on site. Further to this spill kits must be readily available in case of accidental spillages with regular spot checks to be conducted.

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

viii. Develop and implement a stormwater management plan in accordance with GN704 in order to separate dirty/contact water from clean water circuits. All water retention structures, process water dams; storm water dams, retention ponds etc. should be maintained to have adequate freeboard (0.8m below overflow level) to be able to contain water from 1:50 year rain events.

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

x. 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.

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

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

i. It is important to development and implement a post-closure groundwater monitoring program to assess the regional groundwater level rebound as well as pollution plume propagation to serve as early warning mechanism to implement mitigation measures. Should neighbouring boreholes remain affected, necessary actions such as provision of alternative water supply and/or compensation should be taken to ensure continual water supply. It should be noted that, currently no neighbouring boreholes were identified as being impacted on.

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

iii. Down-gradient seepage capturing alternatives i.e., establishment of seepage capturing cut-off trenches or establishment of scavenger boreholes should be implemented as active waste-water management techniques in order to constrain the migration of pollution plumes emanating from pollution sources during the post-closure phase.

iv. Intercepted contact water should be treated to acceptable water quality standards and re-introduced to the catchment water balance.

v. 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.

15. 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 **Error! Reference source not found.** is used as guideline for the development of this water monitoring program.

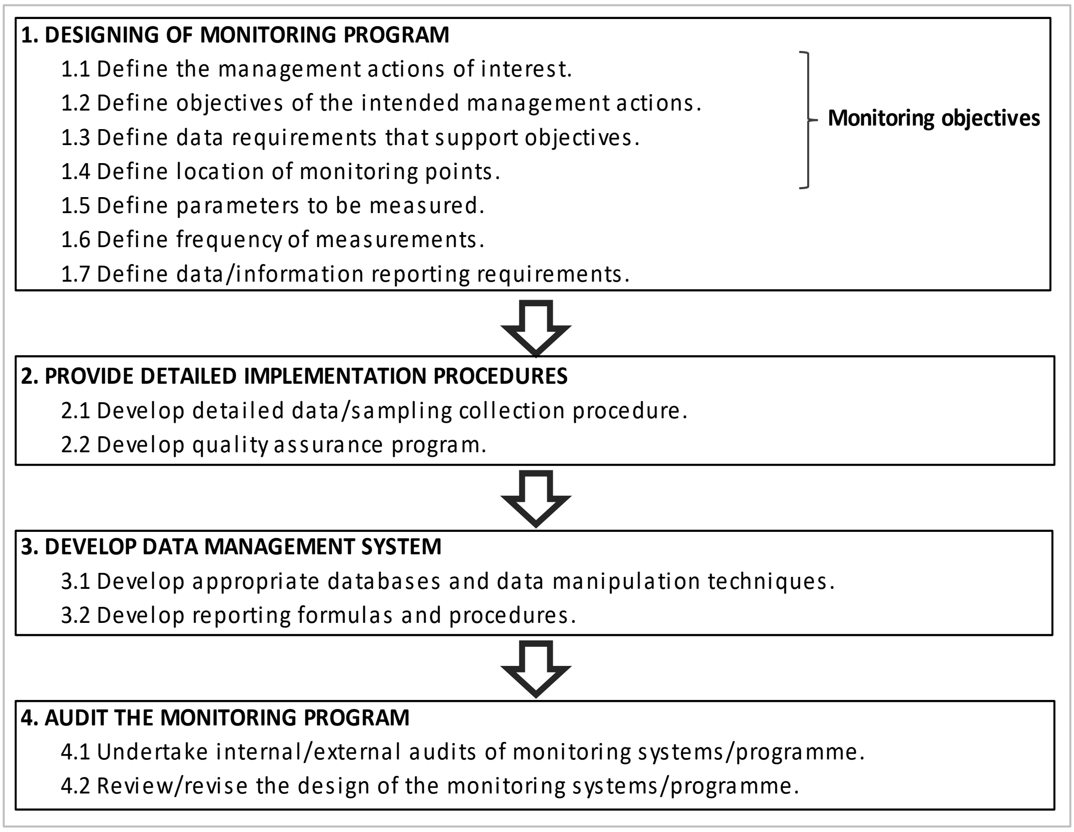


Figure 15-1 Monitoring programme (DWA, 2006).

15.1. Monitoring Objectives

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

i. To provide reliable groundwater data that can be used for management purposes.

ii. The early detection of changes in groundwater quality and quantity.

iii. Provide an on-going performance record on the efficiency of the Water Management Plan.

iv. Obtain information that can be used to redirect and refocus the Water Management Plan.

v. Determine compliance with environmental laws, standards and the water use licence and other environmental authorizations.

15.2. Monitoring network

It should be noted that the applicant is operating under an approved WUL with monitoring a condition of the existing licence. Accordingly, Kelvin Power (Pty) Ltd does currently have an existing monitoring program and network which is being honoured.

It is noted that some monitoring boreholes have been demolished and should be re-incorporated into the existing monitoring network by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms. Depending on the outcome of the geophysical survey, proposed boreholes can be established as a pair in order to target the shallow, intergranular or primary porosity as well as fractured aquifer units should it be applicable. The revised monitoring network proposed, as summarised in Table 15-1 and depicted in Figure 15-2, serve to expand on the existing monitoring network a programme. Due to the close proximity of the waste body footprints to the Modderfonteinspruit drainage system, it is recommended that additional upstream and downstream surface water monitoring points be established in order to assess the potential impacts of the operation and activities on this sensitive environmental receptor.

15.3. Determinants for analysis

Baseline and background water quality results should be evaluated in order to set a site-specific limit per parameter and applied as benchmark for monitoring purposes. Supplementary guidelines i.e., Water Use Licence (WUL) conditions as well as WMA Resource Quality Objectives (RQO) should also be considered as part of the monitoring protocol. All monitoring localities should be subjected to an initial comprehensive water quality analysis to evaluate hydrochemical composition and identify potentially elevated parameters going forward[14]. Chemical variables to form part of the sampling run are listed below. Groundwater monitoring boreholes and spring localities 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), Cyanide (CN), Boron (B), Copper (Cu), Nickel (Ni), Lead (Pb), Cobalt (Co), Mercury (Hg) as well as Zinc (Zn).

15.4. Water levels

Water levels should be monitored in order to evaluate the impact, IF ANY, of the power generation development on aquifer storage and replenishment. It is important to note that the impact on the local and regional groundwater environment can only be determined accurately if comparisons are performed based on static water level conditions. Thus, all production borehole pumps should be switched off and water levels

[14] It is recommended that a comprehensive water quality analysis be repeated annually. Also note that should additional parameters be requested in existing permits/licence conditions, these should be adhered to.

should be allowed to recover prior to water level recordings.

15.5. Monitoring frequency

Groundwater monitoring i.e., quality analysis should be conducted on a quarterly basis whereas water level monitoring is conducted on a monthly basis. Water quality reports summarising monitoring results should be submitted to the Regional Head of the Department on a quarterly and annual basis.

15.6. 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 raising the bottle.
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. A unique sample number and description
    b. The date and time of sampling
    c. 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 15-1 Revised monitoring network and programme.

Monitoring locality	Latitude	Longitude	Locality description	Monitoring frequency		Parameters
				Water quality	Water level	
Existing monitoring boreholes (KPS-BH)						
KPS-BH01	-26.120128	28.182828	Borehole on Western Perimeter - Toe of Ash Dam	Quarterly	Monthly	As in Section 15.3
KPS-BH02	-26.121835	28.186184	Borehole on Southern Toe of Ash Dam	Quarterly	Monthly	
KPS-BH04	-26.122372	28.183966	Borehole on Western Perimeter	Quarterly	Monthly	
KPS-BH05	-26.124138	28.191035	Borehole on Southern Perimeter	Quarterly	Monthly	
KPS-BH06	-26.121860	28.183440	Borehole demolished. Recommended that replacement borehole be drilled	Quarterly	Monthly	
KPS-BH07	-26.122852	28.184274	Borehole on South Western Perimeter	Quarterly	Monthly	
Existing monitoring boreholes (KPS-MON)						
KPS-MON01	-26.111814	28.192642	Borehole on Northern Perimeter next to Coal Stockpile	Quarterly	Monthly	As in Section 15.3
KPS-MON02	-26.112960	28.191769	Borehole on Northern Perimeter South of Coal Stockpile	Quarterly	Monthly	
KPS-MON03	-26.115755	28.188415	Borehole North of Ash Dump - North Western Perimeter	Quarterly	Monthly	
KPS-MON04	-26.118493	28.184629	Borehole on Western Perimeter between the Ash Dump and Ash Dam	Quarterly	Monthly	
KPS-MON05	-26.123390	28.185756	Borehole on Southern Perimeter on southern toe of Ash Dam	Quarterly	Monthly	
KPS-MON06	-26.119647	28.191788	Between Ash Dam A and Southern Coal Stockpile	Quarterly	Monthly	
KPS-MON07	-26.121628	28.194263	Borehole South East of Southern Coal Stockpile	Quarterly	Monthly	
KPS-MON09	-26.117300	28.196333	Background borehole targeting the deep aquifer	Quarterly	Monthly	
KPS-MON10	-26.117236	28.196324	Background borehole targeting the shallow aquifer	Quarterly	Monthly	
KPS-MON11	-26.115280	28.194163	Fuel storage area	Quarterly	Monthly	
KPS-MON12	-26.117401	28.193660	HFO storage area	Quarterly	Monthly	
KPS-MON13	-26.118187	28.189777	Brick Yard	Quarterly	Monthly	
KPS-MON14	-26.114729	28.191912	Switch yard	Quarterly	Monthly	
KPS-MON16	-26.117377	28.182194	Clinker dump (replace KPS-MON03)	Quarterly	Monthly	
Existing monitoring boreholes (KPS NBH)						
KPS-NBH01	-26.121657	28.183386	Newly established monitoring borehole evaluating the impact on the confined & fractured aquifer	Quarterly	Monthly	As in Section 15.3
KPS-NBH02	-26.119402	28.182175	Newly established monitoring borehole evaluating the impact on the intergranular & unconfined aquifer	Quarterly	Monthly	
KPS-NBH03	-26.124178	28.193269	Newly established monitoring borehole evaluating the impact on the confined & fractured aquifer	Quarterly	Monthly	
Newly proposed surface water monitoring points						
KPS-US	-26.130645	28.183964	Newly established monitoring point representative of the Modderfonteinspruit upstream water quality.	Quarterly	Monthly	As in Section 15.3
KPS-DS	-26.118131	28.173001	Newly established monitoring point representative of the Modderfonteinspruit downstream water quality.	Quarterly	Monthly	

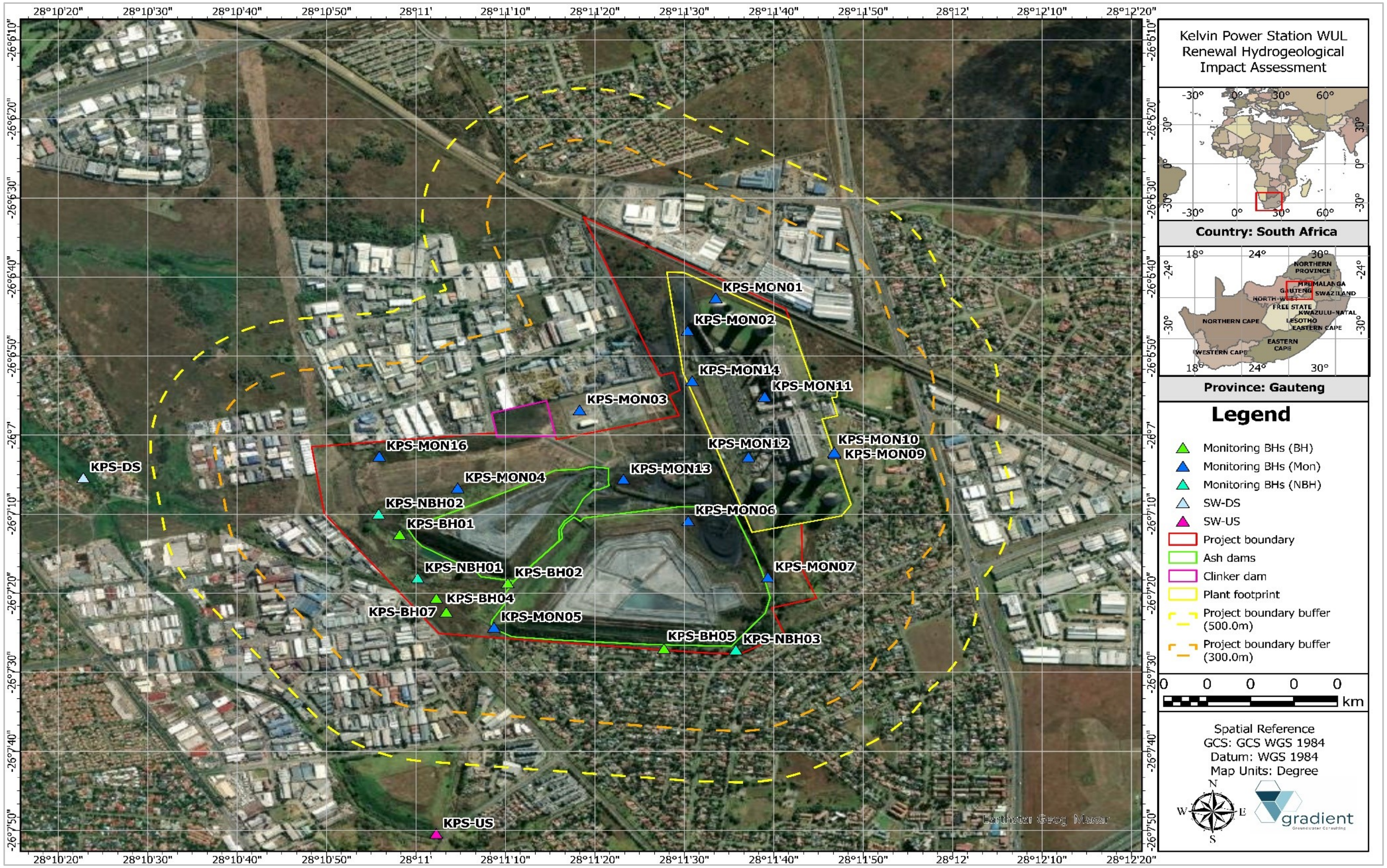


Figure 15-2 **Revised monitoring network.**

16. CONCLUSIONS

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

i. The study area is predominantly underlain by a Class d3 intergranular and fractured aquifer with host aquifers consisting of primarily intermediate or alkaline intrusive formations. The latter can be associated with relatively low hydraulic conductivity, hence, groundwater movement and migration of contaminants may be sluggish.

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

iii. Under natural conditions there is pronounced interaction between surface water and groundwater. Regional drainages can be generally classified as influent or gaining stream systems with groundwater discharging as baseflow within these zones. Accordingly, potentially contaminated groundwater originating from the power generation development and infrastructure may negatively impact on the Modderfonteinspruit and associated drainage system.

iv. A hydrocensus user survey conducted did not identify any privately owned boreholes currently in use in the pollution plume migration pathway.

v. The unsaturated zone within the study area has a mean thickness of approximately ~5.0m. Due to clay/silt lenses throughout the study area, the shallow vadose zone can also be indicative of perched aquifer conditions which may be associated with seepage zones throughout the study area. This implies that, due to the relatively thin unsaturated zone, host aquifers might be vulnerable to potential contamination.

vi. It can be noted that Coefficient of Variation (CV) calculated for the water level database is relatively low, indicating that the regional groundwater system is in quasi-steady state conditions.

vii. Analysed data indicate that the surveyed water levels correlate very well to the topographical elevation and even with dynamic water levels taken into consideration, the correlation is calculated at $R^2 > 0.98$. Accordingly, it can be assumed that, under natural conditions, the regional groundwater flow direction will be dictated by topography. The inferred regional groundwater flow direction of the shallow aquifer will thus be towards the lower laying drainage system and will flow in a general western to south-western direction.

viii. The hydrochemical analysis results suggest the overall ambient groundwater quality is moderate good with the majority of macro and micro determinants of most samples below the SANS 241:2015 limits. It should however be noted that, monitoring boreholes in close proximity to existing waste body footprints indicate an impacted groundwater environment with high salt load (TDS and conductivity) and sulphate being the main diver of the salt content. Neutral conditions as well as below limit metal concentrations suggest that Acid Rock Drainage is currently not occurring.

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

x. Two alternative management and mitigation scenarios which include active as well as passive water management strategies were simulated to evaluate the remedial options available. Based on the constraining effects of these mitigation scenarios on the pollution plume migration, both alternatives can be viewed as the remedial options for implementation. It can be noted that a collective approach can also be evaluated combining these alternatives for a cumulative impact.

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

xii. During the operational phase the environmental significance rating of groundwater quantity impacts on down-gradient receptors are rated as **insignificant** as no groundwater will be removed from storage via dewatering or abstraction. Groundwater quality impacts from existing waste body footprints and associated infrastructure are rated as **high** negative without implementation of remedial measures and **medium** to **low** negative with implementation of mitigation measures.

xiii. The main post-closure activities include rehabilitation and decommissioning of related infrastructure. During the post-closure phase, the environmental significance rating of groundwater quantity impacts on down-gradient receptors remains **insignificant** as not water will be removed from storage**.** Groundwater quality impacts from mining footprints are rated as **high** negative without implementation of remedial measures and **medium** to **low** negative with implementation of mitigation measures.

17. RECCOMMENDATIONS

The following recommendations are proposed following this investigation:

i. It is recommended that the management and mitigation measures be implemented as part of the integrated groundwater management plan (Section 14 of this Report). The Licensee shall appoint a suitably qualified and responsible person and make all of the necessary and reasonable financial, human and equipment resources available to him/her" to give effect to all recommendations as stipulated in specialist reports to ensure compliance to licence conditions pertaining to activities to ensure that potential impact(s) are minimised, and mitigation measures proposed are functioning effectively.

ii. It is recommended that the revised monitoring network and program as set out in this report should be implemented and adhered to. It is imperative that monitoring be conducted to serve as an early warning and detection system. Monitoring results should be evaluated on a quarterly basis by a suitably qualified person for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

iii. Additional monitoring boreholes, as recommended, should be established to replace demolished boreholes down-gradient of existing waste infrastructure in order to evaluate the groundwater drawdown as well as mass load contribution to environmental and sensitive groundwater receptors. Drilling localities should be determined by means of a geophysical survey in order to target lineaments and weathered zones acting as preferred groundwater flow pathways and contaminant transport mechanisms.

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

v. Groundwater flow modelling assumptions should be verified and confirmed. The calibrated groundwater flow model should be updated on a biennial (once every two years) basis as newly gathered site characterisation data and monitoring results become available in order to be applied as groundwater management tool for future scenario predictions.

18. REFERENCES

Aquatico, 2024. Kelvin Power Station Quarterly Water Quality Report December 2024. Report Number: KPS/QWR4/2024/PWB.

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

Barnard, H. C., 2000. An explanation of the 1:500 000 Hydrogeological Map. Johannesburg 2526.

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

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

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

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

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

Chief Directorate. Surveys and Mapping. 2003. Cape Town, 2628AA and 2628AB [Map]. Edition 9. Scale 1:50,000.

Mowbray, South Africa: Chief Directorate of Surveys and Mapping.

Council of Geoscience geological map sheet 2628: Johannesburg (1:250 000).

Department of Water Affairs and Forestry, South Africa. 2004. Internal Strategic Perspective: Crocodile West Marico Water Management Area. Prepared by Golder Associates (Pty) Ltd on behalf of the Directorate National Water Resources Planning. Report no. P WMA 03/000/00/0303.

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

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

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

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

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

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

ENVASS, 2025. 2024 Update of the Annual Integrated Water and Waste Management Plan(IWWMP) for Kelvin Power (Pty) Ltd, Gauteng Province.

ESRI basemaps, 2025.

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

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

Google Earth, 2025. 6.0.12032 Beta.

Groundwater Complete, 2025. Kelvin Power Station Report On Groundwater Monitoring Results For Quarter 4 Of 2024.

Groundwater Complete, 2025. Kelvin Power Station, Kempton Park, Gauteng Province: Phase 1 Report – Results of Short Duration Pumping Tests.

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

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

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

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

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

WR 2016. Rainfall and meteorological data.

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

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

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

19. APPENDIX A: RAINFALL DATA (RAINFALL ZONE A2B)

20. APPENDIX B: WATER QUALITY CERTIFICATE

21. APPENDIX C: SPECIALIST CURICULUM VITAE