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

April 2025

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

Compiled by:
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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.

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

JFW Mostert (Hydrogeologist)

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 in support of an Environmental Impact Assessment (EIA) authorisation process to be followed for the proposed Motuoane Energy (Pty) Ltd gas exploration right (ER386).

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

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

The project entails the establishment of eleven (11) pre-defined drill site locations and associated infrastructure. In addition, the applicant intends to continue drilling within proximity to the geological fault lines which traverse the area. The exact location of the drill sites within these fault corridors is not known at present and will be guided by both the presence of gas resources as well as any potential environmental sensitivities.

The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features. Elevations generally increase towards the south and east of the study area, with the lowest elevation of 1 300 mamsl in the central-western parts of the study area and the greatest elevation of 1 533 mamsl in the eastern parts of the study area.

The greater study is situated in primary catchment (C) of the Vaal River drainage system which covers a total area of approximately 598.0km^2. The resource management falls under the Vaal Water Management Area (WMA5) (previously Middle Vaal WMA) which spans portions of the North West Province, northern Free State as well northern sections of the Northern Cape. The study area encompasses several quaternary catchments of the Vaal WMA. These include Quaternary Catchments C25B, C42H, C42J and C60H.

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

The study area has a summer rainfall regime, with the majority of the precipitation occurring from October to March (80.02%) as high intensity thunderstorms, while June, July, and August are particularly dry.

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

The regional geology consists of various lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort and Ecca Groups within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. A vast network of dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite occurs throughout the study area and is especially prominent in the southern and central parts of the study area. Structural analysis provided by the applicant indicates that five faults run across the study area, four trending NE and one trending SSE. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

The study area is predominantly underlain by a Class d2 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.1 and 0.5 L/s), while small portions towards the northwest of the study area are underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0 L/s). Both the Class d2 and Class d3 aquifers consist of primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however will not only be multi-layered, but also multi-porous with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. The Ecca Group aquifers consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, it should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc.

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

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

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

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.

The average thickness of the unsaturated zones of Groundwater are between 14.90m to 18.20m while an approximation of recharge for the study area is estimated at ~3.50% of MAP i.e., ~19.48 mm/a.

The hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. Historical aquifer tests results confirm that the permeability of the shales is very low ($9E^{-4}$m/d). The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10E^{-6}$ – $10E^{-1}$ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10E^{-9}$ – $10E^{-6}$ m/d. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e., riverbed aquifers can be orders higher and can vary between $10E^{-2}$ – $10E^{1}$ m/d.

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

The following potential sources have been identified:

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

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

iii. Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.

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

The following potential aquifer pathways have been identified:

i. Vertical flow through the unsaturated/vadose zone as well as saturated zone to the underlying intergranular and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.

ii. Preferential flow-paths include the contact between the depth of weathering and fresh un-weathered rock, fractures, faults, joints and bedding planes. Secondary fractures may also potentially act as transport mechanisms.

iii. If not adequately sealed and suitably mitigated, gas exploration wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

The following potential receptors were identified:

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

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

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

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.

Potential impacts associated with the construction phase activities include the following:

i. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area.
ii. Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.
iii. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
iv. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.

Potential impacts associated with the operational phase activities include the following:

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
iii. Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.
iv. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
v. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.

Potential impacts associated with the post-closure and decommissioning phase activities include the following:

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

The following recommendations are proposed following this investigation:

i. It is recommended that this scoping report be incorporated into a detailed hydrogeological specialist investigation in order to verify sensitive environmental and groundwater receptors as well as confirm the proposed source-receptor-pathway mechanisms.

ii. Mitigation and management measures should be formulated and developed as part of the follow-up phase in order to minimize potential impacts of the proposed operations on sensitive environmental and groundwater receptors. Mitigation and management measures should be summarised in a water management plan which should be applicable to the construction, operational and decommissioning/ post-closure phases of the project.

iii. It is recommended that an integrated groundwater and surface water monitoring protocol and network be developed for implementation. It is imperative that monitoring be conducted to serve as an early warning and detection system.

iv. Pre-development monitoring can be considered in order to formulate a baseline to serve as benchmark going forward. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

v. It should be considered to establish aquifer characterisation boreholes in order to obtain site representative hydraulic parameters for host classification and numerical groundwater model calibration purposes.

List of Abbreviations

ABA	**Acid Base Accounting**
ASTM	**American Society for Testing Materials**
Avg	**Average**
AWD	**Accelerated Weight Drop Seismic**
BH	**Borehole**
CMB	**Chloride Mass Balance**
CNG	**Compressed Natural Gas**
CV	**Coefficient of Variation**
b	**Saturated Thickness**
DMR	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs**
EC	**Electrical Conductivity (mS/m)**
EA	**Environmental Authorisation**
EIA	**Environmental Impact Assessment**
E.N.	**Electro Neutrality**
ER	**Exploration Right**
ERA	**Exploration Release Area**
EPA	**United States Environmental Protection Agency**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN	**Government Notice**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
IWULA	**Integrated Water Use License Application**
ISP	**Internal Strategic Perspective**
K	**Hydraulic Conductivity (m/d)**
l/s	**Litre per second**
LoM	**Life of Mine**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute Error**
mamsl	**Metres Above Mean Sea Level**
MAP	**Mean Annual Precipitation**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
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)**
PEG	**Propelled Energy Generators**
REV	**Representative Elementary Value**
RMSE	**Root Mean Square Error**
S	**Storage coefficient**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
Sc	**Specific Storage**
SoW	**Scope of Work**
SRTM	**Shuttle Radar Topography Mission**
T	**Transmissivity (m2/d)**
TCP	**Technical Cooperation Permit**
TDS	**Total Dissolved Solids**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
USGS	**United States Geological Survey**
WGS	**World Geodetic System**
WM	**With Mitigation**
WOM	**Without Mitigation**
WRC	**Water Research Commission**
WUL	**Water Use Licence**

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1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological baseline investigation and groundwater impact assessment in support of an Environmental Impact Assessment (EIA) authorisation process to be followed for the proposed Motuoane Energy (Pty) Ltd gas exploration right (ER386). The investigation will focus on the status quo of the regional groundwater system and quantify and qualify potential impacts from the proposed gas exploration on potential sensitive environmental receptors. This report summarises the main conclusions and recommendations derived from the study.

1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors. This will entail a hydrocensus to cover a total buffer zone of 500.0m in the vicinity of each proposed drill site.

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

iii. Development of a conceptual groundwater flow model.

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

v. Hydrogeological impact assessment and risk matrix.

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

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

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-24-048-V1, submitted in November 2024. This project plan and scope of work was compiled based on the following guidelines and regulations:

i. Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications.

ii. Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07 April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA).

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

1.3.1. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

i. Information gathering and data acquisition.

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

iii. Fatal flaw and gap analysis.

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

Phase B will entail the following activities[1]:

i. Hydrocensus user survey (500.0m buffer zone) to evaluate and verify existing surface and groundwater uses, local and neighbouring borehole locations and depths, spring localities and seepage zones, regional water levels, abstraction volumes, groundwater application as well as environmental receptors in the vicinity of the proposed gas exploration area.

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

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

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

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

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 proposed infrastructure and gas exploration footprint as well as associated activities.

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

iii. Calibration of groundwater flow model using site specific data including hydrocensus geosites information.

iv. Development of a numerical mass transport model utilizing the calibrated groundwater flow model as basis.

v. The calibrated model will be used to simulate management scenario's as follows:

a. Steady state groundwater flow directions, hydraulic gradient and flow velocities.

b. Seepage potential from waste facilities and mass transport plume migration with time.

c. Hydrochemical migration of deeper, saline water towards the shallow aquifer and plume propagation with time.

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

e. Post-closure scenarios.

f. Water management alternatives and best practice mitigation measures.

1.3.4. 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. Field work summary and interpretation.

d. Aquifer classification and vulnerability.

e. Numerical groundwater flow and mass transport model development, calibration and simulations.

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

g. Recommendation on best practise mitigation and management measures to be implemented.

ii. Development of an integrated surface water and groundwater monitoring program for implementation.

1.4. Details and expertise of the author

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

Table 1-1 Details of the authors.

Author	Ferdinand Mostert
Highest qualification	M.Sc. Hydrogeology
Years' experience	17+
Professional registration	SACNASP Member (Reg. No 40057/14 – Water Resource Science). Member of the Groundwater Division of the Geological Society of South Africa (MGSSA).

1.5. Available information

The following information was available and used in this investigation:

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

1.6. Project assumptions and limitations

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

i. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic and spatial data, a lower resolution of 1:250 000 scale for geological data and a 1: 500 000 scale resolution for hydrogeological information.
ii. The Digital Elevation Model (DEM) data was interpolated with a USGS grid spacing of 25.0m intervals.
iii. Rainfall data and other climatic data was sourced from the WR2012 database.
iv. Water management and catchment-based information was sourced from the GRDM and Aquiworx databases.
v. The concept of representative elementary volumes (REV) has been applied i.e. a scale has been assumed so that heterogeneity within a system becomes negligible and thus can then be treated as a homogeneous system. The accuracy and scale of the assessment will result in deviations at point e.g. individual boreholes.

vi. 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[2].

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

2. METHODOLOGY

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

2.1. Desk study and review

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

2.2. Evaluation of potential environmental receptors

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

2.3. Hydrogeological baseline description

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

2.4. Development of a conceptual hydrogeological model

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

2.5. Groundwater impact assessment

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

3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS

The following water management legislation should be adhered to:

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

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

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

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

The National Environmental Management Act 107 of 1998 intends:

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

ii. to provide for matters connected therewith.

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

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

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

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

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

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

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

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

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

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

The gas exploration right and greater study area falls within the Matjhabeng and Moqhaka Local Municipalities, Lejweleputswa and Fezile Dabi District Municipalities covering a total footprint of ~580.0km^2, stretching over various farms which are situated between the towns of Welkom (~7.0km to the west), Virginia (~6.0km to the southwest), Hennenman (situated in the center of the proposed exploration right area) and Ventersburg (~2.0km to the southeast), Free State Province of South- Africa. Fixed coordinates representing the boundaries of the ER386 are ER386 are 28°13'28.95"S; 26°55'2.76"E in the South, 27°57'37.57"S; 26°48'49.15"E in the West, 27°59'13.57"S; 27°11'13.06"E in the East and 27°46'34.45"S; 26°57'44.05"E in the North, the central coordinates are approximately 27°58'23.27"S; 26°59'38.94"E. (EIMS, 2025). The site is accessible via the N1 national route traversing the greater study area in a general north south direction as well as the R70 secondary route in a southeast-northwest orientation. General site coordinates are listed in **Table 4-1** and a map indicating an aerial extent of the greater study area is indicated in **Figure 4-1** with the project boundary and topo-cadastral map depicted in **Figure 4-2.**

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

Latitude	27°58'23.27"S
Longitude	26°59'38.94"E

4.2. Project description, listed activities and proposed infrastructure

The project entails the establishment of eleven (11) pre-defined drill site locations and associated infrastructure. In addition, the applicant intends to continue drilling within proximity to the geological fault lines which traverse the area. The exact location of the drill sites within these fault corridors is not known at present and will be guided by both the presence of gas resources as well as any potential environmental sensitivities. Refer to **Figure 4-3** for a general site layout and infrastructure map.

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

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

The main activities are core exploration drilling and seismic survey activities. The proposed approach is to first determine and map the geographic extent of all boreholes currently emitting gas on and near the ER area. Then measure rates and monitor pressures where possible and perform gas composition analysis. The geophysical wireline logging of existing boreholes (where possible) will include monitoring of water levels. If no existing gas emitting boreholes are identified near a target area, new drilling activities are proposed within that area using percussion or rotary drilling method. Although up to eleven (11) target drilling areas (TA) with 500m buffer (1km corridor) within the exploration right may be undertaken over the 9-year period, the current Works Program caters for only three (3) drilling wells. It must be noted that there may be a single, multiple or no drilling activities within some of the target drilling areas. Should more than 3 drilling wells be required within the ER, the current Works Program will be required to be updated accordingly.

Majority of the drilling target areas, Target Area 3 (ED G), Target Area 4 (ED H), Target Area 5 (ED J), Target Area 6 (ED I), Target Area 7 (ED F) and Target Area 8 (VEG A) as well as seven (7) seismic transects (Transects, ED 1-5, VEG 1-2) are proposed within the western section of the exploration right on the agricultural fields between Saaiplaas, Bronville, Thabong and Whites. Two target drilling areas, Target Area 1 (RSB D) and Target Area 2 (RSB E) are located in the south of ER386, approximately 7km southeast of Meloding while Target Area 9 (HF C) and associated transects (Transects HF 1, HF2 and HF7) is located approximately 6km west the eastern boundary of ER386 (N1). There are currently two target areas proposed within the northern section namely, Target Area 10 (GP B) and Target Area 11 (GP A) and three seismic transect (Transect G1, G2 and G3) R34 located between Odendaalsrus and Kroonstad. Each exploration well will have an overall depth of approximately 650m and a maximum width of 350mm, commencing with a 6m x 323mm spud hole section, followed by 80m x 254mm conductor hole section, then an intermediate hole section of 450m x 203mm and finally an open hole section of 650m x 144mm. The actual casing sizes and configurations will vary depending on the specific geological characteristics and functional requirements. Each borehole will be steel cased and have cement barriers to prevent leaks as well as plugged at the end of exploration to prevent groundwater seepage.

The seismic survey activities are proposed throughout the exploration right as and when necessary. Motuoane will search records at the Council for Geoscience and the Petroleum Agency for seismic data that was acquired on the Exploration Right in the past. If no data are available, Motuoane will either acquire its own seismic or telluric data on the property, following proper environmental protocols and with the written permission of the landowner. There are sixteen (16) preliminary proposed transects for seismic / telluric survey, approximately 100km long around known structures and possible drill locations. Seismic and/or telluric locations and lengths are subject to be changed as knowledge increases. Although the Vibroseis technique is the likely method to be undertaken for the seismic activities. There is also a potential alternative to the Vibroseis known as the Propelled Energy Generators (PEGs), more commonly referred to as the Accelerated Weight Drop Seismic (AWD) which Motuoane may consider over the Vibroseis. It must be noted that there are at least 14 approved renewable energy projects from various applicants located within ER386. Motuoane and the renewable energy applicants will need to discuss the way forward and/or make necessary arrangements to coexist especially for TA 3 (EDG) and Transects EDG1 and EDG2 as the renewable energy projects overlap with the target drilling areas (EIMS, 2025).

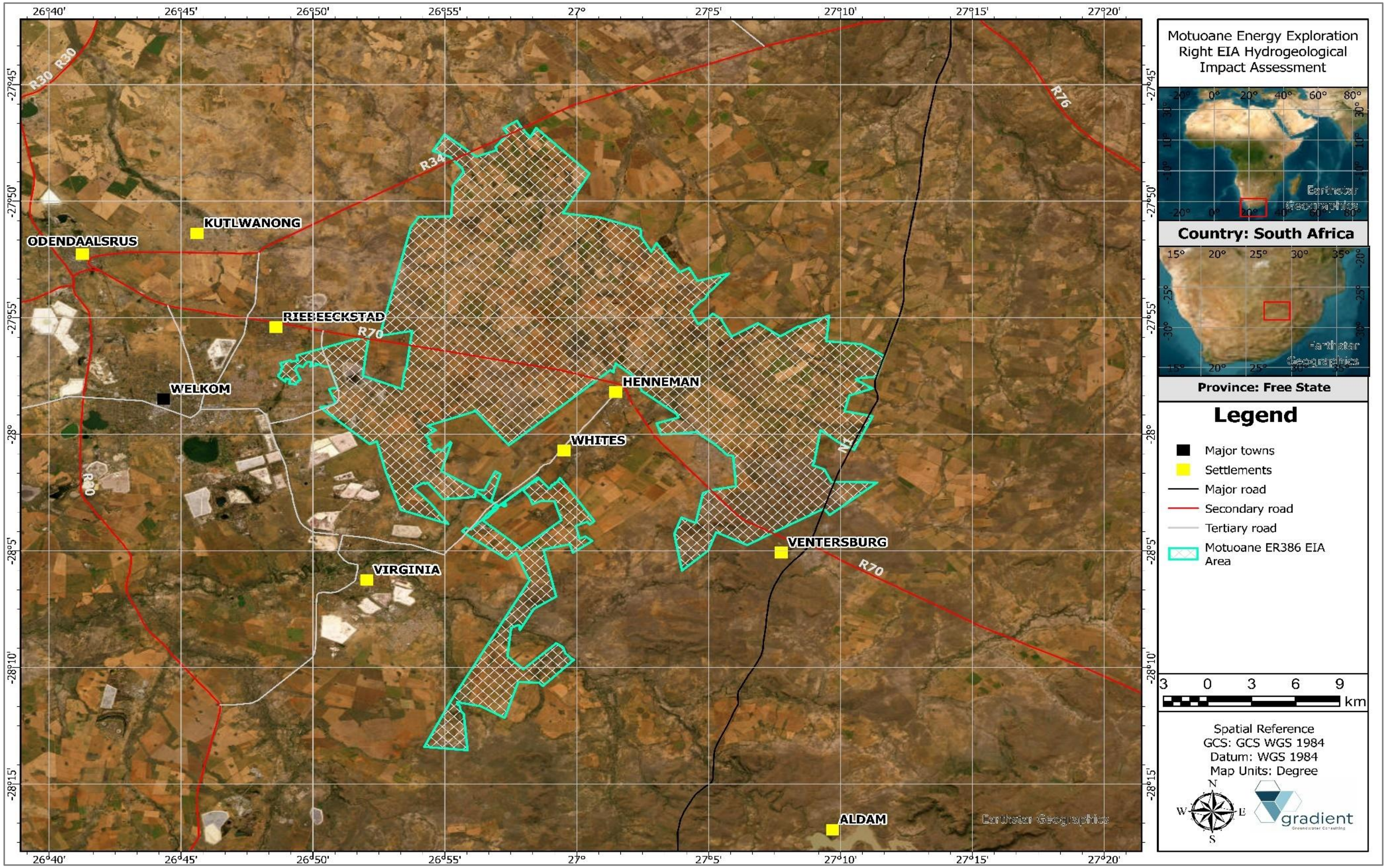


Figure 4-1 **Aerial extent and greater study area.**

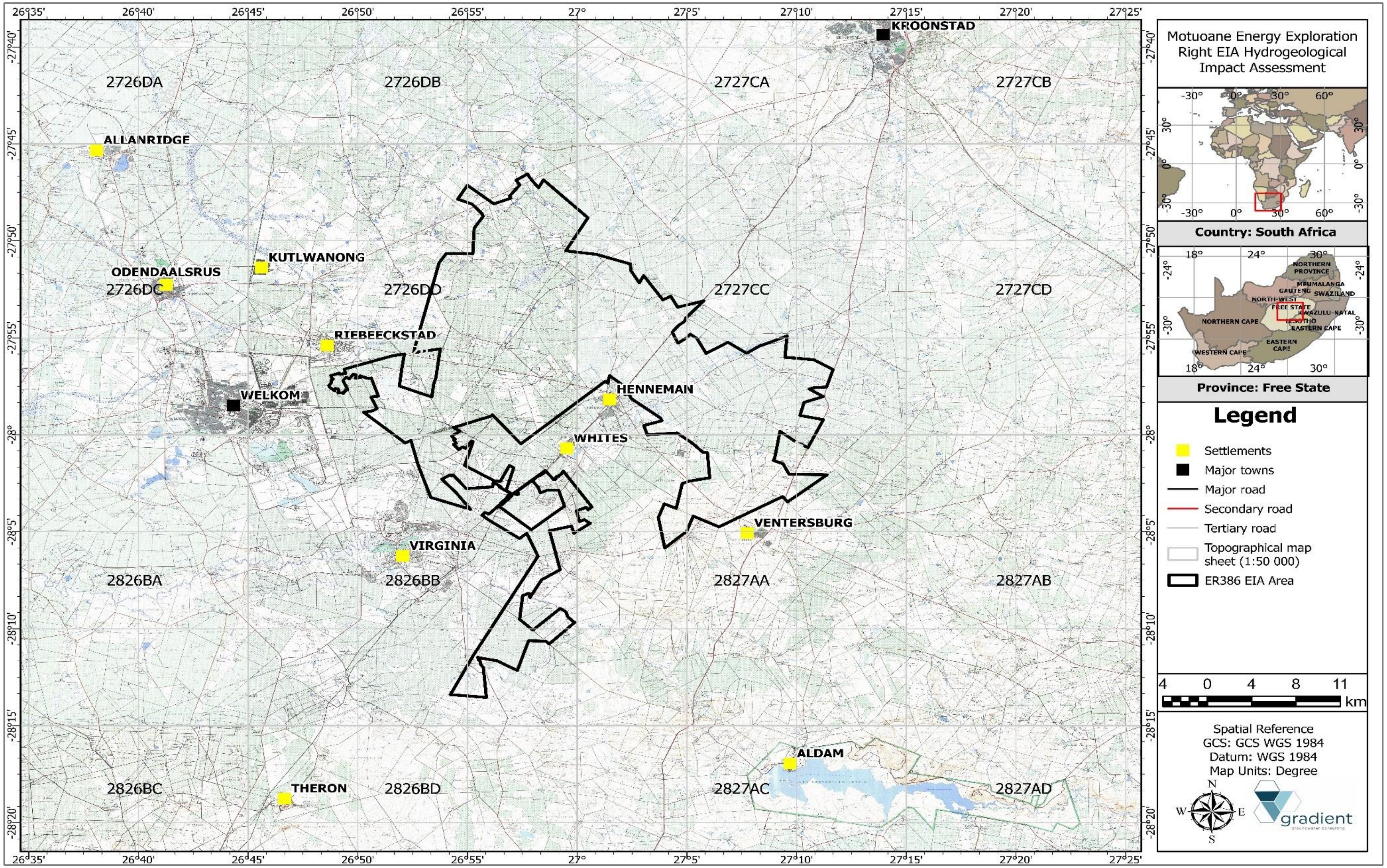


Figure 4-2 **Greater study area (1:50 000 topographical mapsheet 2826 and 2827).**

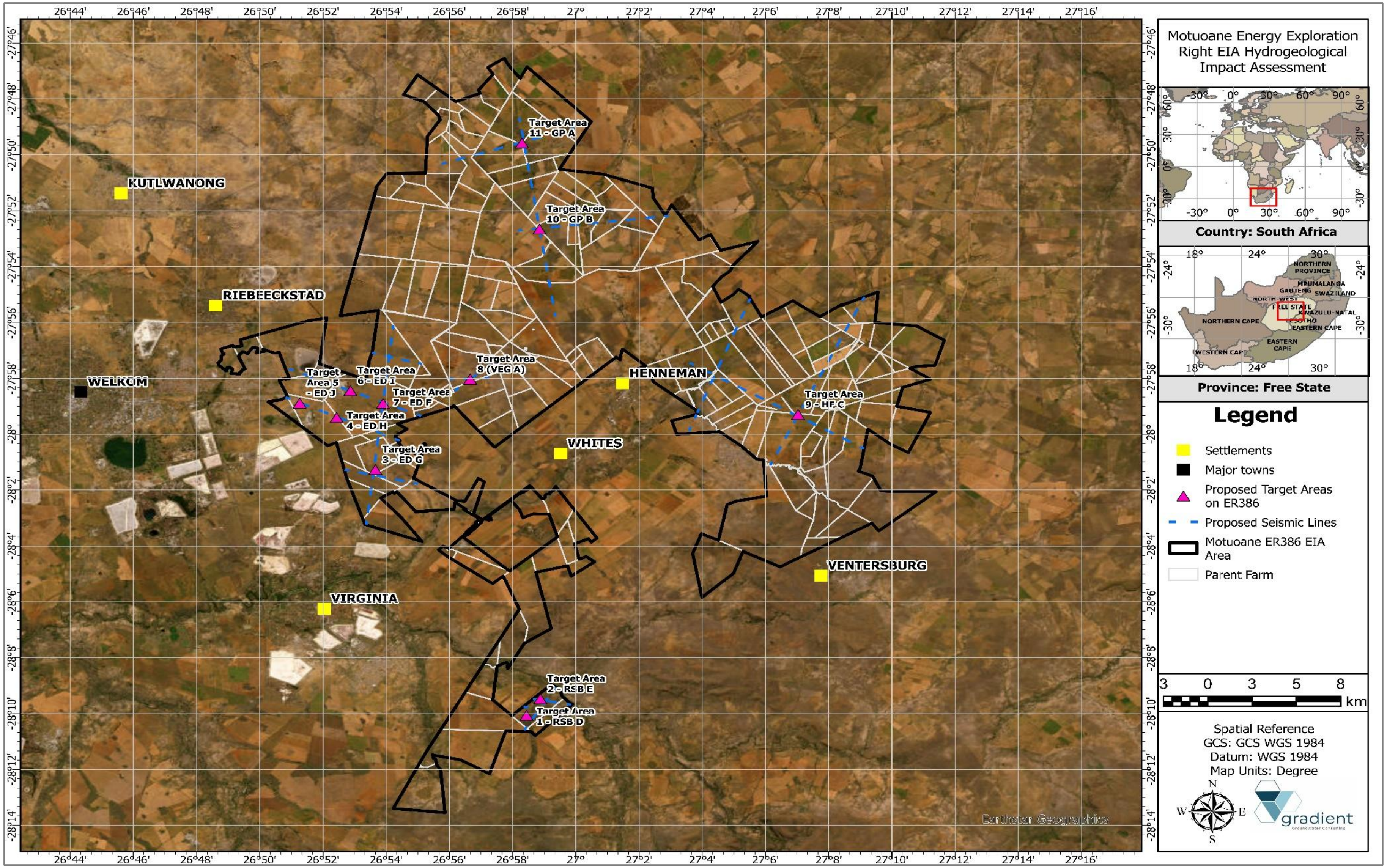


Figure 4-3 **General site layout and infrastrcutre map.**

5. PHYSIOGRAPHY

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

5.1. Topography

The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features (DWAF, 2004). The relief of the area varies between 0 – 130.0m towards the western perimeter and 30 – 210.0m to the south and northern boundaries. Elevations within the study area range between 1 300 and 1 533 mamsl (based on elevations extracted from the SRTM DEM raster interpolation). Elevations generally increase towards the south and east of the study area, with the lowest elevation of 1 300 mamsl in the central-western parts of the study area and the greatest elevation of 1 533 mamsl in the eastern parts of the study area. Based on calculations performed using GIS, the slope of the study area ranges between 0% (indicating water bodies such as wetlands, pans, and dams) and 45.17% (indicating steep hillslopes), while the average slope is calculated as 3.58% with a standard deviation of 2.35%. **Figure 5-1** and **Figure 5-2** indicates elevation profiles for various profiles (refer to **Figure 5-4** for the respective orientations) and it is observed that the greater study flattens out towards the northwest and west which also correlates to the general drainage direction. **Figure 5-3** depicts a topographical cross-section (northwestern aspect) of the greater study area while **Figure 5-4** shows the regional topographical contours and setting.

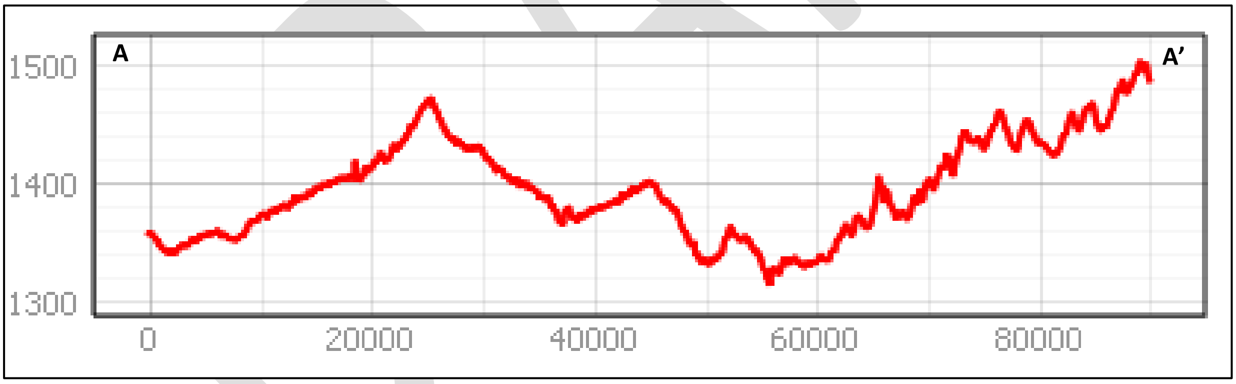


Figure 5-1 North-South Elevation Profile (refer to Figure 5-4 Slice A-A').

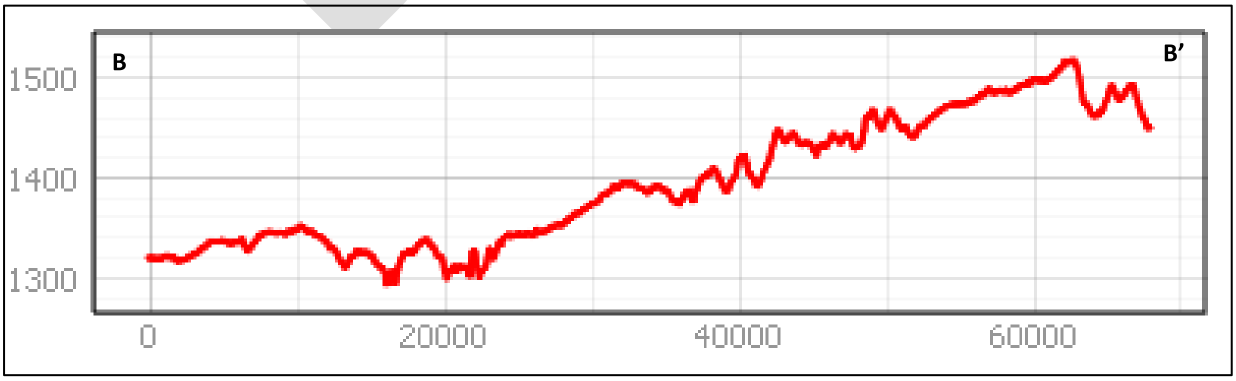


Figure 5-2 West-East Elevation Profile (refer to Figure 5-4 Slice B-B').

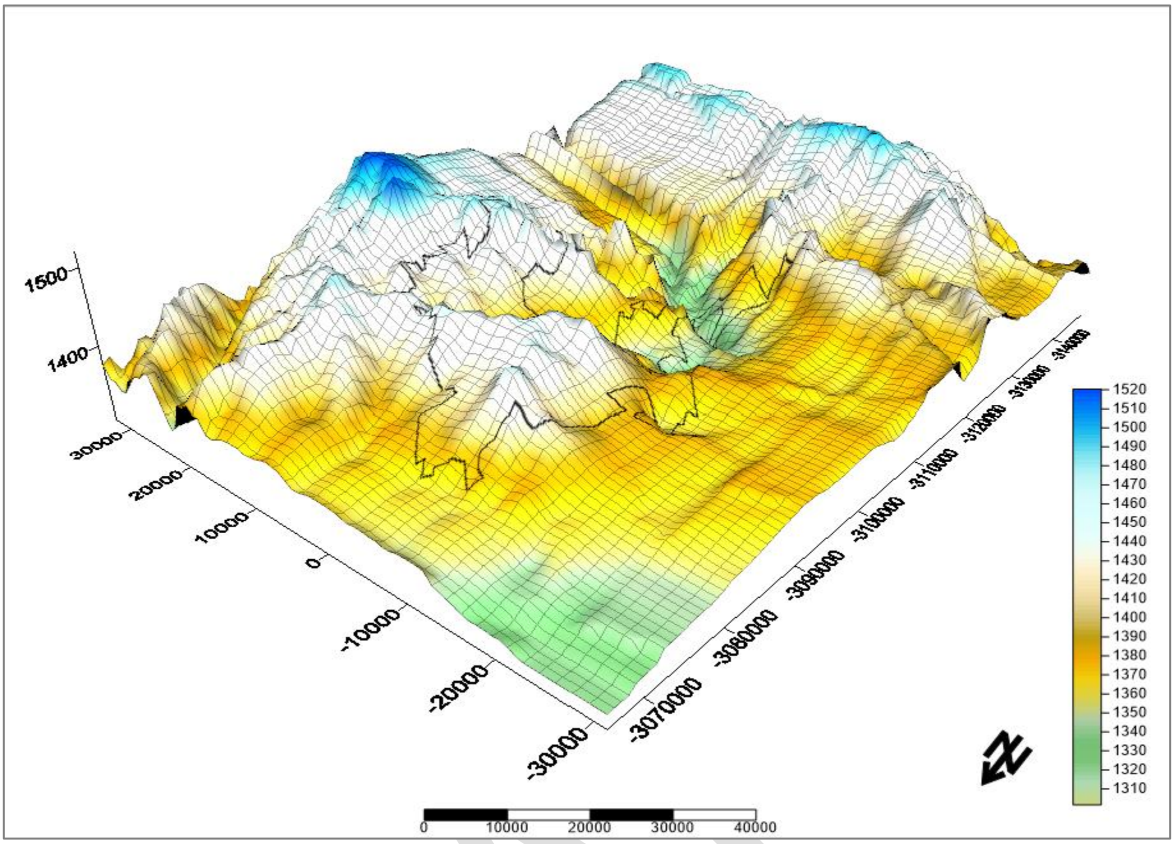


Figure 5-3 **Topographical cross-sections of the greater project area.**

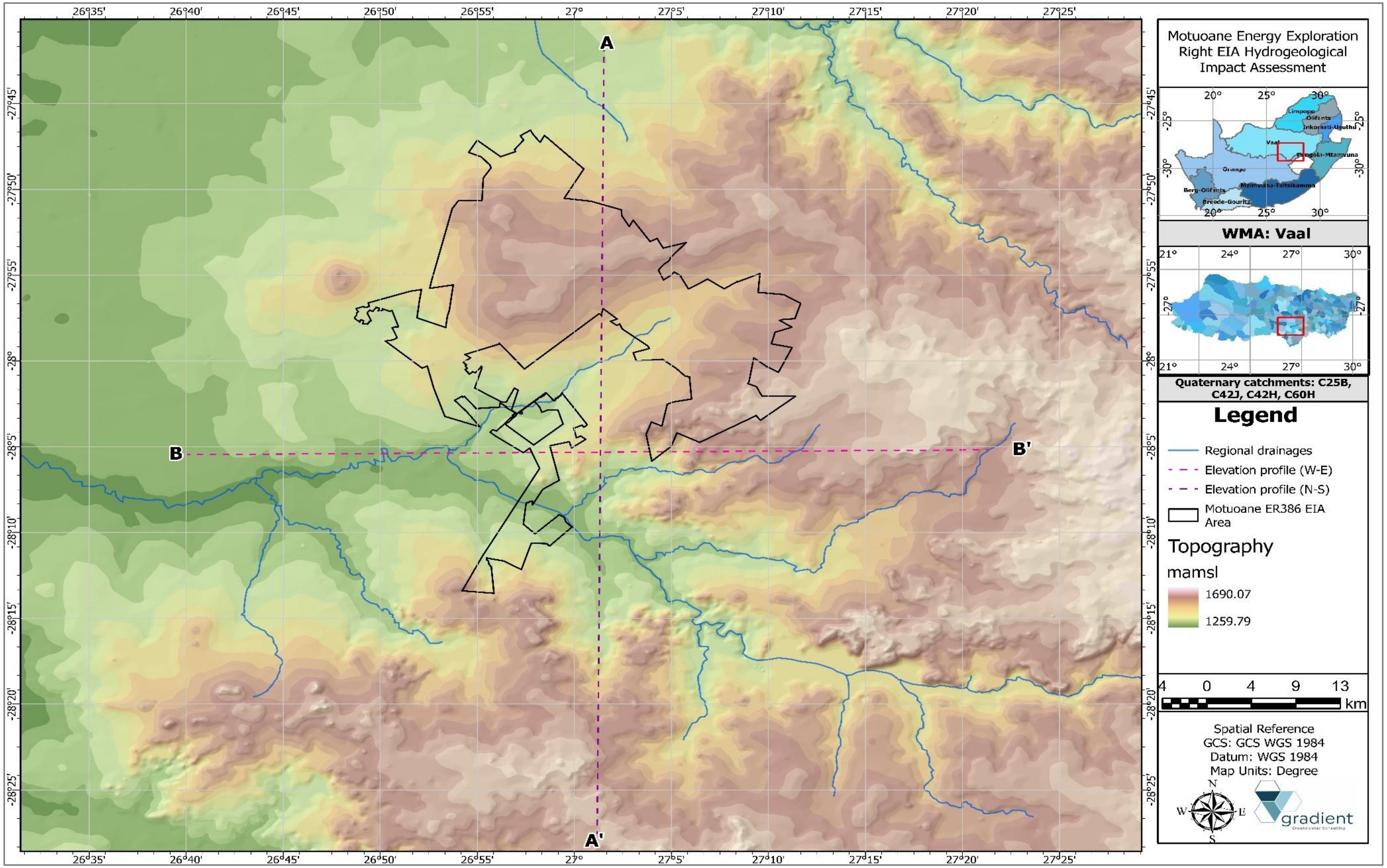


Figure 5-4 **Regional topography and conceptual slice (Refer to Figure 5-1 and Figure 5-2).**

5.2. Drainage and catchment

The greater study is situated in primary catchment (C) of the Vaal River drainage system which covers a total area of approximately 598.0km^2. The resource management falls under the Vaal Water Management Area (WMA5) (previously Middle Vaal WMA[4]) which spans portions of the North West Province, northern Free State as well northern sections of the Northern Cape. The study area encompasses several quaternary catchments of the Vaal WMA. These include Quaternary Catchments C25B, C42H, C42J and C60H. The main watercourses within the Middle Vaal WMA are the Mooi, Vet, and Vaal Rivers (WRC, 2016). The Vaal River is a major tributary of the Orange River, which generally drains in an eastern direction towards the Atlantic Ocean. The primary rivers in and around the study area include the Vals River towards the northeast of the study area, the Sand River in the central parts of the study area, and the Vet River towards the southwest of the study area (WRC, 2016).

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

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

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

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

Table 5-1 Study Area Catchment and Hydrological Properties.

Quaternary Catchment	Area (km^2)	% Covered by Study Area	MAP (mm/a)	MAE (mm/a)	MAR (Mm^3/a)	Rainfall Zone	Evaporation Zone
C25B	1 887.67	1.91	509.21	1 750	7.23	C2H	9A
C42H	445.00	9.83	540.00	1 590	10.16	C4C	19C
C42J	1 013.93	26.69	529.79	1 600	21.26	C4C	19C
C60H	1 232.02	19.39	512.75	1 650	2.64	C6B	11A

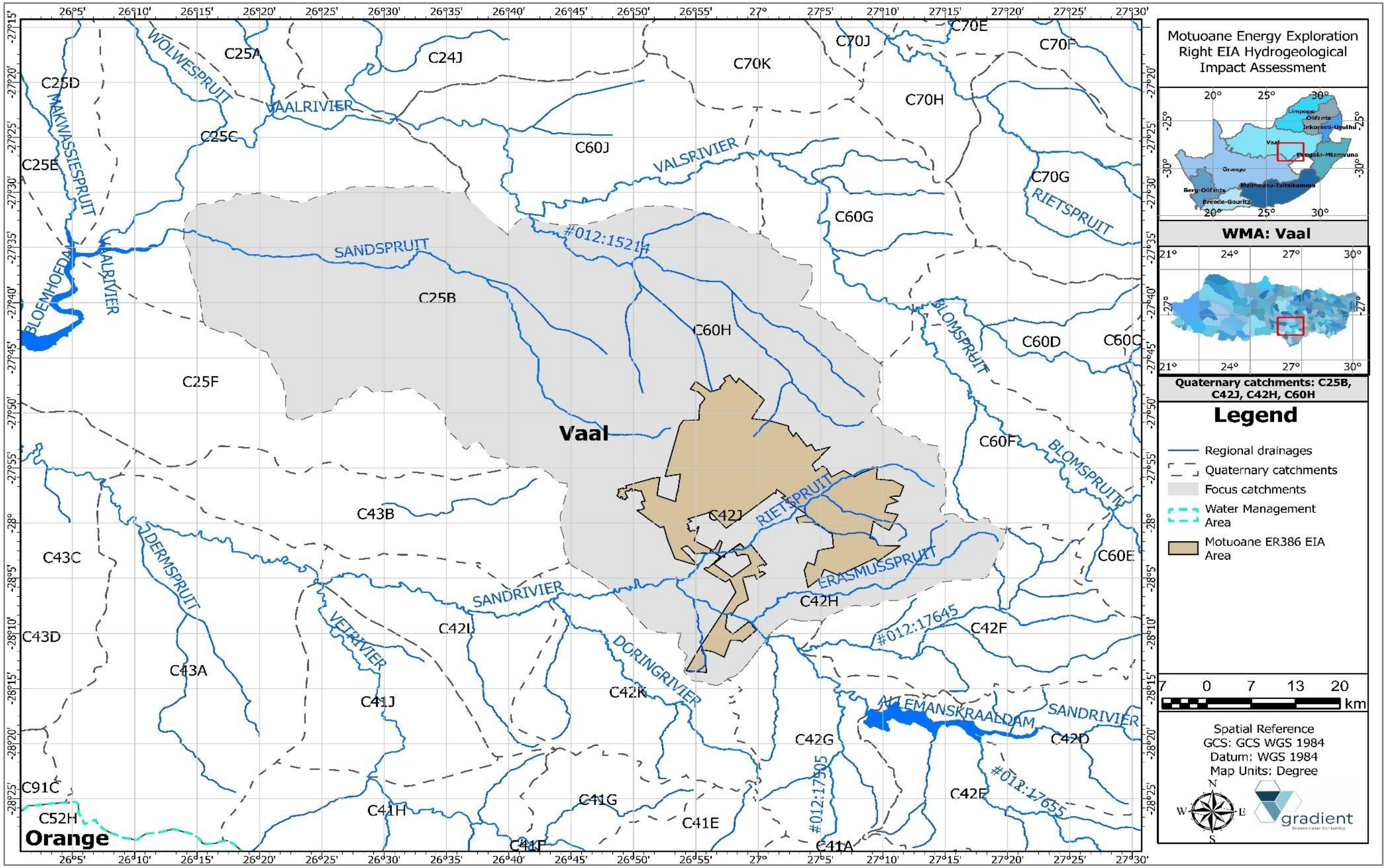


Figure 5-5 **Quaternary catchments and water management area.**

5.2.1. Climate

According to the Koppen-Geiger climate classification system, the climate of the study area is classified as BSk (Climate Change & Infectious Diseases Group, 2023). This classification indicates that the study area has a cold, semi-arid climate characterized by cold, dry winters and warm summers. The average temperature in the Welkom area ranges between 9.7 °C in the winter (July) and 23.3 °C in the summer (January), while the mean annual temperature is 17.7 °C (Climate-Data, 2021). Refer to **Figure 5-6** for the Mean Yearly Temperature Distribution of the greater study area.

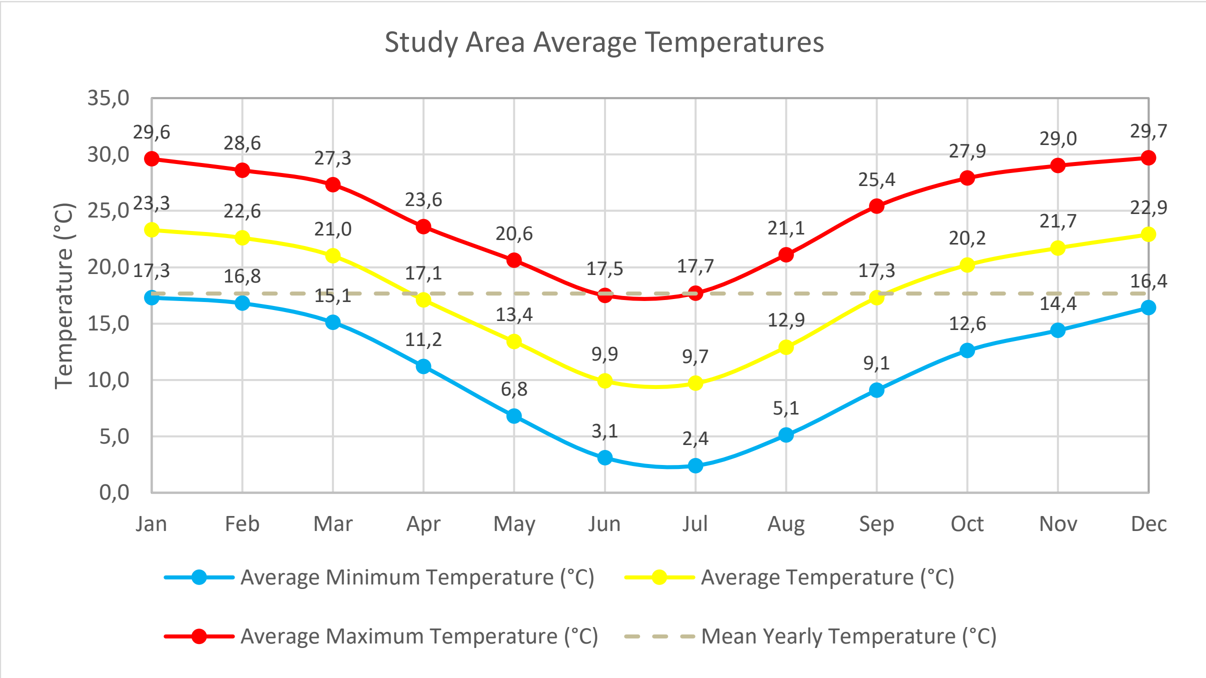


Figure 5-6 Mean Yearly Temperature Distribution of the greater study area, 1991 – 2021 (Climate-Data, 2021).

The mean annual precipitation (MAP) for the study area is estimated at approximately 531.66 mm/a, based on MAP data obtained from WR2012 (WRC, 2016). Using patched monthly precipitation data (ranging from 1920 to 2009), obtained from the WR2012 database (WRC, 2016), the MAP for the study area is calculated as 531.81 mm/a. The 5th percentile of the dataset, which approximately represents a 1:20 year drought, is calculated as 345.32 mm/a. The 95th percentile of the dataset, which approximately represents the 1:20 year flood, is calculated as 760.66 mm/a.

The results from the analysis of the WR2012 datasets indicate that the study area has a summer rainfall regime, with the majority of the precipitation occurring from October to March (80.02%) as high intensity thunderstorms, while June, July, and August are particularly dry. Refer to **Figure 5-7** and **Figure 5-8** for graphical representations of the monthly and annual precipitation distributions for the study area.

The study area falls within evaporation zones 9A, 11A, and 19C (WRC, 2016). The mean annual evaporation (MAE), measured by Symons Pan, for the study area ranges between 1 540 and 1 750 mm/a (WRC, 2016).

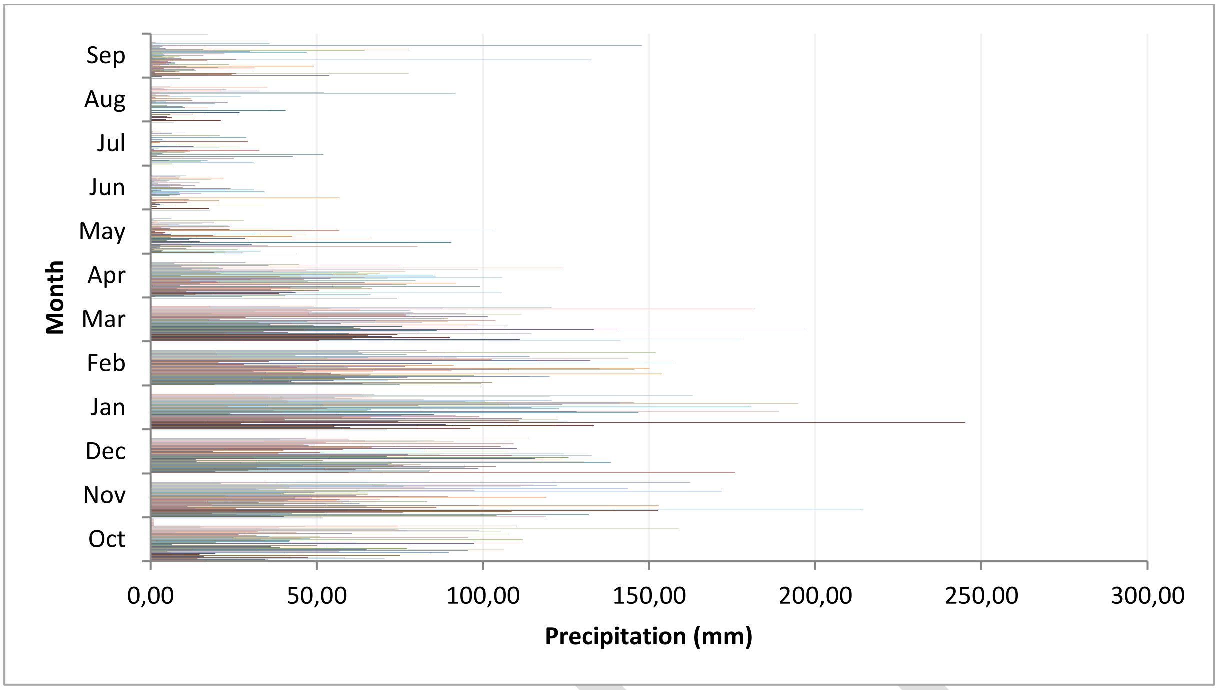


Figure 5-7 **Monthly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

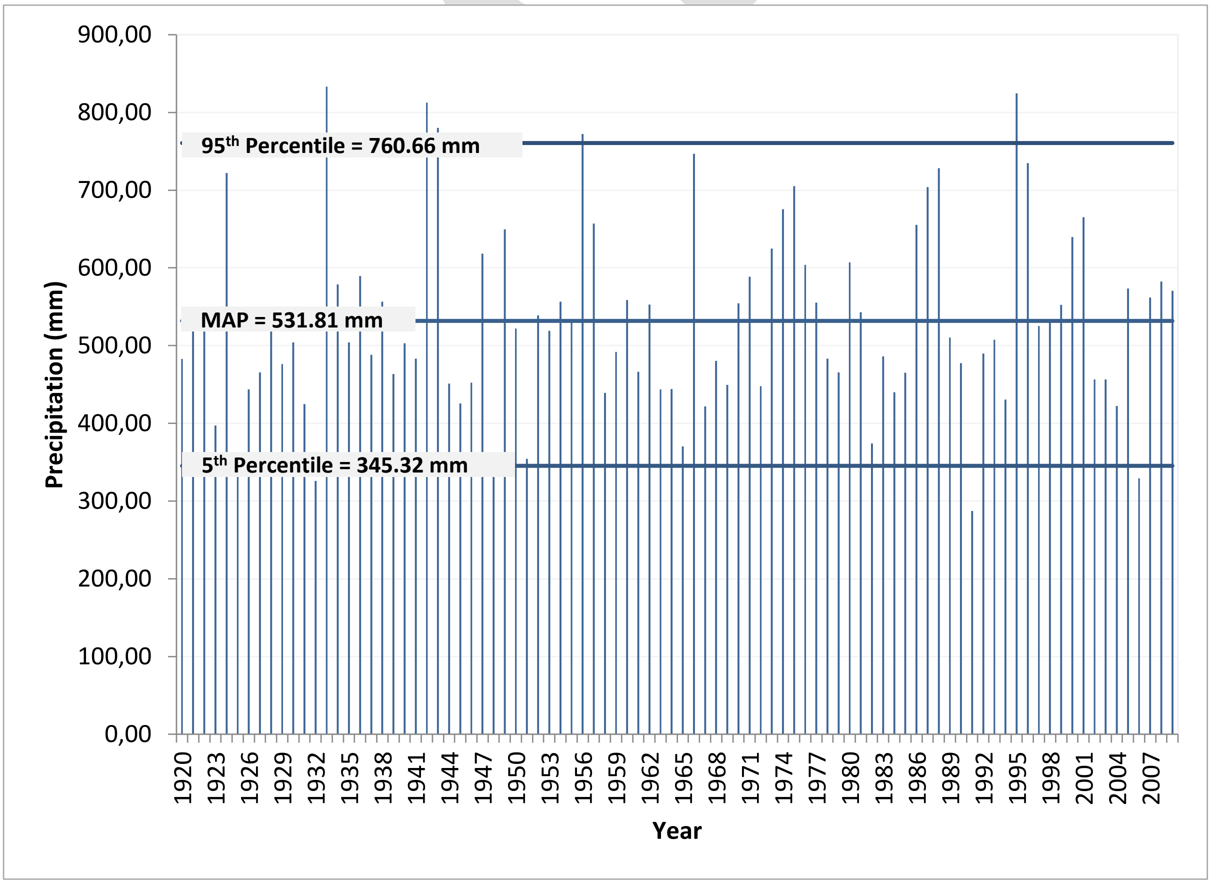


Figure 5-8 **Yearly Precipitation Distribution, 1920 – 2009 (WRC, 2016).**

5.3. Geological setting

The following sections summarises the regional and local geology.

5.3.1. Regional geology

According to the Council for Geoscience (CGS) 1:250 000 geological maps (Geological Map Sheet 2726 Kroonstad and Geological Map Sheet 2826 Winburg) the surface geology of the study area is characterized by a variety of lithologies, formations, and intrusions. These include geologically recent Quaternary deposits; sediments of the Beaufort and Ecca Groups within the Karoo Supergroup; dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite; and post-Karoo kimberlite pipes and dykes. Refer to **Table 5-2** for a summary of the lithostratigraphy of the study area while **Figure 5-9** depicts the regional geology and stratigraphy.

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

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

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

A vast network of dolerite dykes, sheets, and sills associated with the Karoo Dolerite Suite occurs throughout the study area and is especially prominent in the southern and central parts of the study area. The Karoo Dolerite Suite intruded into the Karoo Supergroup approximately 180 million years ago during the early stages of the break-up of Gondwanaland (Woodford and Chevallier, 2002). Furthermore, kimberlite and associated alkaline-rich intrusive rocks, including carbonatite and olivine melelitite, intruded into the Karoo Basin between approximately 130 and 70 million years ago (Woodford and Chevallier).

Table 5-2 Simplified Lithostratigraphy of the Greater Study Area.

Age (Mya)	Supergroup	Group	Subgroup	Formation	Intrusions	Lithology
< 0.01	-	-	-	Quaternary Deposits	-	Aeolian sand, alluvium, calcrete and surface limestone
130 to 70	-	-	-	-	Kimberlite	-
180	-	-	-	-	Karoo Dolerite Suite	-
248 to 239	Karoo	Beaufort	Adelaide	-	-	Mudstone with subordinate sandstone
				Normandien	-	Mudstone, siltstone, shale, rhythmite, sandstone
290 to 248		Ecca	-	Volksrust	-	Mudstone, siltstone, shale

5.3.2. Structural geology

According to the CGS 1:250 000 geological maps (Geological Map Sheet 2726 Kroonstad and Geological Map Sheet 2826 Winburg) dolerite dykes associated with the Karoo Dolerite Suite occur toward the northeast (NS trending), central west (NE trending), and southwest (EW trending) of the study area. Large dolerite intrusions in the form of dykes and sills are observed throughout the study area. The Karoo sediments in this portion of the WMA are much intruded by sub accordant sheets, and to a lesser extent by near-vertical dykes of Karoo dolerite (DWAF, 2004). The Karoo Basin is characterised by a vast network of post-Karoo intrusive dolerite (Jd) sills and dykes that rapidly intruded at 183.0 to 182.3Ma (Svensen et al., 2012). The intrusive Karoo dolerite suite represents a shallow feeder system which occurs as an interconnected network of dykes, sills as well as sheets which typically form resistant caps of hills compromising softer sedimentary strata (Chevallier and Woodford, 1999). Exploration data evaluated suggest dykes are relatively thin, usually not wider than 5.0m while sills may be as thick as 100.0m. The maps further indicate that three kimberlite pipes occur toward in the central west of the study area with a kimberlite dyke (NNW trending) located between the pipes, while another kimberlite dyke (EW trending) occurs in the southwestern parts of the study area. Furthermore, structural analysis provided by the applicant indicates that five faults run across the study area, four trending NE and one trending SSE. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

5.3.3. Soils

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

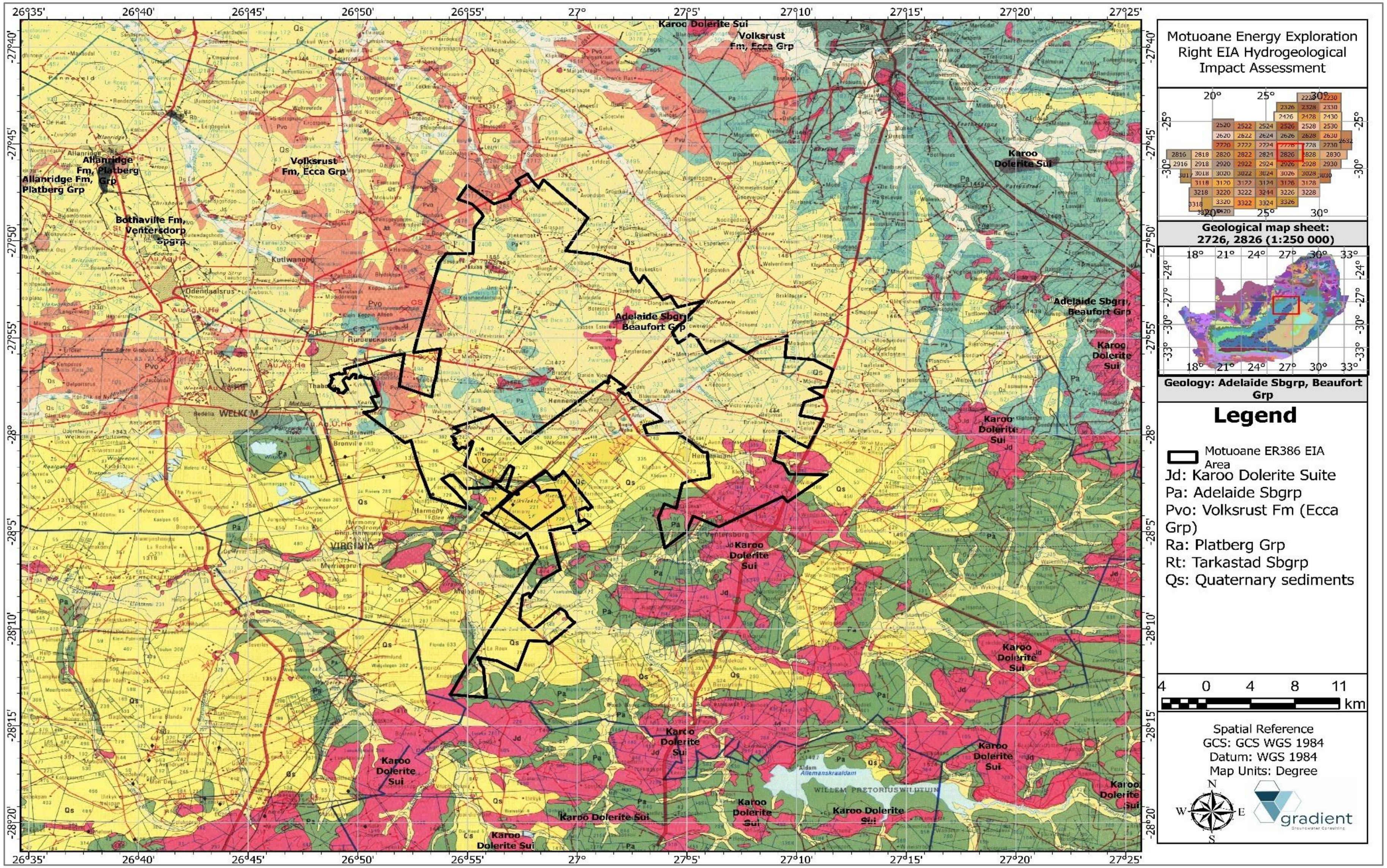


Figure 5-9 **Regional geology and stratigraphy (Geological map sheet 2726: Kroonstad and 2826: Winburg)(1:250 000 scale).**

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

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

6.1. Regional hydrogeology

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

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

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2726 Kroonstad) the study area is predominantly underlain by a Class d2 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.1 and 0.5 L/s), while small portions towards the northwest of the study area are underlain by a Class d3 intergranular and fractured aquifer (typically associated with median borehole yields ranging between 0.5 and 2.0 L/s). Both the Class d2 and Class d3 aquifers consist of primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. Most hard-rock aquifers are secondary in nature with groundwater associated with fracturing, fault zones as well as contact zones of the dolerite intrusions. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however will not only be multi-layered, but also multi-porous with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. The Ecca Group aquifers consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, it should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc. (Barnard, 2000).

According to Vegter's groundwater regions delineated (2000) the study area can be classified as falling under the Northeastern Upper Karoo Region (Region 30) towards the central, eastern and southern areas whereas the northern and northwestern section forming part of the Northeastern Pan Belt Region (Region 33). Groundwater Region 33 comprises of mudstone and sandstone (with dolerite dyke and sill intrusions) of the Adelaide and

Tarkastad Subgroups within the Beaufort Group of the Karoo Supergroup (WRC, 2016). The maximum aquifer thickness i.e., shallow, intergranular aquifer system within the Northeastern Pan Belt Region is <20m while the maximum aquifer thickness within the Northeastern Upper Karoo Region is slightly thicker at 20 – 30m with water stored mainly in decomposed/partly decomposed rock and water bearing fractures principally restricted to a shallow zone below the static groundwater level.The average groundwater level within Groundwater Region 33 is 14.90 mbgl, while the average saturated thickness of the weathered (shallow) and fractured (deeper) zones are 22.60 m and 75.00 m, respectively (WRC, 2016). Groundwater Region 30 comprises of compact, dominantly argillaceous strata of the Ecca Group within the Karoo Supergroup (WRC, 2016). The average groundwater level within Groundwater Region 30 is 18.20 mbgl, while the average saturated thickness of the weathered (shallow) and fractured (deeper) zones are 9.30 m and 185.00 m, respectively (WRC, 2016). Refer to **Figure 6-2** for a map illustrating the typical groundwater occurrence for the greater study area while **Figure 6-3** depicts the hydrogeological map of the greater study area.

6.2. Local hydrostratigraphic units

For the purposes of this investigation, three main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone[5]:

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

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

iii. **A deeper, fractured aquifer within the Ecca Group and pre-Karoo rocks:** In fractured aquifers, pores are well-cemented and do not allow any significant flow of water. Groundwater flow is dictated by transmissive secondary porosity structures such as bedding planes fractures, faults and contact zones fracture zones that occur in the relatively competent host rock. Fractured mudstone, sandstone, shales sequences as well as dolerite dykes and sills are considered as fractured rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone (shallow) aquifer. This aquifer system usually displays

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

semi-confined or confined characteristics with potentiometric heads often significantly higher than the water-bearing fracture position.

6.3. Unsaturated zone

The unsaturated (vadose) zone is defined as the subsurface zone between the ground surface and the main water table where pores are filled with both air and water as depicted in **Figure 6-1** (Fetter and Kreamer, 2023). According to WR2012 (WRC, 2016), the average thickness of the unsaturated zones of Groundwater Region 30 and 33 are 18.20 m and 14.90 m, respectively. According to the 1.0×1.0 km groundwater level grid obtained from WR2012 (WRC, 2016), the thickness of the unsaturated zone ranges between 15.98 to 56.82 m, with an average thickness of 29.48 m.

6.4. Groundwater-surface water interaction

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

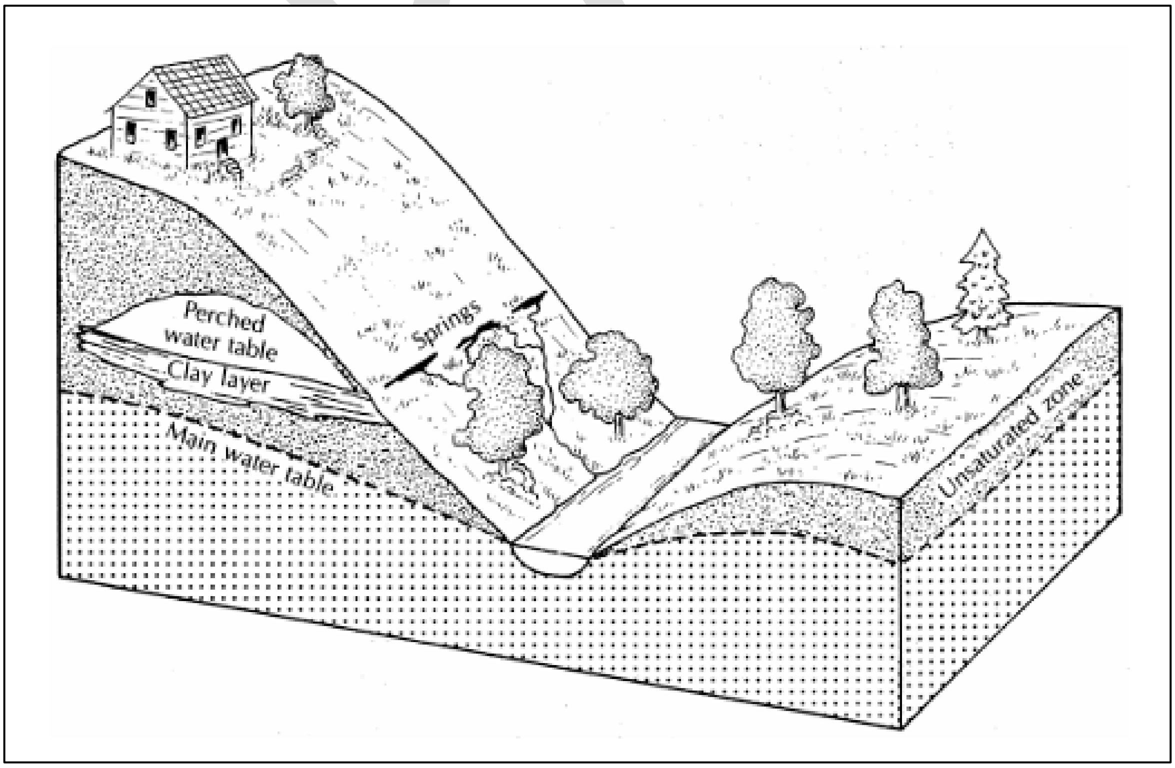


Figure 6-1 Illustration of the Unsaturated Zone (Fetter and Kreamer, 2023).

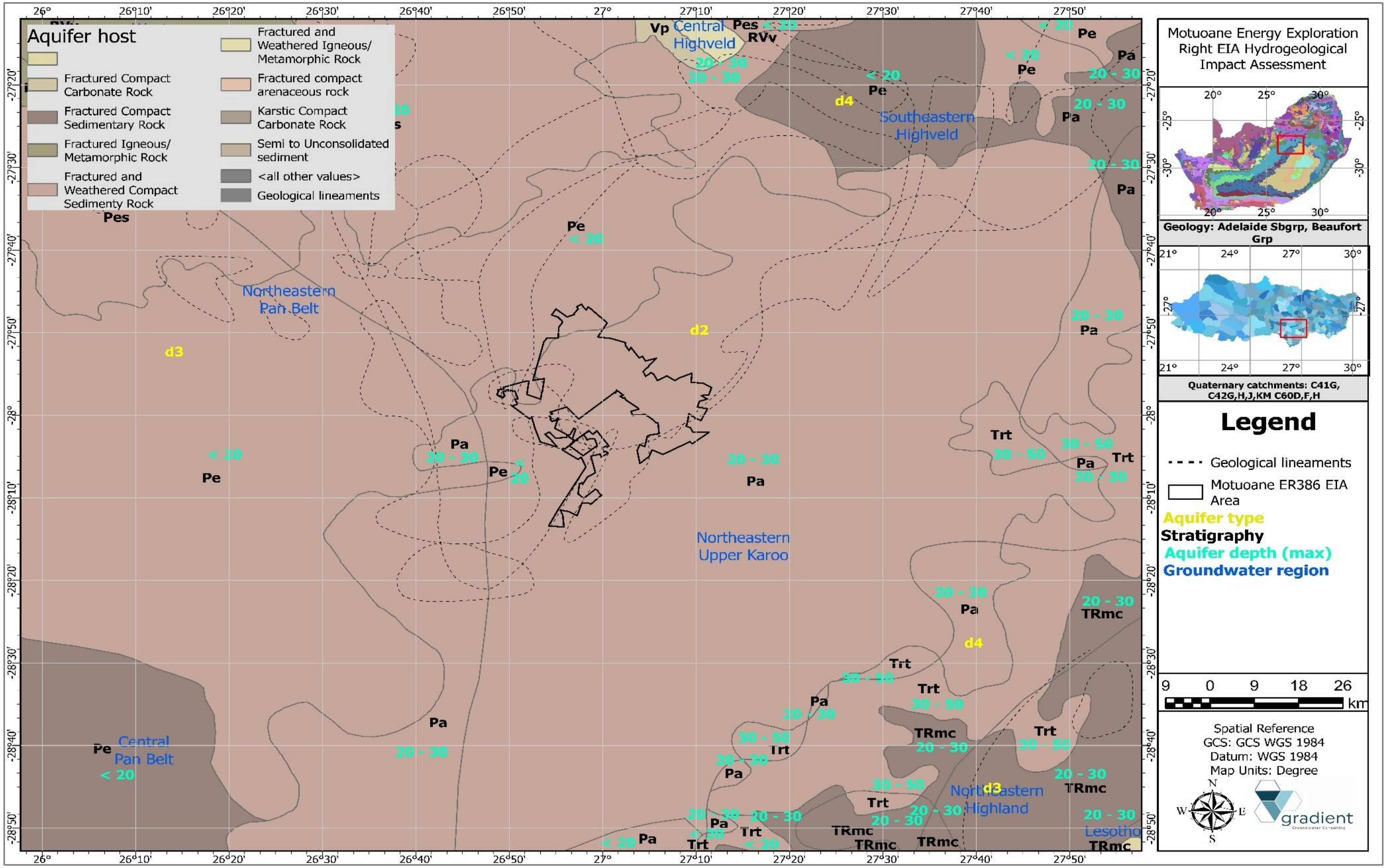


Figure 6-2 **Typical aquifer hosts and groundwater occurrence for the study region (2726 Kroonstad).**

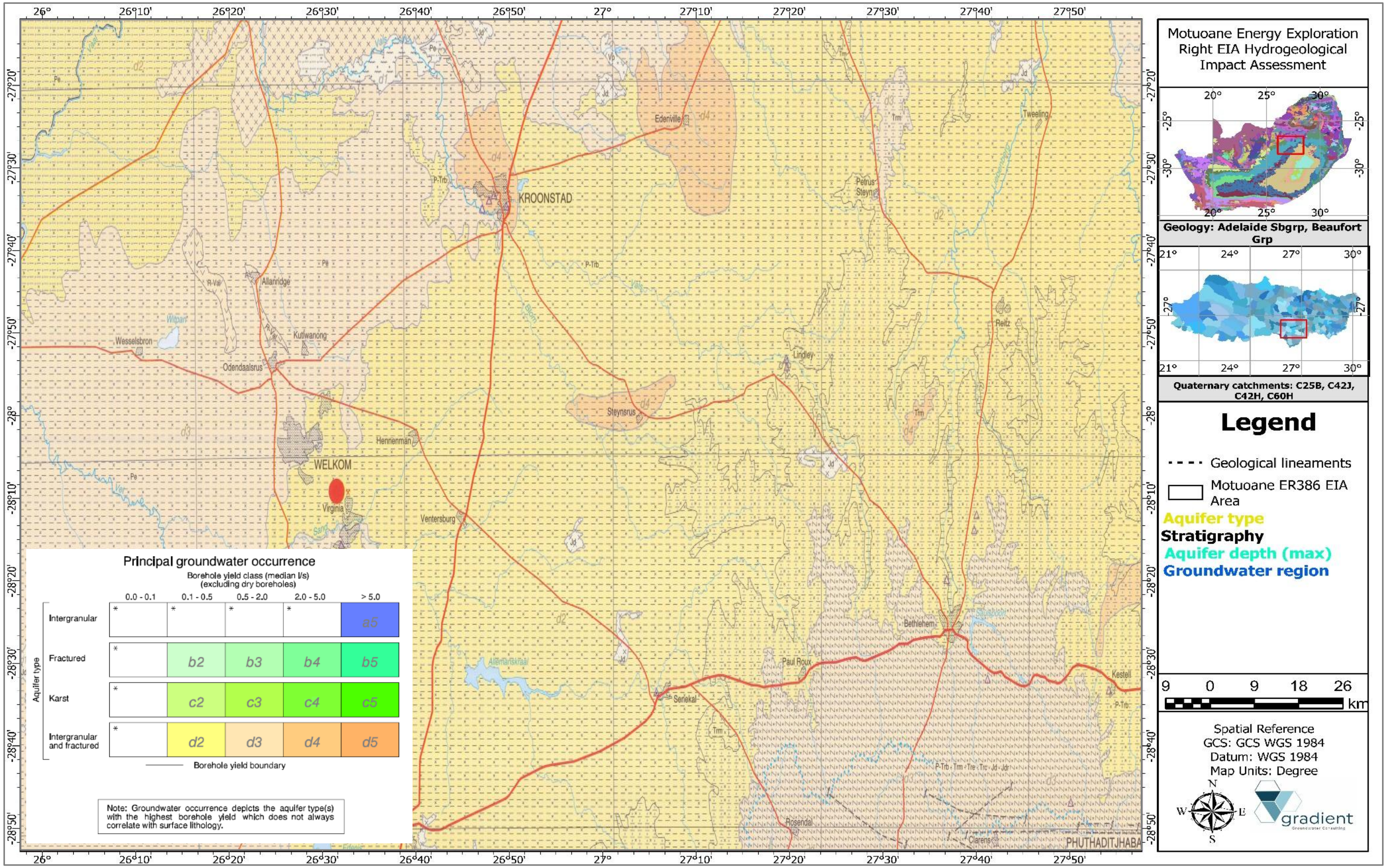


Figure 6-3 **Hydrogeological map of the greater study region (2726 Kroonstad).**

6.5. Hydraulic parameters

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

6.5.1. Hydraulic conductivity and Transmissivity

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

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

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

where:

K = Hydraulic Conductivity (m/d).

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

dh/dl = Hydraulic gradient.

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

The hydraulic conductivity of sedimentary formations such as evident on site can range from $10E^{-6}$ – $10E^{-2}$ m/d. The hydraulic conductivity of fractured igneous rocks (i.e. dolerite) varies between $10E^{-6}$ – $10E^{-1}$ m/d, while conductivity values for un-fractured igneous rocks (i.e. fresh dolerite sill) ranges between $10E^{-9}$ – $10E^{-6}$ m/d. The hydraulic conductivity of quaternary deposits and alluvial pockets associated with the drainage system i.e., riverbed aquifers can be orders higher and can vary between $10E^{-2}$ – $10E^{1}$ m/d (Freeze and Cherry, 1979). Refer to **Figure 6-4** for the typical hydraulic conductivity values for on-site hydrostratigraphical units.

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

Equation 6-2 Transmissivity.

$$\boldsymbol{T} = \boldsymbol{Kb}$$

where:

T = Transmissivity (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

According to the transmissivity GIS data provided by WR2012 (WRC, 2016), the entire study area is underlain by a Class d2 intergranular and fractured aquifer with an average transmissivity of 17.5 m^2/day (WRC, 2016)[6].

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

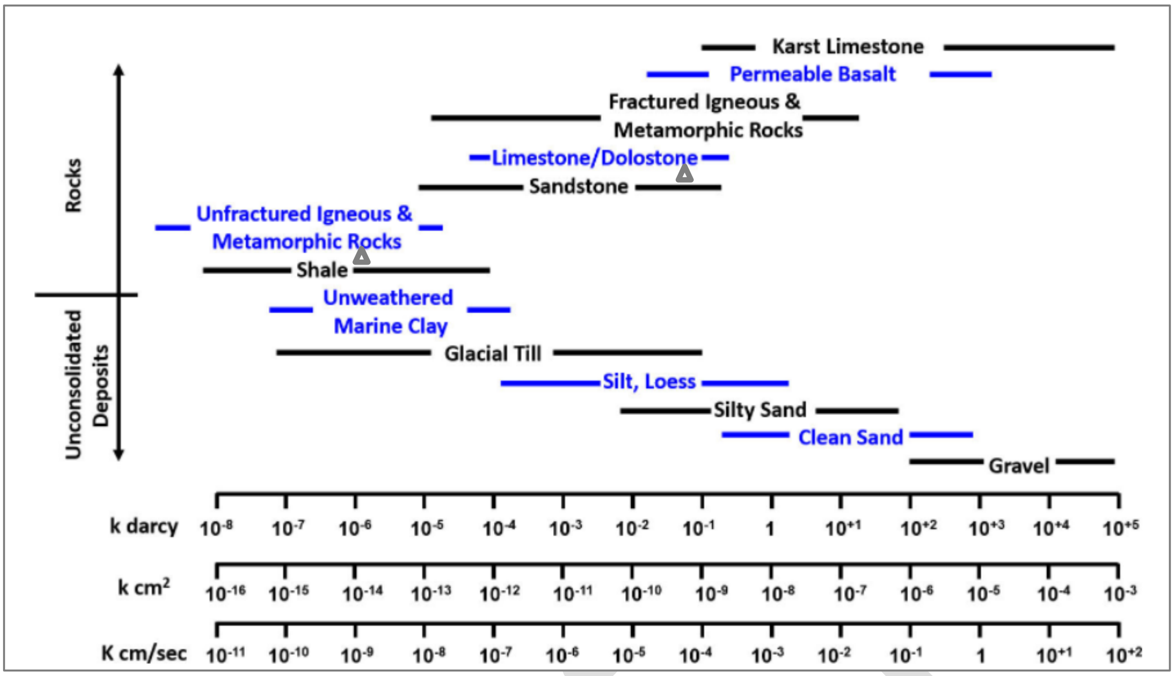


Figure 6-4 **Typical hydraulic conductivity values for on-site hydrostratigraphical units.**

6.5.2. Storativity

Storativity refers to the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. Typical storativity values for fractured rock systems is in the order of $10E^{-5}$ – $10E^{-3}$ (Freeze and Cherry, 1979). Storativity values of the shallow, weathered aquifer will be slightly higher i.e., $10E^{-2}$.

6.5.3. Porosity

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

6.5.4. Recharge

An approximation of recharge for the study area is estimated at ~3.50% of MAP i.e. ~19.48 mm/a as summarised in

Table 6-1. According to the 1 × 1 km recharge grid obtained from WR2012, the average recharge in the greater study area ranges is approximately 9.11 mm/a (WRC, 2016). Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Geology (ii) Vegter Groundwater Recharge Map (**Figure 6-5**) (iii) Harvest Potential (**Figure 6-6)** (iv) Baseflow as a minimum of recharge (v) Qualified opinion and, (vi) Literature review.

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

Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Geology	21.60	4.06	2.00
Vegter	25.00	4.70	1.00
Harvest Potential	20.00	3.76	2.00
Baseflow	15.00	2.82	2.00
Qualified Opinion	17.50	3.29	4.00
Literature	17.80	3.35	4.00
Weighted average	**19.48**	**3.50**	**15.00**

Notes: Recharge per annum were calculated using a MAP of 532.0 mm/a.

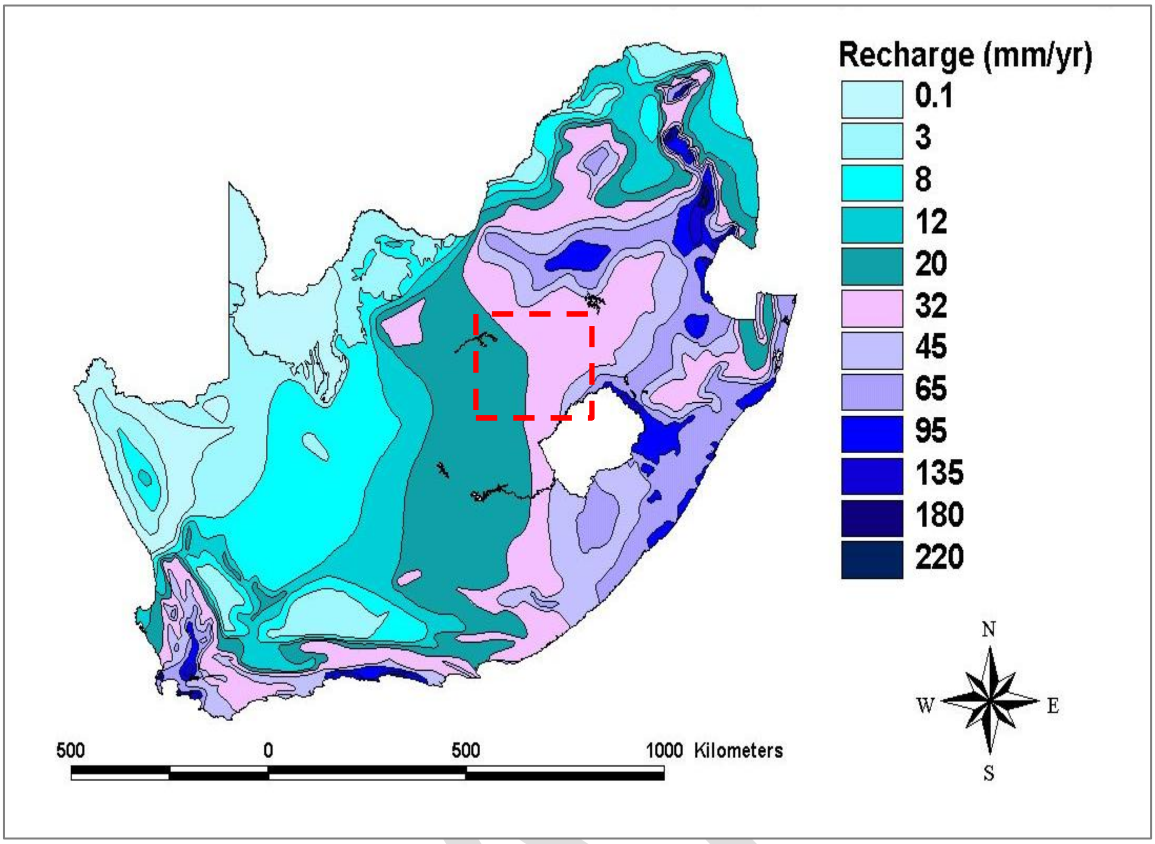


Figure 6-5 **Groundwater recharge distribution in South Africa (After Vegter, 1995).**

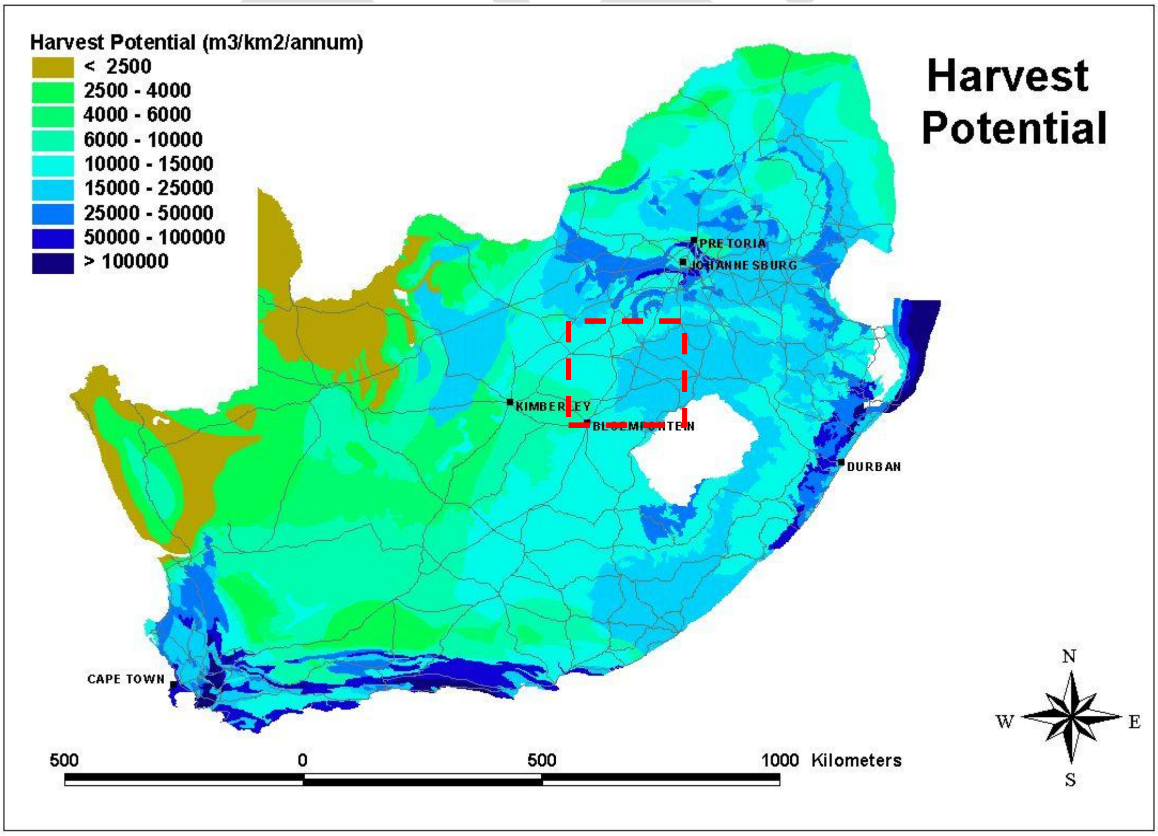


Figure 6-6 **Harvest potential distribution in South Africa (DWS, 2013).**

7. 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 7-1 GMQ Index.

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

7.1. 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 7-1** (DWS, 2013). The classifications and definitions for each aquifer system are summarised in **Table 7-1**.

Table 7-1 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.

7.2. 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 7-2** (DWS, 2013).

7.3. 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 7-3** (DWS, 2013).

Table 7-2 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**

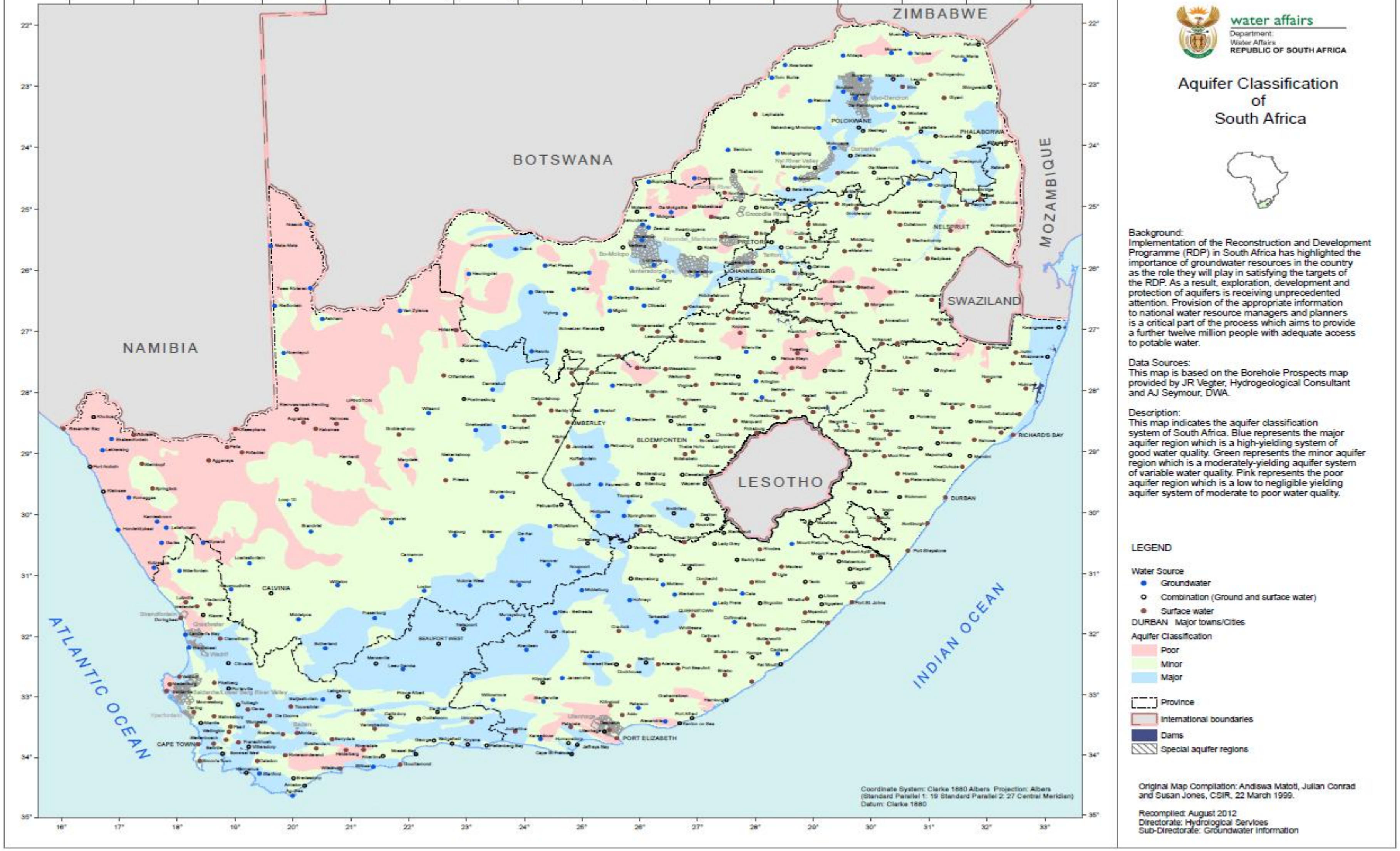


Figure 7-1 **Aquifer classification of South Africa (DWS, 2013).**

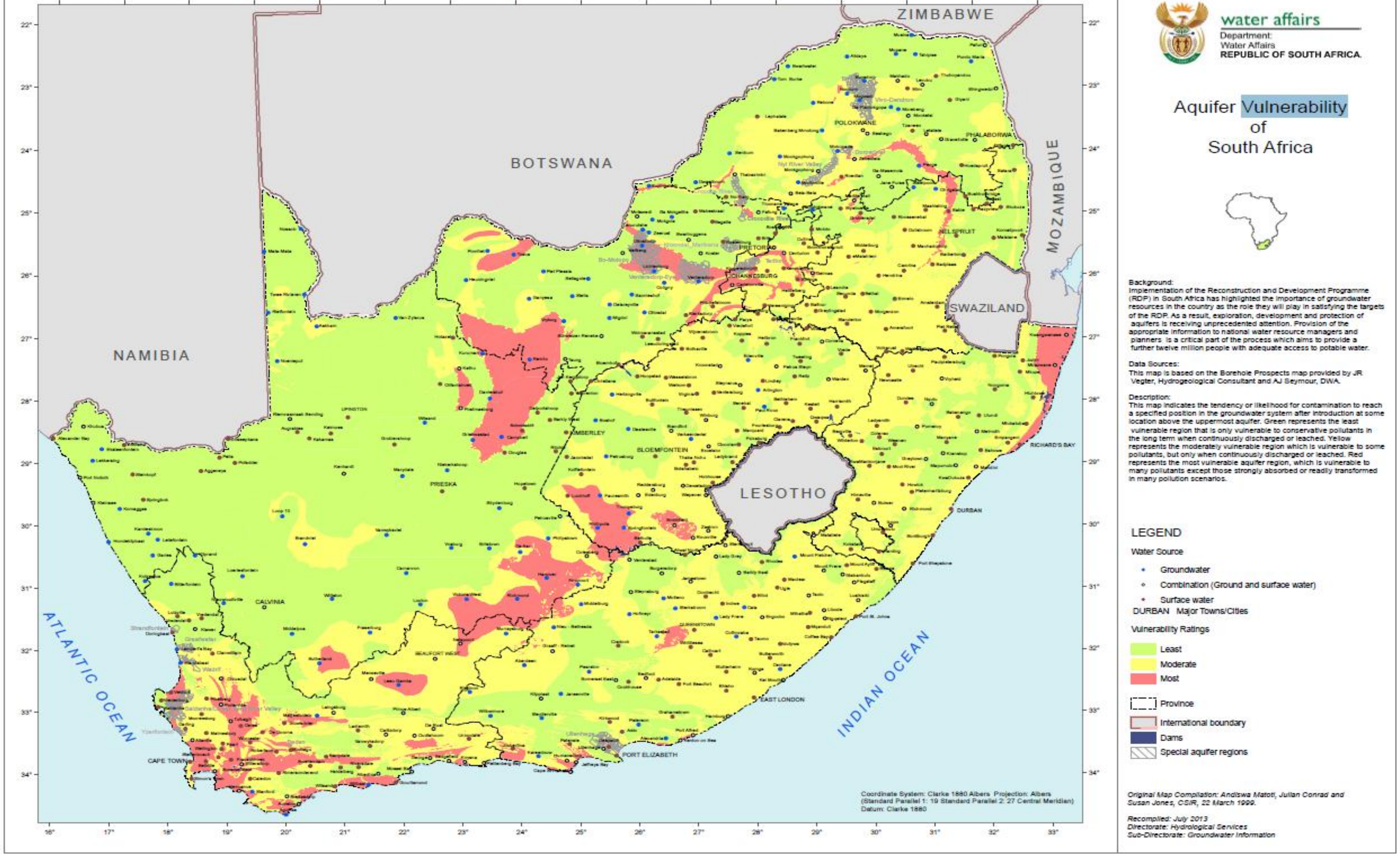


Figure 7-2 **Aquifer vulnerability of South Africa (DWS, 2013).**

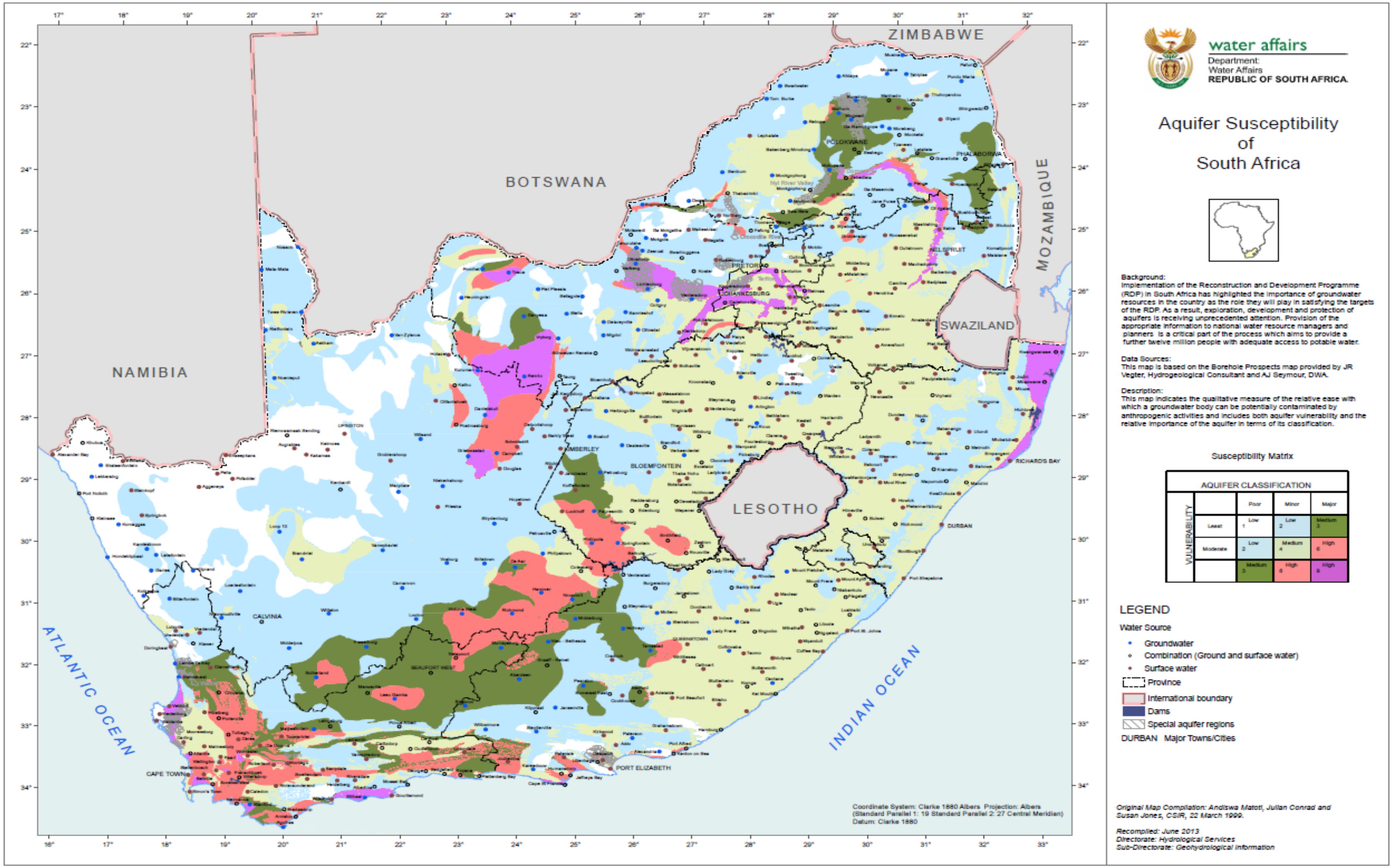


Figure 7-3 **Aquifer Susceptibility of South Africa (DWS, 2013).**

7.4. 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 7-4**).

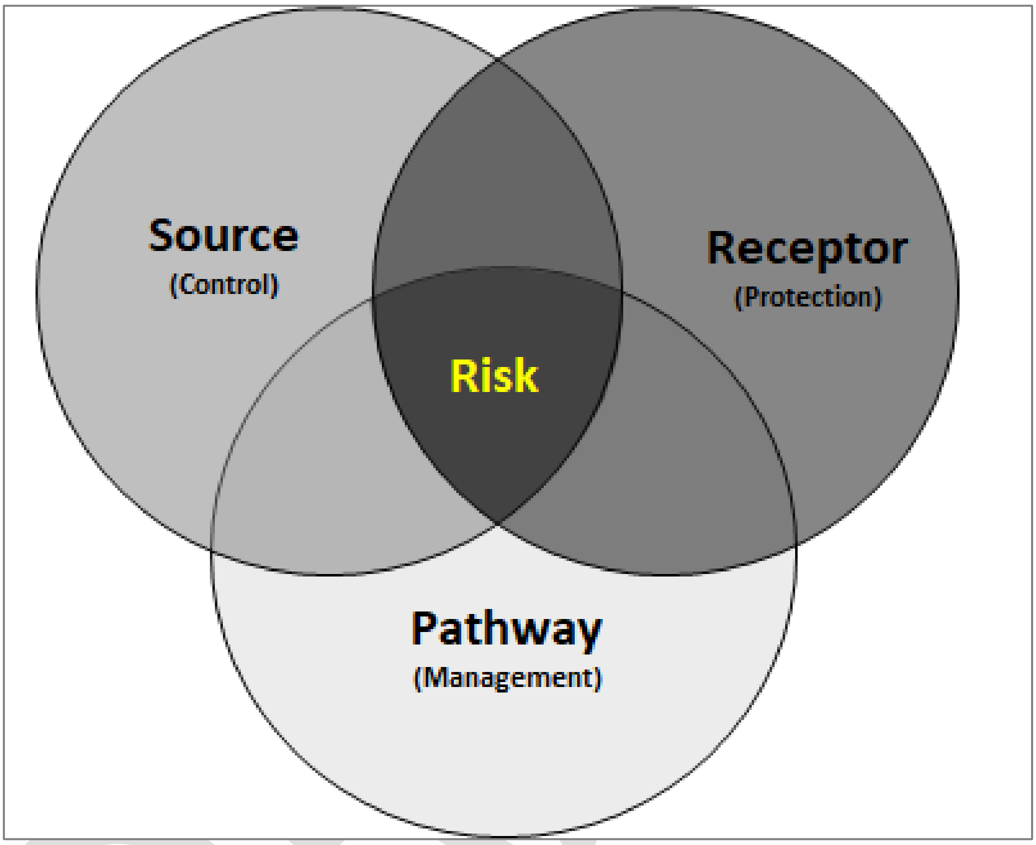


Figure 7-4 Source pathway receptor principle.

7.4.1. Potential sources

The following potential sources have been identified:

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

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

iii. Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.

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

7.4.2. Potential pathways

The following aquifer pathways have been identified:

i. Vertical flow through the unsaturated/vadose zone as well as saturated zone to the underlying intergranular and fractured rock aquifers. The rate at which seepage will take place is governed by the permeability of sub-surface soil layers and host-rock formations.

ii. Preferential flow-paths include the contact between the depth of weathering and fresh un-weathered rock, fractures, faults, joints and bedding planes. Secondary fractures may also potentially act as transport mechanisms.

iii. If not adequately sealed and suitably mitigated, gas exploration and exploration wells will form preferential flow paths and serve as a direct connection between the deeper, fractured aquifer and shallow, potable aquifer unit(s).

7.4.3. Potential receptors

The following receptors were identified:

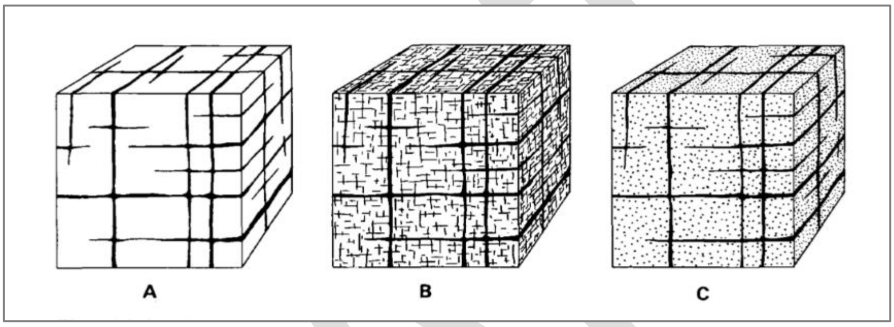
i. Shallow, inter-granular as well as the intermediate, fractured aquifer units situated within the plume migration footprint(s). The riparian zone aquifer associated with drainage patterns throughout the greater study area can also be viewed as a sensitive groundwater receptor.

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

8. 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 8-1** 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.



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

Figure 8-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

9. ENVIRONMENTAL IMPACT ASSESSMENT

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

9.1. 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.

9.2. 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 9-1 Impact Consequence.

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

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in **Table 9-1** below with **Table 9-2** summarising the probability scorings.

Table 9-1 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 9-2 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 9-2 Impact Consequence.

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

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25 as summarised in **Table 9-3**. These **ER** scores are then grouped into respective classes as described in **Table 9-4**.

Table 9-3 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 9-4 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.

9.3. 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 9-5**.

Table 9-5 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 9-3 Impact Consequence.

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

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

Table 9-6 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 9-7**), 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 9-7 Final Environmental Significance Rating.

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

The significance ratings and additional considerations applied to each impact will be used to provide a quantitative comparative assessment of the alternatives being considered. In addition, professional expertise and opinion of the specialists and the environmental consultants will be applied to provide a qualitative comparison of the alternatives under consideration. This process will identify the best alternative for the proposed project. **Figure 9-1** depicts preliminary hydrogeological sensitive areas identified.

9.4. Impact Identification and significance ratings

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

9.4.1. Construction phase: Associated activities and impacts

Potential impacts associated with the construction phase activities include the following:

i. Groundwater deterioration and siltation due to contaminated stormwater run-off from the construction area.
ii. Poor quality leachate may emanate from the construction camp which may have a negative impact on groundwater quality.
iii. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
iv. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.

9.4.2. Operational phase: Associated activities and impacts

Potential impacts associated with the operational phase activities include the following:

i. Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase
ii. Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
iii. Poor quality leachate may emanate from the plant footprint area which may have a negative impact on groundwater quality.
iv. Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.
v. Poor storage and management of hazardous chemical substances on-site may cause groundwater pollution.

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

Potential impacts associated with the post-closure and decommissioning phase activities include the following:

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

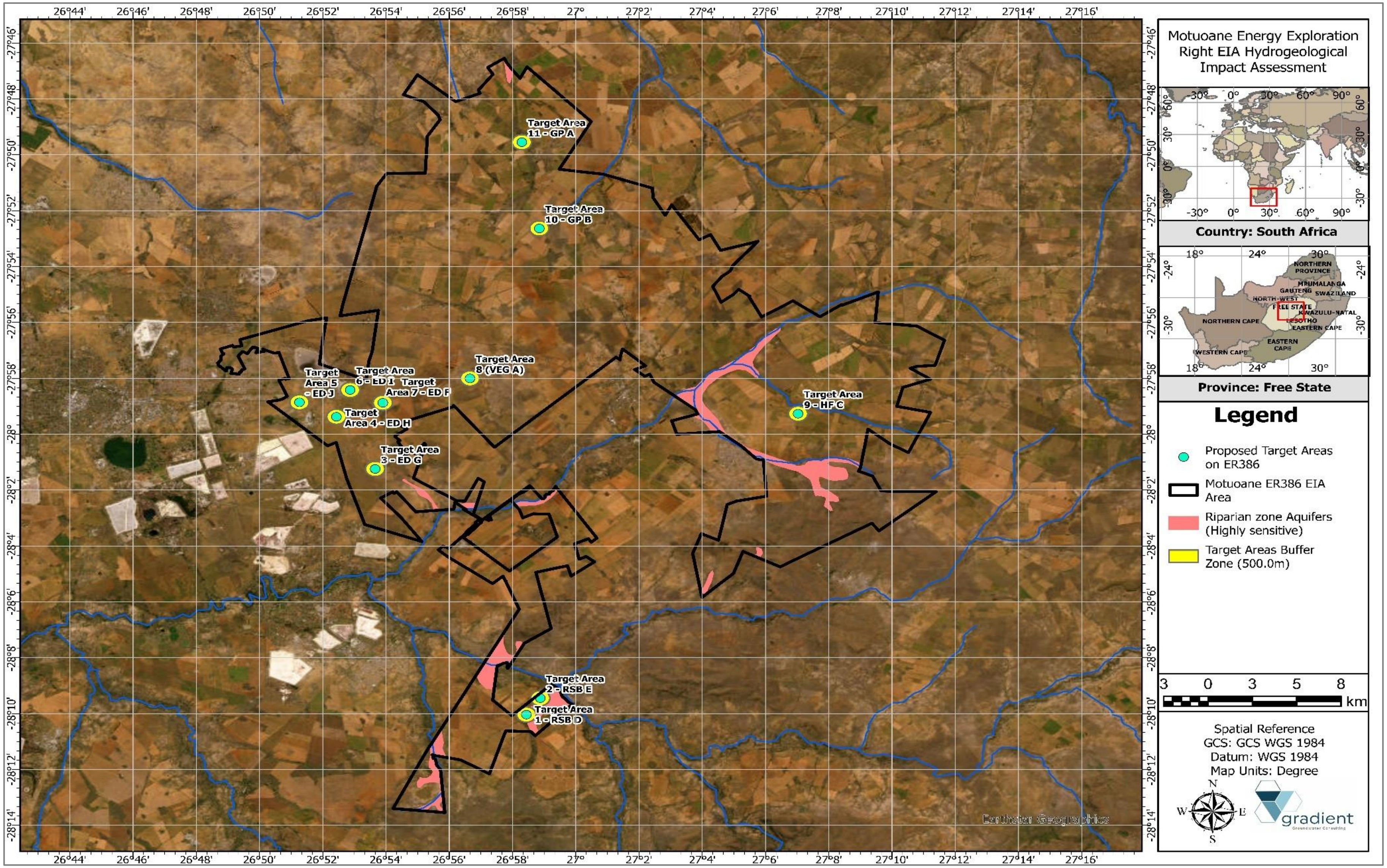


Figure 9-1 **Pre-liminary hydrogeological sensitivity map.**

10. MONITORING

A monitoring program consists of taking regular measurements of the quantity and/or quality of a water resource at specified intervals and at specific locations to determine the chemical, physical and biological nature of the water resource and forms the foundation on which water management is based. Monitoring programmes are site-specific and need to be tailored to meet a specific set of needs or expectations. DWAF Best Practice Guideline – G3: Water Monitoring Systems (DWA, 2006), as illustrated in Figure 10-1 used as guideline for the development of this water monitoring program.

1. DESIGNING OF MONITORING PROGRAM

1.1 Define the management actions of interest.
1.2 Define objectives of the intended management actions.
1.3 Define data requirements that support objectives.
1.4 Define location of monitoring points.

$\Big\}$ **Monitoring objectives**

1.5 Define parameters to be measured.
1.6 Define frequency of measurements.
1.7 Define data/information reporting requirements.

⇩

2. PROVIDE DETAILED IMPLEMENTATION PROCEDURES

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

⇩

3. DEVELOP DATA MANAGEMENT SYSTEM

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

⇩

4. AUDIT THE MONITORING PROGRAM

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

Figure 10-1 Monitoring programme (DWA, 2006).

10.1. 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.

11. CONCLUSIONS

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

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

ii. The topography of the greater study area generally has a jagged topography and can be classified as a central interior plain or plateau. Large dolerite intrusions are observed throughout the study area and because of its relative resistance to erosion, the Karoo dolerite sheets generally give rise to very prominent high-standing topographic features. Elevations generally increase towards the south and east of the study area, thus it can be assumed that, under natural circumstances, surface water and groundwater flow will be in a northwestern direction.

iii. The hydrology of the region is characterised by predominately perennial watercourses with the main rivers draining the greater study area in a general western to northwestern direction. It can be assumed that there will be groundwater contribution to baseflow.

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

v. Structural analysis indicates the presence of faults zones traversing the study area, trending NE as well as SSE. The latter may have an impact on the local hydrogeological regime as it can serve as potential mechanisms and preferred pathways for groundwater flow and contaminant transport.

vi. The study area is predominantly underlain by a Class d2 and d3 intergranular and fractured aquifers consisting primarily argillaceous (clay-containing) rocks, including shale, mudstone, and subordinate siltstone. Aquifer hosts in the Beaufort Group comprise of mudstone and sandstone intruded by dolerite dykes and sheets, however, will not only be multi-layered, but also multi-porous with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. The Ecca Group aquifers consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Accordingly, it can be assumed that the aquifer has a low development potential, it should however be noted that higher yielding boreholes (>5.0l/s) may occur along intruding dyke contact zones and other structural features i.e., fault zones etc.

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

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

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

ix. The average thickness of the unsaturated zones of Groundwater are between 14.90m to 18.20m while an approximation of recharge for the study area is estimated at ~3.50% of MAP i.e., ~19.48 mm/a.

x. The following potential sources have been identified:

- Migration of saline groundwater from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
- Migration of stray gas from the deep, fractured aquifer to the overlying, potable aquifer(s) during the gas exploration phase.
- Migration of contaminants from the plant footprint as well as associated waste facilities and infrastructure into local water resources and host aquifers.
- Mobilisation and maintenance of heavy vehicles and machinery on-site may cause hydrocarbon contamination of groundwater resources.

xi. The following potential aquifer **pathways** have been identified:

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

xii. The following potential **receptors** were identified:

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

12. RECCOMMENDATIONS

The following recommendations are proposed following this investigation:

i. It is recommended that this scoping report be incorporated into a detailed hydrogeological specialist investigation in order to verify sensitive environmental and groundwater receptors as well as confirm the proposed source-receptor-pathway mechanisms.

ii. Mitigation and management measures should be formulated and developed as part of the follow-up phase in order to minimize potential impacts of the proposed operations on sensitive environmental and groundwater receptors. Mitigation and management measures should be summarised in a water management plan which should be applicable to the construction, operational and decommissioning/ post-closure phases of the project.

iii. It is recommended that an integrated groundwater and surface water monitoring protocol and network be developed for implementation. It is imperative that monitoring be conducted to serve as an early warning and detection system.

iv. Pre-development monitoring can be considered in order to formulate a baseline to serve as benchmark going forward. Monitoring results should be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis and submitted to the Regional Head: Department of Water and Sanitation.

v. It should be considered to establish aquifer characterisation boreholes in order to obtain site representative hydraulic parameters for host classification and numerical groundwater model calibration purposes.

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

15. APPENDIX B: SPECIALIST CURICULUM VITAE

16. APPENDIX C: SPECIALIST DECLARATION FORM