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MAGATLE FILLING STATION HYDROGEOLOGICAL BASELINE INVESTIGATION AND IMPACT ASSESSMENT

October 2019

Conducted on behalf of:
Lokisa Environmental Consulting CC

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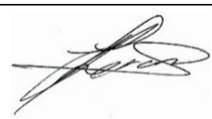
Signature:		**Signature:**	
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List of abbreviations

Avg	**=**	**Average**
BH	**=**	**Borehole**
DNAPL	**=**	**Dense non-aqueous phase liquids**
DRIT		**Double Ring Infiltration Test**
DWS	**=**	**Department of Water and Sanitation**
EC	**=**	**Electrical Conductivity (mS/m)**
FZ	**=**	**Fractured Zone**
ha	**=**	**Hectares**
GIS	**=**	**Geographic Information Systems**
GQM	**=**	**Groundwater Quality Management**
i	**=**	**Hydraulic gradient (dimensionless)**
K	**=**	**Hydraulic Conductivity (m/d)**
LNAPL	**=**	**Light non-aqueous phase liquids**
l/s	**=**	**Litre per second**
m^3/d	**=**	**Cubic meters per day**
MAE	**=**	**Mean Annual Evaporation**
mamsl	**=**	**Metres Above Mean Sea Level**
MAR	**=**	**Mean Annual Runoff**
mbs	**=**	**Metres Below Surface**
n	**=**	**Porosity**
NGA	**=**	**National Groundwater Archive**
NGDB	**=**	**National Groundwater Database**
NWA	**=**	**National Water Act (Act 36 of 1998)**
PES	**=**	**Present Ecological State**
TDS	**=**	**Total Dissolved Solids**
TSS	**=**	**Total Suspended Solids**
SANS	**=**	**South African National Standards**
SANAS	**=**	**South African National Accreditation System**
SoW	**=**	**Scope of Work**
SW	**=**	**Surface Water**
T	**=**	**Transmissivity (m^2/d)**
WGS	**=**	**World Geodetic System**
WM	**=**	**With Mitigation**
WMA	**=**	**Water Management Area**
WOM	**=**	**Without Mitigation**
WZ	**=**	**Weathered Zone**

Executive summary

Project background

Wesst Consulting (Pty) Ltd. was appointed by Lokisa Environmental Consultants CC to conduct a hydrogeological baseline investigation and impact assessment for a proposed filling station and associated infrastructure on a portion of the farm Zebedielas' Location, Limpopo Province, South Africa. This report summarizes main findings and recommendations of the investigation.

Physiography

The site topography is relatively flat with the highest on-site topographical elevation point recorded at 908 mamsl and the lowest point at 904 mamsl. The site falls within quaternary catchment B51G that forms part of the Olifants water management area (WMA).

The calculated mean annual precipitation (MAP) is 528 mm/a. During the cold- dry winter, temperatures in the area can drop as low as 14.0°C on average during the day and reach as high as 25°C during the summer months. Geologically, the site is underlain by the Clarens Formation which is made up out of fine grained red and cream sandstone. Also underlying the site is the Ecca Group, which in turn comprises shale, sandstone, grit, conglomerate.

Hydrogeology

Two main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock can be classified as a secondary porosity aquifer. This aquifer is generally unconfined with phreatic water levels. Usually this aquifer is most susceptible to impacts from contaminant sources.

ii. A deeper fractured aquifer where groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

No site characterization i.e. pump tests were conducted to verify aquifer hydraulic parameters, however literature suggest that the yield of the underlying aquifer is anticipated to be along the vicinity of 10 480 $m^3/km^2/a$. While the available storage is expected to be 13 100 $m^3/km^2/a$ (DWAF, 2006). An approximation of recharge for the study area is estimated at 12 mm/annum.

Site investigation

A hydrocensus user survey was conducted in October 2019 during which relevant hydrogeological baseline information was recorded and samples collected for water quality analysis. Geosites logged include six (6) boreholes of which three (3) were sampled for water quality analysis.

Of the geosites recorded, the majority of water application is for water supply (66 %), where 17 % of boreholes sampled in the area are used for irrigation, and 17 % used for other purposes.

Hydrochemistry

The quality of groundwater samples analyzed is indicative of an overall moderate to poor water quality. Although the sampled water is classed as 'Soft and Neutral' (pH 6 > 8.5), with pH averaging 7.63, elevated salinity was found in all three samples as the Na & Cl significantly exceeded the SANS 241:2015 limits. Also exceeding these limits, are the EC and the TDS. This is indicative of a dry area with a low recharge, also seen in water which has been stagnant for extended periods.

Borehole H01-1284 was also analyzed for TPH content that indicated acceptable levels according to the World Health Organization (WHO) guidelines.

Contamination risk assessment

Geological and hydrogeological information obtained indicate that the DRASTIC Index (Di) lies between 1 – 100, suggesting that the overall potential for groundwater pollution is **low.** The GQM Index was calculated at 2 and as such a "**low**" level groundwater protection is required for this aquifer system.

Impact assessment

The main impacts associated with the construction phase activities include the following:

i. Erosion of site and siltation of surface water features.
ii. Oil, grease and diesel spillages, hydrocarbon contamination from construction vehicles and heavy machinery.
iii. Pollution of groundwater and surface water due to sanitation facilities and related anthropogenic activities.
iv. Groundwater and surface water pollution due to spillage of chemicals and building materials.

The main impacts associated with operational phase activities include the following:

i. Hydrocarbon pollution of groundwater (seepage/percolation) and surface water (drainage).
ii. Hazardous liquids and hydrocarbons spilled on surface will either run off the sealed areas into local surface water drainages or enter the sub-surface soil profile and percolate vertically down the vadose zone to the groundwater level. Light non-aqueous phase liquids (LNAPL's) i.e. petrol and diesel will be transported on the groundwater in an inferred easterly direction, while dense non-aqueous phase liquids (DNAPL's) such as oil will percolate through the vadose zone until solid bedrock is encountered where it will move along the bedding planes and through fractures.

The main impacts associated with the post-operational phase activities include the following:

i. Hydrocarbon pollution of groundwater and surface water.

Recommendations

The following recommendations are proposed following this investigation:

1. The following mitigation and management measures are recommended during the construction phase of the development:

   i. Excavations should be open for as short period as practically possible, while cleared and stripped areas should be vegetated as soon as possible.
   ii. Ensure vehicle and heavy machinery used on-site are regularly inspected for leaks and serviced at frequent intervals. Spill trays to be used where applicable.
   iii. Construction camp should be situated outside riparian buffer. Chemical sanitary facilities must be provided for construction workers and emptied on regular intervals.
   iv. All materials, fuels and chemicals must be stored in a secured, sealed and bunded area to prevent pollution from spillages and leakages. The use of chemicals should be controlled.

2. The following mitigation and management measures are recommended during the operational phase of the development:

   i. The use of all detergents, oil, fuels and chemicals which could potentially leach into underground water must be controlled. This can be done by sealing of the forecourt and refueling bay area to prevent infiltration of hydrocarbon into the aquifer underlying the site.
   ii. Storm water draining from the surfaced areas should be collected in a sealed sump to be treated or removed. All contact water should be discharged into the municipal system and not into any streams, or open fields.
   iii. Subsurface fuel storage facilities should be constructed in concrete encasements with a sump system to prevent spilled fuel from entering the soil and weathered rock. Storage facilities should also be fitted with a leakage detection system.
   iv. Fuel lines and dispensers should be rendered leak-proof by a competent person. Fuel pumped into underground fuel tanks should be accounted for, for the early detection of leakages.

3. The following mitigation and management measures are recommended during the post-operational phase of the development:

   i. Decommissioning of underground storage facilities, decommissioning must be approved and signed-off by a competent person.

4. It is recommended that groundwater monitoring as outlined in this report be conducted on a quarterly basis to serve as an early warning and detection system for the impact on environmental receptors and contaminant migration from the site.
5. Water monitoring results be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis.

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1. INTRODUCTION

1.1. Project background

Wesst Consulting (Pty) Ltd. was appointed by Lokisa Environmental Consultants CC to conduct a hydrogeological baseline investigation and impact assessment for a proposed filling station and associated infrastructure on a portion of the farm Zebedielas' Location, Limpopo Province, South Africa.

The objective of this assessment will be to provide more information on the status quo of the associated groundwater system, characterization of the site and aim to predict potential environmental impacts on the receiving environment as a result of the proposed activities.

1.2. Objectives

The objective of this study was to:

i. Establish site baseline and background conditions and identify potential environmental receptors.
ii. Aquifer classification, delineation and vulnerability rating.
iii. Calculation of soil permeability.
iv. Hydrogeological impact assessment and contamination risk matrix.
v. Formulation of best practise management and mitigation measures.
vi. Compilation of a surface water and groundwater monitoring program.

1.3. Terms of reference

The investigation was based on the terms of reference and scope of work as set out below.

1.4. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

i. Desk study and review of historical groundwater baseline information, specialist reports as well as DWS supported groundwater databases i.e. national groundwater archive (NGA) and National Groundwater Database (NGDB).
ii. Fatal flaw and gap analysis.

1.5. Phase B: Hydrogeological baseline investigation and site characterization - site visit and hydrocensus

Phase B will entail the following activities:

i. Site visit and hydrocensus user survey to evaluate and verify existing surface and groundwater uses, local and neighbouring borehole locations and depths, spring localities and seepage zones, regional water levels, abstraction volumes, groundwater application as well as environmental receptors in the vicinity of the proposed development.

ii. Sampling of existing boreholes and surface water resources according to best practise guidelines and analyses of samples to determine the macro and micro inorganic chemistry (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 spatial maps of the aquifer system, indicating aquifer delineation, groundwater piezometric map, groundwater flow directions and regional geology in relation to the development footprint.

vi. Desktop contamination risk assessment.

1.6. Phase C: Hydrogeological impact assessment and contamination risk matrix

Phase C will entail the following activities:

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

   a. Fatal flaw and gap analyses.
   b. Site baseline characterization.
   c. Field work summary and interpretation.
   d. Aquifer classification and vulnerability.
   e. Groundwater impact assessment and contamination risk assessment.
   f. Recommendation on best practice mitigation and management measures to be implemented.
   g. Contamination risk assessment.

ii. Development of a surface water and groundwater monitoring program.

1.7. Project assumptions and limitations

The following project limitations and assumptions were applicable for this investigation:

i. The findings recorded in this report are limited to site observations and do not represent time series monitoring data.

ii. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic data and 1:250 000 in terms of spatial geological data.

iii. Soil identified on site was done so through spatial data and related literature reviewed of the local and regional area.

iv. No pump tests and/or site characterisation were conducted to verify hydraulic parameters. Aquifer hydraulic parameters were based on literature values for similar environments.

1.8. Methodology

The assessment was initiated with a desk study in order to gather relevant geological and hydrogeological information for evaluation and interpretation. A hydrocensus user survey was subsequently undertaken in order to confirm the presence of potential environmental receptors in the vicinity of the project area, the determination of surrounding groundwater applications and associated hydrochemistry.

A site visit was conducted in order to identify the geological conditions on site. Data collected as part of the desktop assessment, hydrocensus user survey and site visit was evaluated and interpreted in order to formulate conclusions made and identify anticipated environmental impacts associated with the proposed activities. Data collected was further used to establish the vulnerability of the identified aquifer, aquifer classification and aquifer susceptibility. Aspects and their potential impacts were identified and rated using the PLOMP methodology. Mitigation measures were recommended in order to render the significance of impacts identified.

1.9. Declaration of Independence

Wesst Consulting (Pty) Ltd. is an independent consultancy and has no vested interest, be it business, financial, personal or other, in the proposed activity in respect of which they were appointed for, other than reasonable remuneration for worked performed.

2. SITE DESCRIPTION

2.1. Regional setting and locality

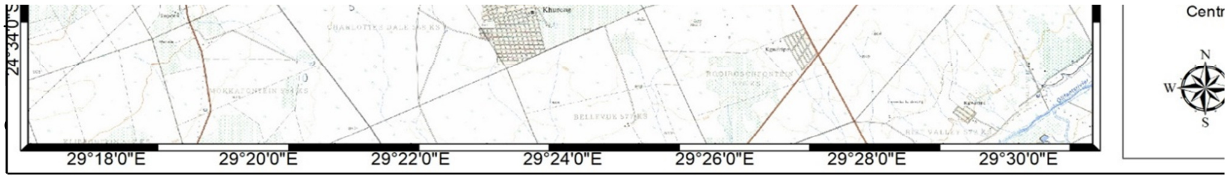


Figure 4 with general site coordinates listed in Table 1.

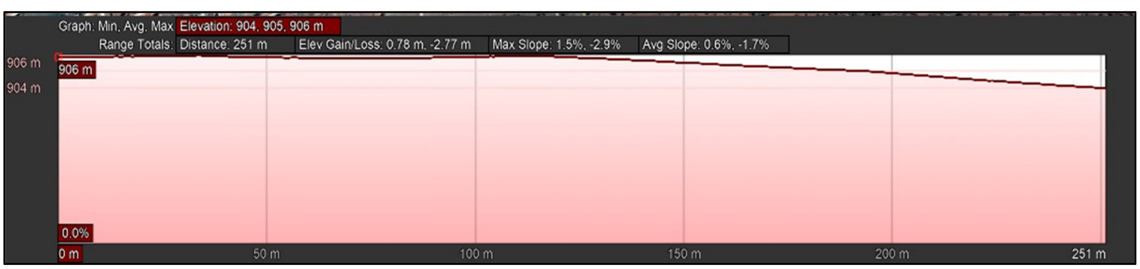
Table 1 Site coordinates Geographic Coordinate System: WGS 1984, Datum: D_WGS84

Latitude	S -24.459221°
Longitude	E 29.413645°

3. PHYSIOGRAPHY

3.1. Topography

The regional topography is relatively flat with slightly undulating plains and hills. The site itself is situated on a topography of approximately 906 mamsl (meters above mean sea level), slightly sloping in a south-eastern direction (refer to Figure 1 and Figure 2). The highest on-site topographical elevation point was recorded at 908 mamsl and the lowest at 904 mamsl, with an elevation loss of 2.5 m over a lateral distance of ~210 m (West-East); and 2.77 m over a lateral distance of ~250 m (North-South). The on-site slope is recorded at an average angle of < 0.6 %. Also refer to



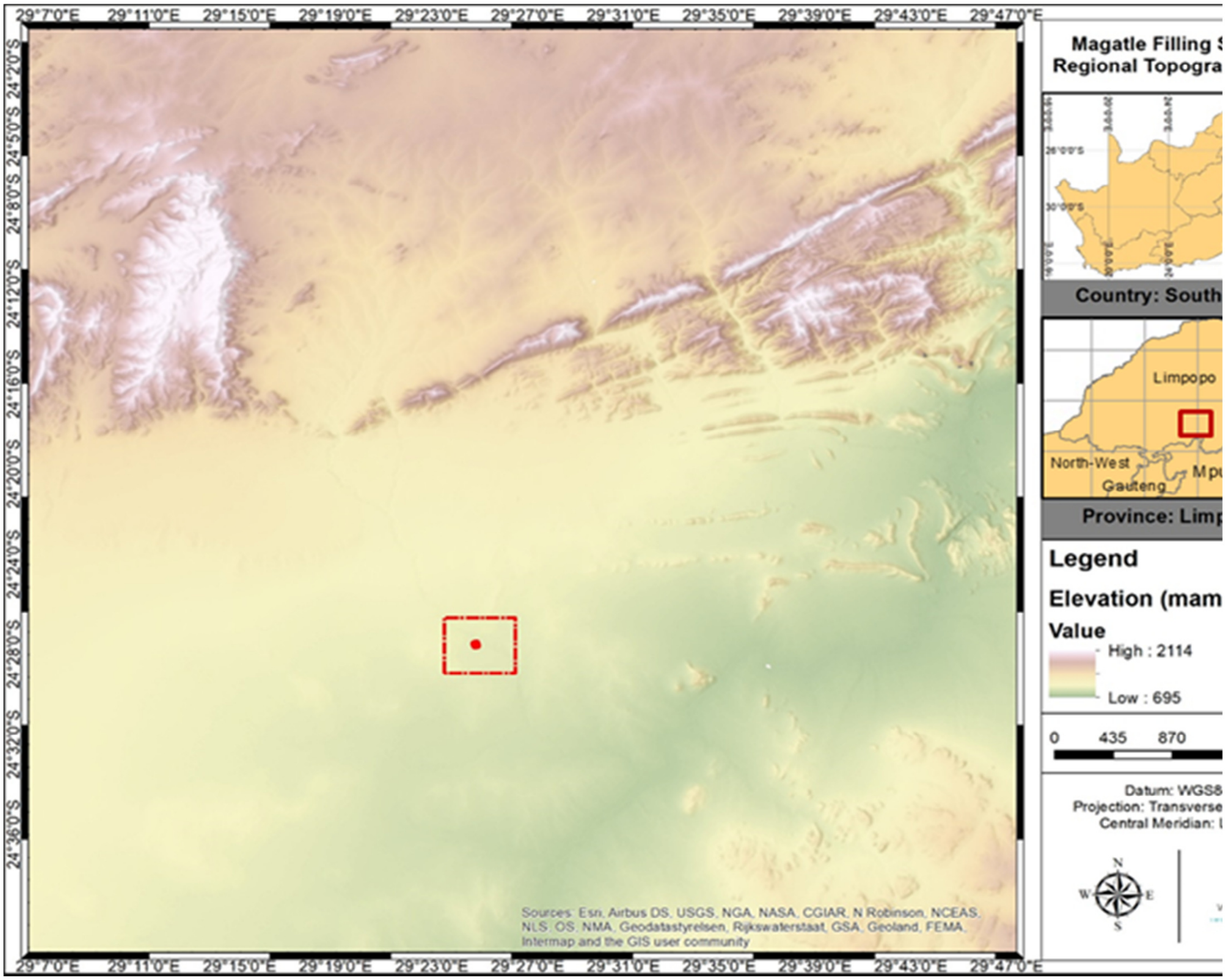
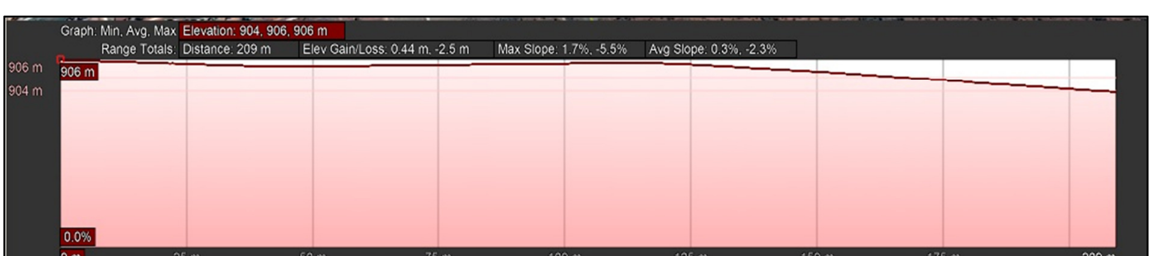


Figure 5 indicating the regional topography.

Figure 1 North-South elevation profile

Figure 2 West-East elevation profile



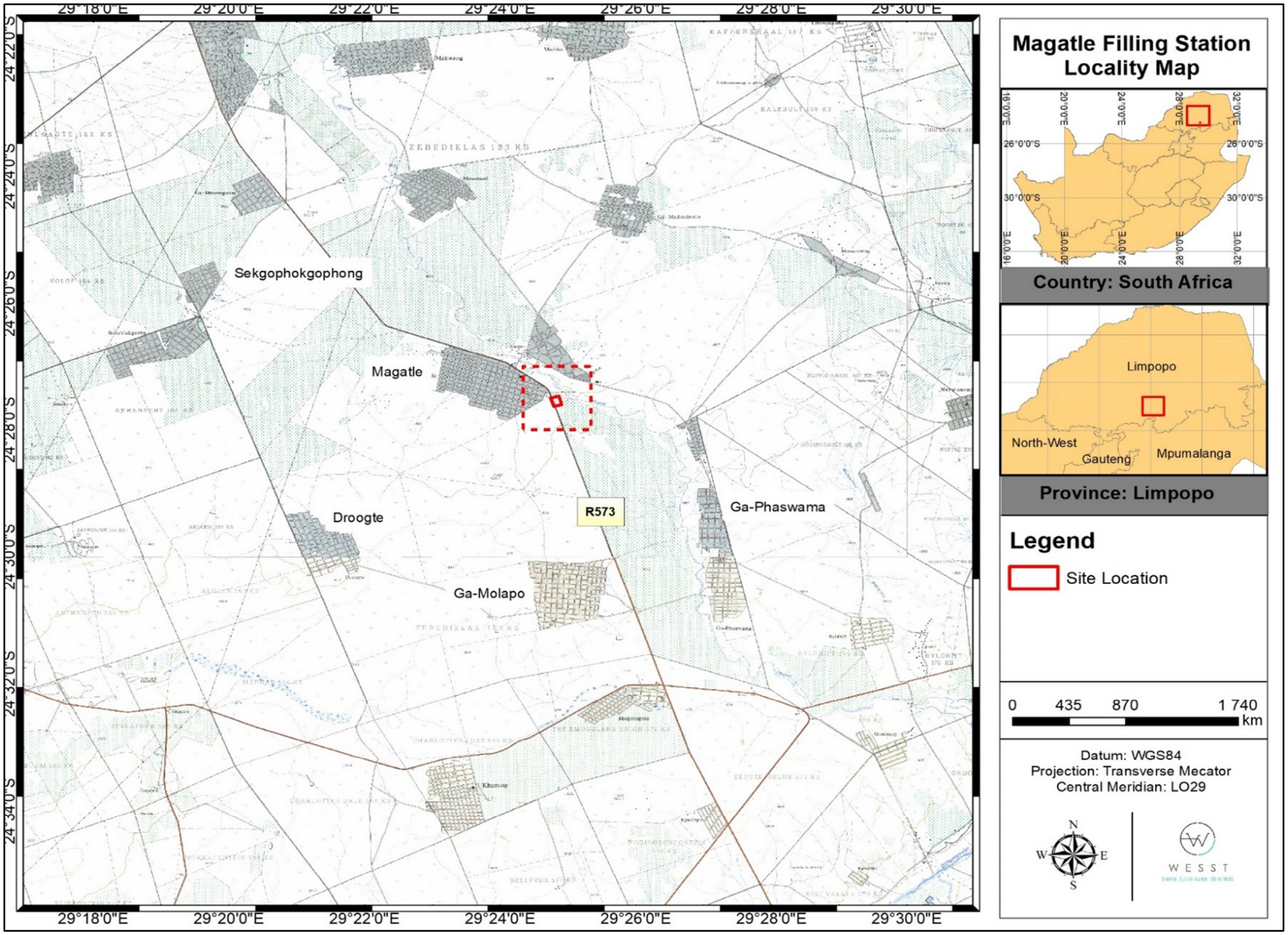

Magatle Filling Station
Locality Map
Country: South Africa
Limpopo
North-West
Gauteng
Mpumalanga
Province: Limpopo
Legend
Site Location
0 435 870 1 740
km
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
Sekgophokgophong
Magatle
Droogte
R573
Ga-Phaswama
Ga-Molapo
29°18'0"E
29°20'0"E
29°22'0"E
29°24'0"E
29°26'0"E
29°28'0"E
29°30'0"E
24°22'0"S
24°24'0"S
24°26'0"S
24°28'0"S
24°30'0"S
24°32'0"S
24°34'0"S

Figure 3 Site locality map and project boundary (Topographical mapsheet 2528CC, 1:50 000)

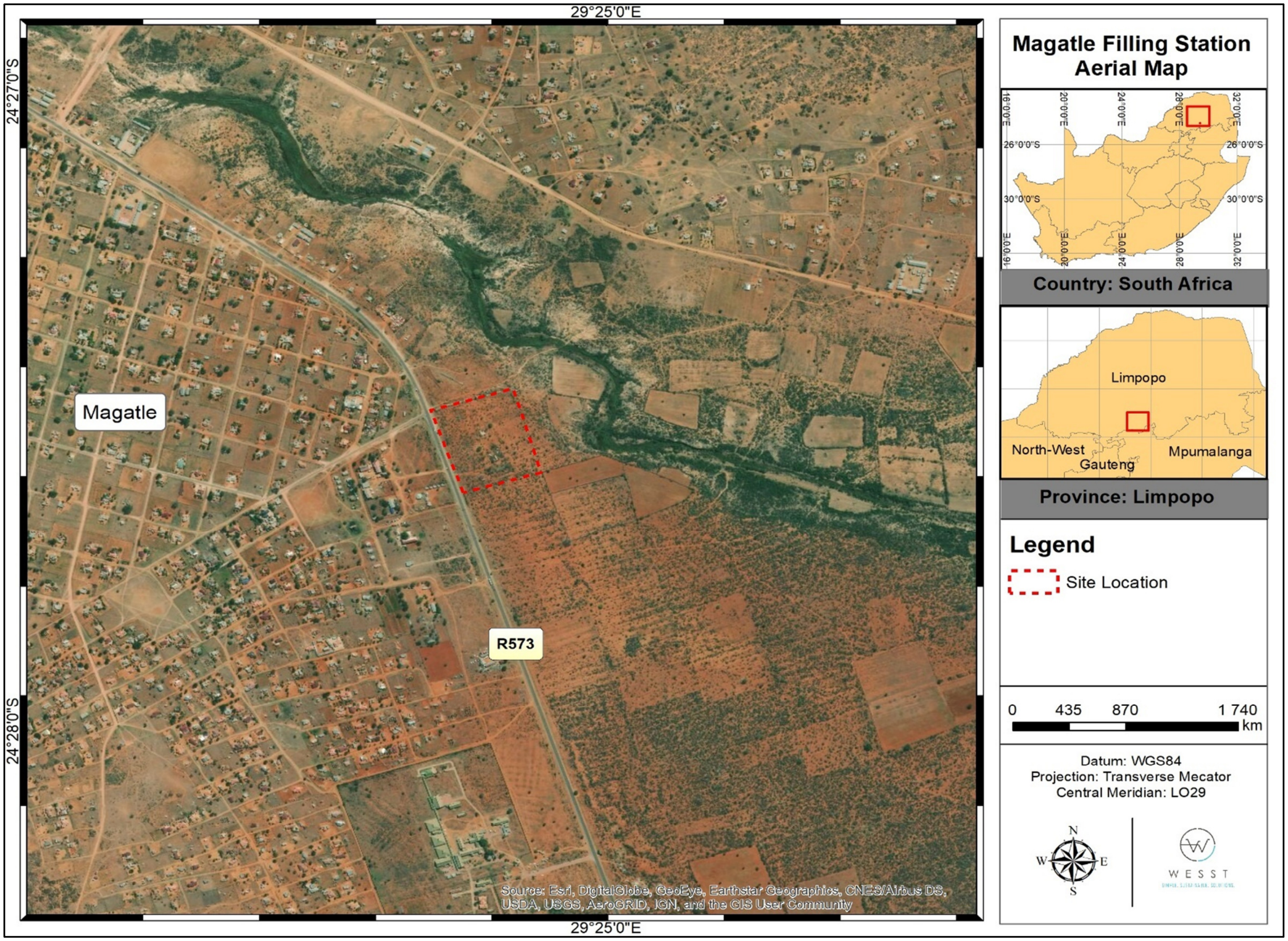

29°25'0"E
24°27'0"S
24°28'0"S
Magatle
R573
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Magatle Filling Station Aerial Map
Country: South Africa
Limpopo
North-West
Gauteng
Mpumalanga
Province: Limpopo
Legend
Site Location
0 435 870 1 740 km
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
WESST

Figure 4 Aerial image of the site

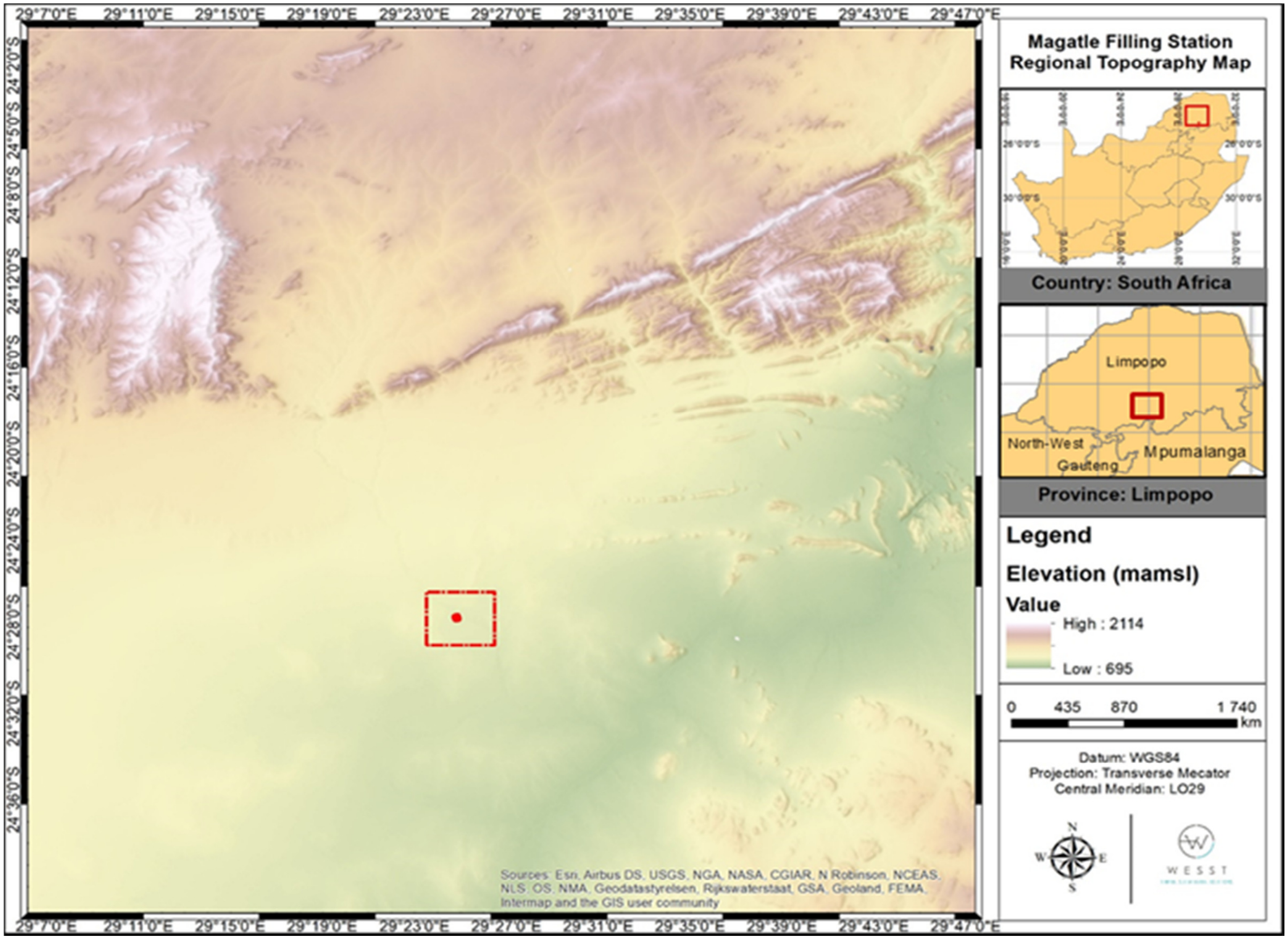
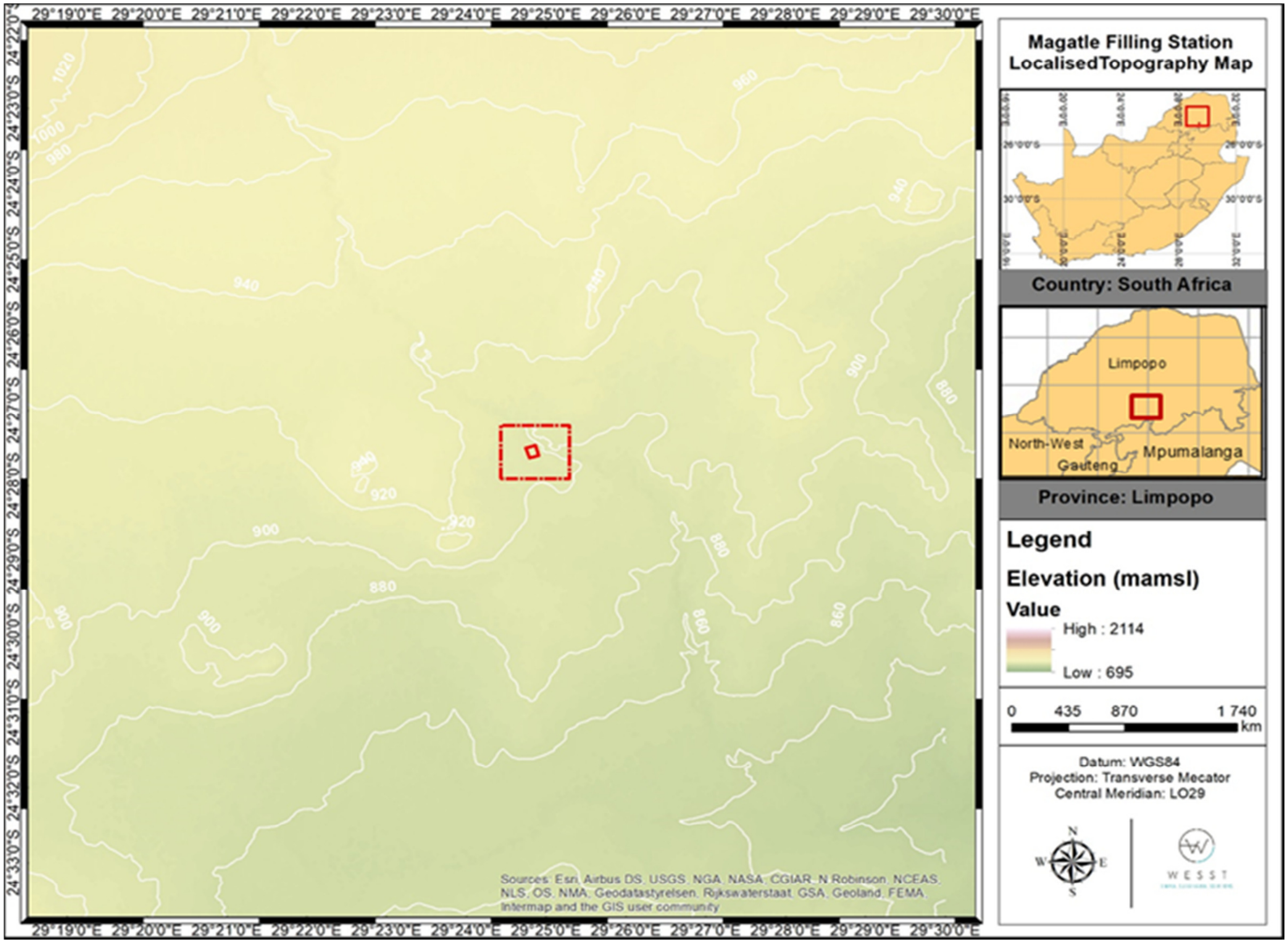

Magatle Filling Station
Regional Topography Map
Country: South Africa
Limpopo
North-West
Gauteng
Mpumalanga
Province: Limpopo
Legend
Elevation (mamsl)
Value
High : 2114
Low : 695
0 435 870 1 740
km
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
N
S
E
W
WESST
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community
29°7'0"E 29°11'0"E 29°15'0"E 29°19'0"E 29°23'0"E 29°27'0"E 29°31'0"E 29°35'0"E 29°39'0"E 29°43'0"E 29°47'0"E
24°2'0"S 24°5'0"S 24°8'0"S 24°12'0"S 24°16'0"S 24°20'0"S 24°24'0"S 24°28'0"S 24°32'0"S 24°36'0"S

Figure 5 Regional topography


Magatle Filling Station
LocalisedTopography Map
Country: South Africa
Limpopo
North-West
Gauteng
Mpumalanga
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Legend
Elevation (mamsl)
Value
High : 2114
Low : 695
0 435 870 1 740 km
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community

Figure 6 Local topograpy

3.2. Drainage and catchment

The project area is situated in primary catchment (B) and quaternary catchment B51G, covering and area of approximately 590 km^2, and falls within the Olifants Water Management Area (WMA). The Olifants WMA lies primarily within Limpopo, Mpumalanga and Gauteng Provinces.

Drainage in the catchment forms part of the Middle Olifants below Flag Boshielo Dam Integrated Analysis Area (IUA), which falls under a Water Management Class 3, which classifies it as 'heavily used and configuration of ecological categories of that water resource significantly altered from its pre-development condition (DWA, 2013). The Present Ecological State (PES) of the Olifants river is in an E category due to changes in flows as a result of the Flag Boshielo Dam and from agricultural impacts (DWA, 2013).

The IUA includes the major Olifants River that itself is a tributary of the great Limpopo River. Secondary rivers located within quaternary catchment B51G are the Doring-, Nkumpi- and the Mogoto rivers that converge to form a non-perennial river that flows past the site in a south eastern direction, towards the Olifants River and the Flag Boshielo reservoir dam.

Locally, surface water drainage drains towards the newly formed Nkumpi river that was formed through the confluence of first the Mogoto- and the Nkumpi rivers, and later with the Dorings river, where it ultimately flows into the Olifants River (refer to Figure 7). Surrounding surface water resources within the local and regional area are listed below.

Table 2 Local and regional surface water resources

Surface water resource	Distance from project site
Nkumpi River	0.18 km
Olifants River	17 km
Flag Boshielo Dam	35 km

3.3. Climate

The study area falls within a semi-arid climatic region and has a summer rainfall region where the mean annual precipitation (MAP) averages between 400 and 600 mm (Refer to Figure 8 and Figure 9). During the cold- dry winter, temperatures can drop as low as 14.0°C on average during the day and reach as high as 25°C during the summer months (Mucina & Rutherford, 2003). The average mean annual gross evaporation (as measured by A-pan) for the greater study area is estimated at 2200- 2400 mm/a.

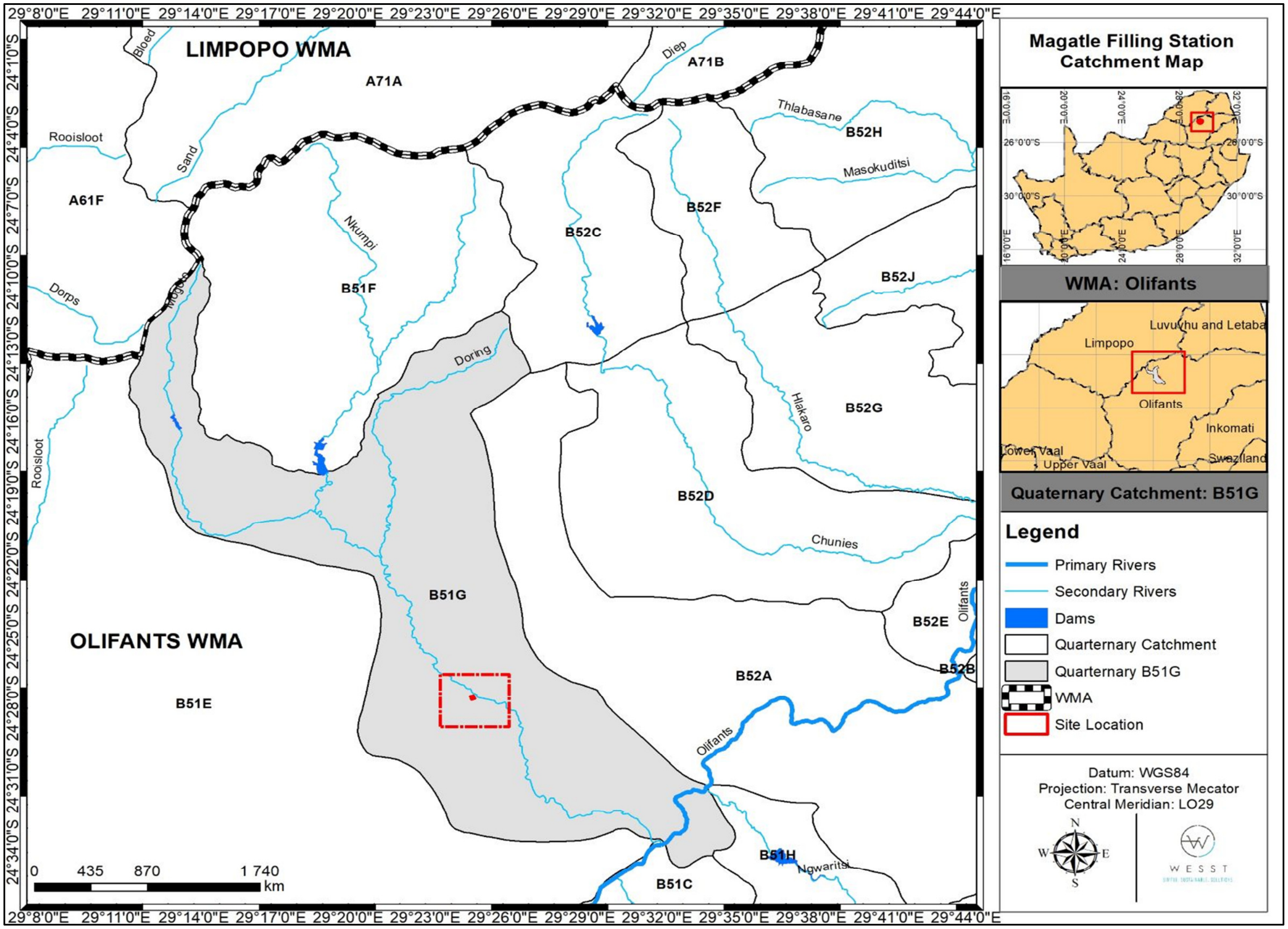

Magatle Filling Station Catchment Map
WMA: Olifants
Quaternary Catchment: B51G
Legend
Primary Rivers
Secondary Rivers
Dams
Quarternary Catchment
Quarternary B51G
WMA
Site Location
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
LIMPOPO WMA
OLIFANTS WMA
A71A
A71B
A61F
B51F
B51G
B51E
B51C
B51H
B52A
B52B
B52C
B52D
B52E
B52F
B52G
B52H
B52J
Limpopo
Luvuvhu and Letaba
Olifants
Inkomati
Lower Vaal
Upper Vaal
Swaziland
0 435 870 1 740 km

Figure 7 Catchment and water management areas

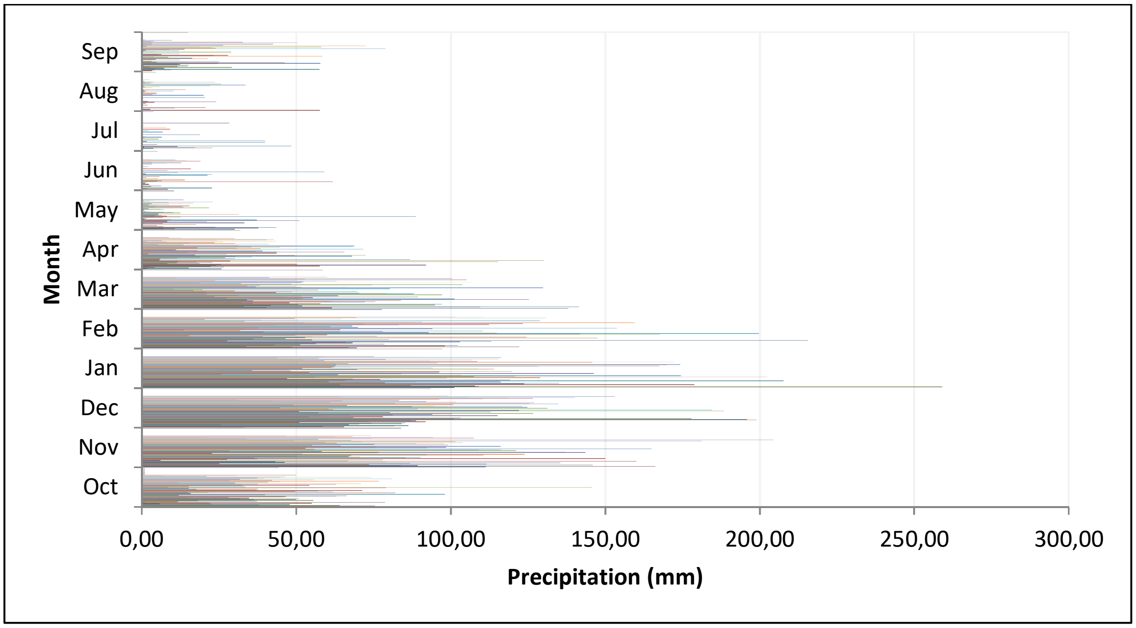


Figure 8 Bar chart indicating yearly rainfall distribution (1920 – 2009) (WR 2012)

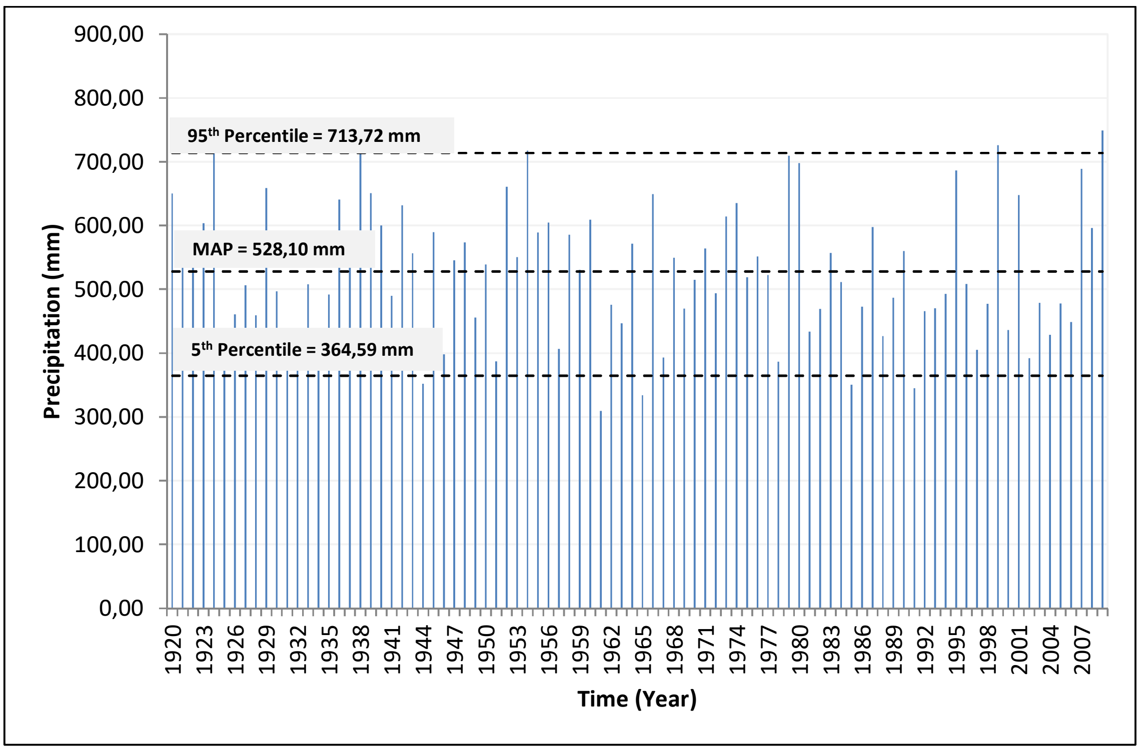


Figure 9 Bar chart indicating yearly rainfall distribution (1920 – 2009) (WR 2012)

3.4. Geological setting

3.5. Regional geology

The regional geology is made up out of the sediments and the rocks of the Karoo Supergroup. The Karoo Supergroup's strata mostly include shales and sandstones that were most likely deposited as marine glacial to terrestrial deposition and between the Late Carboniferous to the Early Jurassic time periods. These accumulated in a foreland basin called the main Karoo Basin (Adelmann & Fiedler, 1996). This basin is thought to form through the processes of subduction (convergence of plates, after which lower plate sinks) and orogenesis (convergence of plates and upwards thrusting to form mountain ranges) all along the southern border of Southern Africa. According to Adelmann and Fiedler (1996), the Super Groups' thickness is an approximate 12 km thick.

The major groups that form part of the Karoo Supergroup are the Drakensberg and the Lebombo Groups-, Dwyka-, Beaufort-, Ecca- and the Stormberg Groups. With the latter two relevant to the site area, shortly discussed below. Refer to Figure 10 for an indication of the regional geology.

3.6. Ecca Group

According to Ryan and Whitfield (1978), the sediments constituting the northern Ecca facies are confined to the northern one third of the basin and the estimated boundary with that of the central Ecca facies is taken as the southernmost limit at which sandstone occurs. The northern Ecca facies reaches a maximum thickness of about 1200 m in the Natal trough from where it thins out in the northerly and easterly direction.

The Upper Ecca Group in which the site is located, is composed of bluish-black shale and mudstone with occasional argillaceous sandstone and limestone. In Swaziland this unit is composed of carbonaceous shale, thick sandstone and coal seams. Nodules of calcium phosphate and calcium carbonate are common, and a further characteristic is the presence of ferruginous shale nodules and lenses which sometimes contain fossilized fish remains (Ryan & Whitfield, 1978).

The sediments of the Ecca Group contain significant reserves of coal and interbedded shale. This coal bearing fluvial deltaic, and peatbog settings are well known for the Ecca Group (Hobday, 1977).

3.7. Stormberg Group

The Stormberg Group is the uppermost geological group and represents the final phase of the sedimentation of the Karoo Basin (Bordy, 2005). The Group is composed of three main geological formations that are found in numerous localities across Lesotho, the Free State, KwaZulu-Natal, Eastern Cape and parts of Limpopo. These formations include:

- Molteno Formation;
- Elliot Formation;
- Clarens Formation.

The Clarens Formation (upon which the site is located) is composed primarily of fine to medium-grained, thickly cross-bedded sandstones that range in color from pale orange or pinkish to cream. It is characterized by its lithological uniformity and that its deposits mainly outcrop as high cliffs (Bordy, 2005). According to Smith *et al*., (1993), the Clarens Formation deposits have been categorized into three notable sedimentary facies, as summarized below:

Sedimentary Facies	Characteristics
Basal Zone 1	Thickly bedded, silt-rich sandstones with minor mudstone lenses. These are interbedded with lenticular sandstones that contain various ripple structures, calcareous concretions and clay-pellet conglomerates.
Middle Zone 2	Exhibits massive or large-scale planar or cross trough bedding structures. Well-sorted coarse sandstones that are composed either of quartz arenites or greywackes.
Upper Zone 3	Silty sandstones occur and grade laterally into fine-grained, massive, and immature sandstone beds. These massive sandstones contain quartz-rich feldspathic wackes and subordinate arkosic arenites.

3.8. Local geology

Geological mapsheet 2428 (Nysltroom, 1:250 000 scale) indicates that the proposed site is located directly on the border between the Stormberg Group and the Ecca Group, both units of the Karoo Super Group. The Clarens Formation which, as part of the Stormberg Group, underlies the northwestern corner of the site and is made up out of fine grained red and cream sandstone. The Ecca Group in turn underlies the majority of the site and comprises shale, sandstone, grit, conglomerate.

3.9. Structural geology

Faults (fractured zones) occur throughout the larger regional area, increasing in abundance more north towards the Chuniespoort Mountain range. Dolerite dykes belived to be formed in the Mokolian era (2050 +/- 0 To 900 Ma) also increase in abundance more north off the site.

Structurally, an inferred fault zone acting as border between the aforementioned Clarens formation and the Ecca group, directly intersects the site area.

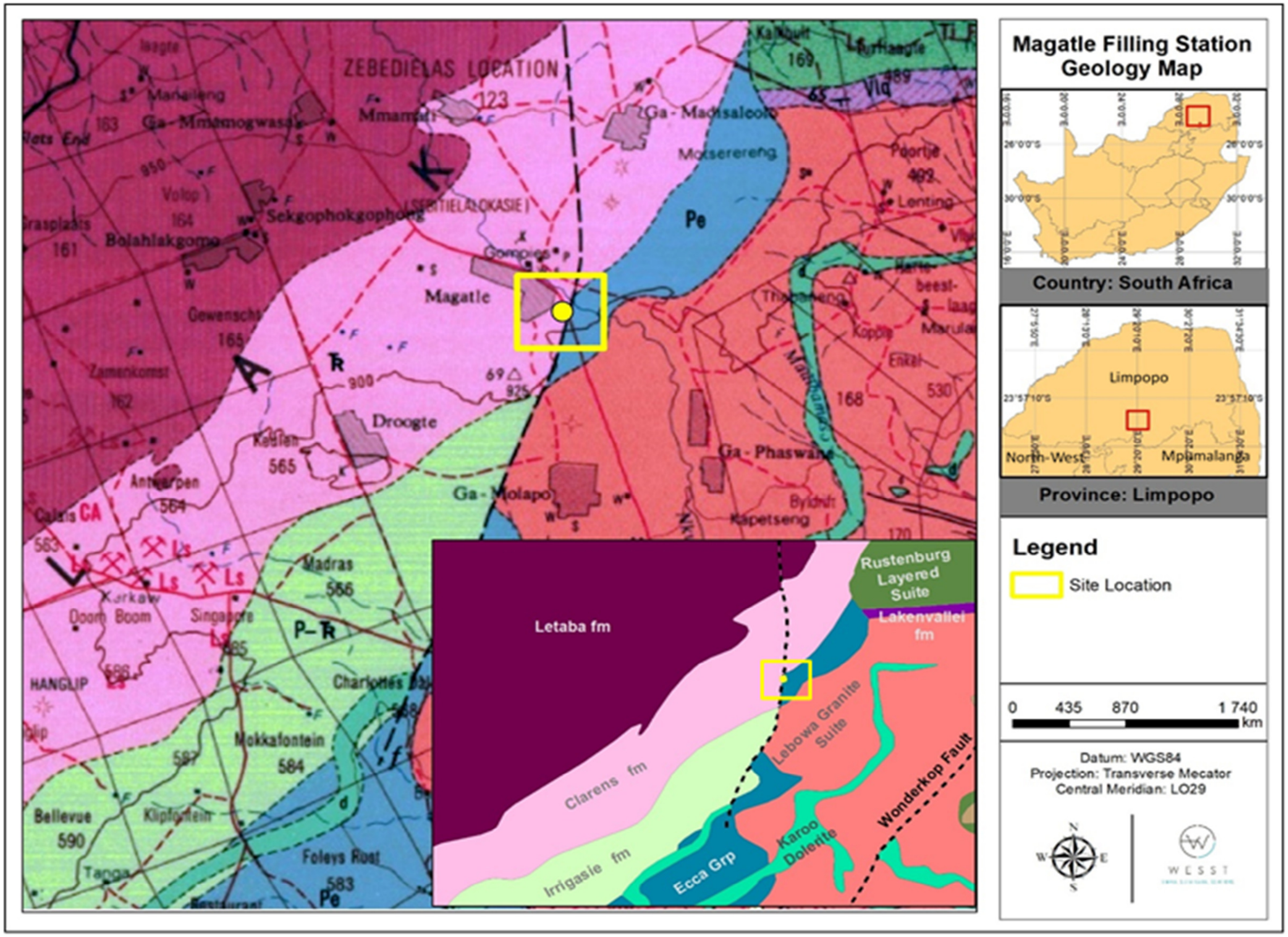


Figure 10 Regional geology (Geological mapsheet 2428, 1:250 000)

3.10. Hydrogeology

The following sub-sections outline the hydrogeology of the proposed study area.

3.11. Regional hydrogeology

The site and surrounds are characterized by informal settlements and as such groundwater abstraction from neighboring properties may take place. These boreholes yields are mainly considered low with typical yields of 0.5 – 2 l/s (DWAF, Olifants WMA ISP, 2004).

The aquifer underlying the B51G quaternary catchment area is that of a fractured and weathered compact sedimentary rock; where the saturated thickness of the weathered zone (Z) is approximately 2 m and the thickness of the fractured zone (FZ) approximately 13 m, with an aquifer thickness of ~24 m. The yield (defined as the maximum rate of withdrawal that can be sustained by an aquifer without causing an unacceptable decline in the hydraulic head of the aquifer) is anticipated to be along the vicinity of 10 480 $m^3/km^2/a$, while the available storage is expected to be 13 100 $m^3/km^2/a$ (DWAF, 2006).

According to Barnard (2000), groundwater occurrence favors weathered shale, brecciated or jointed zones and especially the contact zones between intrusive diabase sheets and shale.

3.12. Hydrostratigraphic units

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

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock can be classified as a secondary porosity aquifer. This aquifer is generally unconfined with phreatic water levels. Usually this aquifer is most susceptible to impacts from contaminant sources.

ii. A deeper fractured aquifer where groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

3.13. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water levels from the topography. The unsaturated zone within the study area has an estimated thickness of 13.56m (this is based on static groundwater levels measured at the surveyed boreholes with potential dynamic water levels not taken into consideration).

3.14. Groundwater gradient and flow directions

The minimum groundwater level recorded for static boreholes is 12.08 mbgl with the maximum measured at 16.16 mbgl, whilst the minimum groundwater level recorded for dynamic boreholes is 21.25 mbgl and the maximum 25.25 mbgl (Refer to Table 3). Analyzed data indicated that 50% of the boreholes investigated are being pumped- resulting in a dynamic water table for the localized region, with 50% being static. No borehole was present on site and as such the inferred groundwater level on-site was determined using data obtained for the static boreholes and is expected to be approximately 13.50 mbgl.

A distribution of borehole water levels recorded as part of the hydrocensus survey was used to interpolate the hydraulic head contours as depicted in Figure 13 (groundwater flow if boreholes being pumped are not taken into consideration) and Figure 14 (groundwater flow direction if both pumped and static boreholes are taken into consideration). The local groundwater flow on site flows in a primarily southern direction from the north as seen on both the static- and the dynamic groundwater flow maps (see Figure 13 and Figure 14 respectively). As Figure 14 is most likely to depict the current groundwater flow direction, it is derived that the groundwater moves away from Borehole H01-3045, and ultimately, from a regional perspective, moves towards the three pumping boreholes in the area i.e. H/BH 02, H01-2184 and H01-2323.

Figure 11 Borehole water levels

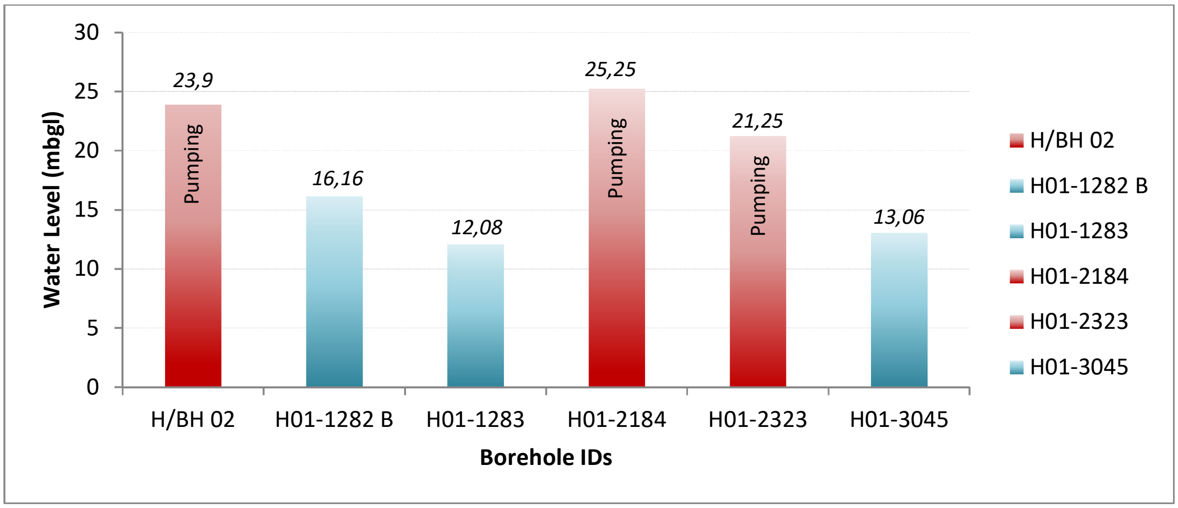
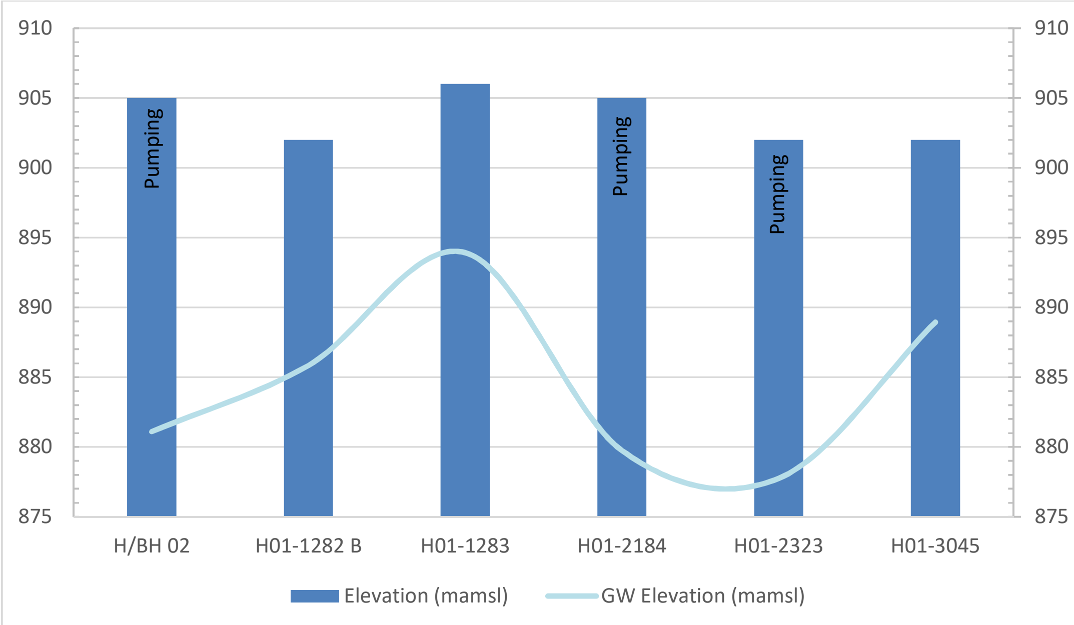


Table 3 Groundwater elevation

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)
H/BH 02	905	23.90	881.10
H01-1282 B	902	16.16	885.84
H01-1283	906	12.08	893.92
H01-2184	905	25.25	879.75
H01-2323	902	21.25	877.75
H01-3045	902	13.06	888.94
Minimum	**902**	**12.08**	**889.92**
Maximum	**906**	**25.25**	**880.75**

Figure 12 Regional groundwater flow direction and depth to groundwater



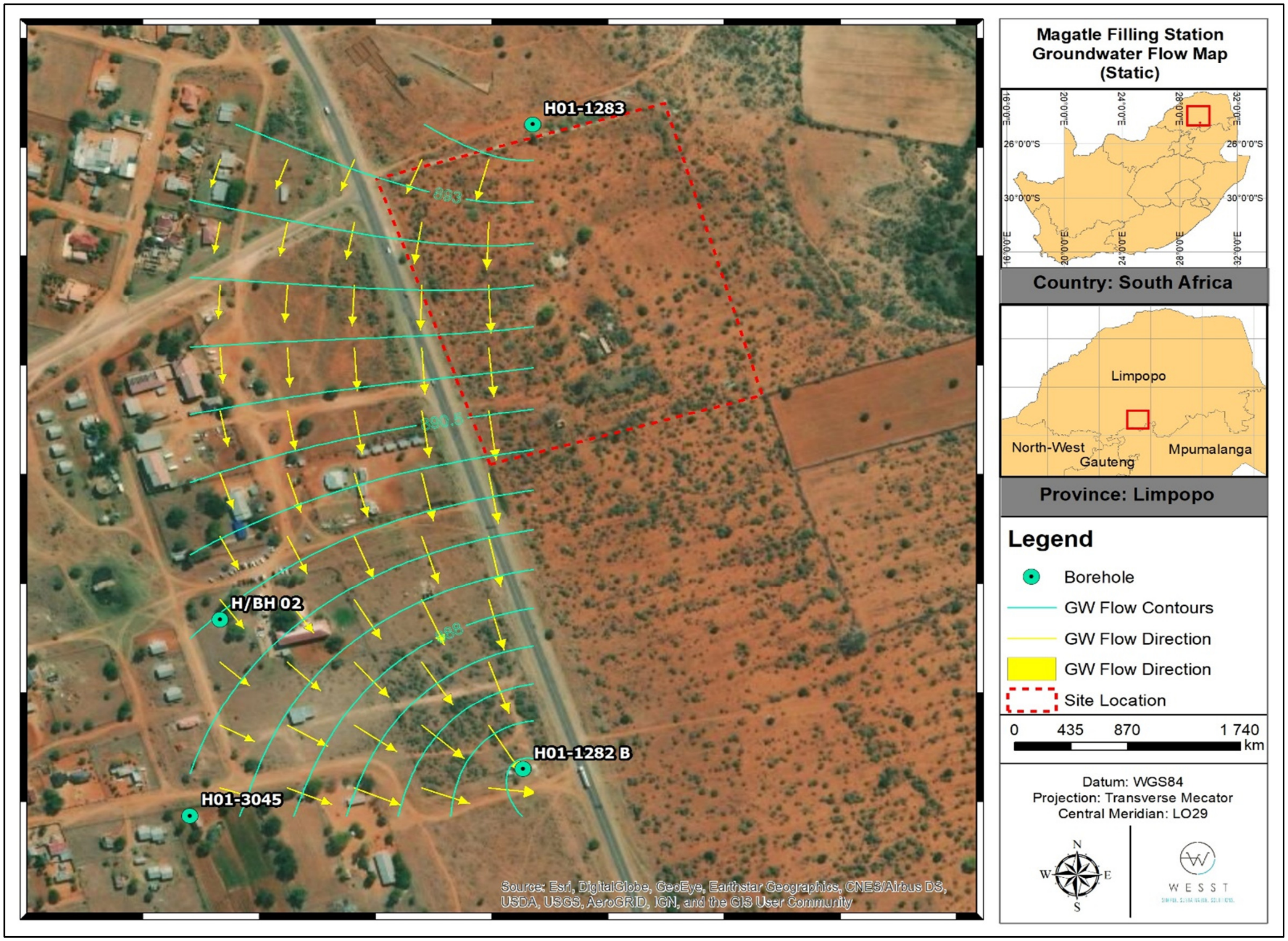


Figure 13 Depth to groundwater and regional flow direction (static)

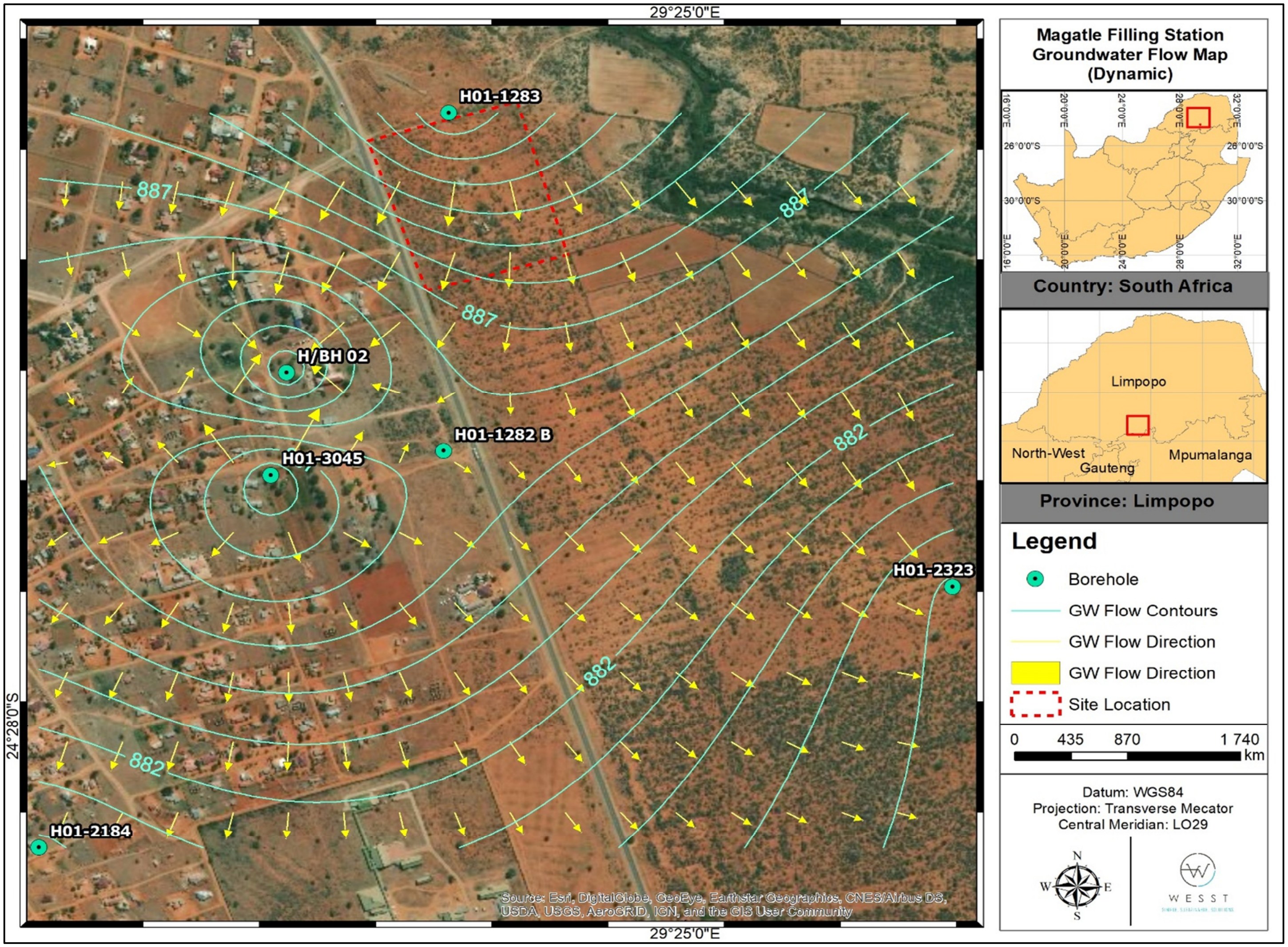


Figure 14 Depth to groundwater and regional flow direction (dynamic)

3.15. Hydraulic parameters

No pump tests were conducted to obtain an estimation of the aquifer's hydraulic parameters. As such, published literature were reviewed for similar hydrogeological conditions and were summarized below.

3.16. Hydraulic conductivity

Hydraulic Conductivity (K) is defined as the volume of water that will move through a porous medium in a unit time under a unit hydraulic gradient through a unit area measured at perpendicular to the flow direction. The permeability, and similarly the hydraulic conductivity of the Ecca Group, as well as the Clarens Formation is relatively low at ~10 -11 to 10 -12 m.s $^{-1}$ (Visser, 1984).

3.17. Storativity

Storativity refers to the volume of water released or taken into storage by an aquifer as a result of a change in hydraulic 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 10^{-5} – 10^{-3} whereas the storativity values of the shallow, weathered aquifer will be slightly higher i.e. 10^{-2} (Freeze and Cherry, 1979).

Specifically, the Clarens Formation consists almost entirely of well-sorted, medium- to fine-grained sandstones, deposited as thick consistent blankets- making it homogenous (Visser, 1984). Although the Formation has a relatively high and uniform porosity, as shown in Table 4, it is poorly fractured and has a very low permeability. The Formation may therefore be able to store large volumes of water, but unable to release it quickly.

The permeability of the soil on site was tested using the DRIT method) and will be discussed in section 5 of the report.

3.18. Porosity

Porosity (n) is the voids or openings of the rock or soil per total volume and can be expressed as a percentage. Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected. Porosity is an intrinsic value of seepage velocity and hence contamination migration. According to Beukes (1969), the typical porosities of the Clarens formation entails the following:

Table 4 Porosities of the Clarens Formation

Type of Sandstone	Porosity (%)
Very Fine grained	6,19-9,82
Cross-bedded	8,87-10,75
Average	8,46

Since these shales are very dense, they were often neglected as sources of groundwater in the past. The porosity of shale in general ranges between 1-10% (Freeze and Cherry, 1979).

Shale porosities of the Ecca Group tend to decrease from approximately >0,1 north of latitude 28° S, to <0,02 in the southern and south-eastern parts, while their bulk densities increase from ~2 000 to >2 650 kg m^{-3}. The possibility therefore exists that economically viable aquifers may be found in areas underlain by the Ecca shales, specifically in the northern parts.

3.19. Recharge

Recharge refers to the addition of water to the saturated zone either through downward percolation from the unsaturated zone or from seepage from an adjacent aquifer. According to the map drawn by Vegter (1995), the groundwater recharge for the area is estimated to be approximately 12 mm/annum.

4. SITE INVESTIGATION

4.1. Hydrocensus user survey

A hydrocensus user survey was conducted in October 2019 during which relevant hydrogeological baseline information was recorded and samples collected for water quality analysis. Geosites logged included six (6) boreholes, of which groundwater was sampled from various points such as taps and the boreholes (refer to Figure 15). Surface water resources in the immediate surrounds were found to be non-perennial and as such were dry at the time of the site visit. Borehole H/BH 01 was not included in the hydrocensus as the borehole could not be accessed. Further to this the water is also thought to be contaminated with fuel evident from the smell. In addition, borehole H/HB 01-1283 could not be sampled as electricity to the pump was not available. Relevant information is summarized in Table 5. Refer to Figure 16 and Figure 17 for a statistical summary of geosites recorded.

Of the geosites recorded, the majority of water application is for domestic purposes such as water supply (66%), with 17% of boreholes sampled in the area being used for irrigation. The remaining 17 % of the recorded geosites is used by the College for gardening and lavatory use. Figure 18 presents a spatial distribution map of visited geosites.

Figure 15 Photographic record of hydrocensus user survey sites visited

Table 5 Geosite information: hydrocensus user survey

Site ID	Latitude	Longitude	Site	Site status	Water application	Water level (mbs)	Water level status	Land owner/occupier
H/BH 02	-24,461620	29,411260	Tap	In use	Garden & Toilets	23,90	Pumping	Mr. Leopang
H01-1282B	-24,462740	29,413390	Borehole	not in use	Water Supply	16,16	Static	No information
H01-1283	-24,457910	29,413460	Not Sampled	not in use	Water Supply	12,08	Static	Police Station
H01-2184	-24,468400	29,407900	Borehole	In use	Water Supply	25,25	Pumping	Hospital
H01-2323	-24,464680	29,420300	Borehole	In use	Water Supply	21,25	Pumping	Police Station
H01-3045	-24,463090	29,411050	Borehole	In use	Irrigation	13,06	Static	Mr. Aprhane

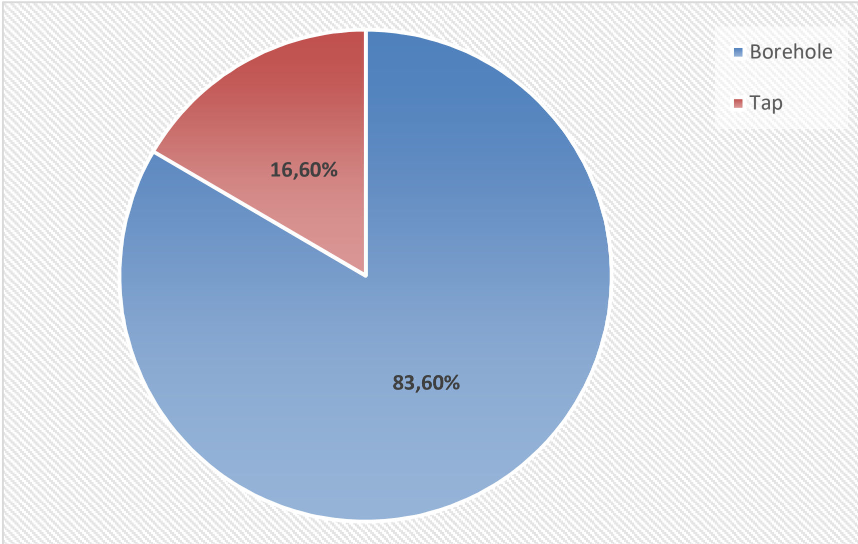


Figure 16 Hydrocensus user survey geosites sampling points statistical summary

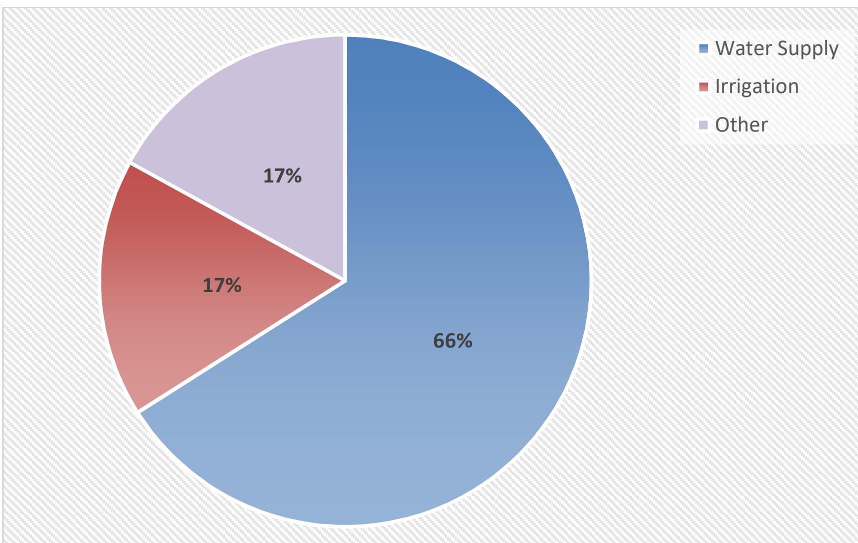
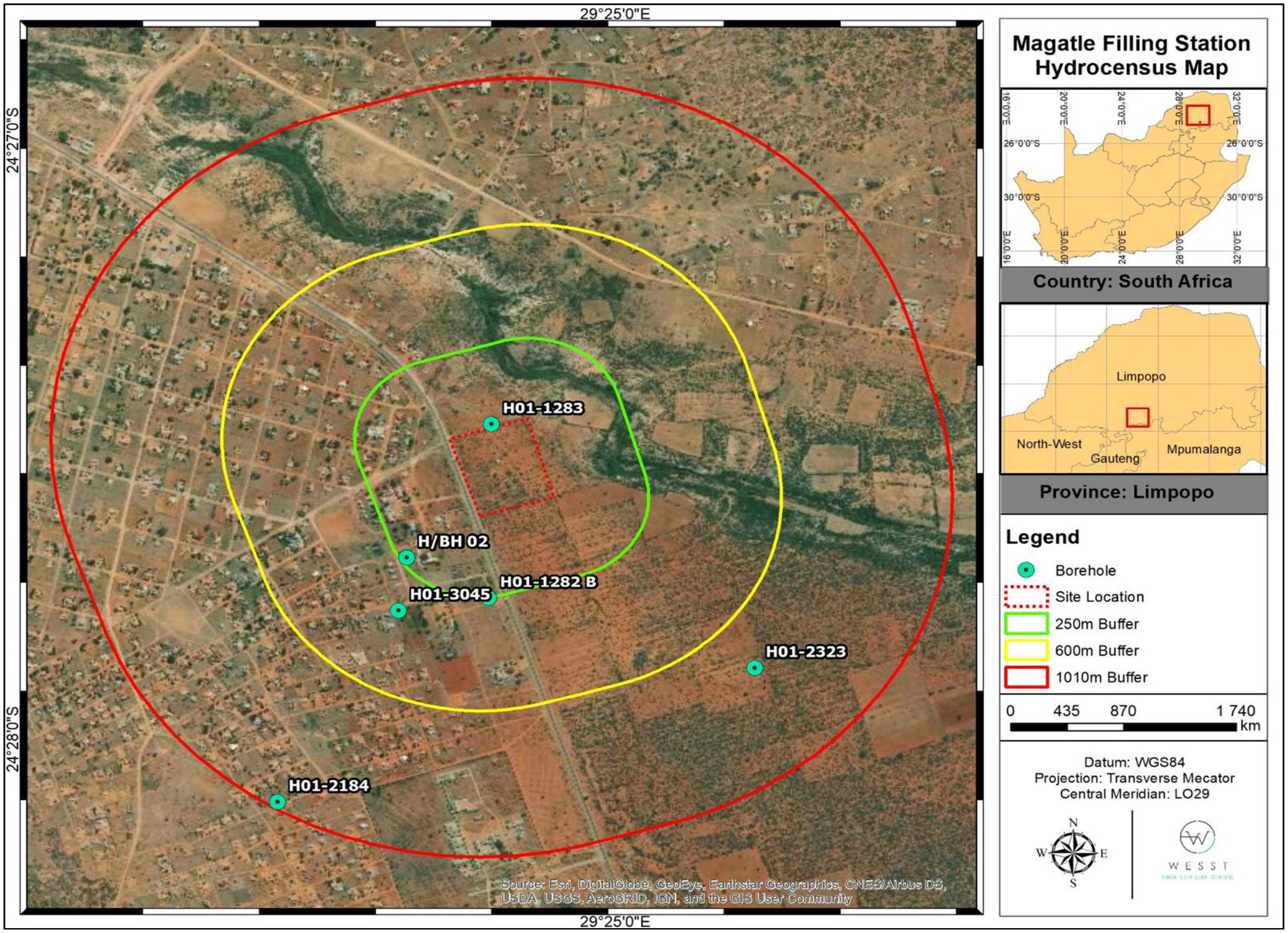


Figure 17 Hydrocensus user survey groundwater application



29°25'0"E
24°27'0"S
24°28'0"S
H01-1283
H/BH 02
H01-1282 B
H01-3045
H01-2323
H01-2184
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Magatle Filling Station Hydrocensus Map
Country: South Africa
Limpopo
North-West
Gauteng
Mpumalanga
Province: Limpopo
Legend
Borehole
Site Location
250m Buffer
600m Buffer
1010m Buffer
0 435 870 1 740 km
Datum: WGS84
Projection: Transverse Mecator
Central Meridian: LO29
N
S
E
W
WESST

Figure 18 Hydrocensus user survey geosite distribution map

5. DOUBLE RING INFILTRATION TEST

The double ring infiltrometer test (DRIT) is used in conjunction with the contamination risk assessment by measuring the upper soil on the proposed Site. Specifically, the Hydraulic Conductivity (K) (or infiltration rate) of the unsaturated zone, and therefore also the permeability of the soil on site, is measured using a double ring infiltration meter. The resulting infiltration rate describes the maximum rate at which water enters the soil and is generally controlled by the least permeable zone in the soils.

The double-ring infiltrometer is used by partially inserting the double- rings (one inside the other) of the meter into the soil and filling it with water, which is then maintained at a constant level. The infiltrometer is used to encourage divergent flow in the layered soils after infiltration occurs, whilst also limiting the lateral spread of water through the outer ring barrier. The volume of water added to maintain the water level constant is equal to the volume of water that infiltrated the soil. The volume infiltrated during timed intervals is then converted to an infiltration velocity. As a result, the minimum infiltration velocity is equivalent to the infiltration rate. The rate of infiltration is therefore determined as the amount of water per surface area and time unit that penetrates the soil. A DRIT test was conducted near the centre of the site, the exact location of which can be seen in Figure 20. The test was conducted on surface level and downstream of the groundwater flow. The results of the DRIT test are summarized in Figure 19 and Table 6 below. As seen in the above table, the average hydraulic conductivity rate measured was **5.5 m/d**, which is indicative of a relative fast hydraulic conductivity.

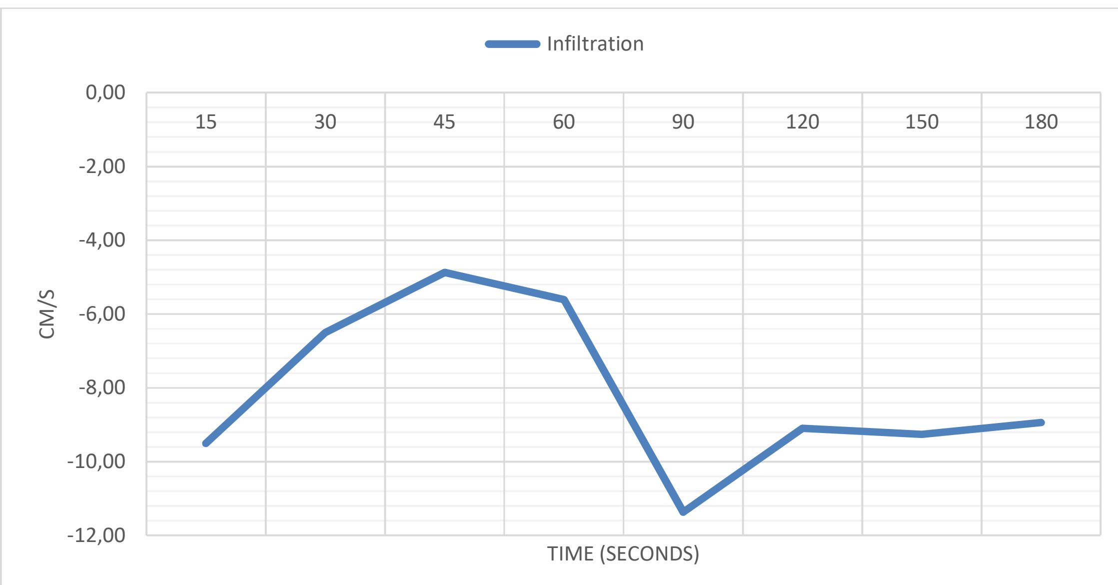


Figure 19 DRIT results graphical representation

Table 6 DRIT Results

Site ID	Latitude	Longitude	Minimum (m/d)	Maximum (m/d)	Average (m/d)	Tested Depth (m)

DT 01	-24,45926	29,41334	4,289613935	9,125178734	5,498505135	Surface

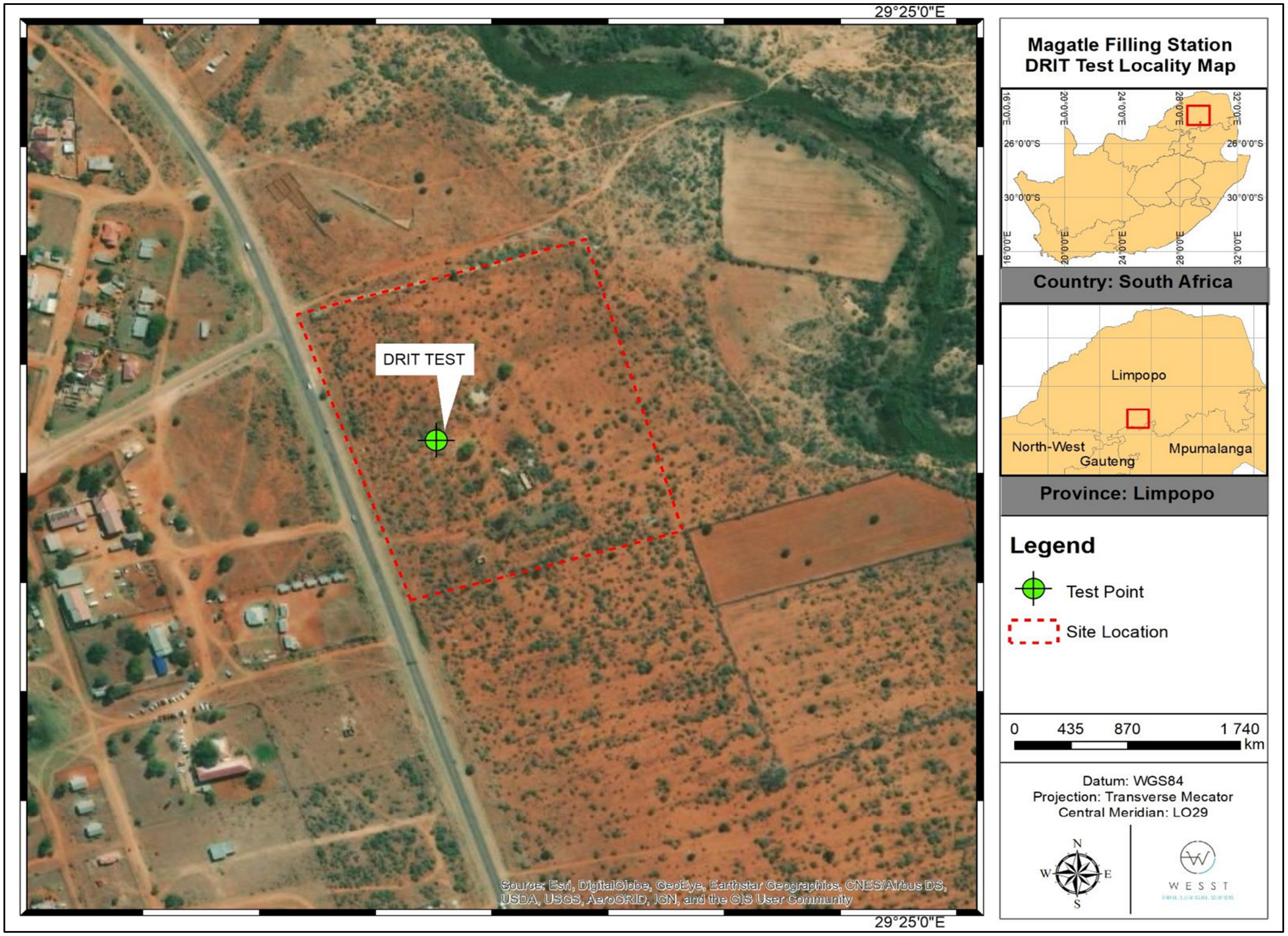


Figure 20 Double Ring Infiltrometer Test (DRIT) location

6. HYDROCHEMISTRY

6.1. Water quality analysis

The South African National Standards (SANS 241: 2015) have been applied to assess the water quality within the project area. The standards specify a maximum limit based on associated risks for constituents (Refer to Table 7). Water samples were submitted for analysis at a SANAS accredited laboratory and include an inorganic analysis.

Table 7 SANS 241:2015 risks associated with constituents occurring in water

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

6.2. Data validation

The laboratory precision was validated by employing the plausibility of the chemical analysis, electro neutrality (E.N.) which is determined according to the equation below. An error of less than 5% is an indication that the analysis results are of suitable precision for further evaluation.

$$E.N. = \frac{\sum cations \left[\frac{meq}{L}\right] + \sum anions \left[\frac{meq}{L}\right]}{\sum cations \left[\frac{meq}{L}\right] - \sum anions \left[\frac{meq}{L}\right]} .100\% = < 5\%$$

Table 8 Laboratory precision and data validity.

Sample Localities	Electro-Neutrality [E.N.] %
	< 5%: Accurate lab precision
H01-1282 B	-1%
H01-2323	0.1%
H01-1284	4.7%

Boreholes H01-1284, H01-2323 AND H01-1282B was sampled and analysed. Ideally borehole H01 -1283 should have been sampled and analysed, as this borehole borders the proposed site, however at the time of the hydrocensus this borehole could not eb accessed, as the pump installed in the borehole is out of order.

Figure 21 summarises the major anion- and cation composition of the samples analysed while Figure 22 indicate a spatial distribution of water samples collected. Inorganic water quality analysis results are tabulated in Table 9 and TPH results are summarised Table 10. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health) whereas yellow highlighted cells indicate parameters above aesthetic limits (refer to Appendix A for laboratory analysis certificates).

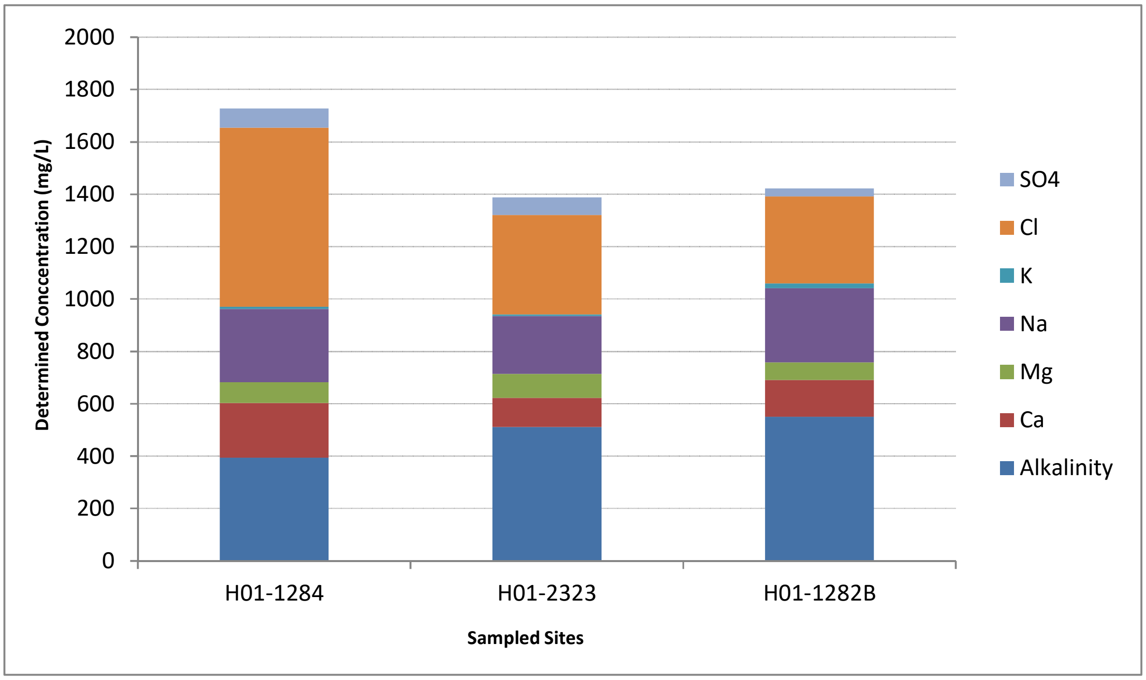


Figure 21 Composite bar-chart indicating sample major anion cation composition (mg/l)

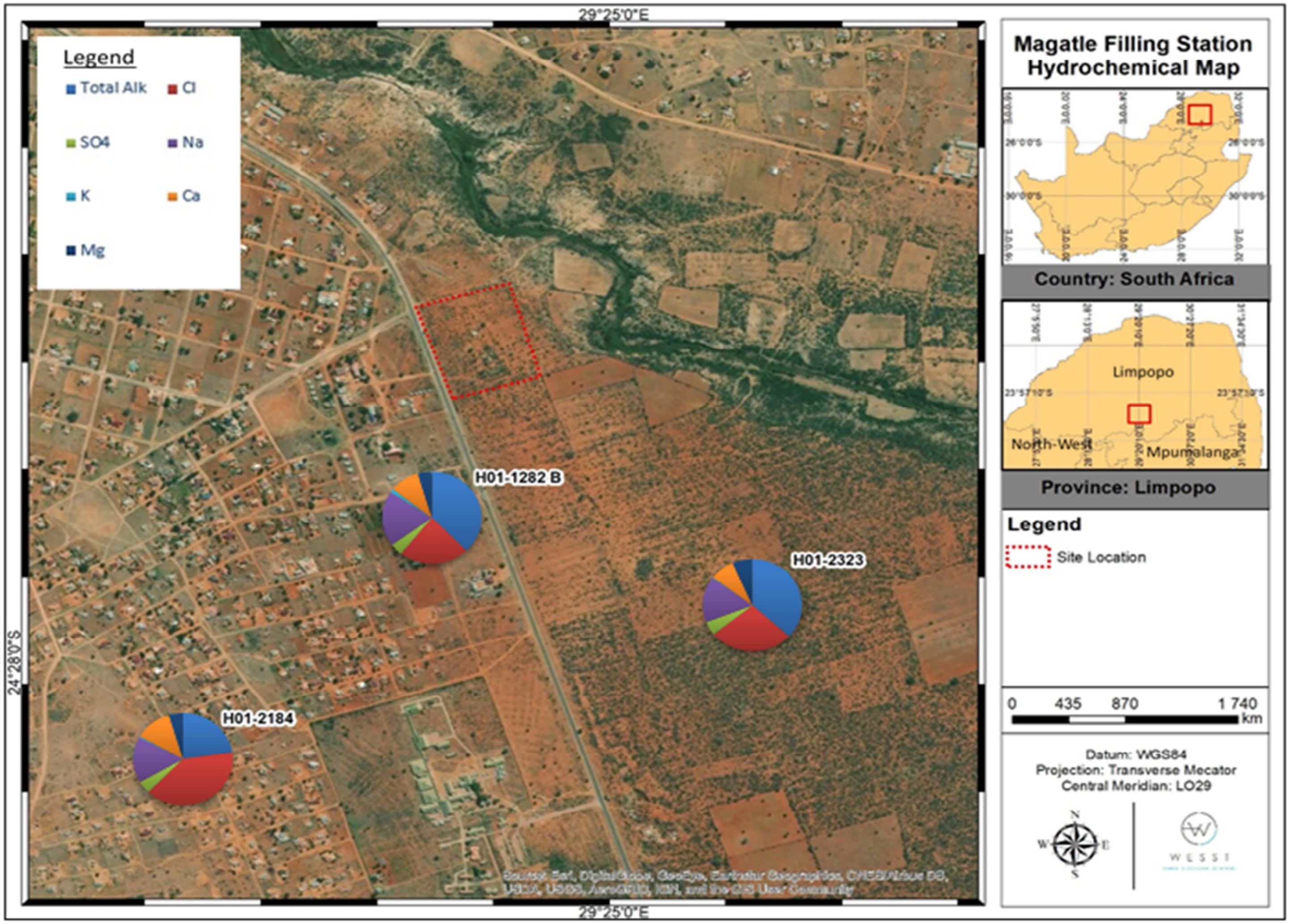


Figure 22 Hydrochemical analysis spatial distribution map

6.3. Groundwater Quality

The quality of groundwater samples analyzed is indicative of an overall moderate to poor water quality. Although the sampled water is classed as 'Soft and Neutral' (pH 6 > 8.5), with pH averaging 7.63, elevated salinity can be found in all three samples as the Na & Cl significantly exceeded the SANS 241:2015 limits. This is indicative of a dry area with a low recharge, also seen in water which has been stagnant for extended periods.

In addition, the Electric Conductivity (EC), as well as the Total Dissolved Solids (TDS) concentrations also exceeded their respective SANS 241:2015 limits for all three samples. This can be attributed to the fact that EC is directly related to the concentration of ions in the water. Conductive ions (that increase the EC level) originates from dissolved salts such a chlorides and sulfide (Stigter et al; 2006). Chloride is one of the major negative ions in both salt- and freshwater. It is sourced from the dissociation of salts, such as calcium chloride (CaCl) or sodium chloride (NaCl) in water i.e. NaCl(s) Na+(aq) + Cl–(aq).

It is therefore understood that the more conductive ions (such as Na & Cl) present in the water- the higher the conductivity, and thus the EC level of the sampled water. Elevated levels of Fluorite (F) was also present in borehole H01-1284.

H01-1284 was also analyzed for TPH content that indicated acceptable levels according to the World Health Organization (WHO) guidelines (refer to Table 10).

6.4. Surface water quality

At the time of the hydrocensus surface water features in the immediate surrounds were found to be non-perennial and as such were dry at the time of the site visit.

6.5. Hydrochemical characterization

Two types of diagnostic plots were used to characterize analyzed water samples based on hydrochemistry. A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 23). Different water types derived from different environments plot in diagnostic areas. The upper half of the diamond normally contains water of static and dis-ordinate regimes, while the middle area generally indicates an area of dissolution and mixing. The lower triangle of this diamond shape is indicative of an area of dynamic and coordinated regimes.

Figure 24 depicts a piper diagram developed from the hydrocensus water quality analysis results. Upon analyses, it was indicated that all three samples fall within the top of the diamond- indicative of static and-disordinate environments.

Table 9 Hydroccensus user survey geosite water quality evaluation (SANS 241:2015)

Determinant	Unit	Risk	SANS 241:2015 limits	Hydrocensus sampling localities		
				H01-1284	H01-2323	H01-1282B
Physical and aesthetic determinants						
pH @25 °C	pH	Operational	≥5.0 ≤ 9.5	7.27	7.49	8.13
EC	mS/m	Aesthetic	≤170.0	272	186	186
Total Hardness ($CaCo_3$)	mg/l	-	-	851	651	627
TDS	mg/l	Aesthetic	≤1200.0	1648	1210	1328
Macro determinants						
Total Alkalinity ($CaCo_3$)	mg/l	-	-	394	511	550
Cl	mg/l	Aesthetic	≤300.0	684	380	332
SO_4	mg/l	Aesthetic/Acute health	≤ 250.0 ≤ 500.0	74.1	67.9	61.0
F	mg/l	Acute health	≤1.5	1.60	1.46	0.506
NO_3-N	mg/l	Acute health	≤11.0	16.2	4.45	19.9
PO_4	mg/l	-	-	0.045	0.035	0.091
NH_4	mg/l	Aesthetic	≤1.5	0.101	0.028	0.779
Na	mg/l	Aesthetic	≤200.0	279	222	284
K	mg/l	-	<100*	8.56	5.13	18.3
Ca	mg/l	-	<300*	209	112	141
Mg	mg/l	-	<100*	79.8	90.3	66.9
Micro determinants						
Al	mg/l	Operational	≤0.3	0.004	0.002	0.004
Fe	mg/l	Aesthetic/Acute health	≤ 0.2	<0.004	<0.004	<0.004
Mn	mg/l	Aesthetic/Acute health	≤ 0.4	0.016	<0.001	0.027
*2006 SABS South Africa National Standard: Drinking Water, SANS 241:2006 Edition 6.1						

Table 10 TPH analysis (WHO guidelines)

Determinant	Unit	WHO Guidelines	H01-1282B
TPH C10-C40	**µg/l**		<10.0
C10-C16	µg/l	300	<10.0
C16-C22	µg/l	300	<10.0
C22-C30	µg/l	90	<10.0
C30-C40	µg/l	90	<10.0

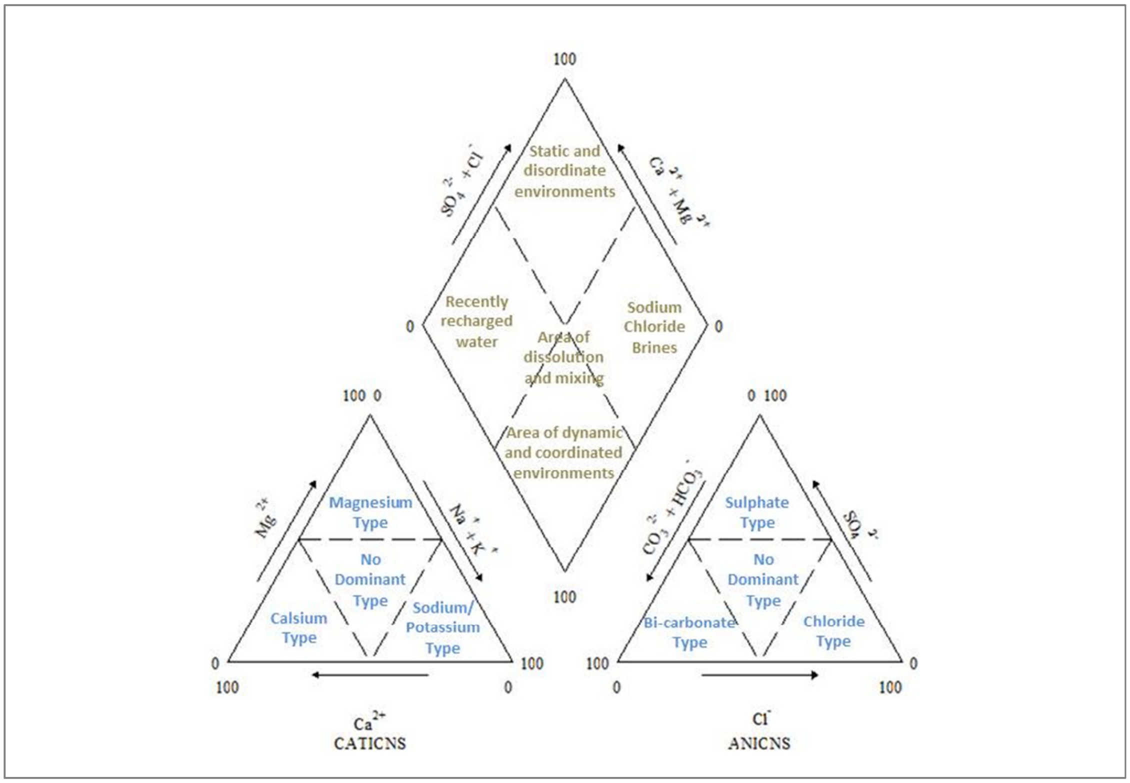


Figure 23 Piper diagram indicating classification for anion and cation facies in terms of ion percentages

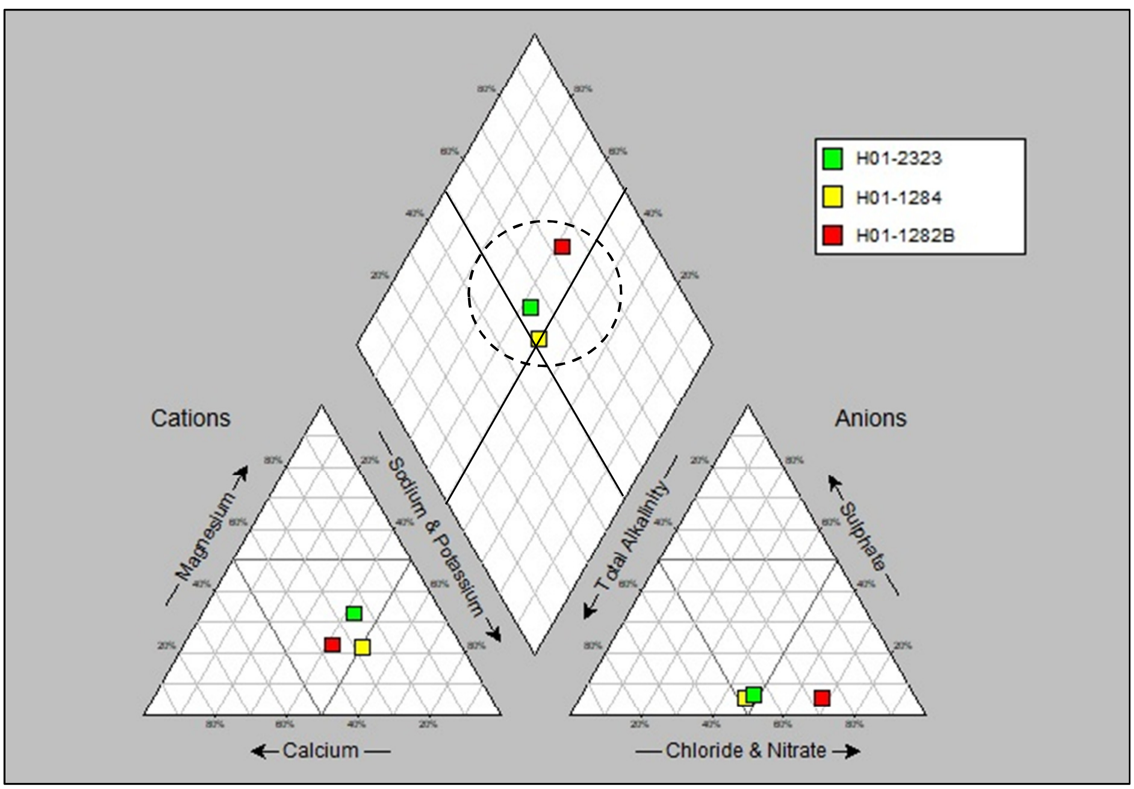


Figure 24 Piper diagram indicating major anions and cations of hydrocnesus water samples

Figure 25 depicts Stiff diagrams compiled from the hydrocensus user survey sampling analysis. It is evident that sampling localities H01-1284 and H01-2323 correspond relatively well to each other and is most likely resulting from the shallow aquifer system and baseflow discharge into the drainage system. Sampling locality H01-1282B reflect a slightly different groundwater hydrochemical composition with increased levels of Cl-NO3, and slightly lower Ca levels when compared to the other two localities. Elevated nitrate levels may be due to antropogenic activities.

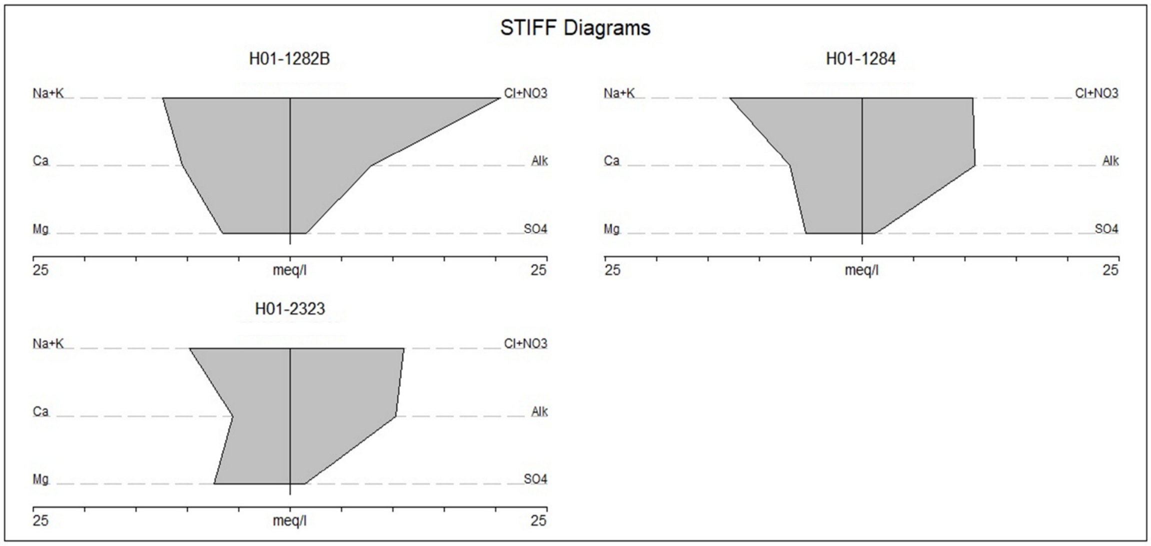


Figure 25 Stiff Diagrams of Samples Taken during the hydrcensus.

7. CONTAMINATION RISK ASSESSMENT

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.

7.1. Groundwater quality management index

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 summary of the GQM index for the study area is presented in Table 12 with cells shaded in blue indicating the rating of the aquifer. A GQM Index of 4 was estimated for the aquifer system and according to this estimate, a "**Low**" level groundwater protection is required for this aquifer system.

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

7.2. 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. As mentioned previously the aquifer host is charaterised by a primary porosity system combined with very good groundwater quality.

The classifications and definitions for each aquifer system are summarised in Table 11 cells shaded in blue indicate the classification of the aquifer.

Table 11 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.

7.3. 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 "**Least**" vulnerability rating (DWS, 2013).

7.4. Aquifer susceptibility

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

Table 12 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	Medium	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		

7.5. DRASTIC

The concept of groundwater vulnerability to contamination by applying the DRASTIC methodology was introduced by Aller et al. (1987) and refined by the US EPA (United States Environmental Protection Agency). DRASTIC is an acronym for a set of parameters that characterise the hydrogeological setting and combined evaluated vulnerability: Depth to water level, Nett Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and Hydraulic Conductivity. Difficulties arise when assigning Hydraulic Conductivities to fractured rock aquifer systems specifically in South Africa, as such the hydraulic conductivity (C) has been omitted from the formula below. The formula has also been adapted from the original to specifically take the South African geology into account.

This method provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeologic parameters. Parameters used as part of the index are summarised in Table 13 below. The DRASTIC index (DI) can be computed using the following formula.

$$\mathbf{Di} = \boldsymbol{DrDw + RrRw + ArAw + Sr\,Sw + TrTw + IrIw + CrCw}$$

(Where r=rating, and w=the assigned weight.)

The proposed site's DRASTIC Index (Di) is calculated at 83, which classifies the aquifer's vulnerability to pollution as **low (Di=1 - 100)** and indicated that the overall potential for groundwater pollution is **low**.

Table 13 DRASTIC Weighting factors (Aller et al. 1987)

Parameter	Range	Rating	Description	Relative Weighting
Depth to water (D) (mbgl)	0-5	10	Refers to the depth to the water surface in an unconfines aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5
	5-15	7		
	15-30	**3**		
	>30	1		
Net recharge (R) (mm/a)	0-5	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal within an aquifer.	3
	5-10	3		
	10-50	**6**		
	50-100	8		
	>100	9		
Aquifer Media (A)	Dolomite	10	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger grain size and more fractures or openings within an aquifer, leads to higher permeability and lower attenuation capacity - hence the greater pollution potential.	4
	Intergranular	8		
	Fractured	6		
	Fractured and Weathered	**3**		
Soil Media (S)	Sand	10	Refers to the uppermost weathered portion of the vadose zone characterized by significant biological activity. Soil has a significant impact on the amount of recharge.	2
	Shrinking and/or aggregated clay	8		
	Loamy sand	6		
	Sandy loam	5		
	Sandy Clay	**4**		
	Silty Loam	3		
	Silty clay- and clay loam	2		
Topography (T) (Slope%)	**0-2**	**10**	Refers to the slope and land surface. It helps a pollutant to either runoff or remain on the surface of an area long enough to infiltrate it.	1
	2-6	9		
	6-12	5		
	12-18	3		
	>18	1		

Impact of vadose zone (I)	Gneiss, Namaqua metamorphic Rocks	3	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5
	Ventersdorp, Pretoria, Griekwaland West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld Basalt, Waterberg, Soutpansberg, Karoo (Northern), Bushveld, Olifantshoek	**4**		
	Karoo (Southern)	5		
	Table Mountain, Witteberg Granite, Natal, Witwatersrand, Rooiberg, Greeenstone, Dominion, Jozini	6		
	Dolomite	9		
	Beach Sands and Kalahari	10		

7.6. Source-pathway-receptor evaluation

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

7.7. Potential sources

The following potential sources have been identified:

- Hydrocarbon spills and overflow at filling ports.
- Hydrocarbon leakage from underground storage facilities.
- Hydrocarbon leakage from fuel lines.
- Poor storm water management on site.

7.8. Common pathways

The following common pathways have been identified:

- Percolation of contaminant through soil media.
- Direct contact with groundwater.

7.9. Potential receptors

The following potential receptors have been identified:

- Neighboring boreholes and residential properties surrounding the site.
- Surrounding riparian areas.
- Groundwater.
- Non-perennial tributary running past the site.

8. IMPACT ASSESSMENT

Identification of potential impacts and ratings related to new developments and/or activities are briefly discussed below and summarised in Table 20, Table 21 and Table 22.

8.1. 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. Assessment of impacts will be based on DEAT's (1998) Guideline Document: EIA Regulations. The significance of the aspects/impacts of the process will be rated by using a matrix derived from Plomp (2004) and adapted to some extent to fit this process. This matrix uses the consequence and the likelihood of the different aspects and associated impacts to determine the significance of the impacts. The significance of the impacts will be determined through a series of the criteria as summarized below (Table 14 to Table 18), with a matrix rating and assigning weights for the impacts shown in Table 19.

$$\textbf{Significance Rating (SR)} = (\boldsymbol{Extent} + \boldsymbol{Intensity} + \boldsymbol{Duration})\boldsymbol{xProbability}$$

Table 14 Probability ratings

Probability: This describes the likelihood of the impact actually occurring	
Improbable	The possibility of the impact occurring is very low, due to the circumstances, design or experience.
Probable	There is a probability that the impact will occur to the extent that provision must be made therefore.
Highly probable	It is most likely that the impact will occur at some stage of the development.
Definite	The impact will take place regardless of any prevention plans, and there can only be relied on mitigatory actions or contingency plans to contain the effect.

Table 15 Duration ratings

Duration: The lifetime of the impact.	
Short term	The impact will either disappear with mitigation or will be mitigated through natural processes in a time span shorter than any of the phases of the project.
Medium term	The impact will last up to the end of the phases of the project, where after it will be negated.
Long term	The impact will last for the entire operational phase of the project but will be mitigated by direct human action or by natural processes thereafter.
Permanent	Impact that will be non-transitory. Mitigation either by man or natural processes will not occur in such a way or in such a time span that the impact can be considered transient.

Table 16 Scale ratings

Scale: The physical and spatial size of the impact.	
Local	The impacted area extends only as far as the activity, e.g. footprint of the project.
Site	The impact could influence the whole, or a measurable portion of the affected properties.
Regional	The impact could affect the area including the neighbouring areas.

Table 17 Magnitude/severity ratings

Magnitude/ Severity: Does the impact destroy the environment, or alter its function.

Low	The impact alters the affected environment in such a way that natural processes are not affected.
Medium	The affected environment is altered, but functions and processes continue in a modified way.
High	Function or process of the affected environment is disturbed to the extent where it temporarily or permanently ceases.

Table 18 Significance ratings

Significance: This is an indication of the importance of the impact in terms of both physical extent and time scale, and therefore indicates the level of mitigation required.	
Negligible	The impact is non-existent or unsubstantial and is of no or little importance to any stakeholder and can be ignored.
Low	The impact is limited in extent, has low to medium intensity; whatever its probability of occurrence is, the impact will not have a material effect on the decision and is likely to require management intervention with increased costs.
Moderate	The impact is of importance to one or more stakeholders, and its intensity will be medium or high; therefore, the impact may materially affect the decision, and management intervention will be required.
High	The impact could render development options controversial or the project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor in mitigation.

Table 19 Rating Matrix Legend for Groundwater impacts

Aspect	**Description**	**Weight**
Probability	Improbable	1
	Probable	2
	Highly Probable	4
	Definite	5
Duration	Short term	1
	Medium term	3
	Long term	4
	Permanent	5
Scale	Local	1
	Site	2
	Regional	3
Magnitude/Severity	Low	2
	Medium	6
	High	8
Significance	**Sum (Duration, Scale, Magnitude) x Probability**	
	Negligible	<20
	Low	<40
	Moderate	<60
	High	>60

8.2. Impact Identification and significance ratings

8.3. Construction phase: Associated impacts

The main impacts associated with the construction phase activities include the following:

i. Erosion of site and siltation of surrounding surface water features.

ii. Oil, grease and diesel spillages, hydrocarbon contamination from construction vehicles and heavy machinery.

iii. Pollution of groundwater and surface water due to sanitation facilities and related anthropogenic activities.

iv. Groundwater and surface water pollution due to spillage of chemicals and building materials.

8.4. Construction phase: Management and mitigation measures

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

i. Excavations should be open for as short period as practically possible, while cleared and stripped areas should be vegetated as soon as possible.

ii. Ensure vehicle and heavy machinery used on-site are regularly inspected for leaks and serviced at frequent intervals. Spill trays to be used where applicable.

iii. Construction camp should be situated outside any riparian buffer. Chemical sanitary facilities must be provided for construction workers and emptied on regular intervals.

i. All materials, fuels and chemicals must be stored in a secured, sealed and bunded area to prevent pollution from spillages and leakages. The use of chemicals should be controlled.

8.5. Operational phase: Associated impacts

The main impacts associated with operational phase activities include the following:

i. Hydrocarbon pollution of groundwater (seepage/percolation) and surface water (drainage).

ii. Hazardous liquids and hydrocarbons spilled on surface will either run off the sealed areas into local surface water drainages or enter the sub-surface soil profile and percolate vertically down the vadose zone to the groundwater level. Light non-aqueous phase liquids (LNAPL's) i.e. petrol and diesel will be transported on the groundwater in an inferred easterly direction, while dense non-aqueous phase liquids (DNAPL's) such as oil will percolate through the vadose zone until solid bedrock is encountered where it will move along the bedding planes and through fractures.

8.6. Operational phase: Management and mitigation measures

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

i. The use of all detergents, oil, fuels and chemicals which could potentially leach into underground water must be controlled. This can be done by sealing of the forecourt and refuelling bay area to prevent infiltration of hydrocarbon into the aquifer underlying the site.

ii. Storm water draining from the surfaced areas should be collected in a sealed sump to be treated or removed. All contact water should be discharged into the municipal system with the required approval and not into any streams, or adjacent areas.

iii. Subsurface fuel storage facilities should be constructed in concrete encasements with a sump system to prevent spilled fuel from entering the soil and weathered rock. Storage facilities should also be fitted with a leakage detection system.

iv. Fuel lines and dispensers should be rendered leak-proof by a competent person. Fuel pumped into underground fuel tanks should be accounted for, for the early detection of leakages.

v. An on-site monitoring borehole should be drilled and monitored on a quarterly basis in order to identify changes in water quality timeously.

8.7. Post-operational phase: Associated impacts

The main impacts associated with post-operational phase activities include the following:

i. Hydrocarbon pollution of groundwater and surface water.

8.8. Post-operational phase: Management and mitigation measures

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

i. Decommissioning of underground storage facilities, decommissioning must be approved and signed-off by a competent person.

ii. Water quality monitoring.

Table 20 Impact and risk assessment matrix: Construction phase

Construction phase														
No.	Activity	Potential impact	Without (WOM) or With (WM) Mitigation	Probability		Duration		Scale		Magnitude/ Severity		Significance	
				Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude
1	Excavation and vegetation clearance, other construction related activities.	Erosion of site and siltation of surface water features.	WOM	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate
			WM	Probable	2	Medium term	3	Site	2	Medium	6	22	Low
2	Construction vehicles and heavy machinery driving on site.	Oil, grease and diesel spillages, hydrocarbon contamination from construction vehicles and heavy machinery.	WOM	Highly Probable	4	Long term	4	Site	2	High	8	56	Moderate
			WM	Probable	2	Medium term	3	Local	1	Low	2	12	Negligible
3	Construction camp.	Pollution of groundwater and surface water due to sanitation facilities and related anthropogenic activities.	WOM	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate
			WM	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible
4	Storage of chemicals and other building materials.	Ground- and surface water pollution due to spillage of chemicals and building materials.	WOM	Highly Probable	4	Medium term	3	Site	2	High	8	52	Moderate
			WM	Probable	2	Medium term	3	Local	1	Low	2	12	Negligible

Table 21 Impact and risk assessment matrix: Operational phase

Operational phase													
No.	Activity	Potential impact	Without (WOM) or With (WM) Mitigation	Probability		Duration		Scale		Magnitude/ Severity		Significance	
				Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude
1	Oil, diesel and petrol spillages from refilling bay.	Hydrocarbon pollution of groundwater (seepage) and surface water (drainage).	WOM	Highly Probable	4	Permanent	5	Regional	3	High	8	64	High
			WM	Probable	2	Long term	4	Site	2	Medium	6	24	Low
2	Storage of diesel and petrol reserves in underground storage facilities.	Hydrocarbon pollution of groundwater.	WOM	Highly Probable	4	Permanent	5	Regional	3	High	8	64	High
			WM	Probable	2	Long term	4	Site	2	Medium	6	24	Low

Post-operational phase														
No.	Activity		Without (WOM) or With (WM) Mitigation	Probability		Duration		Scale		Magnitude/ Severity		Significance	
				Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude
1	Storage of petrol and diesel in underground storage facilities.	Decommissioning of underground storage facilities.	WOM	Highly Probable	4	Permanent	5	Regional	3	High	8	64	High
			WM	Improbable	1	Medium term	3	Site	2	Medium	6	11	Negligible

Table 22 Impact and risk assessment matrix: Post-operational phase

9. 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 26 used as guideline for the development of this water monitoring program.

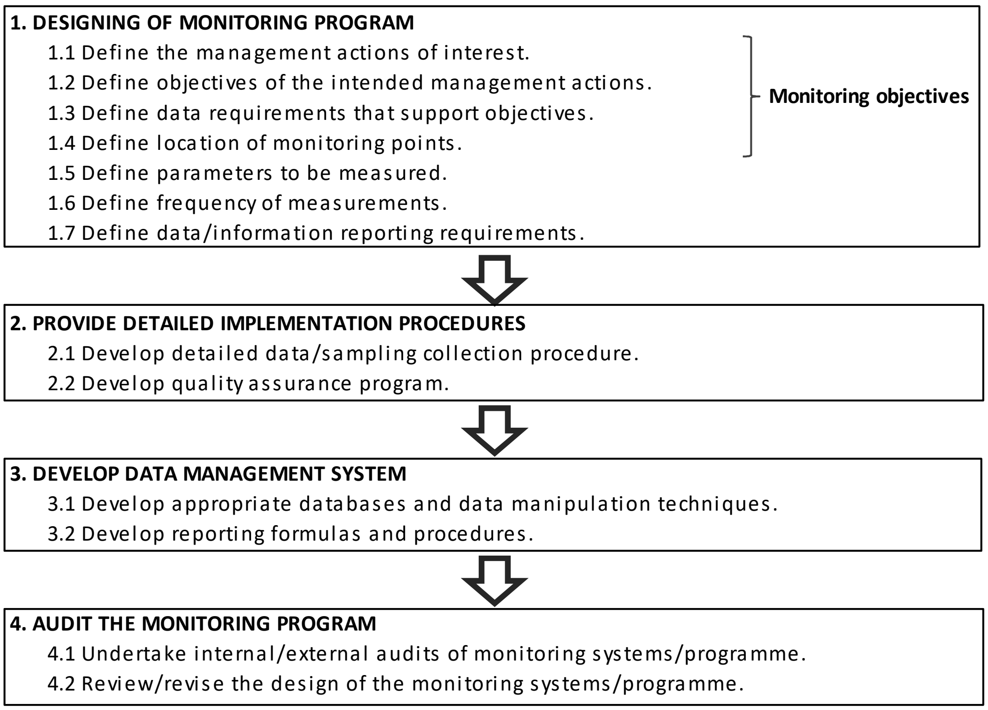


Figure 26 Monitoring programme (DWA, 2006)

9.1. 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.

9.2. Monitoring network

Geosites incorporated into the monitoring network along with relevant information are listed in Table 23 and depicted in Figure 27.

Groundwater: Due to the nature of the proposed site, it is suggested that no groundwater monitoring boreholes be drilled directly on site as it may increase the contamination risk of the aquifer and form a preferred pathway. It is rather recommended that existing hydrocensus boreholes be incorporated into the groundwater monitoring program for monitoring purposes.

Table 23 Monitoring network and programme.

Site ID	Latitude	Longitude	Monitoring frequency		Locality description
			Water quality	Water level	
H01-1283	-24,457910	29,413460	Quarterly	Quarterly	Northern neighbouring borehole, up-gradient of proposed site.
H01-2323	-24,464680	29,420300	Quarterly	Quarterly	Borehole located +/- 750 m southeast of the site, relatively down-gradient of proposed site.

9.3. Frequency

It is recommended that groundwater quality and water-level monitoring be conducted on a quarterly basis. Water quality reports summarising monitoring results should be submitted to the Regional Head with timeframes as stipulated in the water use license (WUL) conditions.

9.4. Determinants for analysis

It is recommended that all water samples undergo an initial comprehensive water quality analysis to evaluate hydrochemical composition and identify potentially elevated parameters going forward[1]. Chemical variables comprising the quarterly water monitoring programme is listed below.

9.5. Groundwater

i. ***Physical and aesthetic determinants:*** pH, electrical conductivity (EC) and total dissolved solids.

ii. ***Macro determinants:*** Total alkalinity (MAlk), sulphate (SO_4), nitrate (NO_3), chloride (Cl), fluoride (F), calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na).

iii. ***Micro determinants:*** Aluminium (Al), iron (Fe) and manganese (Mn).

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

iv. ***Total Petroleum Hydrocarbons (TPH):*** gasoline range organics (GRO) C6 – C10, diesel range organics (DRO) C10 – C28, oil range organics (ORO) C28 – C40 and BTEXN.

9.6. Sampling procedure

The sampling procedure for groundwater should be done according to the protocol by Weaver, 1992. The actions can be summarised as follows:

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

See to it that the sample gets to the appropriate laboratory as soon as possible, samples for chemical analysis should reach the laboratory preferably within seven days.

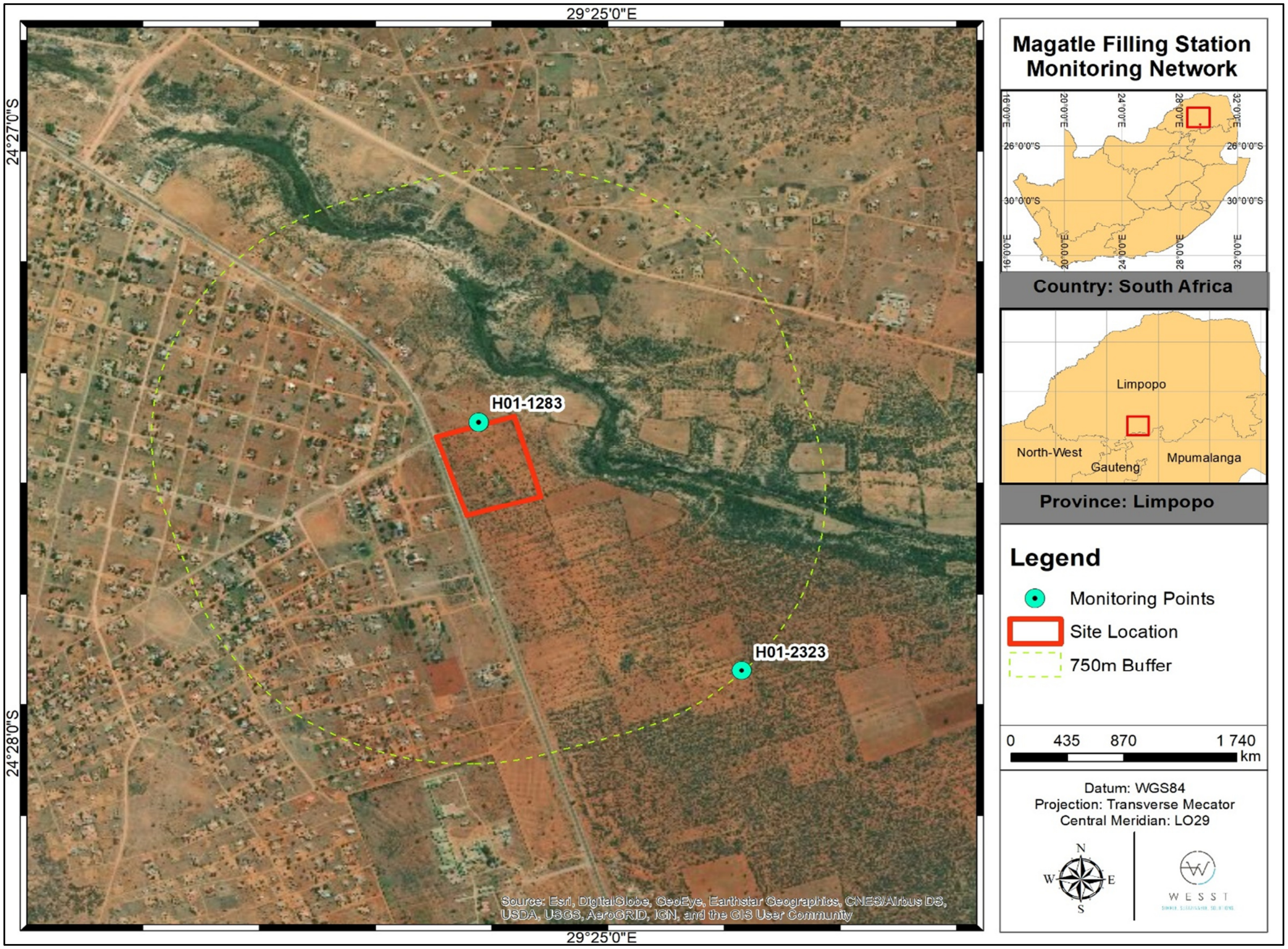


Figure 27 Groundwater monitoring network

10. CONCLUSIONS

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

1. Two main hydrostratigraphic units/aquifer systems can be inferred in the saturated zone:
   i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock can be classified as a double porosity aquifer. The inferred water level on-site is expected to be approximately 13.50 mbgl. This aquifer is usually most susceptible to LNAPL's) i.e. petrol and diesel contamination.
   ii. A deeper fractured aquifer where groundwater yields, although more heterogeneous, can be expected to be impacted by DNAPL's such as oil.
   iii. The local dynamic groundwater flow generally flows in a southern direction, diverting when moving towards the pumping boreholes in the area. Without these pumping boreholes (i.e. static water level), it could be assumed that the groundwater would still follow a southern trend.
2. Of the six boreholes surveyed during the hydrocensus user survey, three were found to be pumped and in use, of which the majority are utilised for water supply.
3. The proposed site's DRASTIC Index (Di) is calculated at 83, which classifies the aquifer's vulnerability to pollution as **low (Di=1 - 100)** and indicated that the overall potential for groundwater pollution is **low**. Similarly, the GQM Index was calculated at 2 and a "**Low**" level groundwater protection is required for this aquifer system.
4. The quality of groundwater samples analyzed is indicative of an overall moderate to poor water quality. Although the sampled water is classed as 'Soft and Neutral' (pH 6 > 8.5), with pH averaging 7.63, elevated salinity was found in all three samples as the Na & Cl significantly exceeded the SANS 241:2015 limits. Also exceeding these limits, are the EC and the TDS. This is indicative of a dry area with a low recharge, also seen in water which has been stagnant for extended periods. Borehole H01-1284 was also analyzed for TPH content that indicated acceptable levels according to the World Health Organization (WHO) guidelines.
5. According to the DRIT test, the Hydraulic Conductivity of the site area (as measured at approximately the center of the site) has average measurement of 5.5 m/d- indicative of a relatively high hydraulic conductivity.
6. During the construction phase the potential impacts without mitigation measures are rated as "Moderate". With mitigation measures the significance of the impact is rated as "Low" to "Negligible".
7. During the operational phase the potential impacts without mitigation measures are rated as "High". With mitigation measures the significance of the impact is rated as "Low".

8. During the operational phase the potential impacts without mitigation measures are rated as "High". With mitigation measures the significance of the impact is rated as "Negligible".

11. RECCOMMENDATIONS

The following recommendations are proposed following this investigation:

1. The following mitigation and management measures are recommended during the construction phase of the development:
   i. Excavations should be open for as short period as practically possible, while cleared and stripped areas should be vegetated as soon as possible.
   ii. Ensure vehicle and heavy machinery used on-site are regularly inspected for leaks and serviced at frequent intervals. Spill trays to be used where applicable.
   iii. Construction camp should be situated outside riparian buffer. Chemical sanitary facilities must be provided for construction workers and emptied on regular intervals.
   iv. All materials, fuels and chemicals must be stored in a secured, sealed and bunded area to prevent pollution from spillages and leakages. The use of chemicals should be controlled.
2. The following mitigation and management measures are recommended during the operational phase of the development:
   i. Borehole H01-1283 be equipped with pump for monitoring purposes.
   ii. The use of all detergents, oil, fuels and chemicals which could potentially leach into underground water must be controlled. This can be done by sealing of the forecourt and refueling bay area to prevent infiltration of hydrocarbon into the aquifer underlying the site.
   iii. Storm water draining from the surfaced areas should be collected in a sealed sump to be treated or removed. All contact water should be discharged into the municipal system and not into any streams, or open fields.
   iv. Subsurface fuel storage facilities should be constructed in concrete encasements with a sump system to prevent spilled fuel from entering the soil and weathered rock. Storage facilities should also be fitted with a leakage detection system.
   v. Fuel lines and dispensers should be rendered leak-proof by a competent person. Fuel pumped into underground fuel tanks should be accounted for, for the early detection of leakages.
3. The following mitigation and management measures are recommended during the post-operational phase of the development:
   i. Decommissioning of underground storage facilities, decommissioning must be approved and signed-off by a competent person.
4. It is recommended that groundwater water monitoring as outlined in this report be conducted on a

quarterly basis to serve as an early warning and detection system for the impact on environmental receptors and contaminant migration from the site. The monitoring points only includes groundwater resources, as no perennial surface water resources are located close to site. However, it is recommended that the non-perennial drainage line adjacent to the site also be monitored from time to time in order to verify water quality results.

5. Water monitoring results be evaluated and reviewed on a bi-annual basis by a registered hydrogeologist for interpretation and trend analysis.

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13. APPENDIX A: LABORATORY ANALSYSIS CERTIFICATES