CONSULTING SCIENTISTS

GEOHYDROLOGICAL STUDY FOR THE LUCKHOFF LANDFILL SITE

for

NSVT CONSULTING

By

GHT CONSULTING

PROJECT TEAM
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Project No.:	289-26-GHD.812	Start Date:	December 2017
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Our Reference No.: RVN812.1/1819

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FOR ATTENTION: MS. E. HARTEL

Dear Miss,

GEOHYDROLOGICAL STUDY FOR THE LUCKHOFF LANDFILL SITE

It is our pleasures to enclose two copies of report RVN812.1/1819: "GEOHYDROLOGICAL STUDY FOR THE LUCKHOFF LANDFILL SITE".

We trust that the report will fulfil the expectations of NSVT Consulting, Luckhoff landfill site and we will supply any additional information if required.

Yours sincerely,

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Copies: Two copies to NSVT Consulting.

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- GLOSSARY OF GEOHYDROLOGICAL TERMS & ABBREVIATIONS -

Geohydrological Term	Definition
Aquifer	A water-bearing geological formation.
Aquitard	An aquitard is a geological unit that is permeable enough to transmit water in significant quantities when viewed over large and long periods, but its permeability is not sufficient to justify production boreholes being placed in it. Clays, loams and shale are typical aquitards.
Confined Aquifer	A confined aquifer is bounded above and below by an aquiclude. In a confined Aquifer, the pressure of the water is usually higher than that of the atmosphere. So that if a borehole taps the aquifer, the water in it stands above the top of the aquifer, or even above the ground surface. We then speak of a free-flowing or artesian borehole.
Contamination	The introduction of any substance into the environment by the action of man.
Diffusivity (KD/S)	The hydraulic diffusivity is the ratio of the transmissivity and the storativity of a saturated aquifer, it governs the propagation of the chances a hydraulic head in the aquifer. Diffusivity has the dimension of lenght^2/Time.
Fractured-rock aquifer	Groundwater occurring in within fractures and fissures in hard-rock formations. Groundwater: Refers to water filling the pores and voids in geological formations below the water table.
Groundwater Flow	The movement of water though openings and pore spaces in rock below the water table i.e. in the saturated zone. Groundwater naturally drains from higher lying areas to low lying areas such as river, lakes and oceans. The rate of flow depends on the slope of the water table and the stransmissivity of the geological formations.
Groundwater Recharge	Refers to the portion of rainfall that infiltrates the soil, percolates under gravity through the unsaturated zone (also called the Vadose zone) down to the saturated zone below the water table (also called the Phreatic zone).
Groundwater Resource	All ground water available for the beneficial use, including by man, aquatic ecosystems and the grater environment.
Groundwater Resource Units (GRU's)	Represent provisional zones defined for the purpose of assessing and managing the groundwater resources of a region, in terms of large-scale abstraction from relatively shallow (depth<300m) production boreholes. They represent areas where the broad geohydrological characteristics (i.e. water occurrence and quality, hydraulic properties, flow regime, aquifer boundary conditions etc.) are anticipated to be similar. Sometimes also called ground water management units (GMU's).
Hydraulic Conductivity (K)	The hydraulic conductivity is the constant of proportionality in Darcy's law. It 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 right angles to the direction of flow
Hydrocensus	A field survey by which all relevant information regarding groundwater is amassed. This typically includes yields, borehole equipment, groundwater levels, casing height / diameter, WGS84 coordinates, potential pollution risks, photos etc.
Intergranular Aquifer	Groundwater contained intergranular interstices of sedimentary and weathered formations.
Leaky Aquifer	A leaky aquifer, also known as a semi-confined aquifer, is an aquifer who's upper and lower boundaries is aquitards, or one boundary is an aquitard and the other is an aquiclude. Water is free to move through the aquitards, either upwards or downwards. If a leaky aquifer is in hydrological equilibrium, the water level in a borehole tapping it may coincide with the water table.
Major Aquifer System	Highly permeable formations, usually with a known or probable presence pf significant fracturing and/or intergranular porosity; may be highly productive and able to support large abstractions for public supply and other purposes; water quality is generally very good.
Minor Aquifer System	Fractured or potentially fractured rocks that do not have a high primary permeability , or other formations of variable permeability; aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow of rivers.
Non-Aquifer	A groundwater body that is essentially impermeable, does not readily transmit water and/or has water quality that renders it unfit for use.

Geohydrological Term	Definition
Non-Aquifer System	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 unusable; groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent pollutants.
Permeability	The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of a aquifer under unit hydraulic gradient in unit time (expressed as m^3/m^2.d or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid; not to be confused with hydraulic conductivity, which relates specifically to the movement of water.
Pollution	The introduction into the environment of any substance by the action of man that is, or results in, significant harmful effects to man or the environment.
Porosity	The porosity of a rock is its property of containing pores or voids. With consolidated rocks and hard rocks, a distinction is usually made between primary porosity, which is present when the rock is formed and secondary porosity, which develops later as a result of solution or fracturing.
Recharge	Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally (through the water cycle) and anthropologically (i.e. “artificial ground water recharge”), where rainwater and or reclaimed water is touted to the subsurface.
Saline Water	Water that is generally considered unsuitable for human consumption or for irrigation because of it’s high content of dissolved solids.
Saturated Zone	The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.
Specific Yield (S_y)	The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table. The values of the specific yield range from 0.01 to 0.3 and are much higher that the storativities of confined aquifers.
Storativity Ratio	The storativity ratio is a parameter that controls the flow from the aquifer matrix blocks into the fractures of a confined fractured aquifer of the double-porosity type. Sustainable Yield: This usually refers to a yield calculated from aquifer test pumping by a professional geohydrologist. The yield refers to the recommended abstraction rate and pumping schedule for continued use.
Storativity (S)	The storativity of a saturated confines aquifer of thickness D is the volume of water released from storage per unit are of the aquifer per unit decline in the component of hydraulic head normal to that surface.
Transmissivity (KD & T)	Transmissivity is the product of the average hydraulic conductivity K and the saturated thickness of the aquifer D. Consequently, transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.
Unconfined Aquifer	An unconfined aquifer, also known as a water table aquifer, is bounded below by an aquiclude, but is not restricted by any confining layer above it. Its upper boundary is the water table and is free to rise and fall.
Unsaturated Zone	That part of the geological stratum above the water table where interstices and voids contain a combination of air and water; synonymous with zone of aeration or vadose zone.
Water Table	The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

Abbreviation	Definition
CRD	Cumulative Rainfall Departure
DWA	Department of Water Affairs
DWAE	Department of Water Affairs and Environment
DWAF	Department of Water Affairs and Forestry
EC	Electric Conductivity
GA	General Authorisation
GHT	GHT Consulting
m	Metres
m^3/a	Cubic metres per annum
m^3/d	Cubic metres per day
magl	Metres above ground level
mamsl	Metres above mean sea level
MAP	Mean annual precipitation
mbgl	Metres below ground level
mm	Millimetres
mS/cm	Milli-siemens per centimetre
mS/m	Milli-siemens per metre
SANS	South African National Standard
SVF	Saturated Volume Fluctuation
TOR	Terms of Reference
WRC	Water Research Commission

1 INTRODUCTION

GHT Consulting was appointed by NSVT Consulting to perform a geohydrological study for the proposed landfill site at Luckhoff. The phases of the project include the following:

Phase 1: Gathering existing information and site assessment

- Perform a desktop study and gather all the project reports and data.
- Natural topography and groundwater flow directions.

Phase 2: Geophysical Survey

The geophysical survey component of the project will encompass the following:

- A GIS aerial magnetic data interpretation will be performed to identify possible dolerite dykes and sills.
- The proposed site will be geophysical surveyed surrounding the premises by a proton magnetometer (G5)
- Compilation of a Geophysical Report and GIS Locality Maps.

Phase 3: Hydrocensus Study

This section summarises the findings of a Hydrocensus that was conducted 12 December 2017 to identify the water users and usage within the possible impact zone of the proposed Luckhoff landfill site. The hydrocensus was therefore divided into three phases, namely:

- A fieldwork investigation;
- Data processing comprising the compilation of GIS MAPS and the capturing of the field information and chemical analyses into the database; and
- Chemical analysis will be done at an Accredited laboratory.

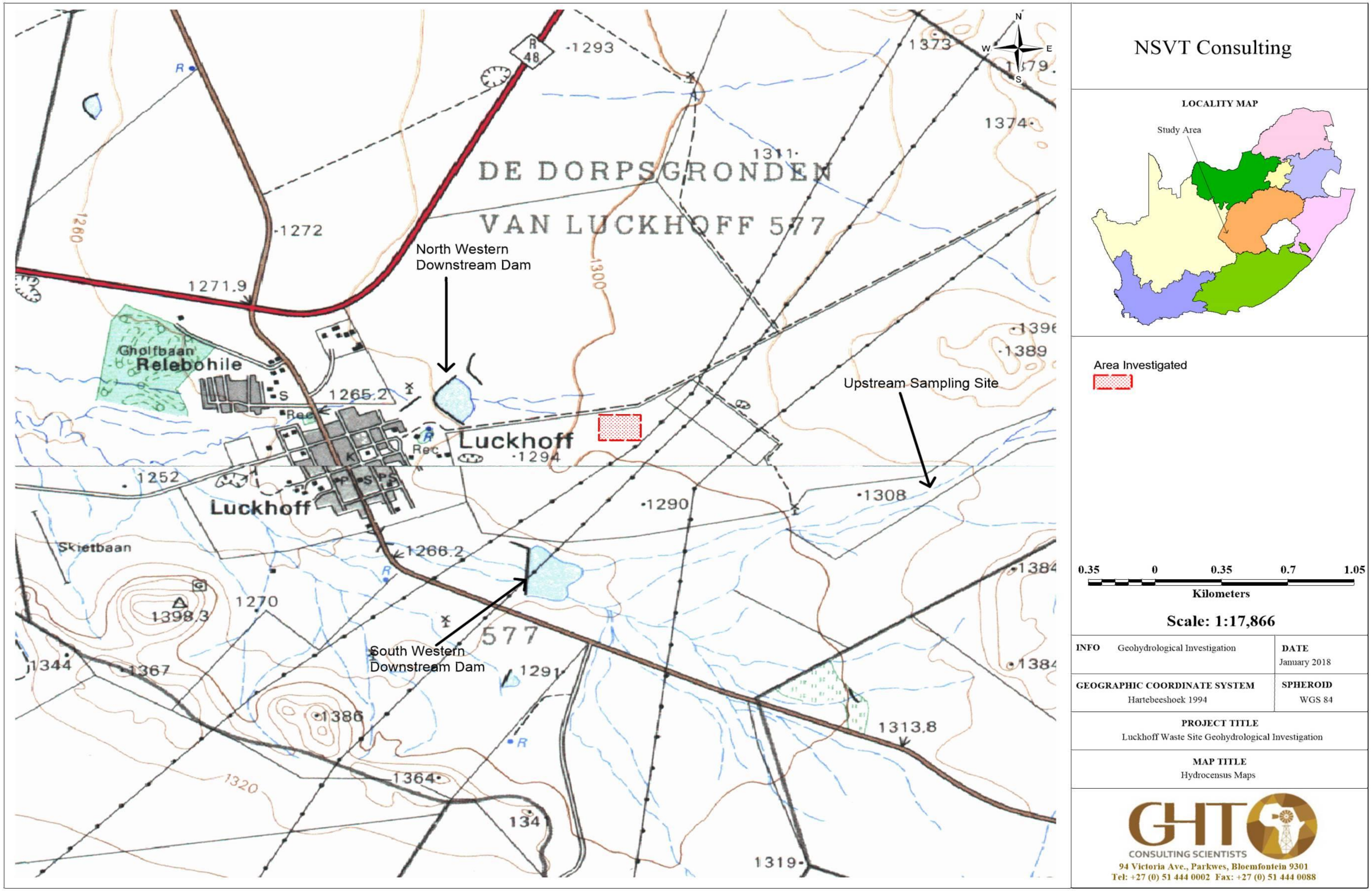

Figure 1. Locality map of the proposed waste site at Luckhoff.

2 PHYSICAL GEOGRAPHY

This section contains the basic information and physical geography of the proposed landfill site.

2.1 EXTENT OF THE INVESTIGATION

The study area of the proposed landfill site is located in western part of the Free State Province on the border between the Northern Cape and the Free State Province approximately 150 km to the south west of Bloemfontein. The study area is located in Drainage Area D, Quaternary sub-catchment D33C (Surface Water Resources of South Africa, First Edition, 1994).

The proposed site is situated to the immediate north east of Luckhoff, approximately 1.1 km from the nearest urban areas.

The extent of the investigation is a comprehensive geohydrological study with surface water components included if applicable to the landfill site. For this investigation 2 prominent downstream water bodies were identified (north west and south west) within close proximity of the site, but was not sampled as these dams were dry during the site investigation. An upstream sample can be obtained by sampling the stream approximately 600meters south east of the waste site before flowing into the downstream dam (refer to Figure 1). This stream was dry during the flied investigation.

2.2 TOPOGRAPHY AND SURFACE DRAINAGE

The topographical data and maps can be perused in, Figure 1 and Figure 2. The surface water drainage direction from the proposed waste site is primarily into a south western and western direction (refer Figure 2). These drainage directions contribute to the two downstream dams as described in the latter.

The surface geology of the proposed site in general consist of Quaternary Deposits (Eoliese Sand and Calcrete) and dolerite sills. The surface geology map of the area can be perused in Figure 22. The dolerite outcrops at the investigated area can be viewed in the photos below.

Photos of the dolerite outcrops observed during the geophysical investigation.

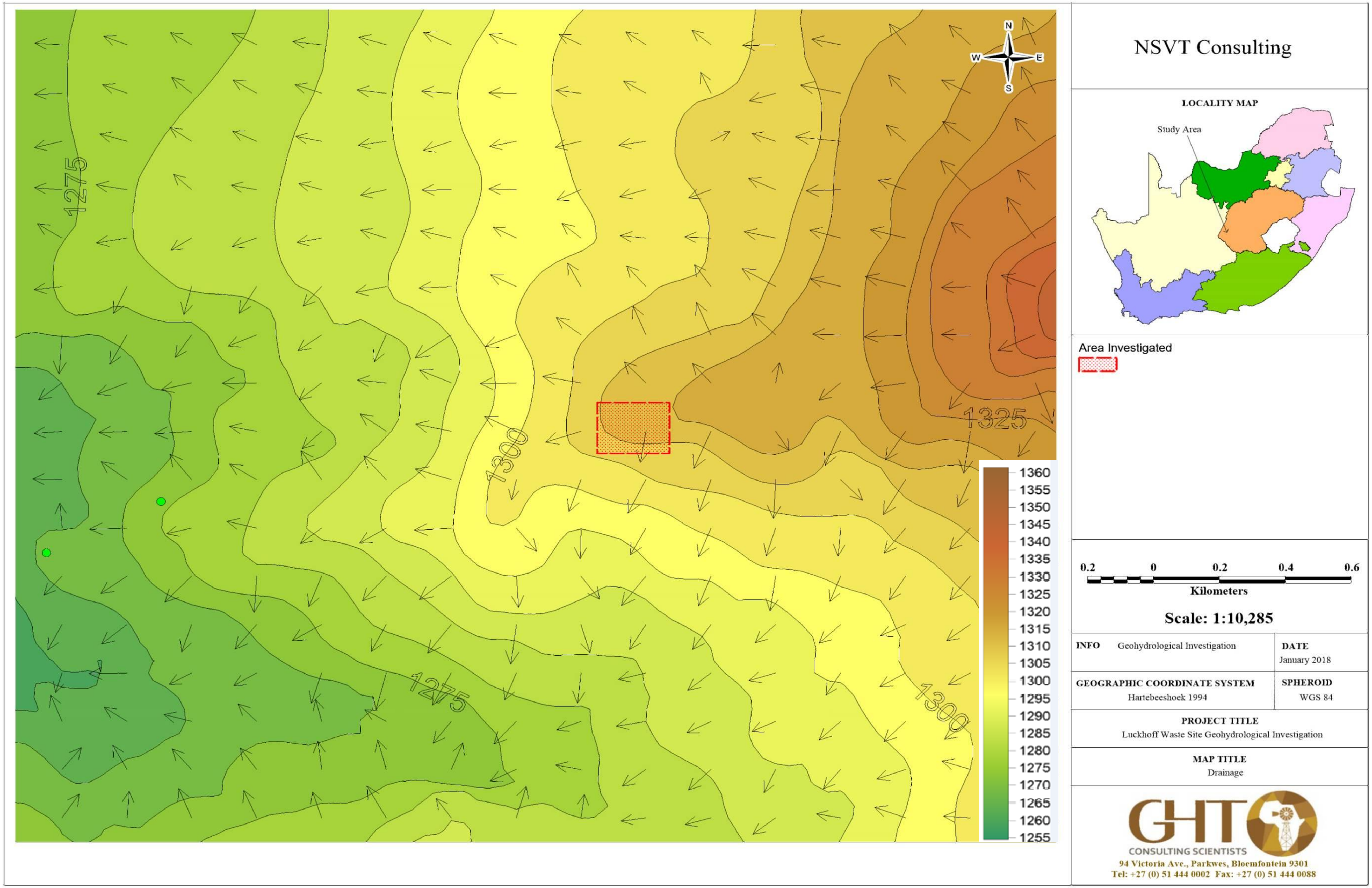

Figure 2. Surface drainage map of the Luckhoff proposed waste site. Note the drainage vector arrows, which indicate the drainage patterns.

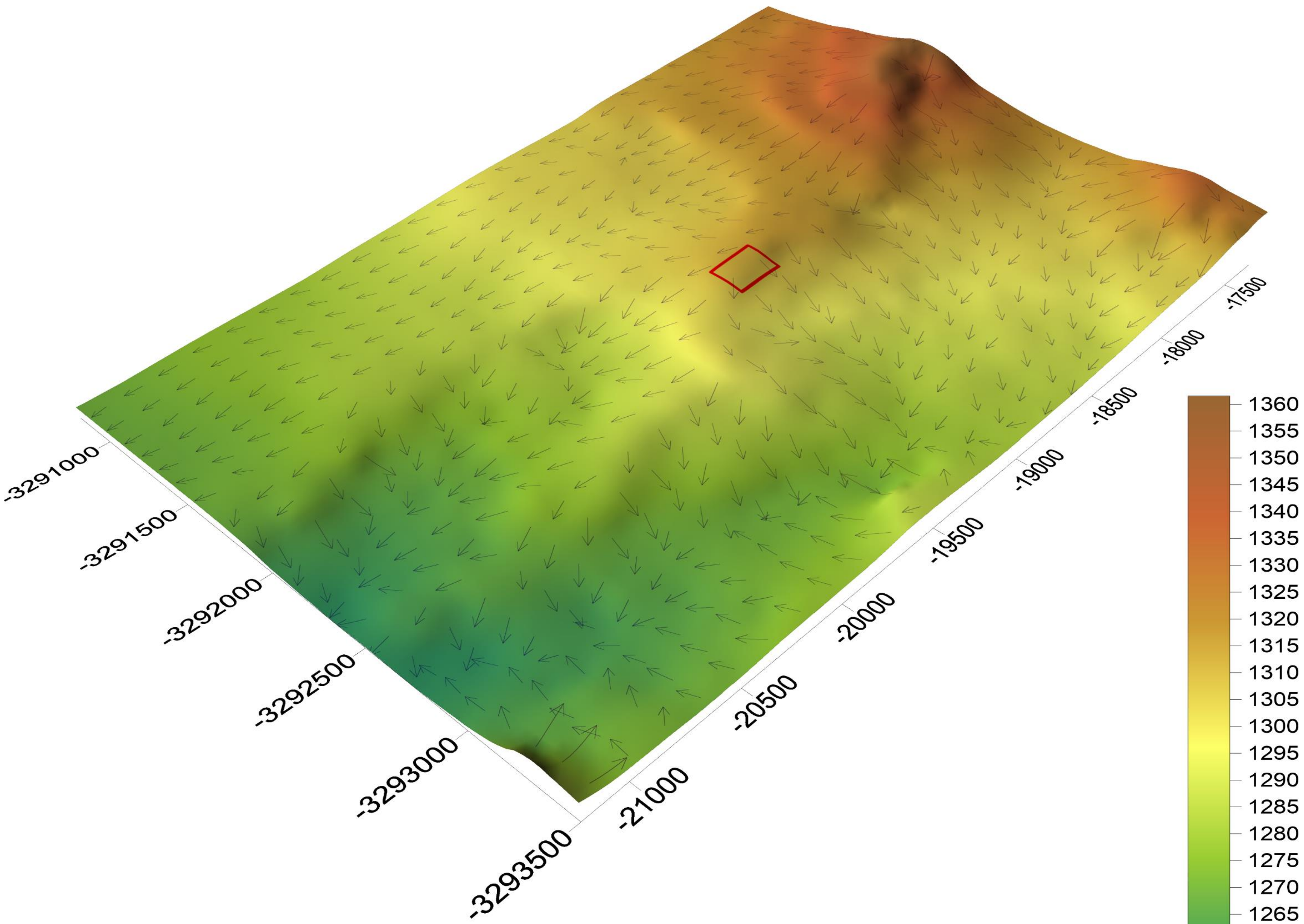

Figure 3. 3 Dimensional representation of the local drainage.

2.2.1 Climate

The followings section includes general information regarding the climate of Luckhoff, which includes temperatures, wind direction information and rainfall records.

2.2.1.1 General Climatic Information

The Luckhoff area has a climate characterized by hot summers and cold winters, and has a predominantly summer rainfall. Air temperature ranges from a maximum of 34 to 32 ^{o}C in January to a minimum of 6 to 4 ^{o}C in July. (https://www.worldweatheronline.com/' title='Historical average weather'>Data provided by WorldWeatherOnline.com).

The predominant wind directions for Luckhoff is as follows utilising the Kimberley wind rose data located closest to Luckhoff (Climate of South Africa, Surface Winds, WS43, 2002):

- Wind direction for January (refer to Figure 6 on page 10): The predominant wind direction is from the north and the minor wind directions is from the north east and north west.
- Wind direction for April (refer to Figure 7 on page 10): The predominant wind direction is from the north and the minor wind directions is from the north east and north west.
- Wind direction for July (refer to Figure 8 on page 11): The predominant wind direction is from the north and the minor wind directions is from the north east and north west.
- Wind direction for October (refer to Figure 9 on page 11): The predominant wind direction is from the north and the minor wind directions is from the south west and north east.

The dominant wind direction for Luckhoff is from the north during the year and the minor wind directions depends on the time of the year.

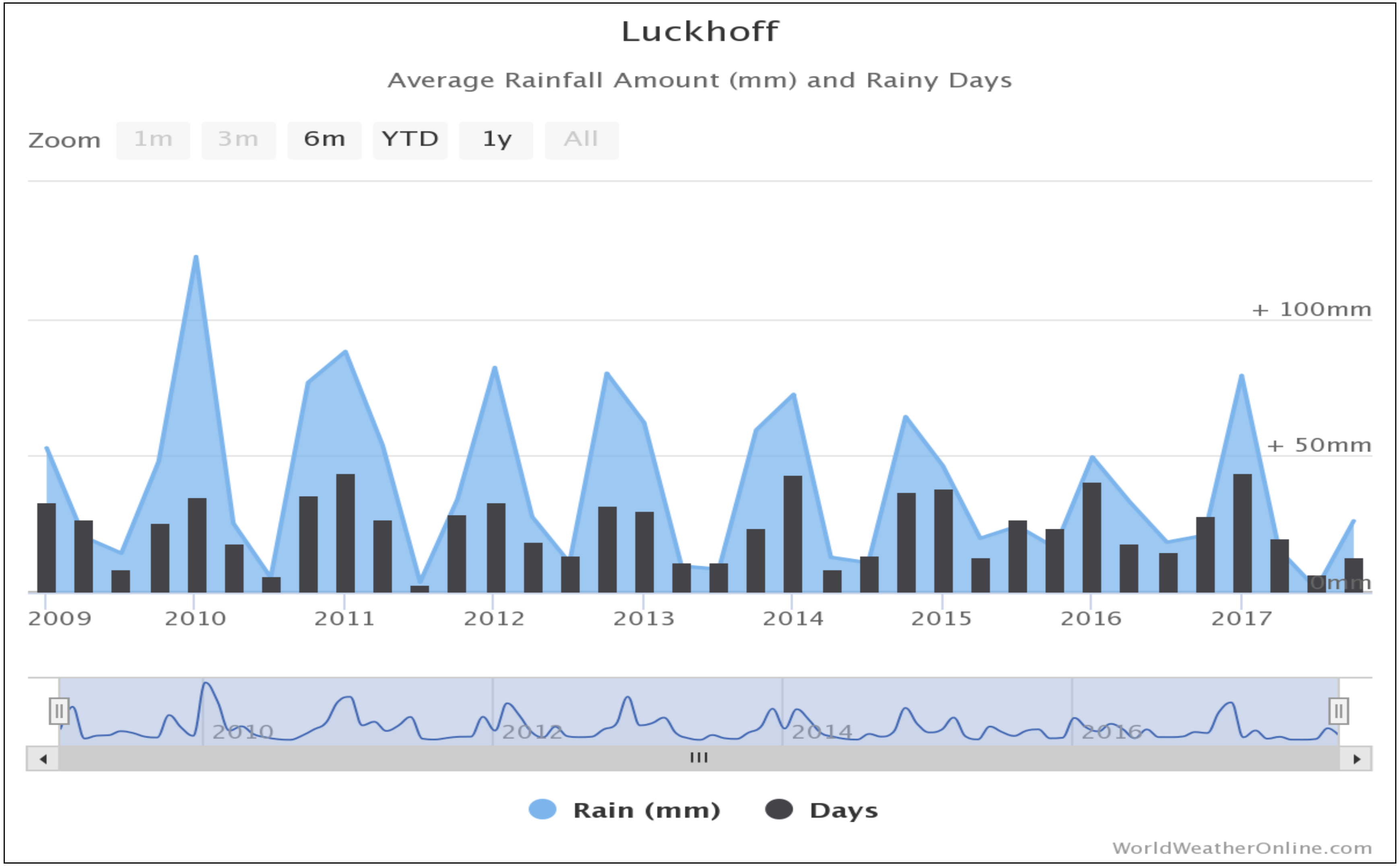

Figure 4. Yearly rainfall records for Luckhoff. (Adapted from https://www.worldweatheronline.com/' title='Historical average weather'>Data provided by WorldWeatherOnline.com)

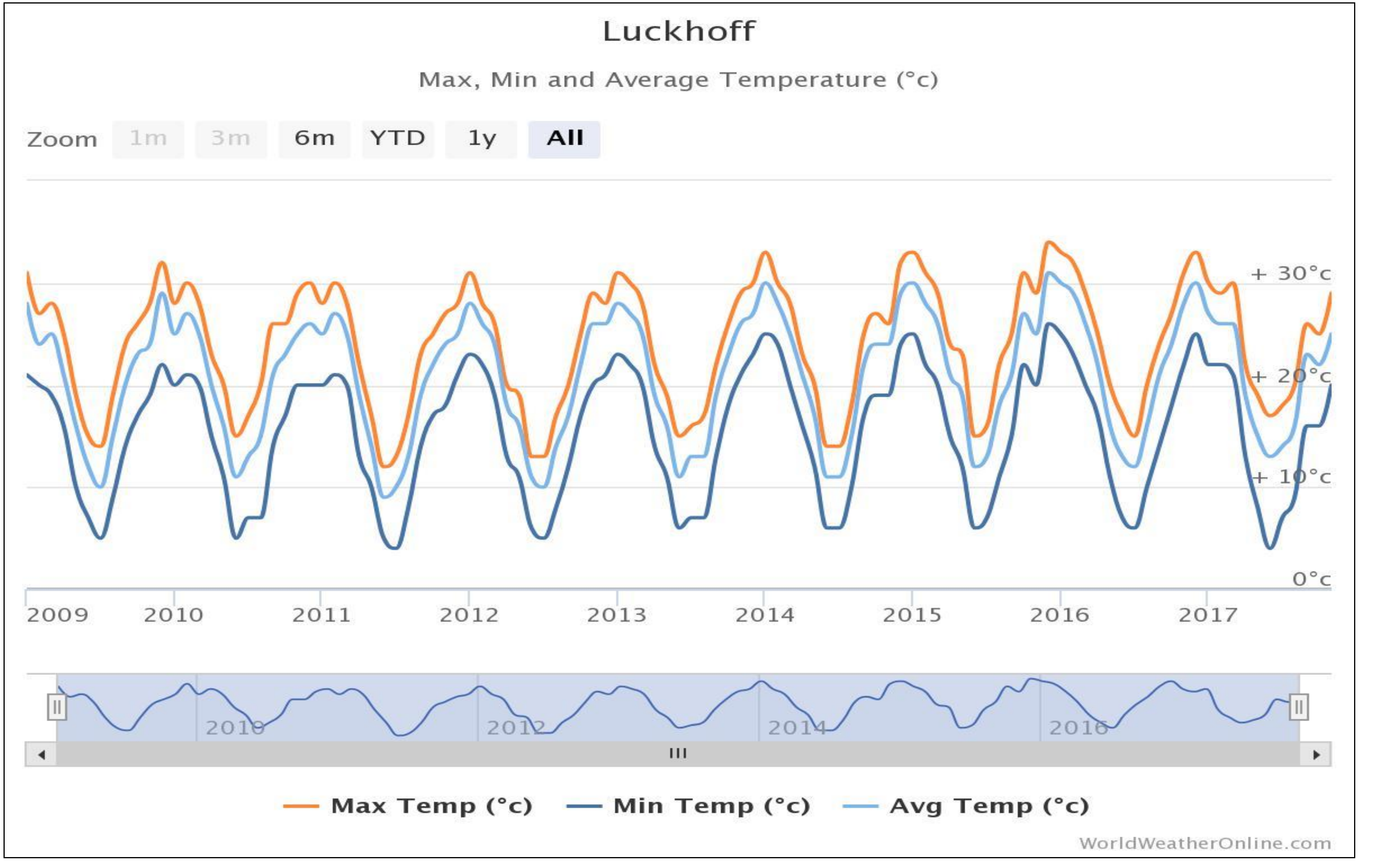

Figure 5. Yearly maximum, ninimum and average temperature records for Luckhoff. (Adapted from https://www.worldweatheronline.com/' title='Historical average weather'>Data provided by WorldWeatherOnline.com)

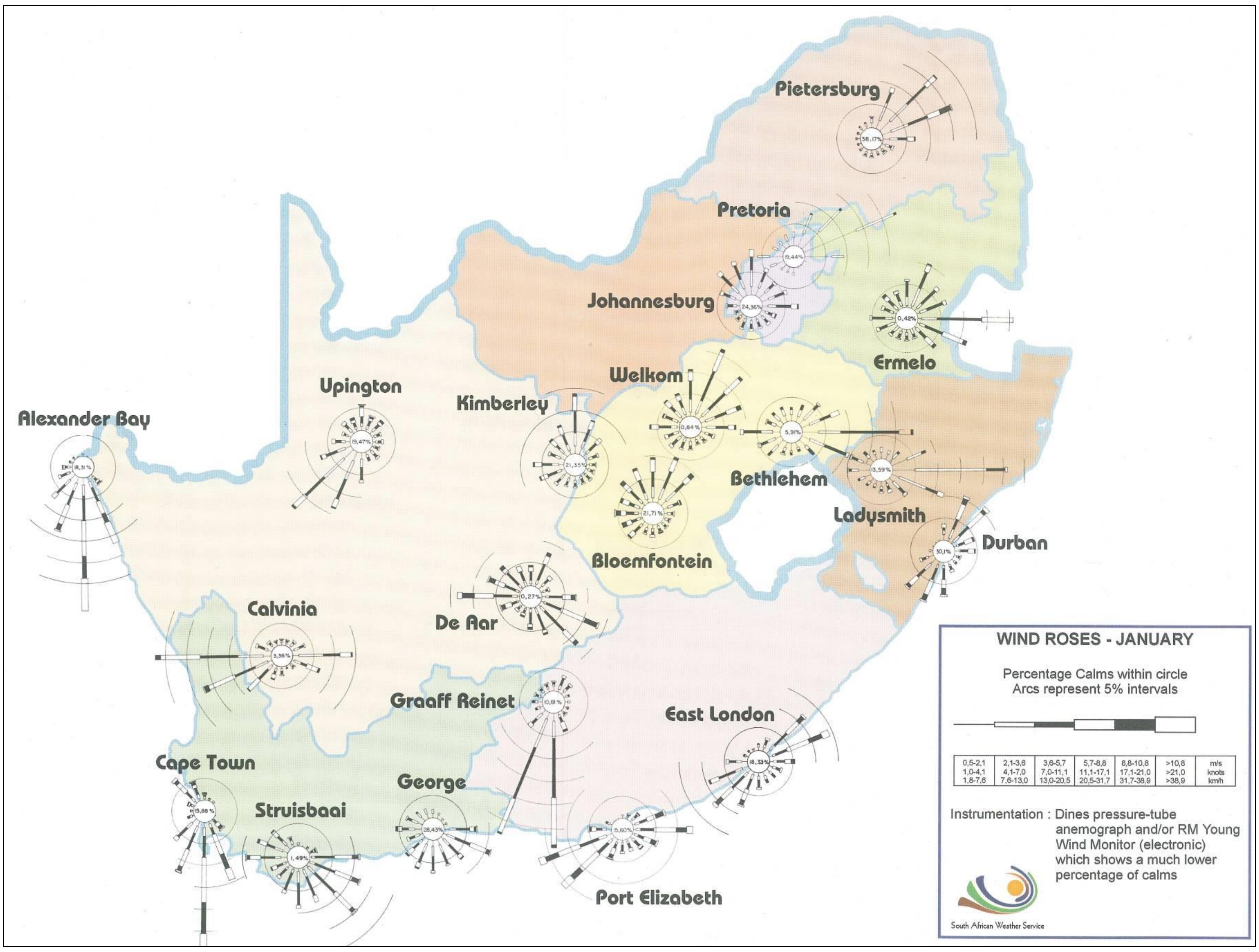

Figure 6. Wind roses for South Africa for the month of January. .

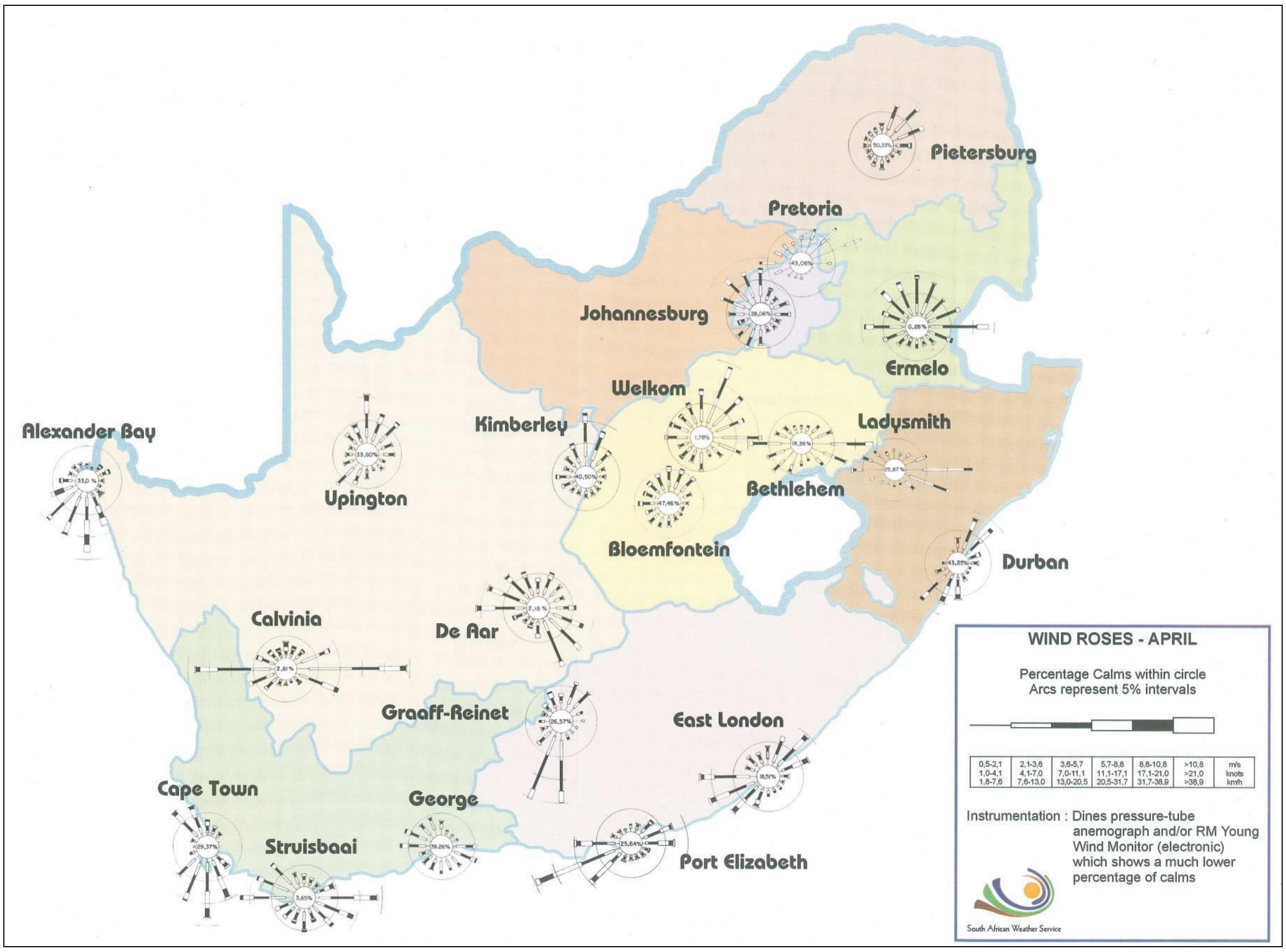

Figure 7. Wind roses for South Africa for the month of April.

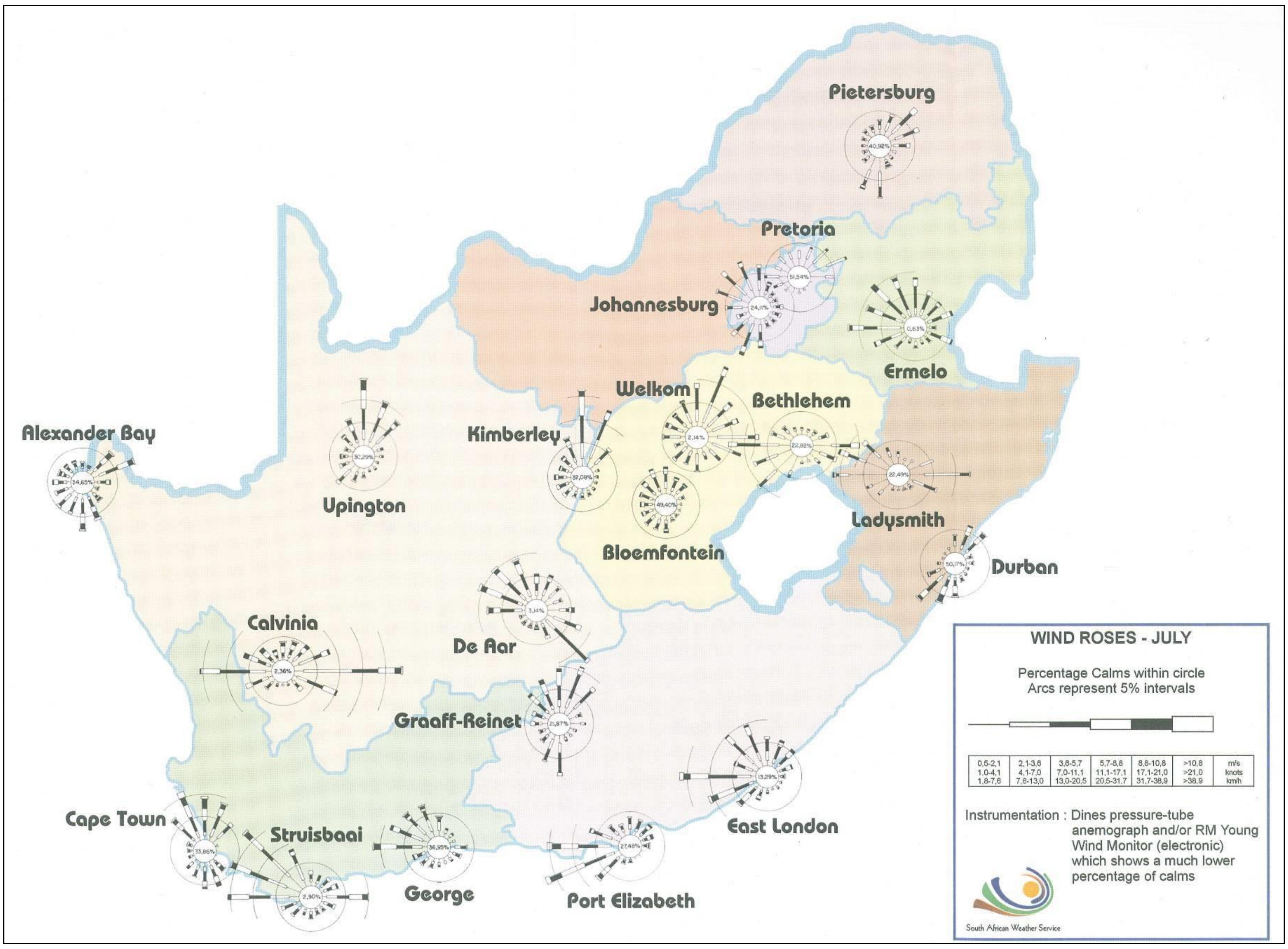

Figure 8. Wind roses for South Africa for the month of July.

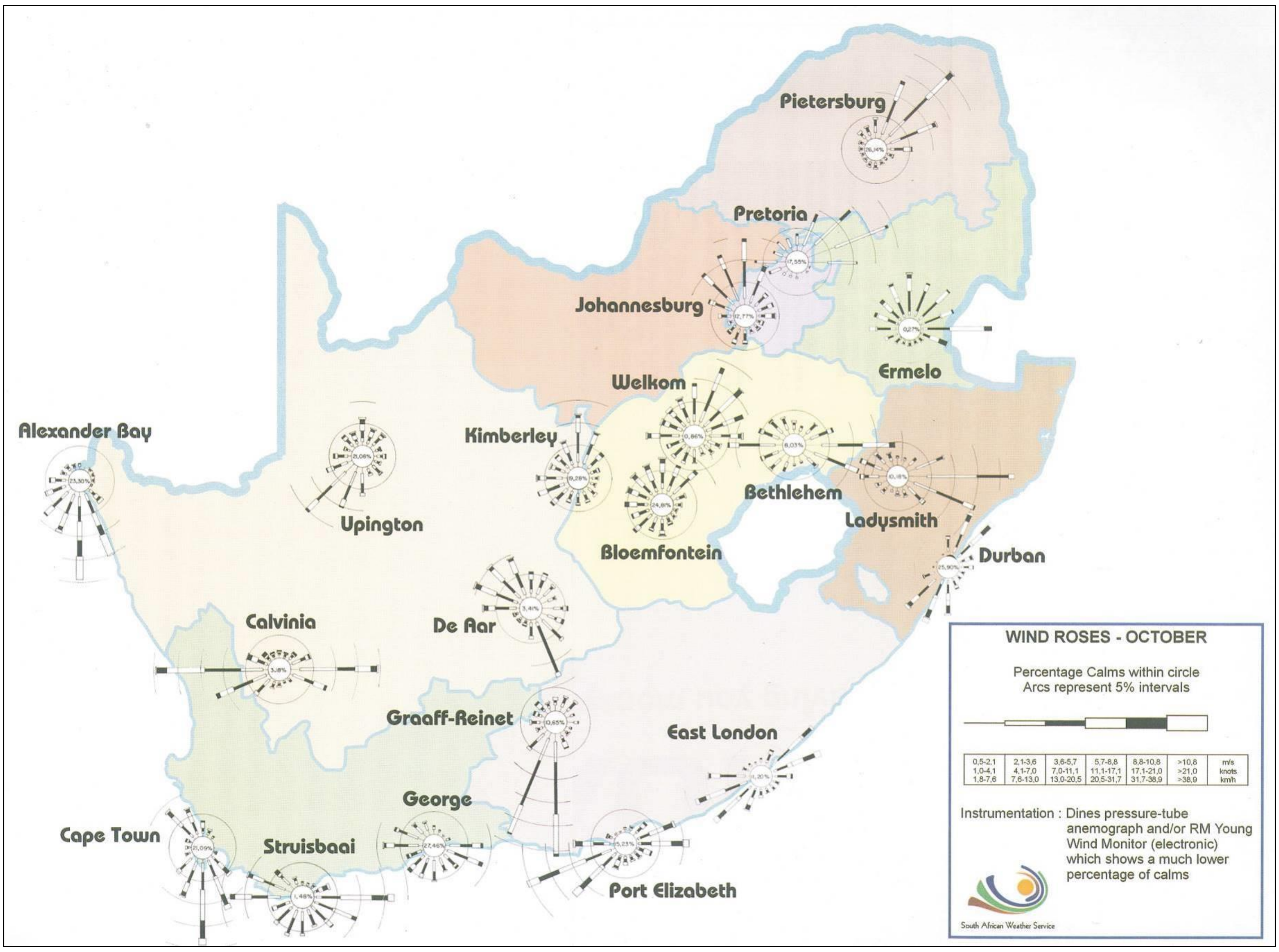

Figure 9. Wind roses for South Africa for the month of October.

2.2.2 Vegetation

The existing vegetation description and investigation will be discussed in the EIA section of the application.

3 SUBSURFACE FEATURES

3.1 GEOHYDROLOGICAL BACKGROUND INFORMATION

The geohydrological background information are as follows.

3.1.1 Catchment and Groundwater Management Unit

The Luckhoff proposed waste site of is located in western part of the Northern Cape Province approximately 150 kilometres to the south west of Bloemfontein. The study area is located in Drainage Area D, Quaternary sub-catchment D33C (Surface Water Resources of South Africa, First Edition, 1994).

3.1.2 General Aquifer Information of the Luckhoff District

The following section is based on the Groundwater Resources of South Africa Maps, DWA, 1995 as well as existing information gathered from varies geohydrological-, hydrological- and civil engineering reports when available.

3.1.2.1 Groundwater Table Depth

The groundwater depth in the study area is approximately 10 - 20 mbgl according to the DWA map, refer to Figure 10.

3.1.2.2 Aquifer Classification

The aquifer of the proposed waste site area is classified as a minor aquifer according to the Aquifer Classification Map of South Africa (refer to Figure 11 on page 15).

3.1.2.3 Recharge to Aquifer

The mean annual recharge of the area is between 15 - 25 mm/a and on average 20 mm/a (refer to Figure 12 on page 16). The Vegter recharge maps estimates the recharge as 20 mm/a (Vegter, 1995, refer to Figure 13 on page 17).

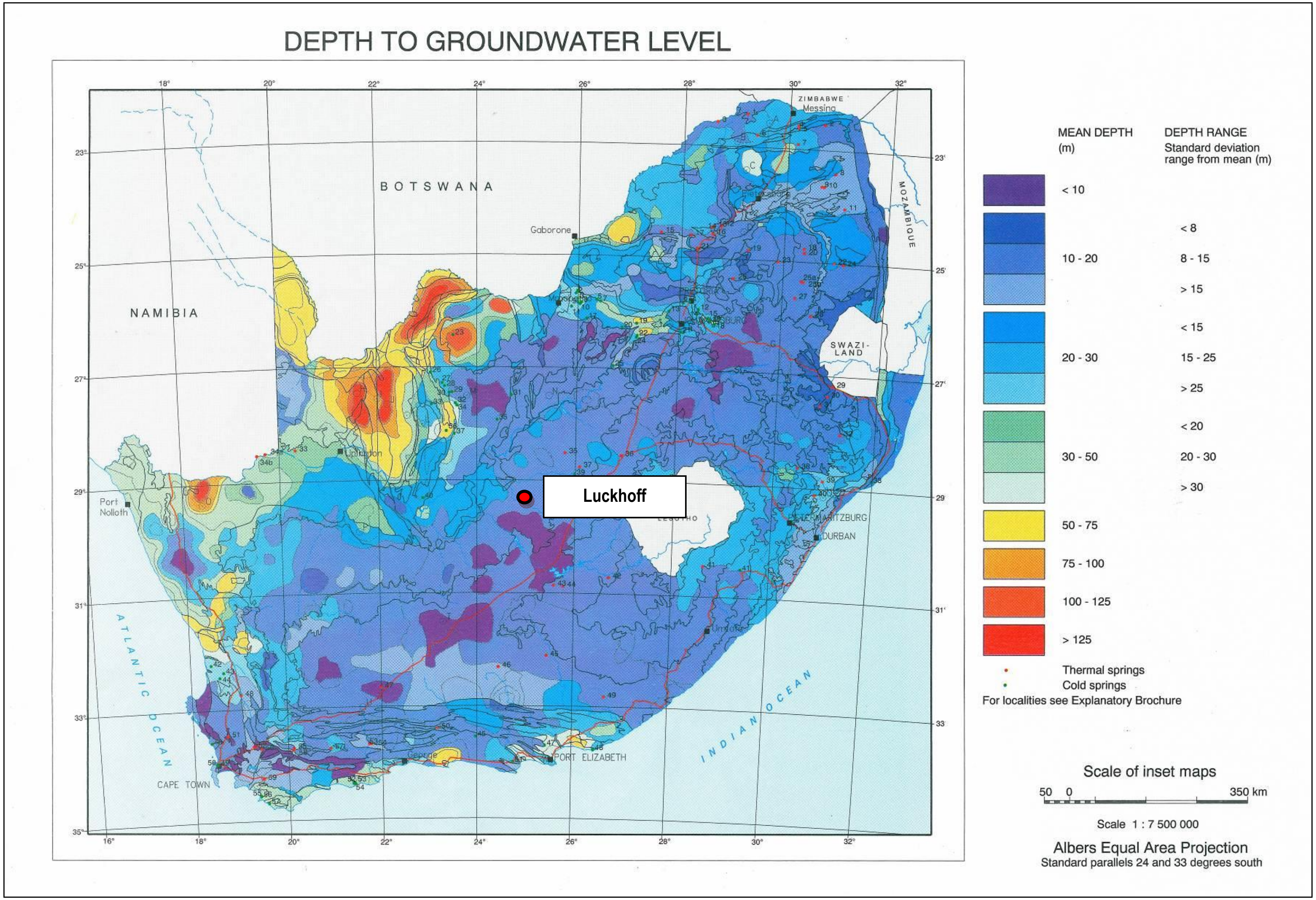

Figure 10. Depth of groundwater level (adapted from the Groundwater Resources of South Africa Map, DWA, 1995)

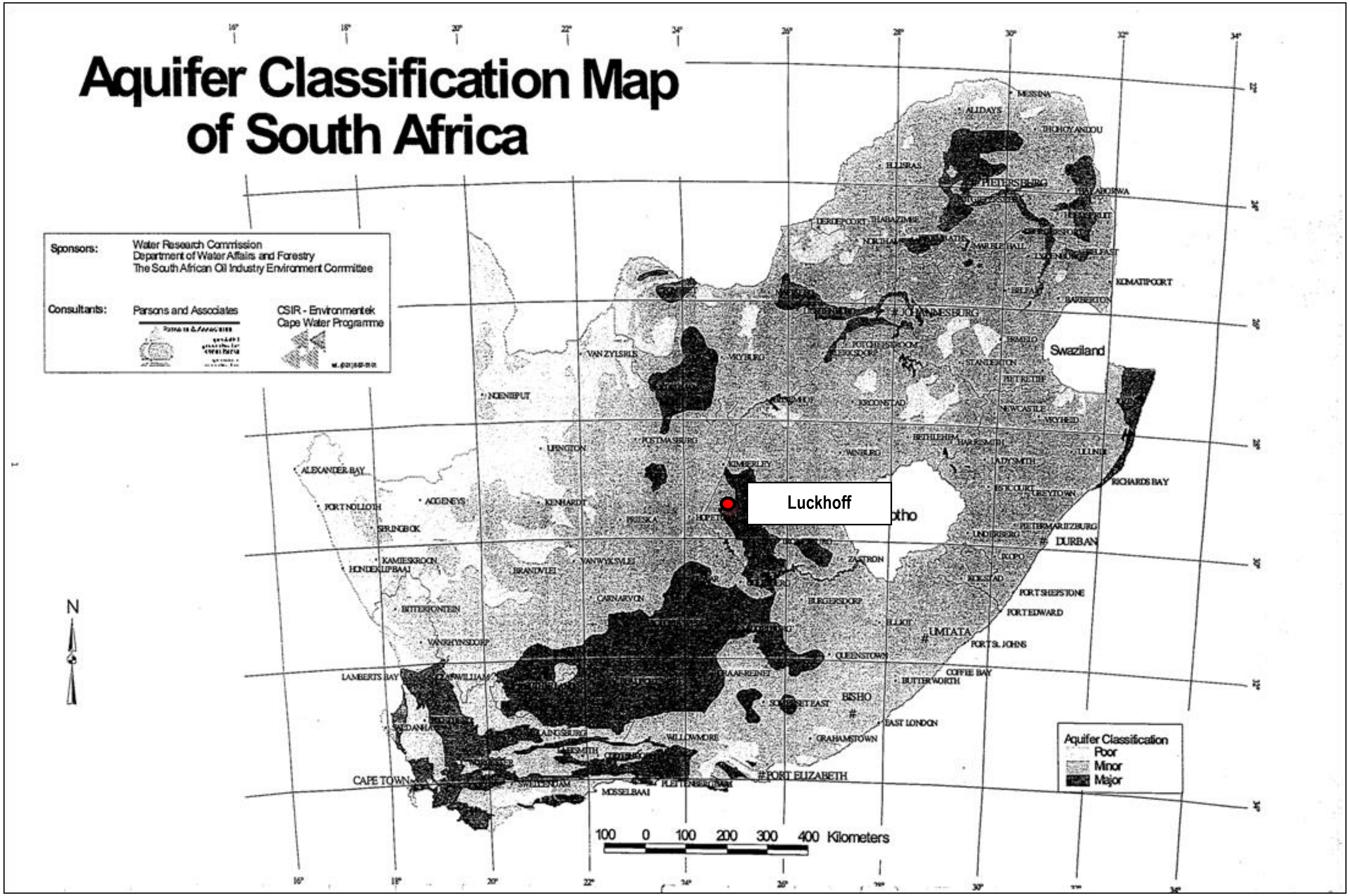

Figure 11. South African Aquifer Classification Map. Luckhoff is situated on a minor classified aquifer.

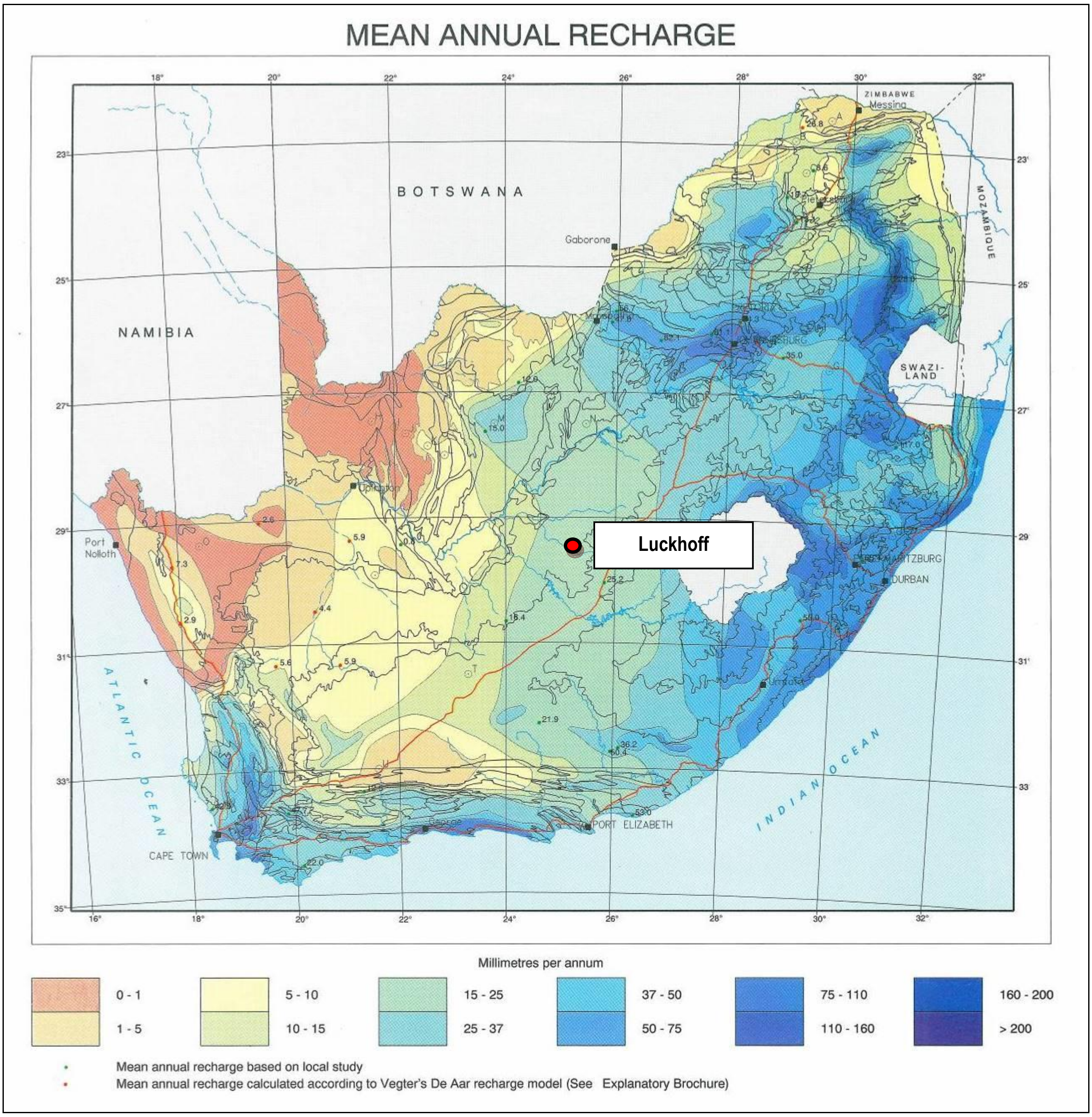

Figure 12. Mean annual recharge (adapted from the Groundwater Resources of South Africa Map, DWA, 1995).

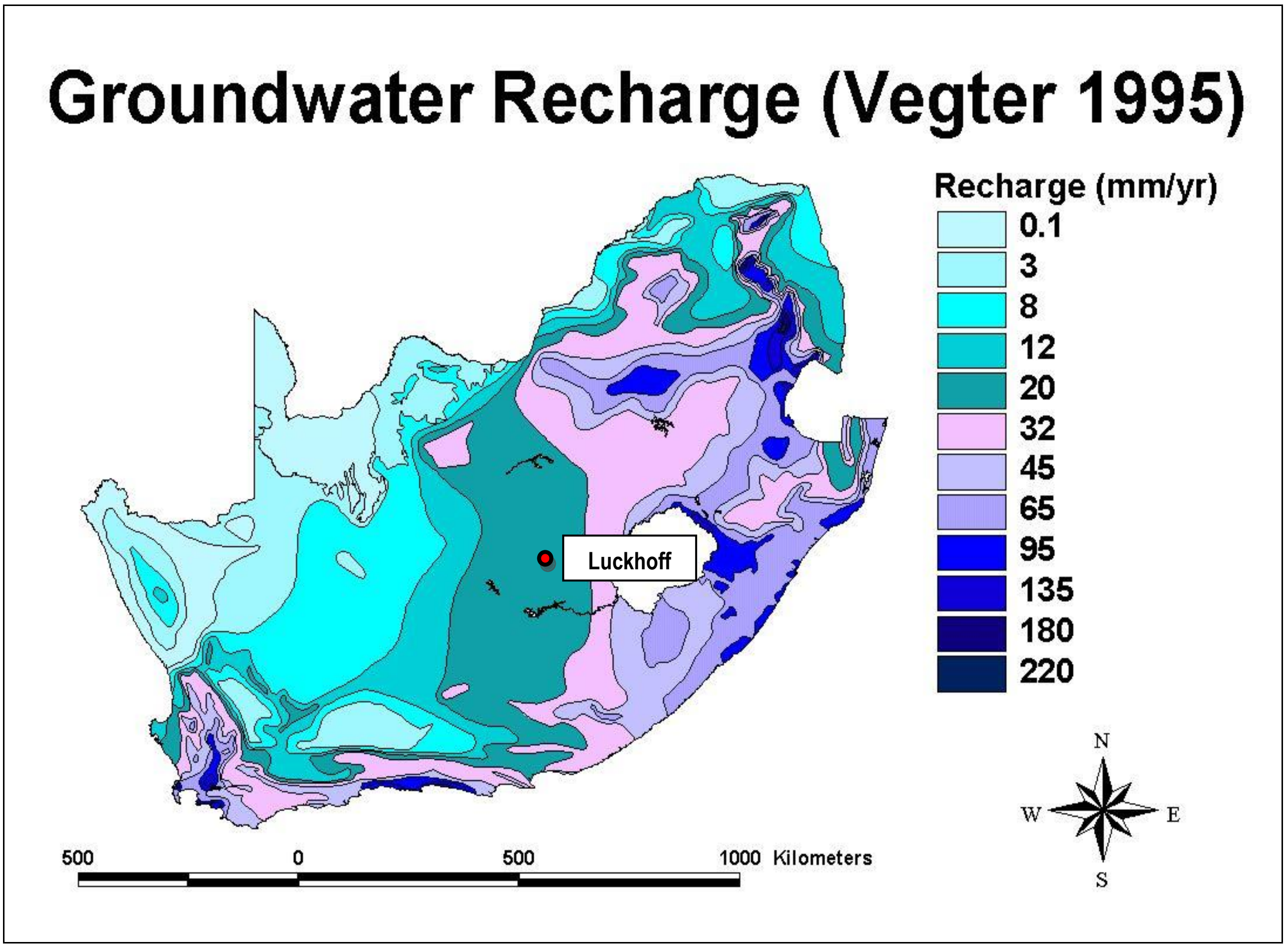

Figure 13. Groundwater recharge estimation map (Vegter, 1995).

3.2 GEOPHYSICS AND MAP INTERPRETATIONS

This section includes the results of geophysical investigation for the Luckhoff proposed waste site.

3.2.1 Map Interpretations

The following section includes the interpretation of the aerial photo map, geological map and the aerial magnetic intensity map.

3.2.2 Aerial Magnetic Intensity Map Interpretation

Airborne magnetic surveys can encompass large areas in a relatively short period of time, using helicopters or low flying aircraft trailing a magnetometer. Although these surveys do not have the same spatial resolution of ground surveys, they are invaluable for tracing larger structural features, and especially major dyke intrusions into the Karoo sediments. The entire Karoo basin has been covered by aeromagnetic surveys, which were carried out on behalf of the Council for Geoscience and are available on digital format.

Airborne magnetometers all measure the total magnetic field and are of two main types, fluxgate magnetometers and proton magnetometers. The fluxgate magnetometer which measures the field relative to a selected datum uses two systems of coils, one, much as in ground magnetometers, measures the relative field, while the second system of coils together with associate electronics and motor driven gimbals maintains the measuring coil in the direction of the total magnetic field irrespective of aircraft heading and attitude. The proton magnetometer measures the absolute value of the total field and needs no sophisticated orient mechanism. Proton magnetometers are favoured in most recent installations. There are other more sensitive magnetometers used in petroleum surveys. The sensing head of the magnetometer is either carried in an extended “stinger” on the tail, mounted on the wingtip or is towed in a “bird” to keep the measuring elements away from the magnetic influence of the aircraft.

Magnetic data is recorded continuously during flight on a paper recorder, magnetic tape or electronically. The flight path of the aircraft is recorded by photographing the ground traversed with a special 35 mm camera. Numbered timing marks, known as fiducials, are recorded on both the film and on the paper record (or magnetic tape) on which the magnetic data appears. A radio altimeter records the aircraft height above ground and feeds height information to the pilot. The aircraft is navigated with the aid of existing aerial photographs, large scale maps or by using electronic navigational aids. The sensitivity of the airborne magnetometers is in the order of 0.5 to 1 nT.

The available aerial magnetic data available for the study area is of a low resolution (refer to Figure 14). No dolerite sill or dyke structures could be discerned directly from the aerial magnetics data.

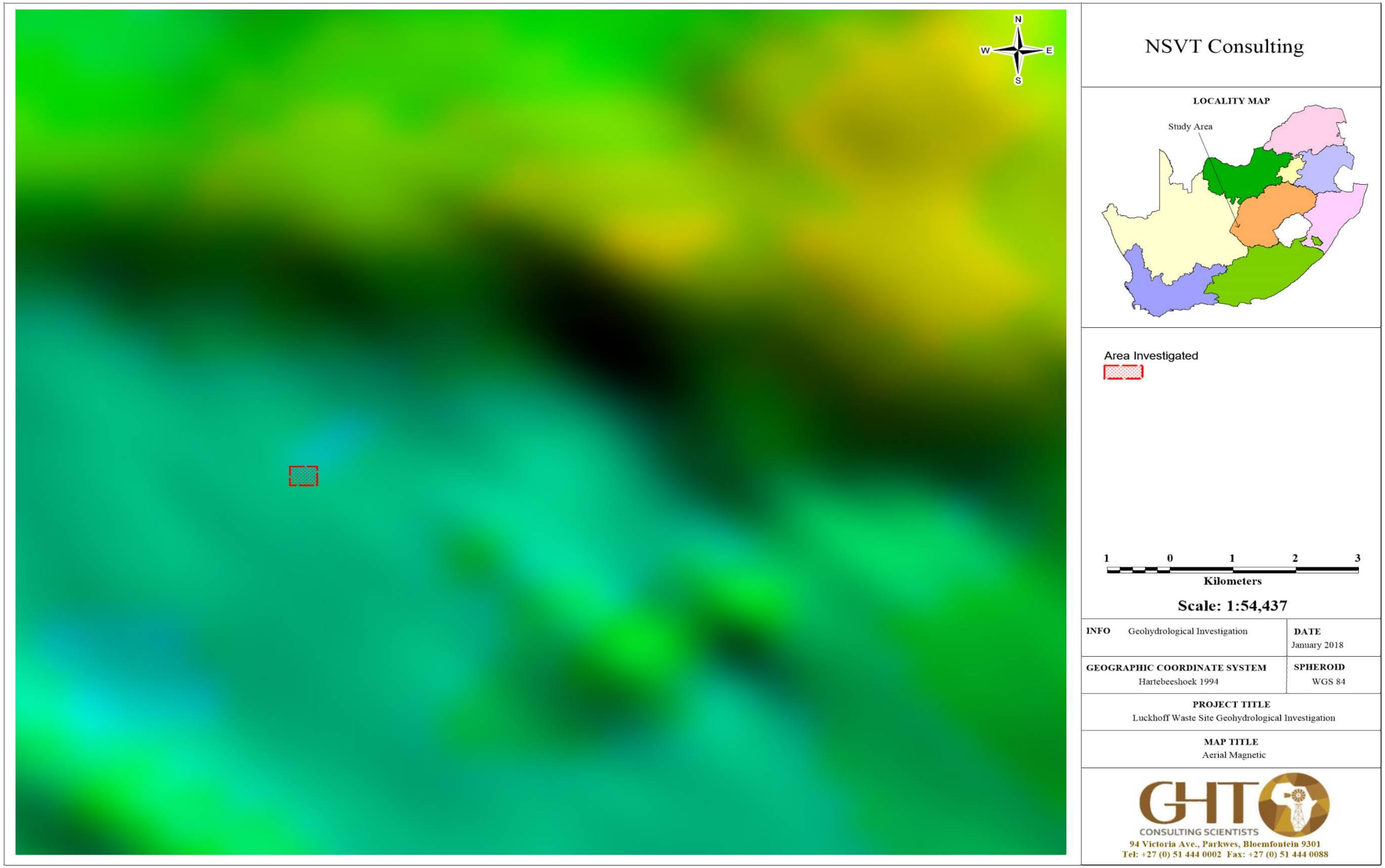

Figure 14. The locality map of the aerial magnetic intensity data for the Luckhoff district. Note that the aerial magnetic data and contours are too rough in nature for local interpretation at the Luckhoff area.

3.2.3 The Magnetic Method

The magnetic geophysical method proved an effective method for the detection of dolerite structures, which includes dykes and sills.

The normal magnetic field of the earth can be visualised as a field of a bar magnet placed at the centre of the earth. Any changes in this "normal" magnetic field superimposed by dykes, for example, can be measured by a magnetometer. These measurements (changes) in magnetism can then, through the process of modelling, be interpreted in terms of the dip, strike, depth and width of the body that causes the anomaly. Since these geological magnetic features might be remnant (i.e. permanently) magnetised, a feature, which is normally not known to the modeller, no unique solution of the model exists. By making certain reasonable assumptions about the geology, restrictions can be placed on some of the geological features of the body. The magnetic method is an extremely useful method to map of dykes, which are good groundwater exploration targets.

3.2.3.1 Results of the Field Geophysical Survey and Borehole Siting

A geophysical field survey was conducted around the Luckhoff proposed waste site. The survey included four (4) magnetic traverse lines. The geophysical traverse charts can be viewed from Figure 16 to Figure 19.

The description of the geophysical traverses of the field survey around the Luckhoff proposed waste site are as follows.

- Traverse line 01 (refer to Figure 16): The traverse was conducted from south east to north west. The variability of magnetic intensity data indicates the presence of the underlying dolerite sill.
- Traverse line 02 (refer to Figure 17): The traverse was conducted from south west to north east. The variability of magnetic intensity data indicates the presence of the underlying dolerite sill.
- Traverse line 03 (refer to Figure 18): The traverse was conducted from south to north. The variability of magnetic intensity data indicates the presence of the underlying dolerite sill.
- Traverse line 04 (refer to Figure 19): The traverse was conducted from east to west. The variability of magnetic intensity data indicates the presence of the underlying dolerite sill.
- In the general the geophysical survey and geological field observations confirmed the presence of the underlying Karoo intrusive, which in this case is a magmatic dolerite sill. These dolerite outcrops can be viewed in 2.2.

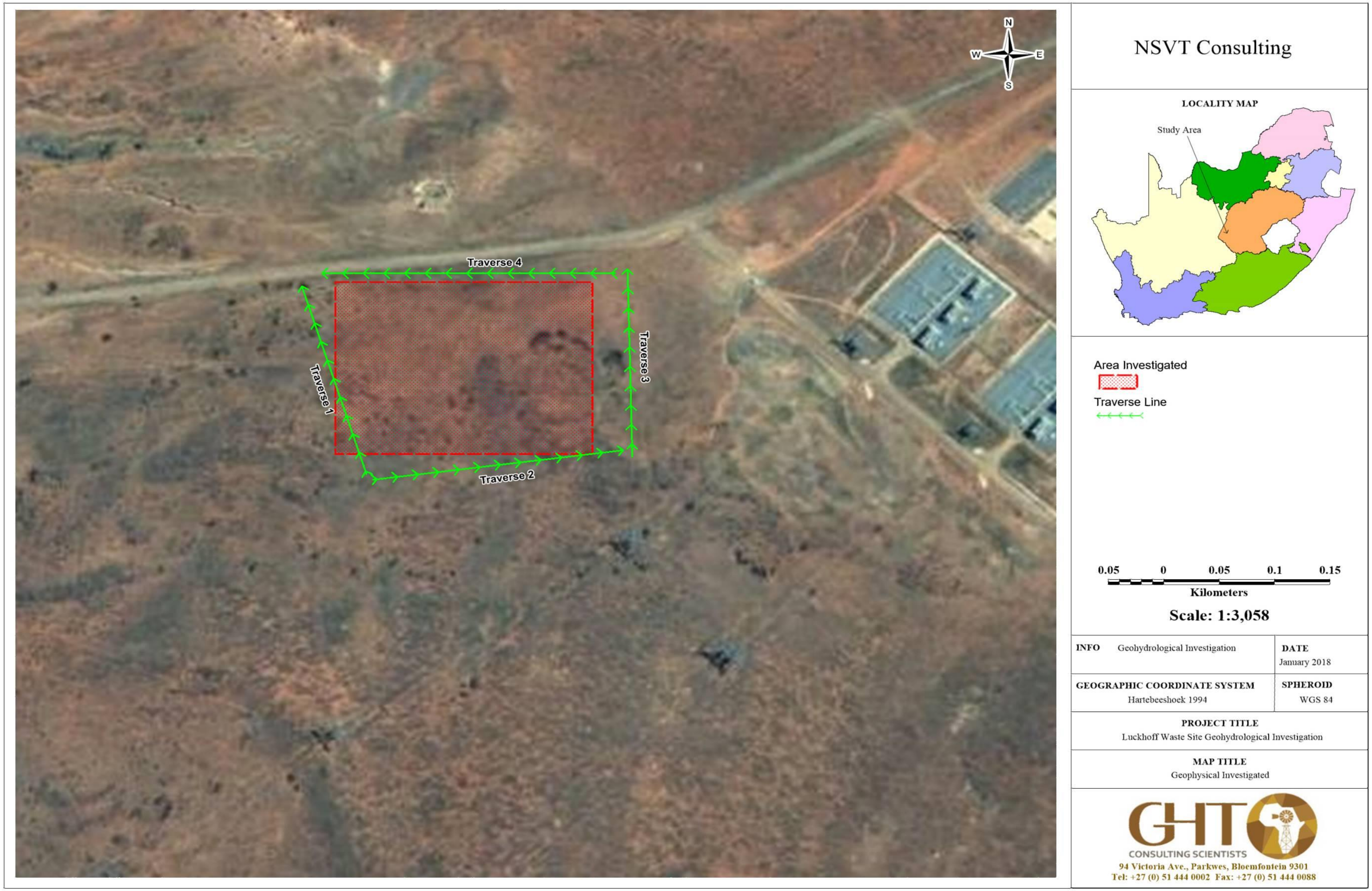

Figure 15. The locality map of the geophysical survey conducted around the Luckhoff proposed landfill site.

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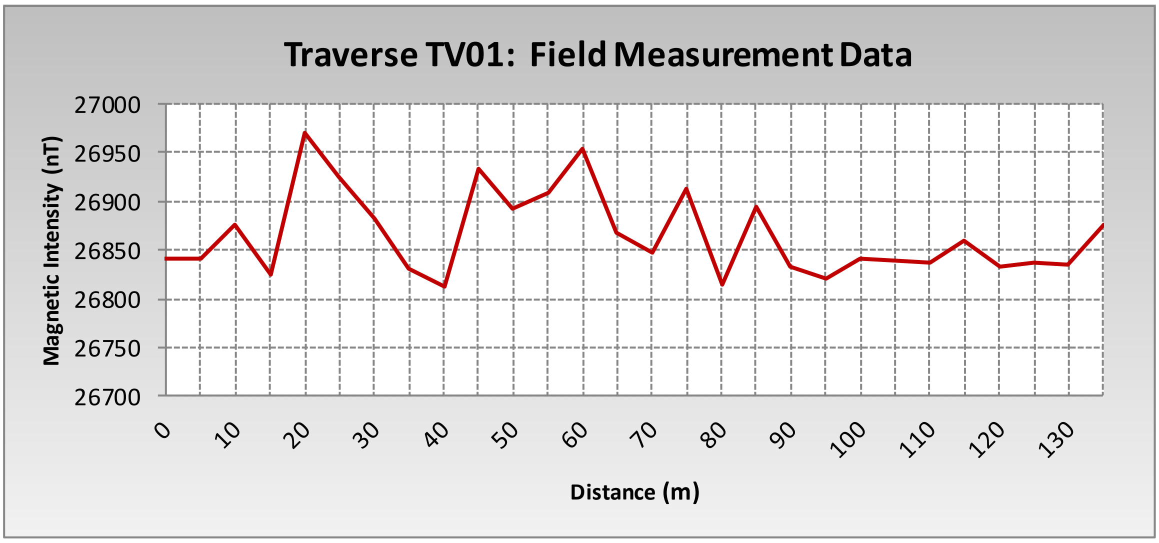
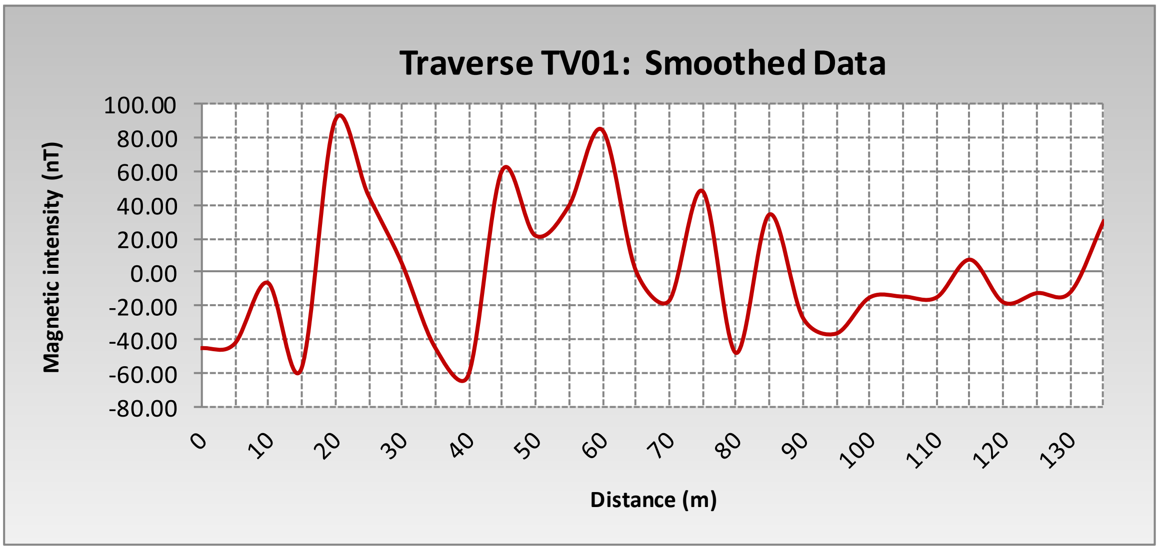
MAGNETIC PROFILES





Project:	Geophysical Survey	**Profile Number:**	TV01
Project Number:	289-26-ghd.812	**Profile Direction:**	SE-NW
Survey Area:	Luckhoff Landfill Site	**Station Spacing:**	5 M
Date of Survey:	12-Dec-17	**Operator:**	D.Moolman

Figure 16. Magnetic intensity graph of traverse 01.

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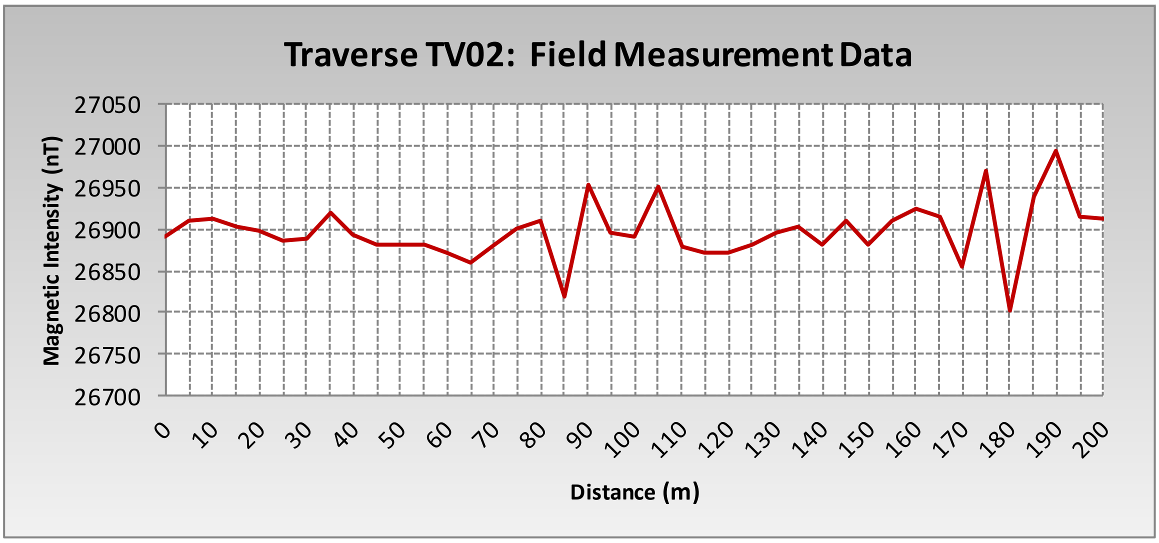
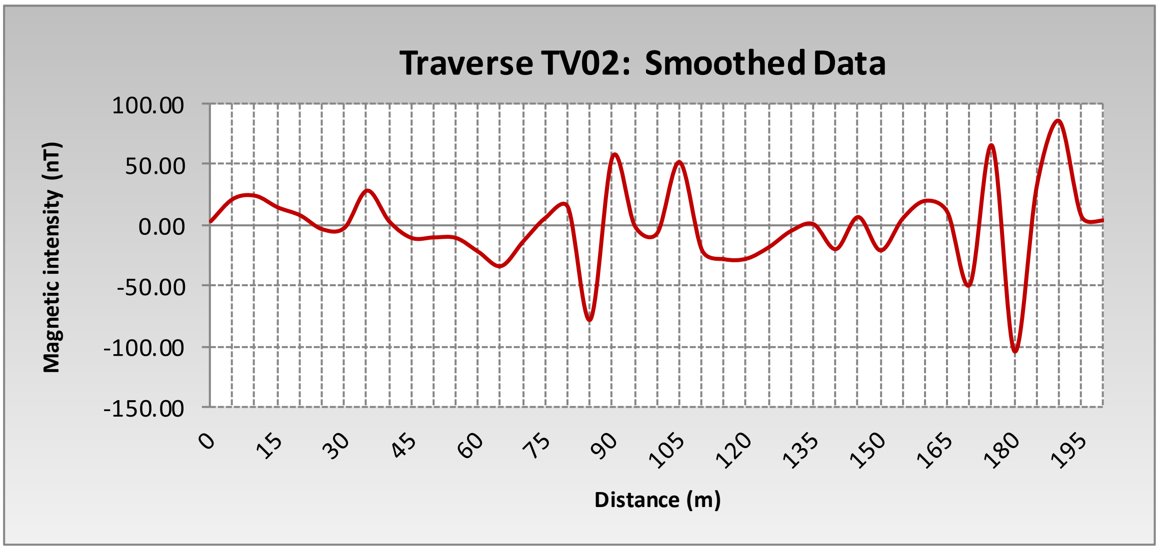
MAGNETIC PROFILES





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Project Number:	289-26-ghd.812	**Profile Direction:**	SW-NE
Survey Area:	Luckhoff Landfill Site	**Station Spacing:**	5 M
Date of Survey:	12-Dec-17	**Operator:**	D.Moolman

Figure 17. Magnetic intensity graph of traverse 02.

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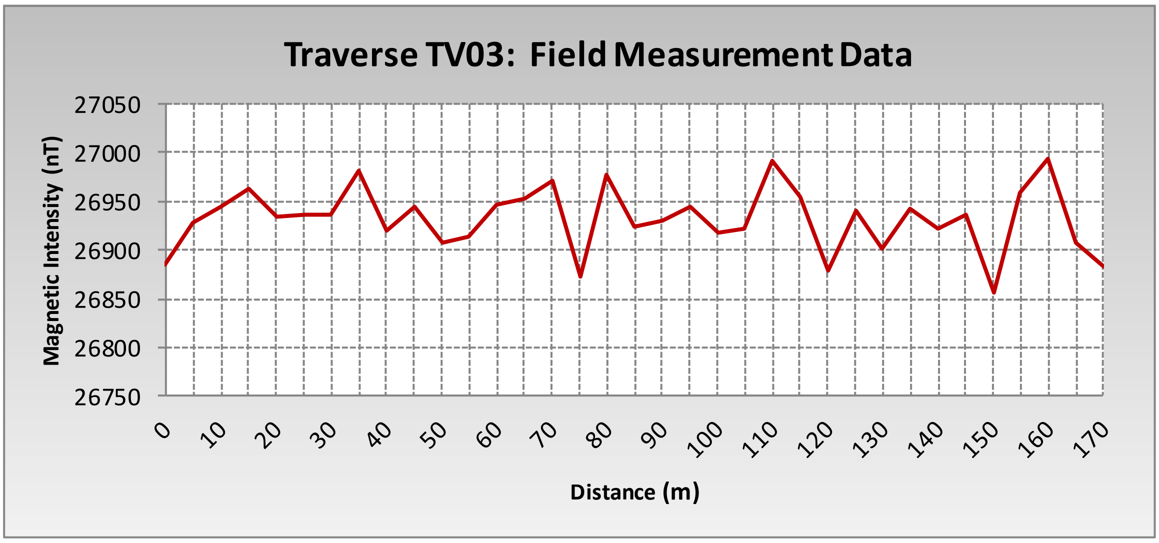
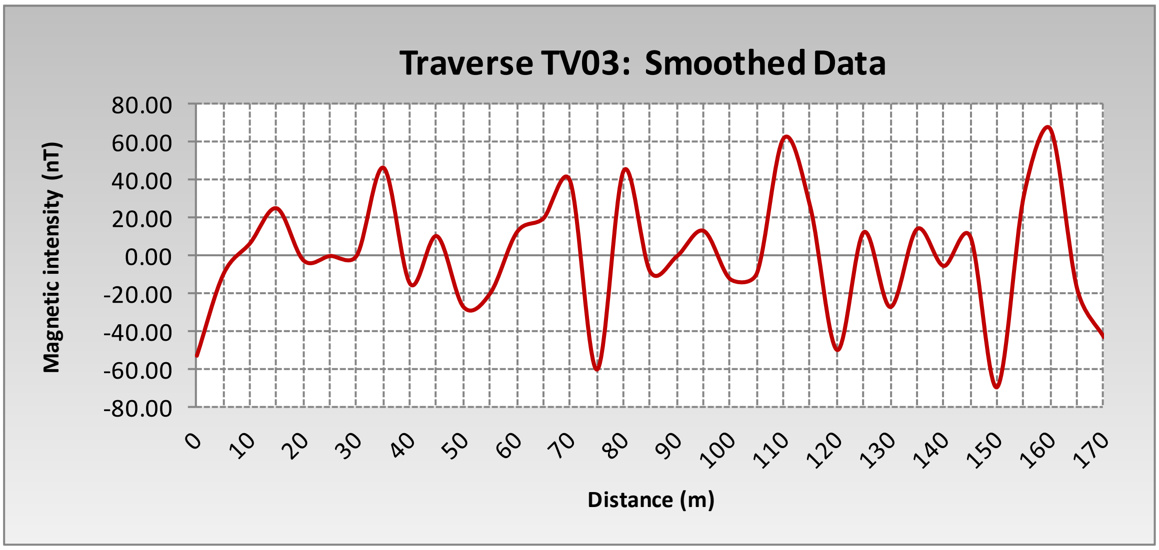
MAGNETIC PROFILES





Project:	Geophysical Survey	**Profile Number:**	TV03
Project Number:	289-26-ghd.812	**Profile Direction:**	S-N
Survey Area:	Luckhoff Landfill Site	**Station Spacing:**	5 M
Date of Survey:	12-Dec-17	**Operator:**	D.Moolman

Figure 18. Magnetic intensity graph of traverse 03.

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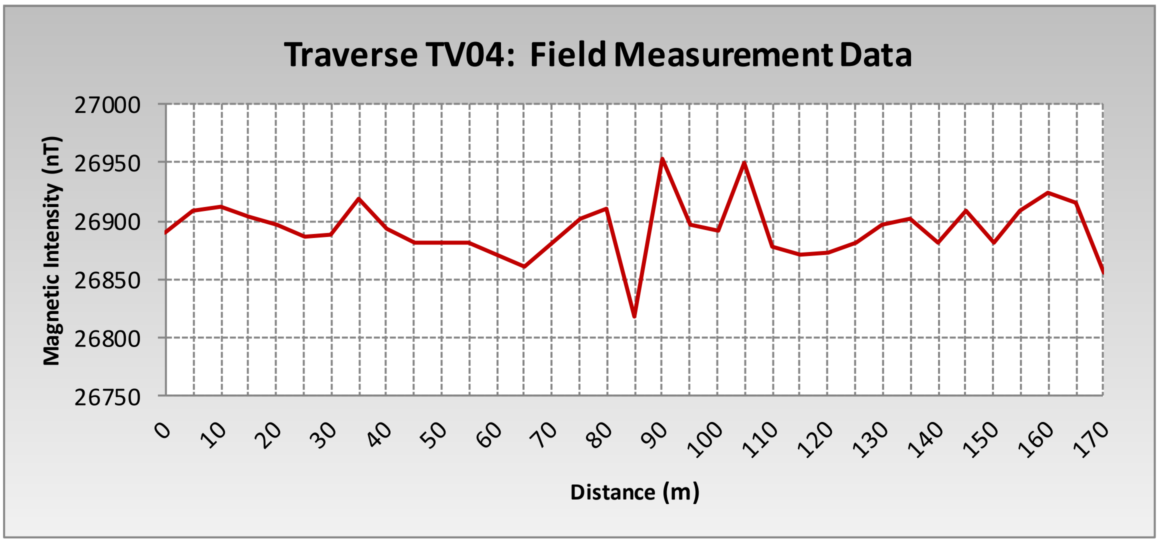
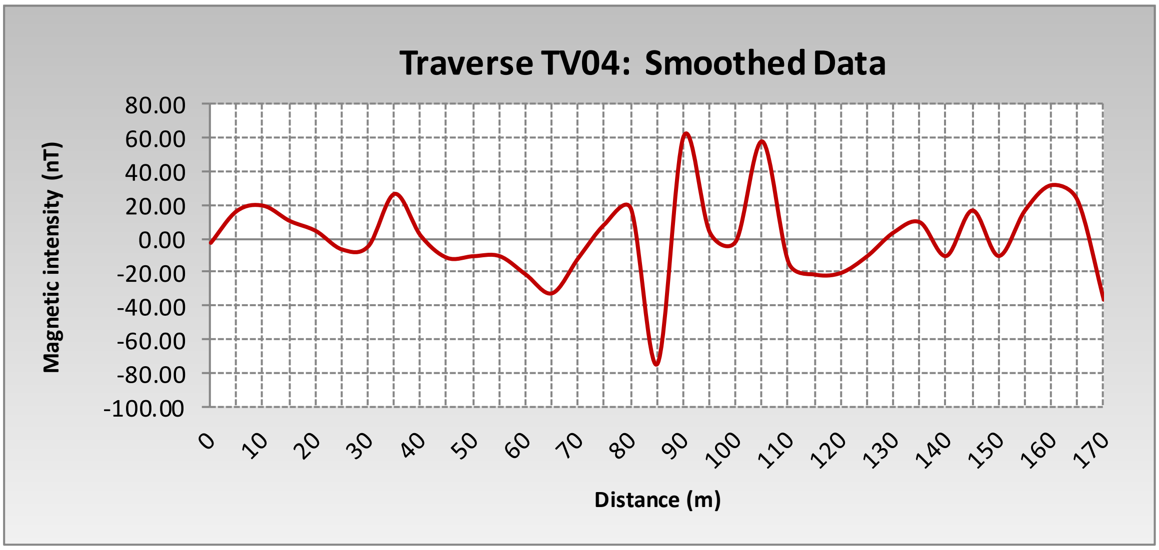
MAGNETIC PROFILES





Project:	Geophysical Survey	**Profile Number:**	TV04
Project Number:	289-26-ghd.812	**Profile Direction:**	E-W
Survey Area:	Luckhoff Landfill Site	**Station Spacing:**	5 M
Date of Survey:	12-Dec-17	**Operator:**	D.Moolman

Figure 19. Magnetic intensity graph of traverse 04.

3.3 GEOLOGY

The following section includes the geological information of the general district geology.

3.3.1 Stratigraphy and Lithology

This section has been adapted from the Hydrogeology of the Main Karoo Basin, WRC Report No. TT179/02 as well as the Geological Survey Map, 2824 Kimberly, 1:250 000 Series.

The lithostratigraphy of the Proposed waste site consists of the Karoo Supergroup Geology Group including Sub-Groups and Formations as well as Surficial or Quaternary Deposits on the surface and Karoo Dolerite Intrusive of the Jurassic Jura age. The lithology can be described as follows:

- **Ecca Group:**
  - **Prince Albert Formation:** grey shales (Geological Survey Map, 2824 Kimberly, 1:250 000 Series).
- **Late Tertiary Surficial or Quaternary Deposits:** Red and grey aeolian dune sand (Geological Survey Map, 2824 Kimberly, 1:250 000 Series).
- **Dolerite Intrusives (Jurassic Jura Age):** The dolerites of the landfill area consist of intrusive sills (Geological Survey Map, 2824 Kimberly, 1:250 000 Series).

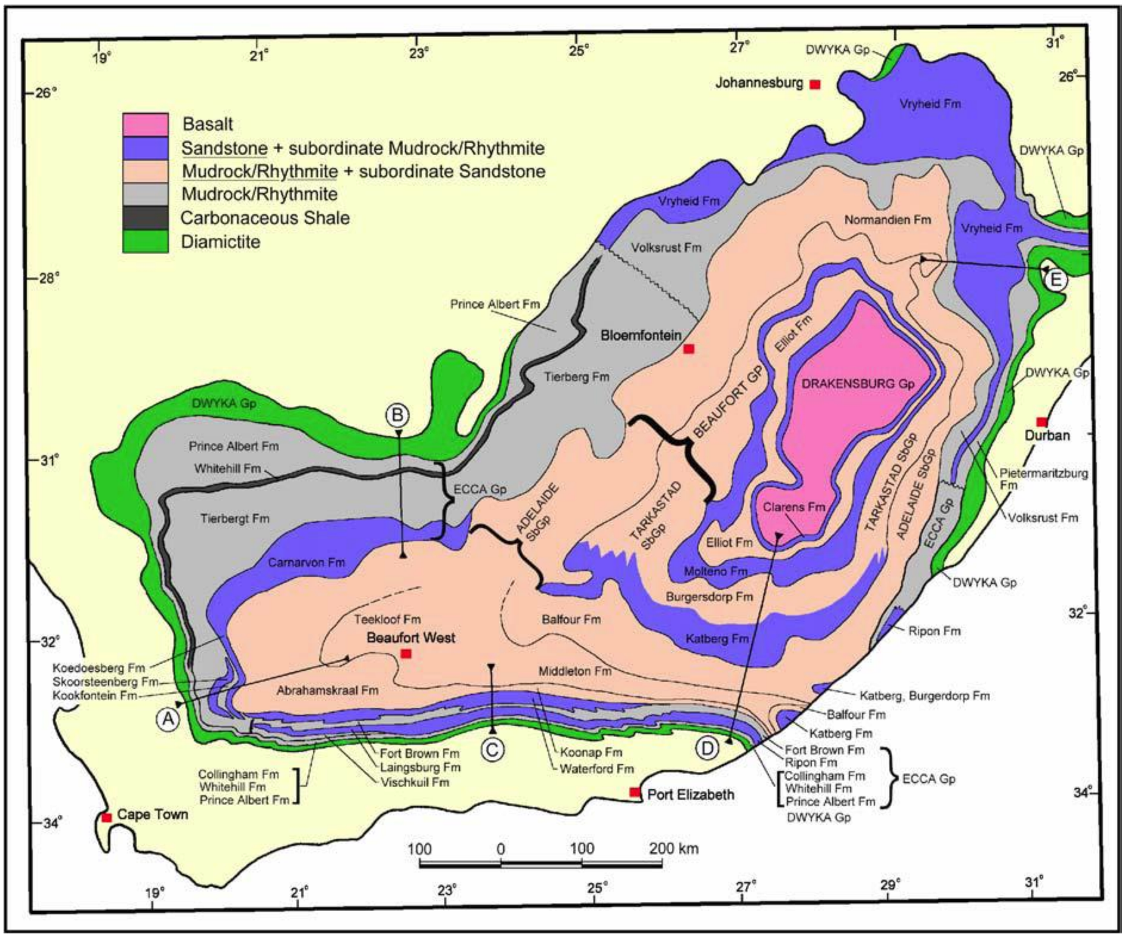


Figure 20. Schematic areal distribution of lithostratigraphic units in the Main Karoo Basin (after Johnson et al., 1997).

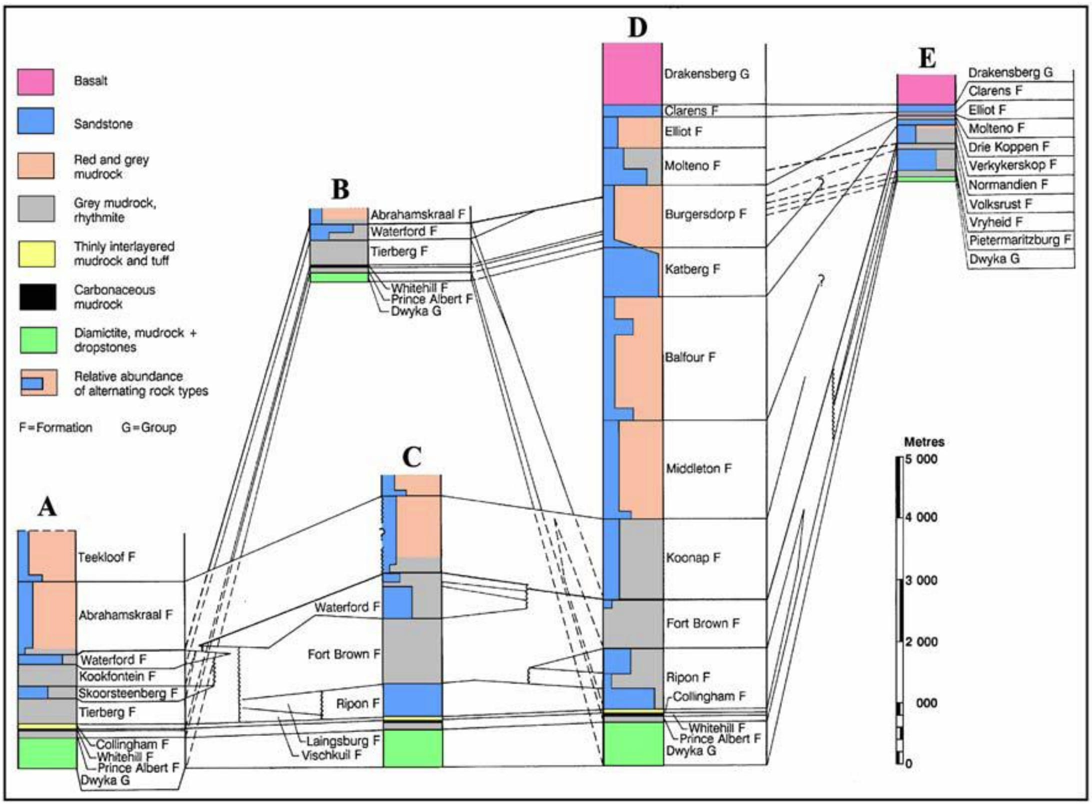


Figure 21. Generalised stratigraphy and lithology of the Karoo Supergroup of the Main Karoo Basin (Johnson et al., 1997).

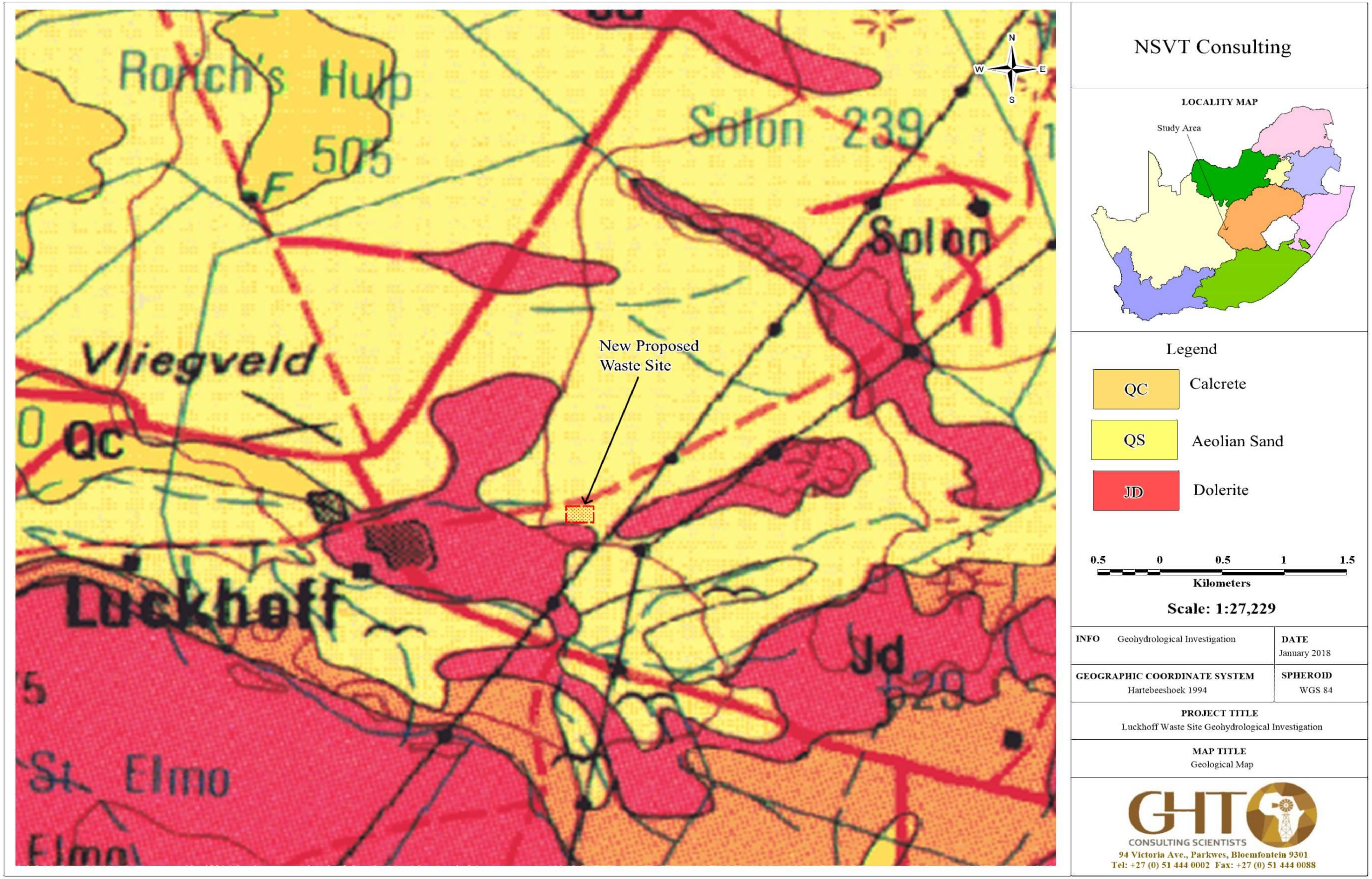


Figure 22. Geological map of the immediate area of the Luckhoff district.

3.3.1.1 Ecca Group Geology

The Permian-aged Ecca Group comprises a total of 16 formations, reflecting the lateral facies changes that characterise this succession. Except for the fairly extensive Prince Albert and Whitehill Formations, the individual formations can be grouped into three geographical zones, the southern, western – north western and north eastern.

The basal sediments in the southern, western and north western zones (Prince Albert and Whitehill Formations) of the basin will first be described, followed by the southern Collingham, Vischkuil, Laingsburg, Ripon, Fort Brown and Waterford Formations. The remaining western and north western sediments of the Tierberg, Skoorsteenberg, Kookfontein and Waterford Formations and the north eastern Pietermaritzburg, Vryheid and Volksrust Formations will then be considered. In addition, a relatively small area along the eastern flank of the Basin, between the southern and north-eastern outcrop areas, contains 600 – 1 000 m of undifferentiated Ecca mudrock, which has not yet been studied in detail.

3.3.1.1.1 Prince Albert Formation (Lower Ecca)

The Prince Albert Formation is confined to the south-western half of the Karoo Basin (refer to Figure 20). Towards the northeast it thins and locally pinches out against the basement or merges with the Vryheid and/or Pietermaritzburg Formations. Along the western and southern outcrop belt its thickness is highly variable (40 – 150 m), while borehole data indicate a maximum thickness of up to 300 m (Veevers et al., 1994).

It is possible to recognise a northern and a southern facies in the Formation. The northern facies is characterised by the predominance of greyish to olive-green, micaceous shale and grey, silty shale, as well as a pronounced transition from the underlying glacial deposits. Dark-grey to black carbonaceous shale and fine- to medium-grained feldspathic arenite and wacke are also present. The southern facies is characterised by the predominance of dark-grey, pyrite-bearing, splintery shale, siltstone and the presence of dark-coloured chert and phosphatic nodules and lenses.

The shale represents suspension settling of mud and the siltstone represents turbidites (Visser, 1991), whereas the arenite and wacke in the northern part of the basin are probably the result of deltaic sedimentation (refer to Figure 23), (Cole and McLachlan, 1991). The lower part of the formation was deposited following final melting of the Dwyka ice-sheets (Visser, 1997) and the presence of marine invertebrate fossils and phosphorite are indicative of marine conditions (Visser, 1992) at least in the lower part (Veevers et al., 1994).

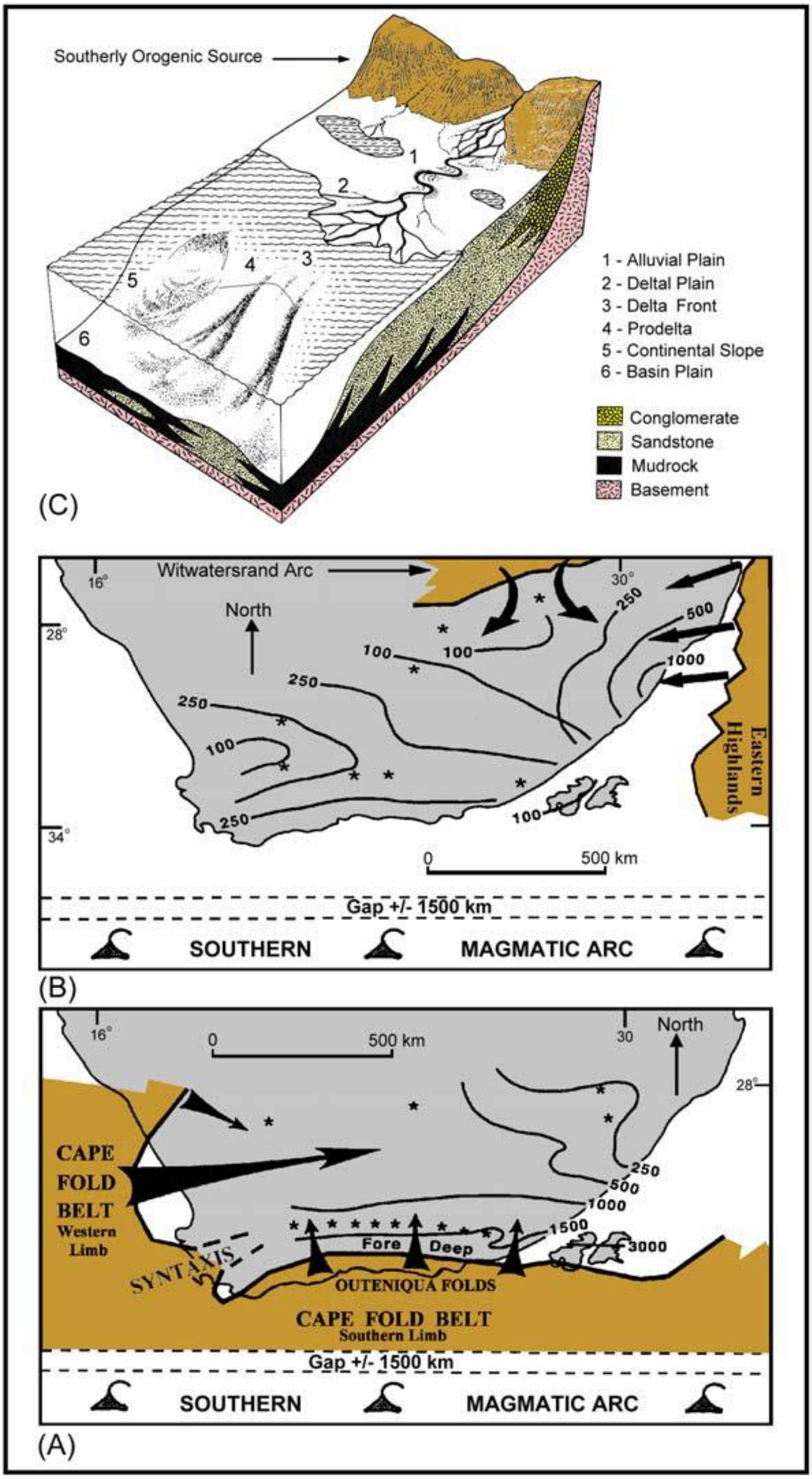


Figure 23. (A) Source areas for the Southern and Western Ecca Formations, (B) and the northern Pietermaritzburg, Vryheid and Volksrust Formations (after Cole, 1992). (C) Depositional environment of the Ecca Group in the southern Karoo trough (after Smith et al., 1993 and Wickens, 1994).

3.3.1.2 In the Intrusive Karoo Dolerite

Towards the end of the Cape Orogeny a thermal dome uplift developed beneath almost the entire South African continent. Dolerite intrusions represent the roots of the volcanic system and are presumed to be of the same age as the extrusive lavas (Fitch and Miller, 1984). Extensive magmatic activity lead to dolerite dykes, inclined sheets and sills to intrude the sedimentary rocks of the Karoo Supergroup during the Jurassic period to the north of the compressional sphere of the Cape Fold Belt. The level of erosion that affected the Main Karoo basin has revealed the deep portions of the intrusive system, which displays a high degree of tectonic complexity. The Karoo intrusives can either occur as dykes (linear features), sills (horizontal or inclined sheets) or ring-complexes. The Karoo dolerite, which includes a wide range of petrological facies, consists of an interconnected network of dykes and sills and it is nearly impossible to single out any particular intrusive or tectonic event. It would, however, appear that a very large number of fractures were intruded simultaneously by magma and that the dolerite intrusive network acted as a shallow stockwork-like reservoir.

Early mapping of the dolerite intrusives was carried out by Rogers and Du Toit (1903) in the Western Cape and Du Toit (1905) in the Eastern Cape. Further contributions on their tectonic and structural aspects include Du Toit (1920), Mask (1966) and Walker and Poldervaart (1949). More recently the Geological Survey has published most of the 1:250 000 maps of the entire Karoo Basin. Detailed mapping of dolerite occurrences at specific localities in the

In the study areas sills are the most abundant dolerite appearance and may be horizontal or slightly inclined. Geophysical data indicated also the presence of dyke structure although very few in number.

3.3.1.3 Geometry, Structure and Mechanism of Emplacement of Dolerite Dykes

Dolerite dykes are the primary targets for groundwater exploration and it is therefore important to understand the geometry, structure and mechanisms of emplacement.

Emplacement Mode: Dolerite dykes, like many other magmatic intrusions, develop by rapid hydraulic fracturing via the propagation of a fluid-filled open fissure, resulting in a massive magmatic intrusion with a neat and transgressive contact with country rock. This fracturing mechanism is in contrast to the slow mode of hydraulic fracturing responsible for breccia-intrusions (i.e. kimberlite). For the intrusion to develop the magma pressure at the tip of the fissure must overcome the tensile strength of the surrounding rock. Dykes can develop vertically upwards or lateral along-strike over very long distances, as long as the magma pressure at the tip of the fissure is maintained. The intrusion of dolerite and basaltic dykes are therefore never accompanied by brecciation, deformation or shearing of the host-rock, at least during their propagation.

Dyke Attitude: All the dykes are sub-vertical with a dip rarely below 70 degrees. Kruger and Kok (1976) reports dips of dykes in the north eastern Free State varying between 65 to 90 degrees. The attitude of dykes often change with depth (i.e. are curved or dislocated), as observed from many detailed borehole logs. This phenomenon can be attributed to vertical offsetting as a result of vertical en-échelon segmentation or due to interconnecting of dykes between sediment layers.

Dyke Width: The average thickness of Karoo dolerite dykes ranges between 2 and 10 m (Woodford and Chevallier, 2001). In general, the width of a dyke is a function of its length. In other words, the wider a dyke is, the longer it will be (this probably also applies to the vertical extension of the feature). For example, the major E-W dykes of Western Karoo Domain can attain widths of up to 70 m, while the Middelburg dyke is 80 m wide. The radiating E-W dykes of Eastern Karoo have widths of up to300 m in places. No relationship has been found between trend and thickness (Woodford and Chevallier, 2001).

En-échelon Pattern: Dolerite dykes often exhibit an en-échelon pattern along strike, which are clearly detected by mapping. This is especially the case with the E-W shear dykes and their associated riedel-shears. Displacements in the vertical section also occur, often associated with horizontal, transgressive fracturing. These offsets are often observed, except through drilling.

Dyke Related Fracturing: The country rock is often fractured during and after dyke emplacement. These fractures form a set of master joints parallel to its strike over a distance that does not vary greatly with the thickness of the dyke (between 5 and 15 m). The dolerite dykes are also affected by thermal- or columnar- jointing perpendicular to their margins. These thermal joints also ex tends into the host rock over a distance not exceeding 0.3 to 0.5 m from the contact. Van Wyk (1963) observed two types of jointing associated with dyke intrusions in a number of coal mines in the Vryheid Dundee area, namely:

- Three sets of pervasive-thermal, columnar joints that are approximately 120 degrees apart; and
- Joints parallel to the contact, confined mainly to the host rock alongside the dyke.

Many cases of tectonic reactivation of the dolerite have been observed in the Loxton-Victoria West area (Woodford and Chevallier, 2001), especially on the N-S dykes that have been reactivated by cretaceous kimberlite activity or by more recent master jointing. Reactivation often results in sub-vertical fissures within the country rock and/or dyke itself, which are commonly highly weathered and filled with secondary calcite / calcrete (width of up to 150 mm) uplifting or brecciation of the sediment along the dyke contact. Deformation and Contact Metamorphism of Host Rock: Localised upwarping of the country rock is often observed adjacent to dipping dykes. Hydraulic fissure propagation, as mentioned above, cannot be responsible for this phenomena, as the magma would have to be cool and become viscous in order cause such deformation. This upwarping of the country rock is commonly a near-surface phenomenon related to supergene formation of clays with a high expansion coefficient resulting in the ‘swelling’ of rock mass. In nearly every case, the dolerite magma shows marked chilling against the sediments into which it has been injected. The chill zone generally exhibits the effects of contact metamorphism, where argillites are altered to hornfels or lydianite and arenaceous units are crystallised to quartzite. Enslin (1951) and Van Wyk (1963) state that the jointed contact zone is less than 30 c wide, irrespectively of dyke thickness.

Petrography and Dyke Weathering: The effect of variable cooling of dykes following intrusion is also apparent in the way which dykes weather in the Western Karoo, namely:

- Thick dykes (>8 m) generally exhibit a prominent chill-margin containing a fine grained, porphyritic, melanocratic dolerite that weathers to produce well-rounded, small, white-speckled boulders (i.e. spheriodal weathering). This zone is normally only 0.5 to 1.5 m wide and exhibits well-developed thermal-shrinkage joints. The central portion of such dykes consist of medium to coarse grained, mesocratic and occasionally leucocratic dolerite that decomposes to a uniform ‘gravely’ material, which exhibits an exfoliation type of pattern. Sporadic fractures or meta-sedimentary veins are encountered in this zone and they often do not extend into the country rock. Magnetic traverses across these features normally produce two distinctive peaks.

Thin dykes (<3 m) commonly consist of fine-grained, porphyritic, melanocratic dolerite (Vandoolaeghe, 1979). These tend to be more resistant to weathering than the thicker dykes and in outcrop exhibit a uniform pattern of shrinkage-joints. The dyke weathers to produce small rounded, white-speckled boulders set in finer angular groundmass.

3.3.1.4 Geohydrological Implications of Geology

This section describes the general geohydrological implications of Karoo geology in terms of the sedimentary rocks and the younger intrusive dolerites.

3.3.1.5 Sediments

Van Wyk (1963) and Vegter (1992) state that the porosity and permeability of the Karoo sediments appears to be highest in the near-surface (i.e. the upper 30 m), which generally corresponds to the weathered zone. There is no clear relation, however, between the occurrence of groundwater and the weathering of the different Karoo lithologies. In this regard, the following generalisation may be stated:

- Dwyka diamictite may represent potential 'weathered' aquifers due to their low resistance to weathering;
- Weathering of Karoo shale and mudrock produces clays, which often reduces the permeability of the sediments; and
- Karoo sandstone is highly resistant to weathering and thus these processes are unlikely to direct affect the hydraulic properties of these rocks.

Composite alluvial-weathered bedrock aquifers are commonly developed along the major drainage systems.

It must be noted that low to medium yielding boreholes in the order of 0.5 to 3 L/s can be drilled in sedimentary rocks. No proven geophysical technique currently exists that can locate fractures. Therefore these fracture systems in sedimentary rocks are only discovered by coincidence.

3.3.1.6 Dolerite Intrusions

Extensive weathered zones often develop in dolerite sills that are situated in low lying and well drained areas – 'similar to weathered basins' described in other crystalline basement rocks (Enslin, 1943; Wright and Burgess, 1992). These localised, shallow intergranular aquifers are capable of storing large volumes of groundwater. Although abstraction from these dense-massive structures are only possible where extensive weathering has occurred at depth (below the aquifer water table).

Dolerite ring-dykes and inclined sheets seldom form negative features of the landscape, as they are more resistant to weathering. The hydrological properties weathered dolerite rings and inclined sheets seem very variable. Vegter (1995) states that the upper or lower contact sills located within the weathered zone, i.e. 20 to 50 mbgl, are favourable zones for striking groundwater. Recent extensive exploration drilling along dolerite inclined sheets and ring dykes in the Victoria West area (Chevallier et al., 2001), shows that the contact between the sediment and the dolerite within the first 50 m below surface did not yield significant volumes of groundwater.

The contact between dolerite dykes and the host rock, within the weathered zone, remains the most important target for groundwater exploration (Vegter, 1995 & Smart, 1998).

3.3.2 Hydrostratigraphy

This section outlines the general hydrological characteristics of the various lithostratigraphic units, related more to the processes of sedimentation and diagenesis (i.e. the primary hydraulic properties). These properties are more important when considering the longer-term sustainable utilisation of the Karoo aquifers (storativity), rather than individual borehole yields.

3.3.2.1 Hydrostratigraphy of the Ecca Group

The Ecca Group consists mainly of shales, with thicknesses varying from 1 500 m in the south, to 600 m in the north. Since the shales are very dense, they are often overlooked as significant sources of groundwater. However, their porosities tend to decrease from ~0.10% north of latitude 28°S to < 0.02% in the southern and south eastern parts of the Basin, while their bulk densities increase from ~2 000 to > 2 650 kg.m-3. The possibility thus exists that economically viable aquifers may exist in the northern parts of the Basin underlain by the Ecca shale. It is therefore rather surprising to find that there are areas, even in the central parts, where large quantities of water are pumped daily from the Ecca formations. For example, some 4 500 ha are irrigated from boreholes drilled into the Ecca shales in the Petrusburg district (central Free State), compared to the 2 000 ha from the Modder River. One should thus not neglect the Ecca rocks as possible sources for groundwater, especially the deltaic sandstone facies. Rowsell and De Swardt (1976) report that the permeabilities of these sandstones are usually very low. The main reason for this is that the sandstones are usually poorly sorted, and that their primary porosities have been lowered considerably by diagenesis.

The deltaic sandstones represent a facies of the Ecca sediments in which one would expect to find high-yielding boreholes. Unfortunately, Rowsell and De Swardt (1976) have found that the permeabilities of these sandstones are also usually very low. The main reason for this is that the sandstones are usually poorly sorted, and that their primary porosities have been lowered considerably by diagenesis. However, the Vryheid Formation sandstones in KwaZulu-Natal (west of Pietermaritzburg) appear to be more permeable, with a median borehole yield of 0.33 L/s and 62% yielding greater than 1 L/s (KwaZulu-Natal project, 1995, unit 8).

4 HYDROCENSUS INVESTIGATION

This section contains the general information of the surface and groundwater sites identified during the hydrocensus. The general information tables can be perused in Table 1 and the locality map of sites can be viewed in Figure 24. The photos of the boreholes and surface water sites can be viewed below.

The hydrocensus was conducted within a 2km radius around the proposed waste site. Only three boreholes and 2 surface sites were found. The boreholes are located within the town area of Luckhoff approximately 1.7km west from the proposed waste site. The abstracted groundwater is utilised for domestic purposes. Little boreholes are located within the study area as Luckhoff is mainly dependant on surface water from the canal system from Vanderkloof dam. The surface sites were dry and no access could be obtained to borehole 3, thus no samples were obtained for these sites.

Hydrocensus sites identified during site visit:

Photo 1. Hydrocensus borehole B01.

Photo 2. Hydrocensus borehole B02.

Photo 3. Hydrocensus borehole B03.

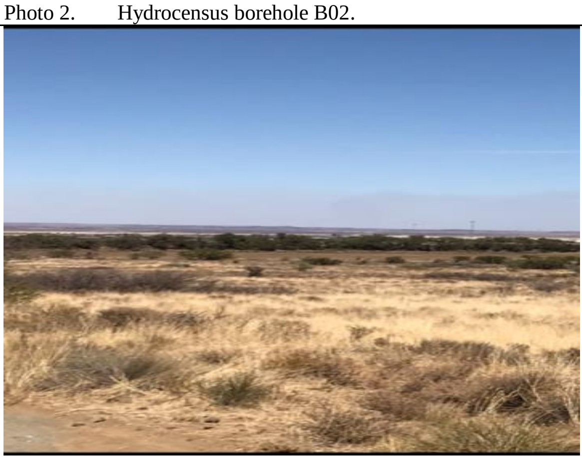


Photo 4. Surface water site S01.

Table 1. General information regarding identified hydrocensus sites.

Number on map	Sample Number	Date	Time	Latitude (°S)	Longitude (°E)	Site Description	Sample Depth (m)	Borehole Depth (m)	Est. YIELD	WL	Sampled	Equipment	Status (G In Use, U Unused)	Use (Agricultural, Domestic)
B01	B01	12-Dec-17	11:25	24.78882	-29.74980	Private borehole located in suburb South West of proposed site	~	~	~	~	Y	Submersible	G	Domestic Use
B02	B02	12-Dec-17	12:10	24.78129	-29.75175	Private borehole located in suburb South West of proposed site	~	~	~	~	Y	Submersible	G	Domestic Use
B03	B03	12-Dec-17	12:55	24.78523	-29.75128	Private borehole located in suburb South West of proposed site	~	~	~	~	Y	Windpump	~	~
S01	S01	12-Dec-17	13:10	24.79360	-29.74556	Dam located west of proposed waste site	~	~	~	~	Y	~	U	~
S02	S02	12-Dec-17	13:30	24.79583	-29.75729	Dam located south of proposed waste site	~	~	~	~	Y	~	U	~

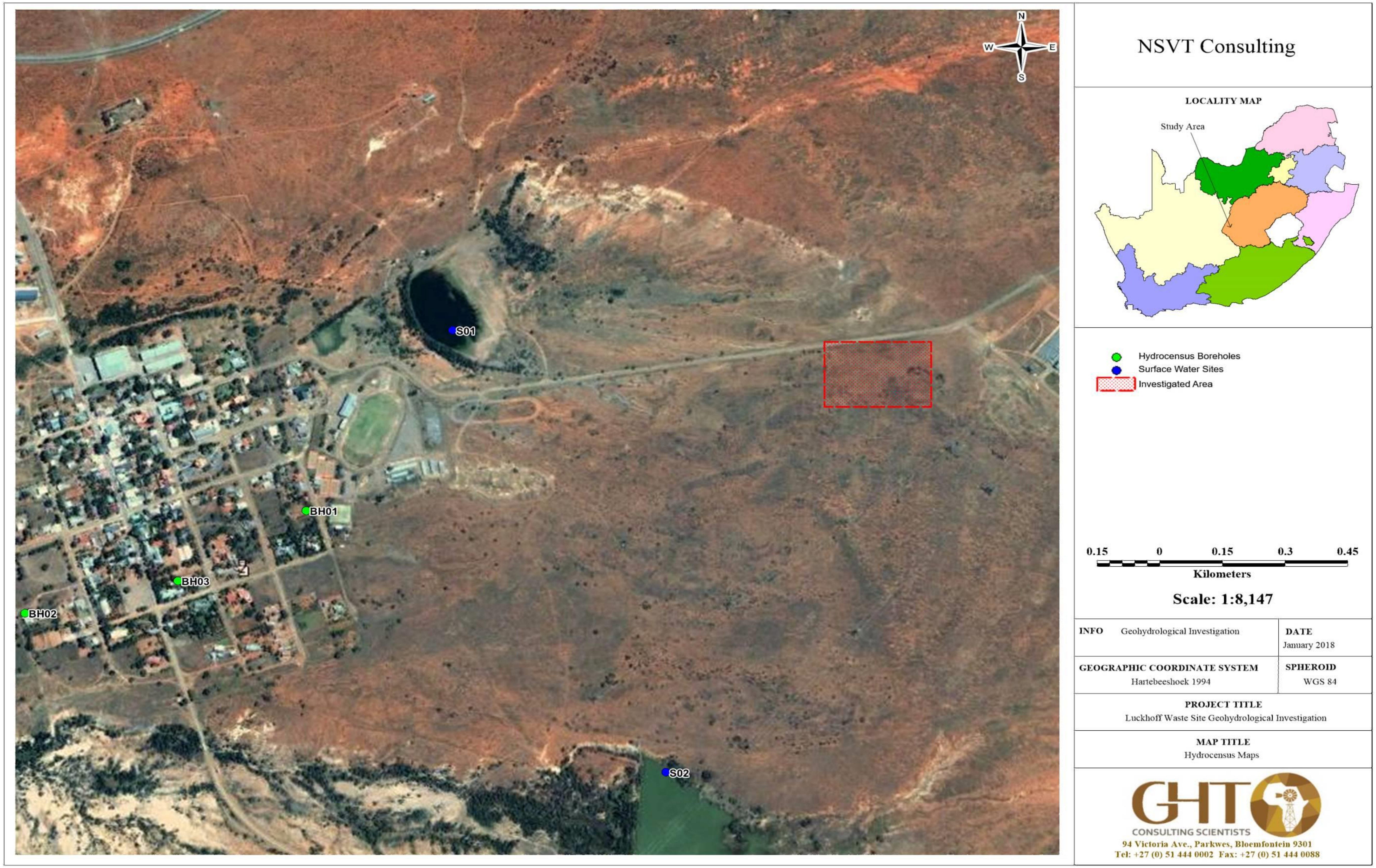


Figure 24. Locality map of hydrocensus sites.

4.1 INORGANIC WATER QUALITY

This section contains the inorganic water quality results for the local aquifer. (refer to Table 3 below). The groundwater qualities are classified according to the “South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWAF, First Edition 1993” and the “South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWAF, Second Edition 1996”, as well as according to the publication “Quality of Domestic Water Supplies, DWAF, Second Edition 1998” as well as “The South African National Standard (SANS 241:2006 Edition 6.1, SANS 241-1:2011 Edition 1 and SANS 241-1:2015 Edition 2)”according to the publication a description of the various classes is given in Table 2.

Table 2. Water quality class ranges

1993,1996 — **South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 & Second Edition 1996**

NR	- **Target water quality range** - No risk.
IR	- **Good water quality** - Insignificant risk. Suitable for use, rare instances of negative effects.
LR	- **Marginal water quality** - Allowable low risk. Negative effects may occur in some sensitive groups
HR	- **Poor water quality** - Unsuitable for use without treatment. Chronic effects may occur.

2006 — **SABS South Africa National Standard: Drinking Water, SANS 241:2006 Edition 6.1**

Class 1	- **Recommended operational limit** - Suitable for lifetime use.
Class 2	- **Maximum allowable limit** - Suitable for limited duration use only.
AMA	- **Above maximum allowable limit** - Unsuitable for human consumption.

2011 — **SABS South Africa National Standard: Drinking Water, SANS 241-2:2011 Edition 1**

Class 1	- **Recommended standard limit** - Suitable for lifetime use.
ARS	- **Above recommended standard limit** - Unsuitable for lifetime human consumption.

2015 — **SABS South Africa National Standard: Drinking Water, SANS 241-1:2015 Edition 2**

Class 1	- **Recommended standard limit** - Suitable for lifetime use.
ARS	- **Above recommended standard limit** - Unsuitable for lifetime human consumption.

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Test Report Page 1 of 1

Client: GHT Consulting Scientists
Address: 94 Victoria Street, Bloemfontein
Report no: 47748
Project: GHT

Date of certificate: 05 January 2018
Date accepted: 15 December 2017
Date completed: 05 January 2018
Revision: 0

Lab no:				98718	98719
Date sampled:				14-Dec-2017	14-Dec-2017
Sample type:				Water	Water
Locality description:				B1	B2
	Analyses	Unit	Method		
A	pH @ 25°C	pH	ALM 20	8.31	8.25
A	Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	20.1	117
A	Total alkalinity	mg CaCO3/l	ALM 01	86.7	363
A	Chloride (Cl)	mg/l	ALM 02	5.72	117
A	Sulphate (SO_4)	mg/l	ALM 03	9.32	159
A	Nitrate (NO_3) as N	mg/l	ALM 06	0.589	1.61
A	Nitrite (NO_2) as N	mg/l	ALM 07	0.058	0.091
A	Ammonium (NH_4) as N	mg/l	ALM 05	0.062	0.250
A	Orthophosphate (PO_4) as P	mg/l	ALM 04	0.045	0.051
A	Fluoride (F)	mg/l	ALM 08	<0.263	0.415
A	Calcium (Ca)	mg/l	ALM 30	24.2	50.9
A	Magnesium (Mg)	mg/l	ALM 30	8.24	101
A	Sodium (Na)	mg/l	ALM 30	7.52	84.1
A	Potassium (K)	mg/l	ALM 30	1.77	4.33
A	Aluminium (Al)	mg/l	ALM 31	<0.002	<0.002
A	Iron (Fe)	mg/l	ALM 31	<0.004	<0.004
A	Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001
A	Chromium (Cr)	mg/l	ALM 31	<0.003	<0.003
A	Hexavalent chromium (Cr^{6+})	mg/l	ALM 09	<0.002	<0.002
A	Copper (Cu)	mg/l	ALM 31	0.019	0.028
A	Nickel (Ni)	mg/l	ALM 31	<0.002	<0.002
A	Zinc (Zn)	mg/l	ALM 31	<0.002	0.028
A	Cobalt (Co)	mg/l	ALM 31	<0.003	<0.003
A	Cadmium (Cd)	mg/l	ALM 31	<0.002	<0.002
A	Lead (Pb)	mg/l	ALM 31	<0.004	<0.004
A	Total hardness	mg CaCO3/l	ALM 26	94	542
A	Boron (B)	mg/l	ALM 33	<0.013	0.192
N	Bromide (Br)	mg/l	ALM 13	0.230	<0.010

A = Accredited N = Non accredited O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report ; The results relates only to the test item tested.
Results reported against the limit of detection.
Results marked 'Not SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory.
Uncertainty of measurement available on request for all methods included in the SANAS Schedule of Accreditation.

M. Swanepoel
Technical Signatory

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Figure 25. Accredited laboratory results.

Table 3. Inorganic groundwater quality class of the ground water sites (according to the SANS241-1:20011 and SANS241:2006 standards).

Site No.	Date	Quality Class				pH	EC	Na	Ca	Mg	K	Cl	SO4	F	NO_2N	NO_3N	NH4-N	PO_4	Fe	Mn	CN	Co	Cd	Cu	Al	Cr	Cr6+	Pb	Zn	B	MALK
							mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Reference Standard:		1993,1996	2006	2011	2015	2015	2015	2015	2006	2006	2006	2015	2015	2015	2015	2015	2015		2015	2015	2015	2011	2015	2015	2015	2015	1993,1996	2015	2015	2015	
B01	23/10/2017	NR	Class 1	Class 1	Class 1	8.31	20.1	7.52	24.2	8.24	1.77	5.72	9.32	-0.26	0.589	0.058	0.062	0.045	-0	-0.001	-0.002	-0.003	-0.002	0.019	-0	-0	-0.002	-0	-0	-0.01	86.7
B02	23/10/2017	NR	AMA	Class 1	ARS	8.25	117	84.1	50.9	101	4.33	117	159	0.42	1.61	0.091	0.25	0.051	-0	-0.001	-0.002	-0.003	-0.002	0.028	-0	-0	-0.002	-0	0.028	0.192	363

GHT Consulting Scientits
Document number: GHT-CON-RDS 002.1

1993,1996 **South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 & Second Edition 1996**

NR	- **Target water quality range** - No risk.
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2011 **SABS South Africa National Standard: Drinking Water, SANS 241-2:2011 Edition 1**

Class 1	- **Recommended standard limit - Suitable for lifetime use.**
ARS	- **Above recommended standard limit** - Unsuitable for lifetime human consumption.

2015 **SABS South Africa National Standard: Drinking Water, SANS 241-1:2016 Edition 2**

Class 1	- **Recommended standard limit** - Suitable for lifetime use.
ARS	- **Above recommended standard limit** - Unsuitable for lifetime human consumption.

4.2 HYDROCHEMISTRY RESULTS

- The water sampled at borehole B1 is classified as “Class 1 – recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is suitable for lifetime use.
- The water sampled at borehole B2 is classified as “ARS – above recommended standard limit” (inorganic water quality, SANS241-1:2011). According to SANS241-1:2011 the water quality of the borehole is unsuitable for consumption due to high Magnesium (Mg - 101 mg/L) and Nitrite (NO_2 as N – 1.61 mg/L) concentrations. The high nitrite concentration is likely to be caused by the livestock that are kept in a bead nearby the borehole.

5 ALTERNATIVE SITE

A new site was proposed for the construction of the waste site by the client. The following maps are included indicating the alternative site, however no funds are available for full on-site investigations, thus only new maps are created to indicate the alternative site on different maps. These maps can be viewed from Figure 26 to Figure 29.

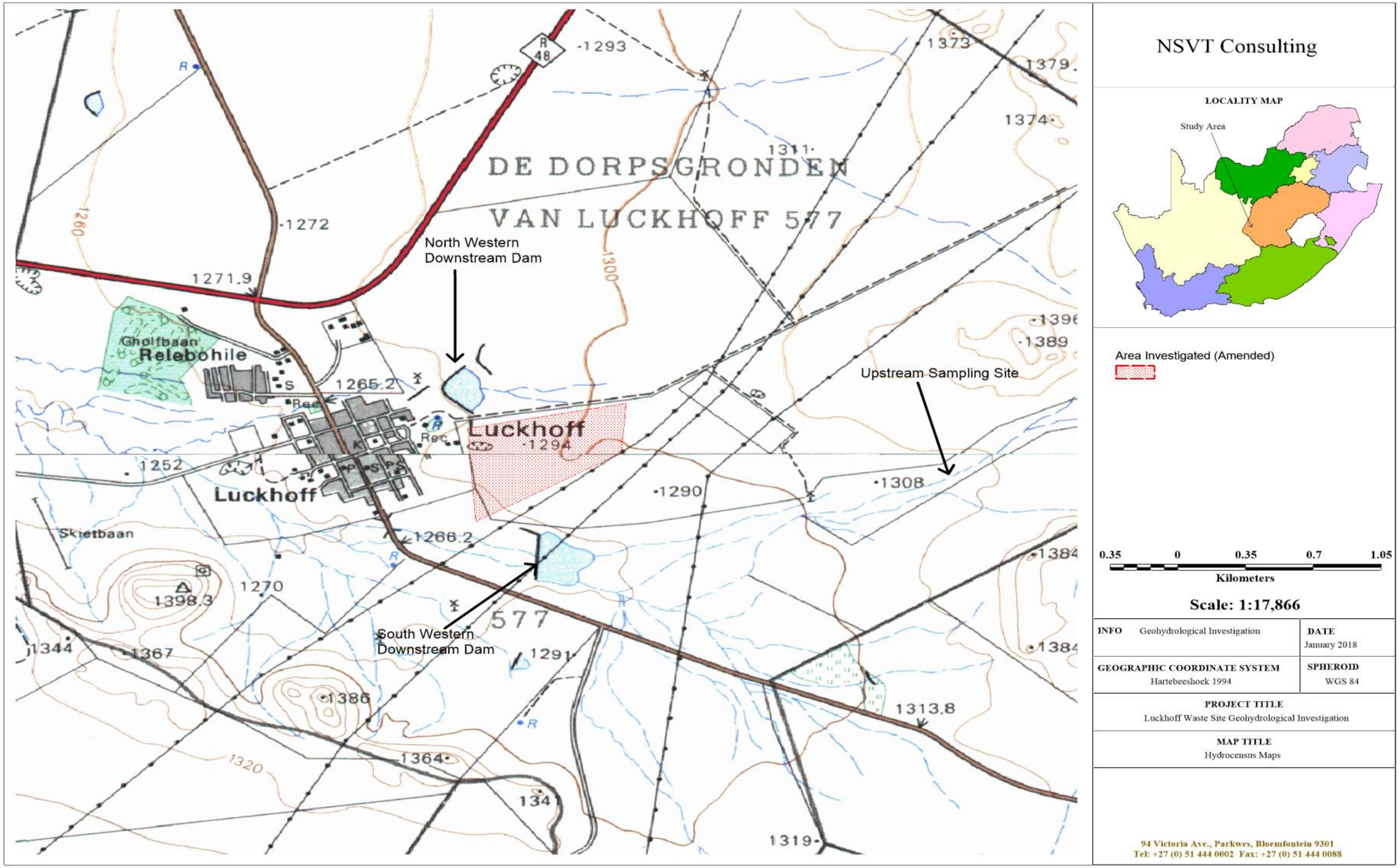

Figure 26. Amended locality map of the proposed waste site at Luckhoff.

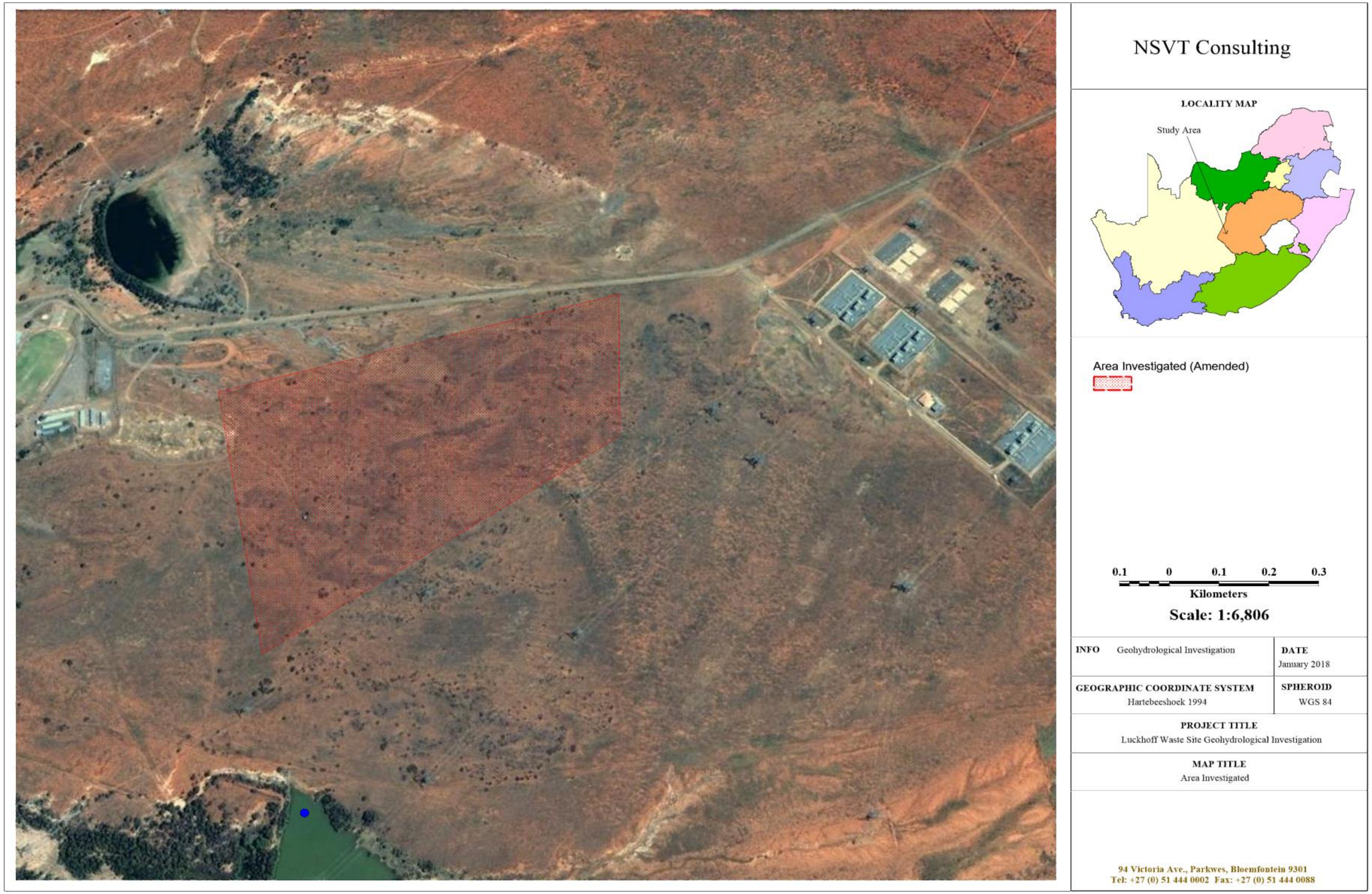

Figure 27. Amended locality map of proposed site.

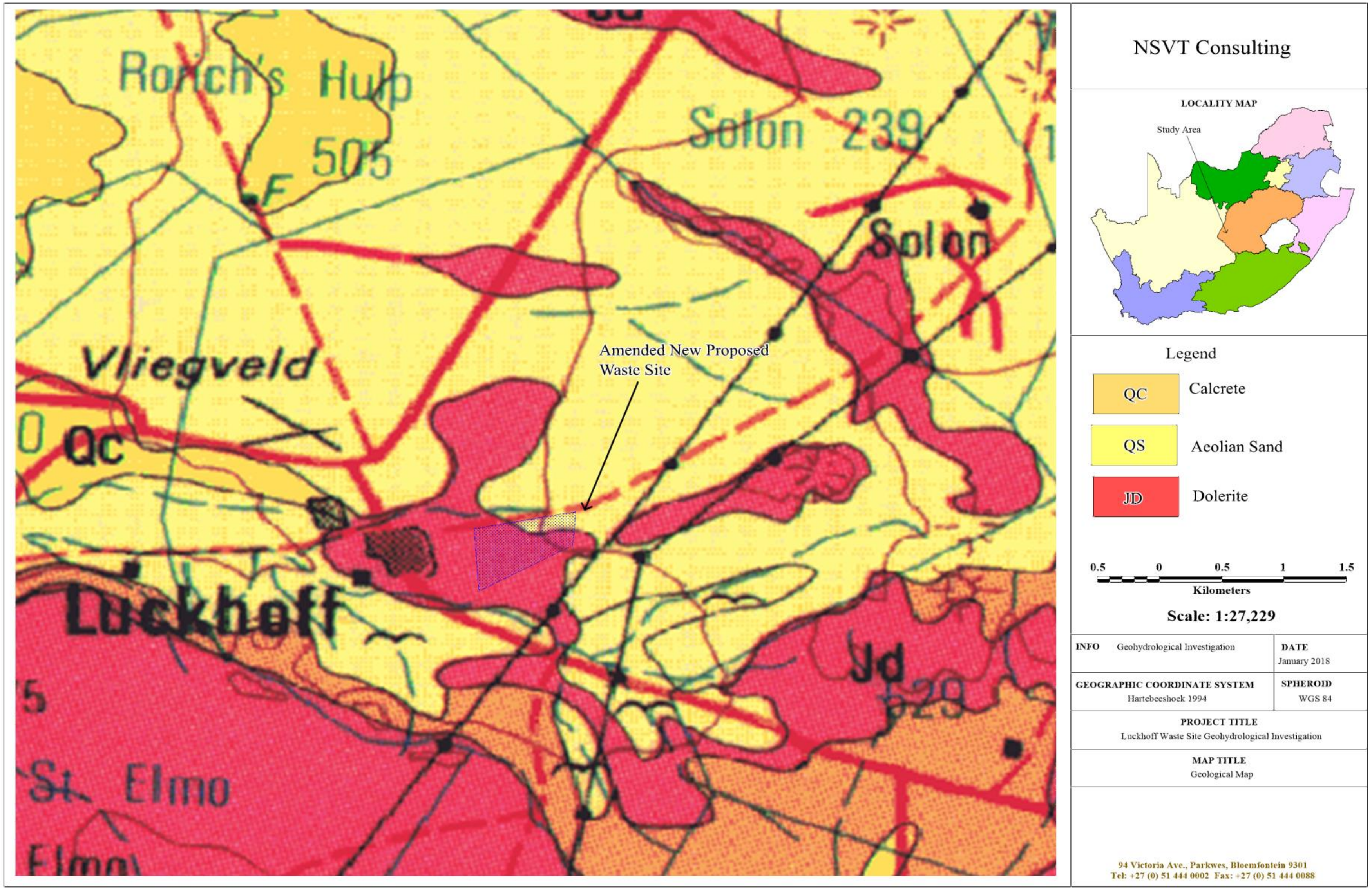

Figure 28. Amended geological map.

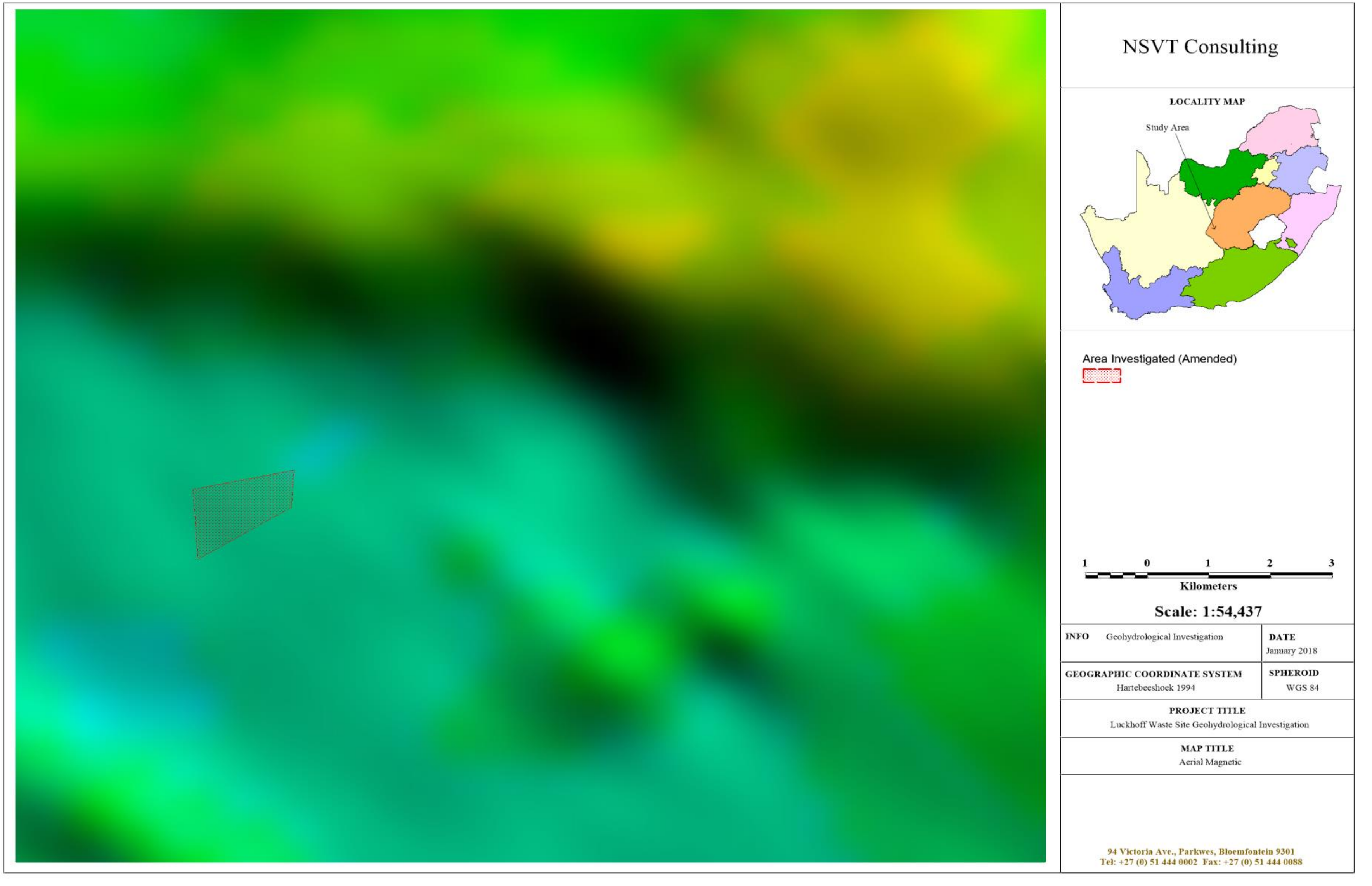

Figure 29. Amended aerial magnetic map.

6 CONCLUSIONS AND RECOMMENDATIONS

- The drilling of (two) monitoring boreholes up and downstream of the proposed site is recommended. These boreholes will form part of the monitoring network and sampling will give an indication of the water quality of the local aquifer and future sampling will give an indication if the waste site has an impact on the groundwater quality. The monitoring boreholes will act as an early warning detection system as the hydrocensus users can be notified if it is found that that the waste site is impacting on the groundwater.
- The drilling of monitoring boreholes will determine the yield of the local aquifer (permeabilities), water level depth and the local geology.
- Water level data of the local area (measured at suggested monitoring boreholes) will be crucial information to determine the aquifer vulnerability of the area.

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