GEOHYDROLOGICAL REPORT

FRANKFORT SOLID WASTE SITE

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GEOHYDROLOGICAL REPORT

OCTOBER 2018

FRANKFORT SWS

FOR

NSVT CONSULTANTS

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GLOSSARY GEOHYDROLOGICAL TERMS AND ACRONYMS	
GEOHYDROLOGICAL TERMS	DEFINITIONS
Aquiclude	An aquiclude is an impermeable geological unit that does not transmit water at all. Dense unfractured igneous or metamorphic rocks are typical aquiclude.
Aquitards	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 shales are typical aquitards.
Borehole census	A field survey by which all relevant information regarding groundwater is gathered. This typically includes yields, borehole equipment, groundwater levels, casing height/diameter, co-ordinates, potential pollution risks, photos etc.
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 often speak of a free-flowing or artesian borehole.
Diffusivity (KD/S)	The hydraulic diffusitivity is the ratio of the transmissivity and the storativity of a saturated aquifer. It governs the propagation of chances a hydraulic head in the aquifer. Diffusivity has the dimension of $Lenght^2/Time$
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.
Leaky Aquifer	A leaky aquifer or semi-confined aquifer, is an aquifer whose 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.
Porosity	The porosity of a rock is its property of containing pores or voids. With consolidated rocks and hard rocks, a distinction is 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.
Specific Yield (S_y)	The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area or 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 (S)	The storativity of a saturated confined aquifer of thickness D is the volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface.
Storativity 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.

Susceptibility	A qualitative measure of the relative ease with which a groundwater body can be potentially be contaminated by anthropogenic activities.
Sustainable Yield	The yield calculated from aquifer test pumping by a professional geohydrologist. The yield refers to the recommended abstraction rate and pumping schedule for continues use.
Transmissivity (KD or 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.
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 and anthropologically, where rainwater and or reclaimed water is routed to the subsurface.
Vulnerability	The likelihood for contamination to reach a specified position in a groundwater system after introduction at some location above the uppermost aquifer.

GEOLOGICAL TERMS	
Argillaceous rock	A type of sedimentary rock that contains a substantial amount of clay or clay-like compounds
Fault (Brittle Shear)	A planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement
Intrusive rock	Rock that formed due to the cooling of magma that forced its way into fractures and cavities of other rock types without reaching the surface.(usually large crystal sizes)
Metasedimentary Rock	A sedimentary rock that appears to have been altered by metamorphism.
Sedimentary rock	A type of rock that formed by sedimentation material on the earth surface or in water bodies
Shear Zone	A shear zone is a structural discontinuity surface in the Earth's crust and upper mantle which forms as a response to inhomogeneous deformation partitioning strain into planar or curviplanar high-strain zones.

Acronym/Abbreviation	Definition
magl	Metres Above Ground Level
MAP	Mean Annual Precipitation
mbgl	Metres Below Ground Level
mamsl	Metres Above Mean Sea Level
WWTW	Waste Water Treatment Works

1. INTRODUCTION

Tucana Solutions was appointed by ***NSVT Consultants*** to perform a preliminary geohydrological investigation for the upgrading of the Solid Waste Site in Frankfort.

The objectives of the study are as follows:

- Desk study and site visit to establish a conceptual model of the area.
- Detailed borehole census of boreholes within a 1km radius to determine the potential utilization of existing boreholes as well as the current use.
- Investigate geological, topographical and airborne magnetics maps of the study area to gain an understanding of the local geological conditions and to identify geological structures that could influence the rate and direction of groundwater migration and possible contaminant transport.
- A topographical map of the study area was constructed in order to visually understand surface and groundwater drainage directions of the area surrounding the sewage plant.
- Compile Geohydrological Report

2. BACKGROUND INFORMATION

2.1. LOCATION

The study site is located south of Frankfort in the Free State Province of South Africa. The area of investigation is situated at and Latitude -27.293841° and Longitude 28.497422°. The location of the investigated site is given in Figure 1, indicating the relation to Frankfort.

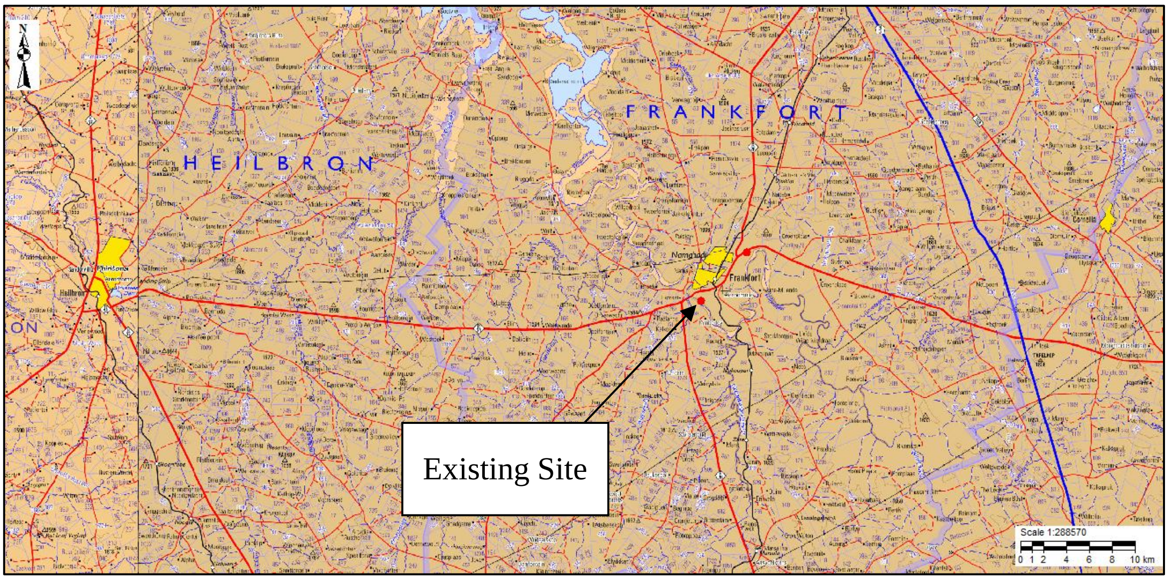

Figure 1: Location of the investigated site

2.2. CLIMATE

Frankfort is situated within a summer rainfall district whilst receiving 546 mm of rain annually. During July months it receives its lowest rainfall values (0 mm) whilst receiving the most in January (101 mm). Temperatures for this area range from average midday temperatures of 16.3°C in June to 26.8°C in January

2.3. TOPOGRAPHY

The study area that is located south of Frankfort is situated on a topographical slope. In Figure 2, these changes in elevation are shown with an added surface water drainage direction. The study site itself is situated on an elevation of 1545 mamsl whilst the lowest elevation is 1520 mamsl and the highest elevation 1566 mamsl. The difference in elevation between the highest and lowest points on the project site is 46 m.

Since groundwater flow tends to mimic surface drainage direction, groundwater is expected to flow through the study area from east to west.

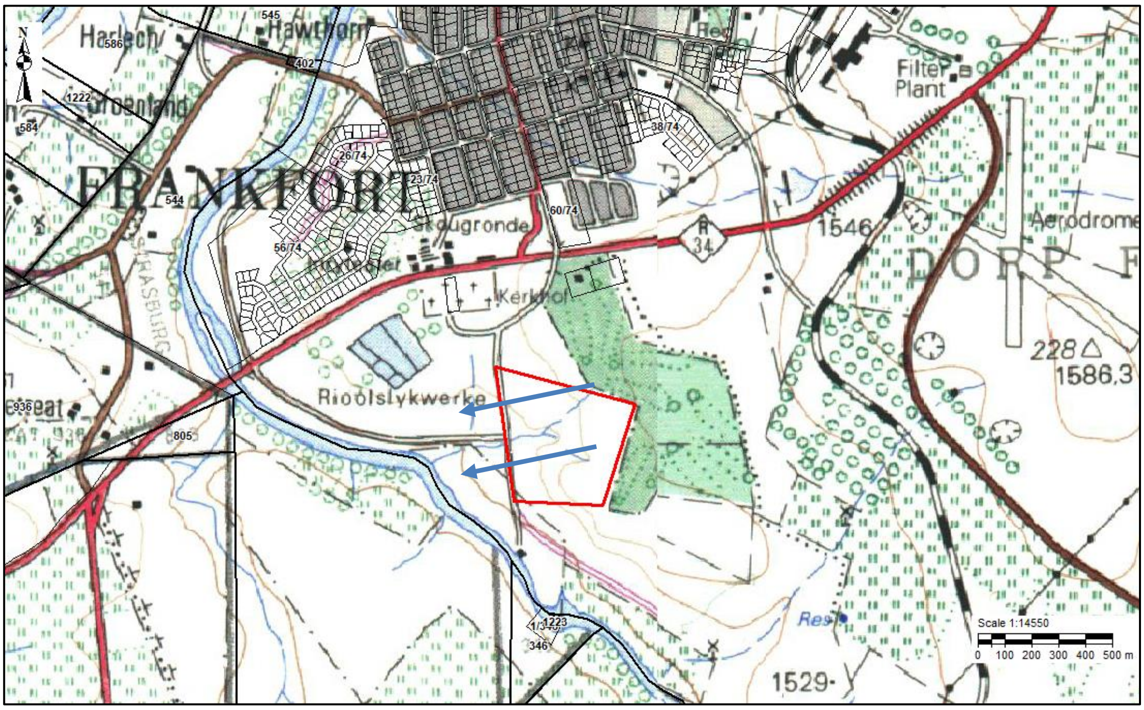

Figure 2: Topographical Map with drainage directions of the study area.

2.4. GEOLOGY

This section consists of information such as general geology, geological logging and soil characteristics as observed during the field survey and desk study.

2.4.1. LITHOSTRATIGRAPHY

The lithostratigraphy consists mainly of the following as adapted from the Hydrogeology of the Main Karoo Basin, Water Research Commission Report number TT179/02:

Karoo Super group

Beaufort Group: Consists of the Adelaide and Tarkastad Subgroups. Frankfort is situated on the Normandien & Escourt Formations of the Adelaide Subgroup which consist of Blue-grey and purple mudstone interbedded with yellow sandstone and siltstone.

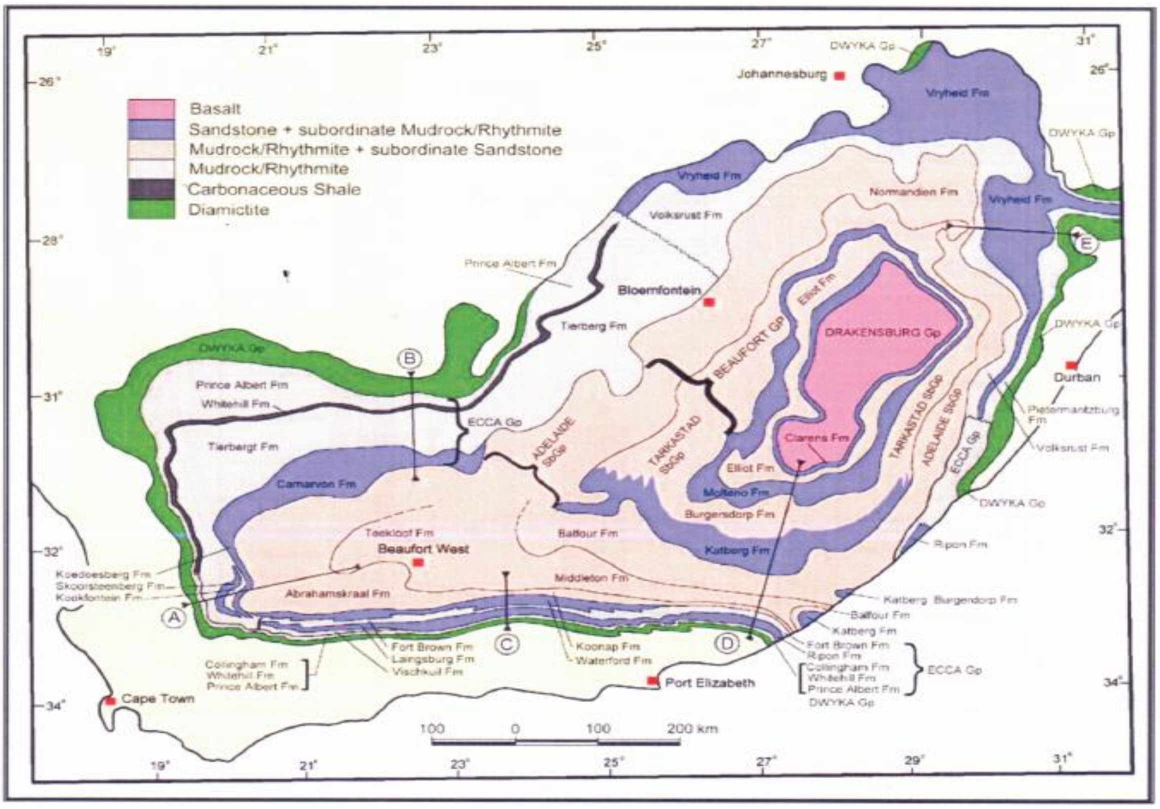

Figure 3: Schematic areal distribution of lithostratigraphic units in the Main Karoo Basin (*Johnson et al, 1997*)

Adelaide Subgroup

In the southeastern part of the basin, the late Permian Adelaide Subgroup comprises the Koonap, Middleton and Balfour Formations. In the west, the Abrahamskraal and Teekloof Formations are the approximate equivalents of the Koonap and Middleton Formations, respectively as indicated in Figure 3. The Middleton and Teekloof Formations are characterized by a greater relative abundance of red mudstone compared to the underlying and overlying units, in practice the boundaries are linked to specific sandstone-rich marker units, thus the arenaceous Poortjie and Oudeberg Members constitute the base of the Teekloof and Balfour Formations, respectively. In the northeastern region, the *Normandien Formation* is present.

The Adelaide Subgroup attains a maximum thickness of approximately 5000m in the southeast, which decreases rapidly to approximately 800m in the centre of the Basin and thereafter more gradually to 100-200m in the extreme north. The Koonap Formation attains a maximum thickness of approximately 1300m, the Middleton 1600m and the Balfour 2000m. In the west, the Abrahamskraal and Teekloof Formations are up to 2500m and 1400m thick, respectively.

In the southern and central parts of the Basin the Adelaide Subgroup consists of alternating bluish-grey, greenish-grey or grayish-red mud rock and grey, very fine to medium-grained, lithofeldspathic sandstone. In the northern part of the Basin, coarse to very coarse sandstone, or even granulestone, are common in the *Normandien Formation*. Sandstone constitutes 20% to 30% of the total thickness, but in certain areas may be as little as 10%, while some sandstone-rich intervals may in places contain up to 60% sandstone.

Individual sandstone units are thickest in the south (averaging 6m; maximum 60m) and become thinner northwards, except for the extreme northeast where thick, laterally extensive units are also present in the *Normandien Formation*. They generally extended laterally for a few hundred meters to a few kilometers, but many are markedly lenticular. Calcareous concentrations 20cm to 100cm in diameter are present in some sandstone layers.

In the Daggaboersnek Member, which occurs towards the middle of the Balfour Formation in the southeastern part of the Basin, the sandstones tend to be thin and tabular, possibly reflecting a lacustrine depositional environment.

Palaeocurrent data indicate that the bulk of the sediment was derived from a source area situated to the south and southeast of the Basin, with subordinate influxes from the southwest, west-northwest and northeast. The source area situated to the south, southeast and southwest of the Basin coincides with the second major tectonic paroxysm of the Cape Fold Belt, dated at approximately Ma (*Hälbich et al, 1983*). The margin of the Basin was probably close to the present South African coastline (*Cole, 1998*). Source areas to the west-northwest and northeast were sited on the continental regions of western Namaqualand/north-eastern Patagonia and the Mozambique Ridge/East Antarctica respectively (*Cole, 1998*).

Except in the lower part of the *Narmandien Formation*, where coarsening-upward cycles of sedimentation are present, the sandstone units normally form fining-upward cycles. The cycles vary from a few meters to a few tens of meters in thickness and were probably formed by the lateral migration of meandering rivers. The subordinate, horizontally bedded sandstone units that show no upward change in grain-size were deposited by ephemeral sheet-floods. The mudstone represents deposition in a flood plain and lacustrine environment.

2.4.2. INTRUSIVE KAROO DOLERITE

Towards the end of the Cape Orogeny thermal dome uplift developed beneath almost the entire South African continent. Dolerite represents the roots of the volcanic system and is presumed to be of the same age as the extrusive lavas (*Fitch and Miller, 1984*). Extensive magnetic activity lead to dolerite dykes, inclined sheets and sills to intrude the sedimentary rocks of the Karoo Super group 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 intrusive can either occur as dykes, sills, 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 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 intrusive was done by Rogers and Du Toit (1903) in the Western Cape and Du Toit (1905) in the Eastern Cape. Contributions to 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 1:250000 maps of the entire Karoo Basin. Detailed mapping of dolerite occurrences at specific localities in the southern Free State were done by Burger et al, (1981) and in the Western Karoo by Chevallier and Woodford (1999).

In the study area sills are the most abundant dolerite appearance and may be horizontal or slightly inclined.

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 breccias-intrusions such as 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 development 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 seldom 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 changes with depth, 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 meters. In general, the width of a dyke is a function of its length. 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 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.

Dyke Related Fracturing: The country rock is often fractured during and after dyke emplacement. These fractures from a set of master joints parallel to its strike over a distance that does not vary greatly with the thickness of the dyke (between 5m and 15m). The dolerite dykes are also affected by thermal- or columnar- jointing perpendicular to their margins. These thermal joints also extend into the host rock over a distance not exceeding 0.3m to 0.5m 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 are, namely:

1 Three sets of pervasive-thermal, columnar joints that are approximately 120 degrees apart; and

2 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 150mm) uplifting or brecciation of the sediment along the dyke contact. Deformation and Contact Metamorphism of Host Rock: Localised up warping 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 up warping of the country rock is commonly a near-surface phenomenon related to supergene formation of clays with a high expansion coefficient in the “swelling” rock mass. 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 crystallized to quartzite. Enslin (1951) and Van Wyk (1963) state that the jointed contact zone is less than 30cm 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 such as:

Thick dykes greater than 8m exhibit a prominent chill-margin containing a fine grained, porphyritic, melanocratic dolerite that weathers to produce well-rounded, small, white-speckled boulders. This zone is normally only 0.5m to 1.5m 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 o 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 less than 3m 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.

2.4.3. LOCAL GEOLOGY – GEOLOGICAL MAP

From the geological map shown in Figure 4 it is evident that the study area is underlain by a dolerite sill. Other formations that is visible in the area is the sedimentary rock from the Normandien formation of the Adelaide subgroup of the Beaufort Group and alluviums in the lower laying areas.

Figure 4 is a representation of the local geology in relation to the investigated site.

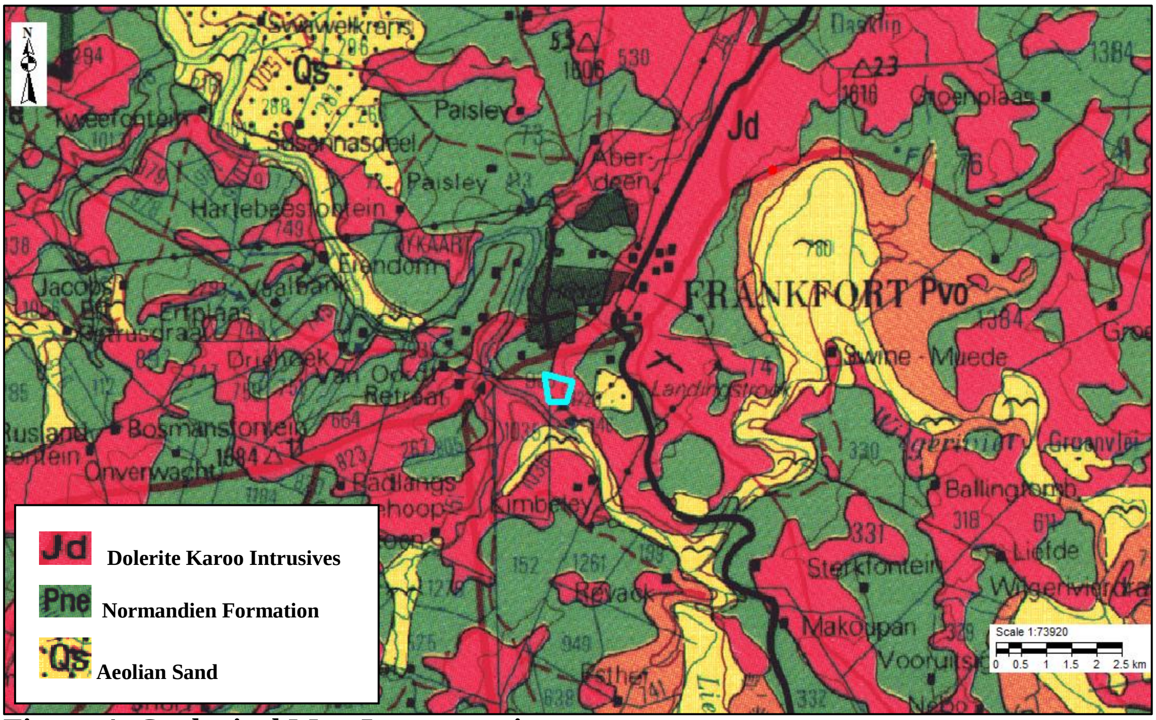

Figure 4: Geological Map Interpretation

The Normandien formation consists of olive green and grey mudstone with subordinate sandstone.

2.4.4. GEOHYDROLOGICAL IMPLICATIONS OF GEOLOGY

General geohydrological implications of Karoo geology in terms of the sedimentary rocks and the younger intrusive dolerites are described below.

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, 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 lithology, therefore the following are generalized:

Weathering of Karoo shale and mudstone 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 directly affect the hydraulic properties of these rocks.

Composite alluvial-weathered bedrock aquifers are commonly developed along the major drainage systems. Low to medium yielding boreholes with yields between 0.5 and 2 liters/second can be drilled in sedimentary rocks.

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 localized, 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 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 of weathered dolerite ring structures and inclined sheets seem variable. Vegter (1995) mentioned that the upper or lower contact sills located within the weathered zone, for example 20 to 50 meters below ground level, 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*), indicated contact between the sediment and the dolerite within the first 50m 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*).

Sedimentary rocks usually have low permeabilities and storativity values. Boreholes drilled into sedimentary rock formations are usually low yielding with the exception where bedding plane fractures are encountered within the sedimentary rocks or fractured baked contacts zones between the sedimentary rocks and magnetic dolerite intrusions such as dykes and sills.

2.4.5. HYDROSTRATIGRAPHY OF THE BEAUFORT GROUP

The main sediment source area for the Beaufort rocks lay along the high-lying, southern margin of the Basin. The coarser grained rocks are, therefore, found near the Cape Fold Belt, while mudstone, shale, and fine-grained sandstones dominate the more distal central and northern portion of the Basin. The sedimentary units in the Group therefore usually have very low primary permeabilities. The geometry of these aquifers is complicated by the lateral migration of meandering streams over a floodplain. Aquifers in the Beaufort Group will thus not only be multi-layered, but also multi-porous with variable thicknesses.

The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. The pumping of a multi-layered aquifer will thus cause the piezometric pressure in the more permeable layers to drop faster than in the less permeable layers. It is therefore possible to completely extract the more permeable layers of the multi-layered Beaufort aquifers, without materially affecting the piezometric pressure in the less permeable layers. This complex behavior of aquifers in the Beaufort Group is further complicated by the fact that many of the coarser and thus more permeable, sedimentary bodies are lens-shaped. The life-span of a high-yielding borehole in the Beaufort Group may therefore be limited, if the aquifer is not recharged frequently.

2.5. GENERAL AQUIFER INFORMATION OF THE FRANKFORT AREA

This section is based on the Groundwater Resources of South Africa Maps, DWAF, 1995.

In general, the recommended drilling depths are 60 to 100 meters or deeper for the study area. The storage types of the aquifer quantified as fractures, restricted principally to a zone below the groundwater level, pores in disintegrated, decomposed, and partially decomposed rock and fractures which are principally restricted to a zone directly below the groundwater level.

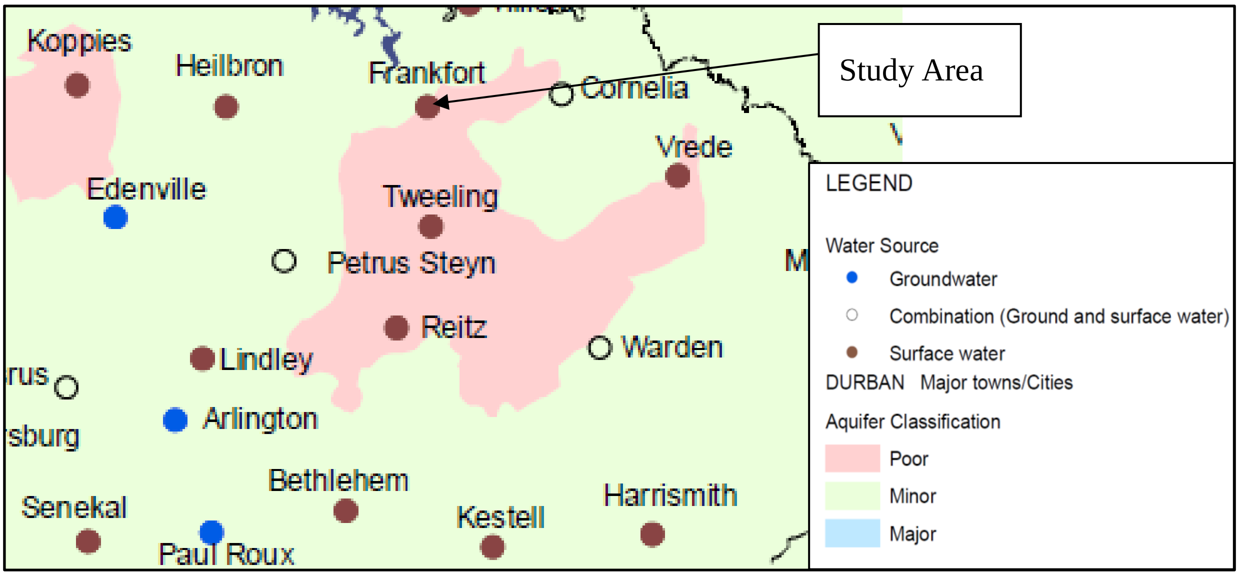

Figure 5: Aquifer Classification Map

The study area is situated on a minor to poor aquifer system where the expected yields of boreholes are <0.4 l/s.

Due to the fact that the project area is situated on a poor aquifer and the aquifer vulnerability is least, it can therefore be assumed that the aquifer has a low susceptibility for contamination.

3. GEOPHYSICS

The purpose of the geophysical surveys was to detect and delineate geological structures that could potentially act as, or be associated with, preferential pathways for groundwater migration and contaminant transport.

3.1. INTRODUCTION

Geophysics is considered one of the most cost effective, non-intrusive methods to investigate subsurface properties. The layout of a geophysical survey is not uniform (Al-Garni, 2005), and it is therefore necessary to understand the purpose, limitations and capabilities of each selected geophysical method. All geophysical data is analysed and interpreted in terms of local geology and geohydrological aspects.

The geophysical survey includes a desktop study of the area's geophysical properties, followed by a ground geophysical survey. The desktop study included the use of various resources such as geological, topographical and airborne magnetic maps. By incorporating these different maps with one another, an appropriate on site geophysical investigation layout may be designed, implemented and interpreted in accordance to local geological conditions.

3.2. APPROACH TO THE GEOPHYSICAL INVESTIGATION

As part of the geophysical investigations, the following actions were taken:

- A geological map covering the area under investigation was obtained from the Council for Geoscience. It was studied to determine the geological conditions that can be expected and to ascertain whether any large-scale geological features have been mapped in the immediate vicinity of the study area.
- An airborne magnetics map was purchased from the Council for Geoscience to identify large-scale magnetic features in the vicinity of the study area that may be indicative of changes in the subsurface geological conditions.
- Magnetic data were recorded on four traverses across the survey area. The aim of the magnetic survey was to investigate the presence of magnetic structures, such as dolerite dykes and sills, in the vicinity of the investigated site.
- All the geophysical data recorded during the investigations were processed and interpreted in terms of the local geological and hydrogeological conditions.

3.3. MAGNETIC METHOD AND EQUIPMENT

By incorporating existing knowledge on the geological conditions of the site being surveyed, the magnetic anomalies recorded during a survey may be interpreted in terms of the local geological conditions. The magnetic survey near the WWTW was conducted using a proton magnetometer. The purpose of the magnetic survey was to measure the magnetic response of possible dolerite structures within the area. Changes in the magnetic response were to be interpreted in terms of probable geological causes.

3.4. THE MAGNETIC METHOD

The magnetic method is the oldest of all applied geophysical techniques. During the Middle Ages, dip needles and compasses were already used in Sweden to find magnetite (Milsom, 2003).

The aim of a magnetic method is to detect and analyse magnetic variations in earth’s magnetic field caused by magnetic properties in subsurface structures or formations

(Mariita, 2008). These variations, referred to as anomalies, may be interpreted in terms of local geological structures.

According to Fourie et al. (2015), the behavior of recorded anomalies is influenced by the depth, geometry, anomalous structure, direction and degree of magnetisation of a subsurface structure or formation with respect to earth's magnetic field. Dykes, faults and lava flows are common causes of magnetic anomalies (Mariita, 2008) as they contain magnetic properties. Figure 7 shows an example of magnetic anomalies influenced by different geological structures.

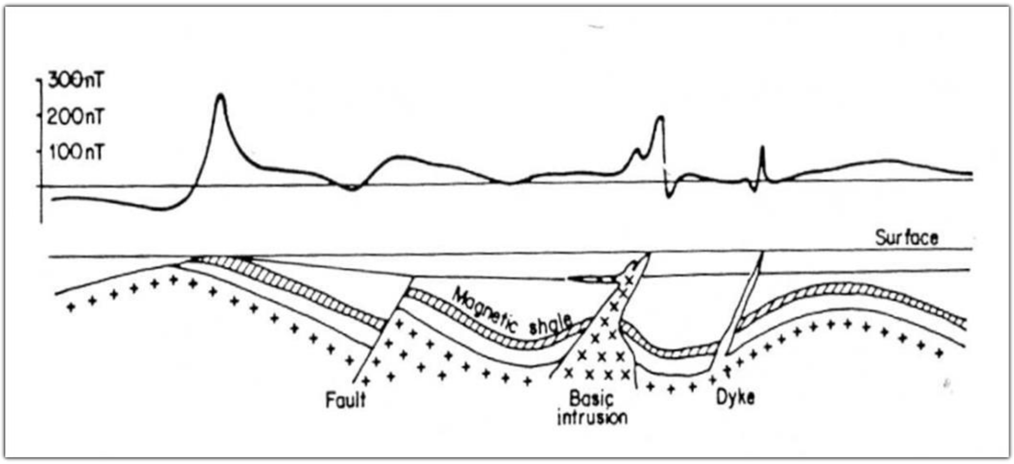

Figure 6: Basic concept of magnetic anomalies caused by geological structures

The inherent magnetism of a rock is called magnetic susceptibility. The earth's crust contains magnetic minerals such as magnetite (Fe3O4), pyrrhotite (FeS) and ilmenite (FeTiO3) which are widely distributed in various quantities (Fourie et al. 2015). Magnetite is the most abundant of the lot. Fourie et al. (2015) describes that due to metamorphic or igneous rocks having high magnetite (common magnetic mineral) content, sedimentary rocks generally have very small magnetic susceptibility in comparison. This is supported by Table 1 illustrating magnetic susceptibilities of different ores and rocks, adjusted from (Milsom, 2003).

Common Rocks	
Slate	0 - 0.002
Dolerite	0.01 - 0.15
Greenstone	0.0005 - 0.001
Basalt	0.001 - 0.1
Granulite	0.0001 - 0.05
Rhyolite	0.00025 - 0.01
Salt	0 - 0.001
Grabbo	0.001 - 0.1
Limestone	0.00001 - 0.0001
Ores	
Hematite	0.001 - 0.0001
Magnetite	0.1 - 0.0001
Chromite	0.1 - 20.0
Pyrrhotite	0.001 - 1.0
Phyrite	0.0001 - 0.005

Table 1: Magnetic susceptibilities of different rocks and ores (Milsom, 2003)

3.5. MAGNETIC INSTRUMENTATION

In modern times, magnetometers are widely used to measure the orientation and strength of a magnetic field with accuracies of up to 0,002 %. Various types of magnetometers exist such as rotating coil-, proton precession-, hall effect-, overhauser effect-, fluxgate-, caesium vapor– and spin-exchange relaxation-free (SERF) atomic magnetometers. For this study, a proton recession magnetometer was selected for use. Mariita (2008) explains the functioning of proton-precession magnetometers as follows:

Different proton magnetometers operate on broadly similar principles such as utilising proton rich fluids which are surrounded by an electric coil. The electrical coil receives momentary currents and protons are temporarily polarised by the corresponding magnetic field. Once the momentary current is removed, protons either press into the orientation of earth's magnetic field or realign. A small electrical current is in turn generated in the surrounding electrical coil caused by the precession. This electrical current is at a frequency directly proportional to the local magnetic field intensity.

The magnetometer is used to record magnetic measurements along a profile, at an angle that is preferably perpendicular to the extent of the investigated structure. Recorded magnetic measurements are used to create a graph representing local magnetic field intensity. These recordings are then interpreted in terms of local geological structures.

3.1. REGIONAL MAGNETIC SETTING

Airborne magnetic data is given in Figure 3, representing the regional airborne magnetic settings surrounding the study area. As seen within this figure, there are several geological structures surrounding the study site, giving rise to prominent and linear magnetic lineaments. A negative lineament can be seen intersecting the study area from a north west to a south east direction. Although this is not a prominent lineament, it is important to keep in mind when citing or monitoring boreholes in the area.

Prominent magnetic lineaments are associated with preferential groundwater flow paths. Although there seems to be a lineament intersecting the study area, it is not expected that this structure will greatly affect groundwater flow. The magnitude and extent of this structure will however be determined during an onsite geophysical investigation.

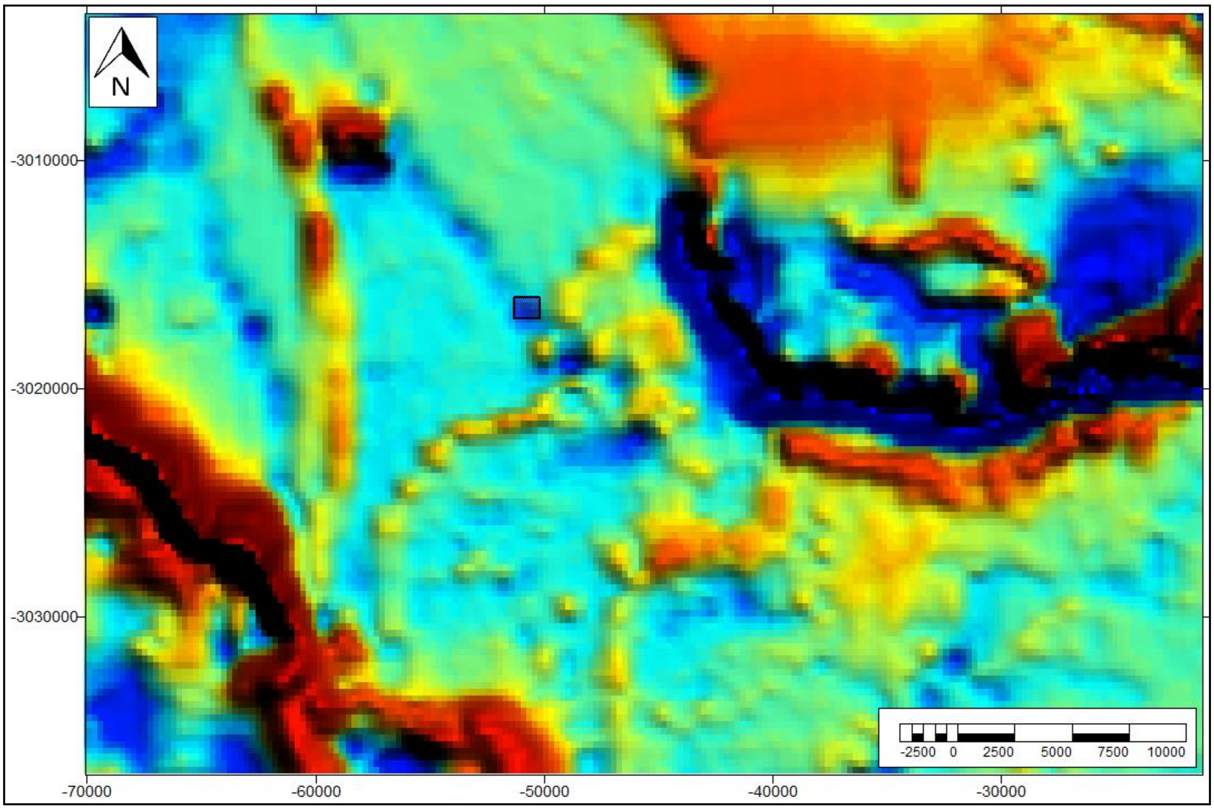

Figure 7: Regional aeromagnetic setting of the study area

3.2. MAGNETIC SURVEY

An appropriate geophysical layout structure plays an important role in the collection and analysis of subsurface geophysical data that accurately represent site properties.

The positions and orientations of the magnetic traverses are shown in Figure 8, relative to the Frankfort WWTW. Magnetic data was recorded across four traverses in directions indicated in Figure 8

Figure 8: Layout of magnetic traverse 1 and 2

Figure 9 below represents magnetic data recorded west of the existing SWS from east to west.

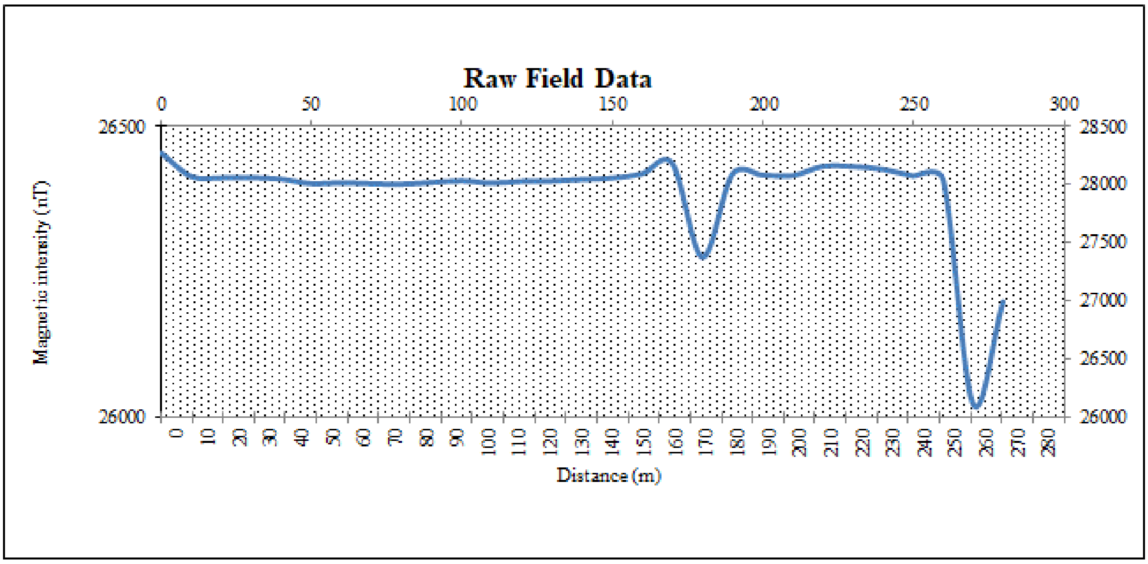

Figure 9: Traverse 1 from east to west

The anomaly at 170m is typical of a dolerite dyke that intruded the sill. Apart from this anomaly, magnetic data plots relatively flat with no suspicion of dolerite intrusions. The anomaly at 260m is due to overhead power cables.

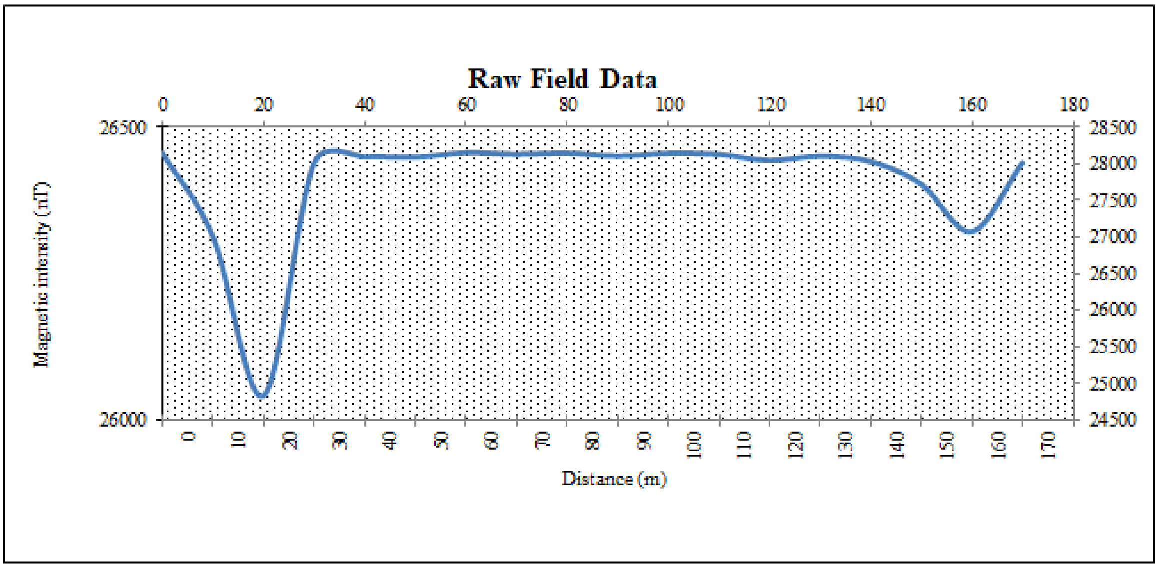

Figure 10: Traverse 2 from west to east

Magnetic data recorded along traverse 2 is given in Figure 10. A clear negative magnetic anomaly can be seen at 160m in the graph, above. The negative anomaly at 20m was recorded in close proximity to overhead power cable, causing a major influence on the recorded magnetic value. Apart from this negative anomaly, magnetic data recorded within this traverse plot characteristically flat for sedimentary geology.

4. BOREHOLE CENSUS

A borehole census was conducted on 4 September 2018 but no existing boreholes were detected. Therefore, it was impossible to determine the groundwater level in the area.

5. WATER QUALITY

Due to the fact that no boreholes could be found in the vicinity of the existing solid Waste Site, the groundwater quality could be determined.

6. PRELIMINARY GEOHYDROLOGICAL RISK ASSESSMENT

The risk of groundwater pollution is directly related to the nature of the activity. It is essential that maintenance be done on site at a regular basis to prevent leachate into the subsurface and groundwater. It is highly recommended that three (or at least two) boreholes be drilled east and west of the SWS in order to detect any possible seepage from the SWS as well as to determine the groundwater flow direction. The preliminary geohydrological risk may be contained by the appropriate instalment of monitoring boreholes and a proper management plan.

7. CONCLUSIONS AND RECOMMENDATIONS

With the available information at hand it can be concluded that:

- The study area is situated on a poor aquifer system which is associated with boreholes with an average yield less than 0.4 l/s.
- No boreholes could be identified in the vicinity of the study area and only one is currently in use.
- Due to the low yields, no groundwater use was detected in the proximity of the SWS.
- The risk for groundwater pollution is least due to the fact that the proposed site is situated on a poor aquifer.
- Should pollution occur, it is expected to stay relatively localized and follow a topographical down gradient direction at a relatively slow rate.

It is therefore recommended that:

- At least two boreholes be drilled in the vicinity of the SWS. One borehole upstream and one downstream of the SWS. If the groundwater flow direction should be determined, a third borehole will be necessary.
- The newly drilled borehole should be tested in order to determine the aquifer parameters and enhance the understanding of groundwater flow in the vicinity of the SWS.
- Water quality samples be collected after drilling of monitoring boreholes in the vicinity of the SWS.
- A water monitoring plan should be compiled and submitted to DWS for approval.

8. REFERENCES

- BREDENHOEFT, JD (2002) The Water Budget Myth Revised: Why Hydrogeologist Model, Vol. 40, No. 4 – Groundwater – July – August 2002 on pages 340 – 345.
- MIDGLEY DC, PITMAN WV & MIDDLETON BJ (1994) Surface Water Resources of South Africa, Volume 2 Appendices, WRC Report No. 298/2.1/94 and the Department of Water Affairs and Forestry (DWAF).
- MIDGLEY DC, PITMAN WV & MIDDLETON BJ (1994) Surface Water Resources of South Africa, Book of Maps, WRC Report No. 298/2.2/94 and the Department of Water Affairs and Forestry (DWAF).
- The geology of the Bloemfontein area, Council of Geoscience - Geological survey of South Africa
- HOUGH, JJ GHT Consulting, Report No. RVN588/1077
- ROUX AT, Geophysical Field Manual for Technicians, No. 1, The Magnetic Method, South African Geophysical Association.
- BOTHA, J.F., VERWEY, J.P., VAN DER VOORT, I., VIVIER, J.J.P., BUYS, J., COLLISTON, W.P. AND LOOCK, J. C. 1998. Karoo Aquifers – Their Geology, Geometry and Physical Properties. Report to the Water Research Commission by the Institute for Groundwater Studies, University of the Free State – WRC Report No. 487/1/98, Pretoria.
- BREDENHOEFT, JD. 2002. The Water Budget Myth Revised: Why Hydrogeologist Model, Vol. 40, No. 4 – Groundwater – July – August 2002 on pages 340 – 345.
- JOHNSON, M.R., VAN VUUREN, C.J., WICKENS, H.D., CHRISTIE, A.D., VISSER, J.N., AND ROBERTS, D.L. 2006. “SEDIMENTARY ROCKS OF THE KAROO SUPERGROUP”. IN M.R. JOHNSON, C.R. ANHAEUSSER, R.J. THOMS, M.R. JOHNSON, C.R. ANHAEUSSER, & R.J. THOMS (eds.), The Geology of South Africa, Johannesburg, Gauteng: Geological Society of South Africa, Johannesburg and the Council of Geoscience, Pretoria, pp. 475-576.
- UYS, J. 2007. LITHOSTRATIGRAPHY , Depositional Environments and Sedimentology of the Permian Vryheid Formation (Karoo Supergroup), Arnot North , Witbank Coalfield , South Africa. University of Johannesburg.

- HODGSON, F.D.I.; KRANTZ, R.M., (1998), "Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam Sub-Catchment", WRC Report no. 291/1/98.
- WOODFORD, A.C., CHEVALLIER, L., BOTHA, J.F., COLE, D., JOHNSON, M.R., MEYER, R., SIMONIC, M., VAN TONDER, G.J., VERHAGEN, B.TH. 2002. Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs. Water Research Commission. WRC Report No.TT 179/02.
- JMA Consulting (Pty) Ltd Sustainable Environmental Solutions through Integrated Science and Engineering. 2011. Sasol Shondoni EAIR Vol1 Part2. Available at: https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjEkaiDps_NAhUhBMAKHXYpBpMQFggaMAA&url=http%3A%2F%2Fwww.sahra.org.za%2Fsahris%2Fsites%2Fdefault%2Ffiles%2Fadditionaldocs%2FPrj5451%2520MiddelbultShondoniEIAR-VolumeI-FINAL%2520-%2520Part2.pdf&usg=AFQjCNF2HIBzQgnqe6d38PUJWTaDM6QYPw&sig2=tCj0Ubww5ldSQTOMtSGJKA.
- AL-GARNI, M. 2005. Application of Magnetic and Electrical Geophysical Methods in the Exploration of Groundwater Resources of Wadi Malakan, Saudi Arabia. Journal of King Abdulaziz University-Earth Sciences, [online] 16 (1), pp.67–93. Available at: <http://prod.kau.edu.sa/centers/spc/jkau/Data/Review_Artical.aspx?No=290>.
- MILSOM, J. 2003. Field Geophysics, 3rd ed. THIRD EDIT ed. [online]. The Geological Field Guide Series. Available at: <http://www.deu.edu.tr/userweb/emre.timur/dosyalar/Field Geophysics - John Milsom.pdf>.
- MARIITA, N.O. 2008. The Magnetic Method. Training, pp.1–8.
- FOURIE, S., VAN SCHOOR, M., VOGT, D., VAN DER WALT, J., JIKELO, A., CAMPBELL, G. AND DU PLESSIS, A., 2015. Introduction to the Geophysical Methods Applicable to Coal.
- SCHULZE RE, MAHARAJ M, LYNCH SD, HOWE BJ & MELVIN-THOMSON B (1997) South African Atlas of Agrohydrology and – Climatology. WRC Report No. TT82/96.
- WOODFORD AC & CHEVALLIER (Editors) (2002) Hydrology of the Main Karoo

Basin: Current Knowledge and Future Research Needs. WRC Report No. TT179/02.

- Google Earth Images