Report on Geotechnical and Geohydrological Investigations for the Proposed Decommissioning (Closure) of a Waste Landfill at Utrecht, eMadlangeni Local Municipality, KwaZulu-Natal Province

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I, _*Clement Rikhotso*_, declare that:

- I act as the independent practitioner in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting geotechnical and geohydrological assessments, including knowledge of the applicable Acts, Regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, Regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- I will ensure that information containing all relevant facts in respect of the application is distributed or made available to interested and affected parties and the public and that participation by interested and affected parties is facilitated in such a manner that all interested and affected parties will be provided with a reasonable opportunity to participate and to provide comments on documents that are produced to support the application;
- I will provide the competent authority with access to all information at my disposal regarding the application, whether such information is favourable to the applicant or not;
- All the particulars furnished by me in this form are true and correct;
- I will perform all other obligations as expected in terms of the Acts and the constitutions of my affiliated professional bodies; and
- I realise that a false declaration is an offence in terms of applicable Regulations.

DECLARATION OF INTEREST

This report has been professionally and independently prepared by North Arrow Consulting and Advisory Services (Pty) Ltd (Nacas), a South African Consulting firm with experience and expertise in Mineral Exploration/Mining and Engineering Geology. I hereby declare that to the best of my knowledge that Nacas nor any of its members does not have any vested interest (either business, financial, personal or other) in the project or associated projects nor with the briefing client other than appropriate remuneration for work performed in terms of the Regulations.

I undertake to inform the responsible representative of the client of any change in this information or any new information that needs to be reported, which occurs before or during the meeting or work itself and through the period up to the publication of the final report.

Name: CT Rikhotso
Date: 16 November 2017

Signature________________________________

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1.1 **EXECUTIVE SUMMARY**

GA Environment (Pty) Ltd (GAE) has been appointed by the Department of Environmental Affairs (DEA) to undertake the Basic Assessment and Waste Management Licence Application for the proposed decommissioning (closure) and rehabilitation of the existing eMadlangeni landfill situated on the outskirts of the town of Utrecht, KwaZulu-Natal Province. The Department of Environmental Affairs (DEA) is assisting the eMadlangeni local Municipality with this process. As part of the closure procedure geotechnical and geohydrological input is required for the conceptual end use plans. GAE, on behalf of the Client, requested North Arrow Consulting and Advisory Services (Nacas) to undertake combined geotechnical and geohydrological assessments at the site.

Waste disposed at landfills always carries the potential risk of contamination of the aquatic environment (e.g. groundwater) such that a suitably engineered landfill site which matches the risk profile of the waste should be designed accordingly. Geotechnical investigations of waste fills are rarely undertaken, and consequently the geotechnical community has little knowledge of their engineering properties. The investigations were aimed at identifying geotechnical and geohydrological factors that would have an impact on the development, to enable economic design and construction of the proposed closure development and to serve as a mitigating measure against unknown and/or variable ground conditions. The investigation comprised an initial desk study followed by a site walkover and an invasive test pitting investigation of the waste body and surrounds.

This existing landfill site located, 4km east of Utrecht, occupies an area of ~63,000m^2 (~6ha). It is located on the foot of a koppie, with topography gently sloping northeastwards (1.5km away) towards a river and dam. It receives general waste from the surrounding areas. Its date of inception is unknown. In the absence of any accurate records, the landfill is estimated to be approximately 70 tonnes per annum receiver of waste.

A hallmark of the local topography in the vicinity of the landfill is active serious sheet erosion resulting in the formation of dongas (gulleys) where there are large bare patches of veld with a hard surface and low amounts of organic material, making plant growth virtually impossible. The water and soil run-off direction are to the NW direction downslope towards the nearby river and dam water resources.

The Landfill site is underlain by sedimentary sandstone, shale (of the Ecca Group) which are overlain by post Karoo dolerite (of the Drakensburg Group). The site is located inside a valley covered on northwest and southeast sides by resistive dolerite plateaus which form the topography of the area escarpment consisting of hills and cliffs. Where dolerite has weathered it tends to form deep red residual soils. The runoff from the landfill site washes the sediments into a stream and a dam located approximately 1.5km downhill. There are no major geological lineaments visible from the geological map.

Predominantly NNW-SSE tending lineaments were interpreted from 1km resolution magnetic data on the area surrounding the eMadlangeni site. Should these structures be water-bearing, the direction of the water flow will be NNW-wards down gradient towards the dam and river. Any plume of polluted groundwater will also follow this similar path. The static groundwater level in the vicinity of the site is of the order of 10-30m below surface. Borehole yields are generally very low as illustrated by the boreholes in the 5m radius vicinity.

Geohydrologically, the site is in a minor aquifer with potentially low to moderately yielding aquifers of variable water quality. The country rock below the landfill is sandstone, shale and dolerite. In undisturbed and unweathered form the sandstone and shale rocks are hard and tight and their potential as water bearing aquifers is low. Where affected by faulting and fracturing, they form secondary aquifers of limited storativity but potentially high transmissivity particularly in the sandstones. Contact between dolerite intrusions and surrounding country rock often tend to act as water conduits. The landfill site is located in an area where faults and fracture zones are not so prominent and therefore the likelihood of encountering groundwater potentially is low. This is subject to detailed ground geophysics at closer spacing being done to verify this postulation.

Exposure of sandstone rock and boulders of dolerite were observed as part of the site walkover. Where dolerite has weathered it tends to form deep red residual clayey sandy soils. Donga erosion has incised these soils down to some 3-4m depth below ground surface.

Six (6) test pits were excavated (to 2m depth) on site on 31 October 2017. The exposed test pit profiles in the waste body generally comprise layers of cover soil (thickness ranging from 0.5m to 1m) underlying the landfill waste. No groundwater or perched leachate tables were encountered within the test pits. The landfill is does not have a basal liner. There are no existing monitoring boreholes on the landfill.

Laboratory results indicate that in general the sample tested comprises the following:

- In general, the soils tested comprise of silt (15%), clay (21%) and sand (64%). In terms of the Unified Soil Classification system the soil classifies mainly as a “SC” soil type, these clayey sand and poorly graded sand-clay mixtures. The Grading Modulus of 0.72 seems to reflect the soils as of fairly fine nature as corroborated with the sieving analysis results. Based on the indicator tests, the soil is of fair workability as a cover material, semi to impervious.
- The plasticity indices (a measure of the plasticity of the clay) recorded show low values (< 12) which are indicative of fairly low activity (low expansiveness) for the soils. These should therefore not constitute any serious problems under conditions of moisture migration.
- Permeability (hydraulic conductivity) tests conducted in the laboratory on disturbed samples indicate an order of magnitude of coefficient permeability of 1.3×10^{-9}m/s suggesting impervious nature of the soil. This soil is therefore suitable to use as cover together with other liner systems.

The potential risks that could impact the decommissioning of the landfill site comprise soil erosion, slope stability, settlement of waste and potential surface and ground water pollution.

- The site is situated close to two local surface water resources (a river and a dam) and the non-perennial drainage lines that connect the landfill with these water resources.
- Slope failure due to the slope height and angles is a potential collapse risk, should wet conditions become excessive.
- The site does not reflect any risk for the formation of sinkholes or subsidence caused by the presence of water-soluble rocks (dolomite or limestone) and there is no evidence of mining activity beneath the site.

Based on the geological and geohydrological conditions of the area investigated it is worth noting whilst recognising that the identified risks can typically be mitigated to a certain extent by the implementation of an appropriate and effective Environmental Management Plan (EMP) as part of the closure process.

These identified risk aspects as well as the outcomes of other specialist studies, should enable the appointed design engineers to determine the most cost effective conceptual closure design alternative for the landfill site.

It is recommended that further detailed studies of the existing geological and geohydrological information available for the site and the surrounding areas are conducted at a Class 0 (+-45% accuracy) estimated inclusive (VAT & 10% contingency) cost of R1,922,000. The aim of the additional work to support the next Detailed engineering design phase of the project will be three-fold:

- Clarify the groundwater flow and the likely migration of a pollution plume around landfill and determine the groundwater conditions to the northwest of the existing site towards the river and dam.
- Establish a more comprehensive groundwater monitoring system around the entire landfill area.
- Further determine the geotechnical and geohydrological properties of the soils and underlying bedrock.

Presently there are no monitoring boreholes on the landfill site. As part of the closure, a monitoring programme is recommended to be implemented. The outcomes from the aforementioned additional studies will be the basis for developing the monitoring programme. The development of a groundwater monitoring programme will be important for assessing the impacts of the decommissioned Landfill on the groundwater and the environment. Monitoring can be described as the repetitive and continued observation, measurement and evaluation of geohydrological information such as water level and groundwater quality to follow changes over a period of time to assess the efficiency of control measures.

DEFINITIONS AND ABBREVIATIONS

ACRONYM	Description
BA	Baseline Assessment
CBR	California Bearing Ratio
CEMP	Closure Environment Management Plan
CEMP	Construction Environmental Management Plan
CGS	Council for Geoscience
DEA	Department of Environmental Affairs
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
EDTEA	KwaZulu-Natal Province Department of Economic Development, Tourism and Environmental Affairs (EDTEA)
EIA	Environment Impact Assessment
GAE	Glad Africa Environment (Pty) Ltd
ha	1 Hectare = 10,000m^2
IWWMP	Integrated Water and Waste Management Plan
l/s	Litres per second
LTP	Leachate Treatment Plant
m	Metres
m^2	Square metres
m^3	Cubic metres
mbgl	Metres below ground level
mm	Millimetres
NEMA	National Environmental Management Act, 1998 (Act 107 of 1998)
NEMWA	National Environmental Management: Waste Act, 2008 (ACT No. 59 of 2008)
NGA	National Ground Aquifer database
NWA	National Water Act, 1998 (Act 36 of 1998)
ORP	Oxidation reduction potential
TLB	Tractor, Loader Backhoe
WCSF	Waste collection and sorting facility

2. INTRODUCTION

2.1 **Background and Project Description**

GA Environment (Pty) Ltd (GAE) has been appointed by the Department of Environmental Affairs (DEA) to undertake the Basic Assessment and Waste Management Licence Application for the proposed decommissioning (closure) and rehabilitation of the existing eMadlangeni landfill situated on the outskirts of the town of Utrecht, KwaZulu-Natal Province. The Department of Environmental Affairs (DEA) is assisting the eMadlangeni local Municipality with this process. GAE have in turn appointed North Arrow Consulting and Advisory Services (Pty) Ltd (Nacas), to carry out supporting specialist geotechnical and geohydrological studies which is input required for the engineering conceptual end use plans, the basis for the closure process.

According to the NEM: WA, 2008 (Act No. 59 of 2008), the disposal of general waste at the landfill requires a Waste Management License as per Category B (Activity No. 8 & 9) of Government Notice 921 of 2013, and an Environmental Impact Assessment process, as stipulated in the NEMA EIA Regulations (2014) as amended, made under section 24(5) and 44 of the NEMA, 1998 (Act No. 107 of 1998) as amended. As the eMadlangeni landfill is located within the KwaZulu-Natal Province, the Waste Management Licence for the landfill will be issued by the KwaZulu-Natal Province Department of Economic Development, Tourism and Environmental Affairs (EDTEA).

The report reviews the geological and geohydrological conditions around the landfill based on published regional and local geological investigations as well as information collected during a site walkover carried out on 31 October 2017. The report forms part of the specialist studies required for an Environmental Impact Assessment (EIA) by GAE. The investigation has been undertaken to meet with the requirements of Chapter 6 of the document Minimum Requirements for Waste Disposal by Landfill (1). As such the report contains the following information:

- brief description of the position and access routes to the area, climate of the region,
- hydrology of the region
- a description of the regional and local geological conditions and other subsurface conditions,
- the results of a hydrocensus of the site and surrounds
- the regional and local geohydrological conditions,
- aquifer classification,
- groundwater use and quality, and
- an evaluation of geological and geohydrological conditions in terms of the suitability of the area for the closure of the waste disposal facility.

2.2 **Terms of Reference**

As an independent Environmental Practitioner, GAE are managing the Waste Management Process to ensure that the unlicensed landfills are licenced. The process entails the following:

- Submission of signed Application forms to Competent Authority.
- Undertaking of Basic Assessments or Environmental Impact Assessments as part of the Waste Licence project based on the NEMWA Waste Activities and.

- Management of the required specialists to support the BA's and EIA's as well as to fulfil the legislative requirements pertaining to the licensing of landfills.

In support of the above-mentioned legislative imperatives, Engineering Conceptual designs for the landfill are required. In turn, associated geotechnical and geohydrological Studies (assessments) need to be undertaken on this site earmarked for decommissioning (closure) to support Engineering Conceptual designs which will eventually lead to construction.

2.3 Objectives

The objectives of the geotechnical investigation were to determine the nature and stability of the upper portions of the existing waste bodies so to provide suitable recommendations with regards to proposed future developments (end use plan of landfill site). In this regard, review information relating to the geology, geomorphology, geohydrological, geotechnical aspects, surface and underground water on the landfill and vicinities as well as the consequent impact on conceptual engineering design principles. The studies therefore seek to:

- identify geotechnical and geohydrological risks associated with the sites;
- evaluate geotechnical and geohydrological parameters of the sub-base soils at the sites;
- review the geotechnical and geohydrological requirements for the development of cells and associated infrastructure for a landfill at the sites;
- assess the requirements, and availability and suitability of cover material for the operations of the landfills and capping material for those landfills to be decommissioned for closure;
- assess and evaluate the requirements, and risk issues for the landfills including, slope stability and permeability of soils;

2.4 Available Information

The following information was supplied by GAE to facilitate the investigation:

- Location of the landfill in the form of Google Earth kmz files.
- Notes taken during meetings held with GAE personnel detailing the description of the site following their initial site visit.
- Notice of Basic Assessment Process for the closure of the landfill.
- No other landfill specific information/data (e.g. weighbridge records) was available for this study.

3. LEGISLATIVE CONTEXT

The general objective of environmentally acceptable waste disposal is to avoid both short and long-term impacts and any degradation of the environment in which the disposal facility is located. More specific objectives are to prevent pollution of the surface water, groundwater, air and to ensure public acceptance by ensuring environmental acceptability. The current legislation is written in that spirit.

Previously, landfill classification was based on:

- Type of waste
- Size of waste stream

- Potential for leachate generation (climate, etc)

New Landfill Classification focusses on barrier design (GNR 635) and chemical characteristics of the waste (SANS 10234, GNR 636, etc)

The implications from a design perspective are as follows:

- Far more chemical analysis and laboratory testing of waste sample
- More cautious (simplified) approach to basal and top lining systems
- Improved record keeping and controls on sites

All studies were conducted in accordance with the latest Norms and Standards documents as published as part of the National Environmental Management: Waste Act, 2008, the Minimum Requirements for Waste Disposal by Landfill, 2005 compiled by the Department of Water Affairs, site Investigation Code of Practices by the South African Institution of Civil Engineering Geotechnical Division (however, there is no specific legislation relevant to the geotechnical work undertaken, specifically to the decommissioning of landfills). and the geotechnical mapping procedures of the Council for Geoscience amongst others.

4. NATURE OF INVESTIGATIONS

The respective investigations commenced with a desk study, which entailed obtaining as much information as possible of the site that may provide an indication of the most likely geotechnical and geohydrological conditions prevailing within the area. For example, by determining the underlying geological setting together with the prevailing topographical and climatic conditions, the weathering characteristics of the host rock can be estimated and an indication of the most likely geotechnical conditions underlying the site established. The information obtained from the desk study is discussed in in the Section below.

The desk study was followed by a site reconnaissance which was carried out on 31 October 2017 and entailed Nacas' senior engineering geologist visiting the site and walking over the entire area whilst noting and recording information from visible surface features. Limited invasive test pit excavations of the waste body, soil profiling and collection of samples for laboratory analyses were also carried out. Information from this phase of the investigation, together with the desk study, provided a preliminary assessment of the geotechnical and geohydrological conditions underlying the site and identified areas necessary for further investigation.

4.1 **Desk Study**

The purpose of the desk study was to provide background information and technical guidance as well as to refine the scope of works for the follow-up geotechnical and geohydrology assessment. The scope of study includes collecting available and public geological, geohydrological and geophysical data in order to identify the lithology, geological structures, potential aquifers or/and aquitards. A general briefing session with GAE personnel was attended to meet and collaborate with relevant team members to ensure that project milestones were feasible and to prevent possible duplication of work.

The geotechnical and geohydrological desk study involved the following literature review at regional and local scale:

- 1:250 000 geological map series of Vryheid 2730

- 1:500 000 Hydrogeological Map series of the Republic of South Africa 2730 (Vryheid)
- Department of Water and Sanitation - National Groundwater Archive (NGA)
- Department of Water and Sanitation – GRA2 Project maps
- Aquifer Classification Map of South Africa
- 1 km resolution airborne magnetic data
- Published relevant literature: Engineering Geology of South Africa (Brink, 1979 -1985), etc
- Weinert's climatic N-value, temperature, rainfall & wind direction of the area
- Reference to published literature on the characteristics of the anticipated rock and soils profiles (and related stability and permeability characteristics) to be encountered, as well as foundation solutions in such materials and potential construction materials.
- Geophysics and structural interpretations maps
- Limited Baseline hydrocensus within a 5km radius of the site - information regarding probable location of sources of surface and groundwater in the radius of 5km with potential to be polluted will be located, surface and ground water movement, direction and compartments.
- Investigate conceptual placement of future groundwater monitoring boreholes.

The methodology adopted for the desk study was as follows:

4.1.1 Geography - Location, size and land-use

The eMadlangeni) Landfill is located on Erf 10000 and Erf 1006 on the nearby outskirts (4km eastwards) of Utrecht CBD within the eMadlangeni local municipality under the Amajuba District Municipality, KZN Province (Figure 1). The landfill occupies and area of approximately 6ha. The town of Utrecht in KwaZulu-Natal (on the R34 between Newcastle and Vryheid) Utrecht is located some 52 km east of Newcastle and 68 km west of Vryheid on the R34 and lies within the confines of the Balele Game Park and the Utrecht Community Game Farm, with a total Game Park area of 2500ha. Utrecht is the seat of the local eMadlangeni Municipality and the Amajuba District Municipality.

4.1.1.1 Infrastructure

The landfill is accessible from a tar road (President street) which becomes a well serviced gravel road outside the CBD and is located off a gravel road out of town. The proximity to the CBD means there is available typical small-town infrastructure and amenities.

4.1.1.2 Topography

A hallmark of the local topography in the vicinity of the landfill is active serious sheet erosion resulting in the formation of dongas (gulleys) where is a large bare patch of veld with a hard surface and low amounts of organic material, making plant growth virtually impossible. These dongas have formed when flowing water cuts a channel into the soil (Figure 2). Where ground falls away, a donga head forms that gradually works its way upstream, widening and deepening the donga. The water and soil run-off direction are to the NW direction via non-perennial streams/rivulets or surface drainage features, downslope towards the nearby (~1.5km) river and dam water resources.

Figure 1: Location of the eMadlangeni landfill site (yellow pin) near Utrecht.

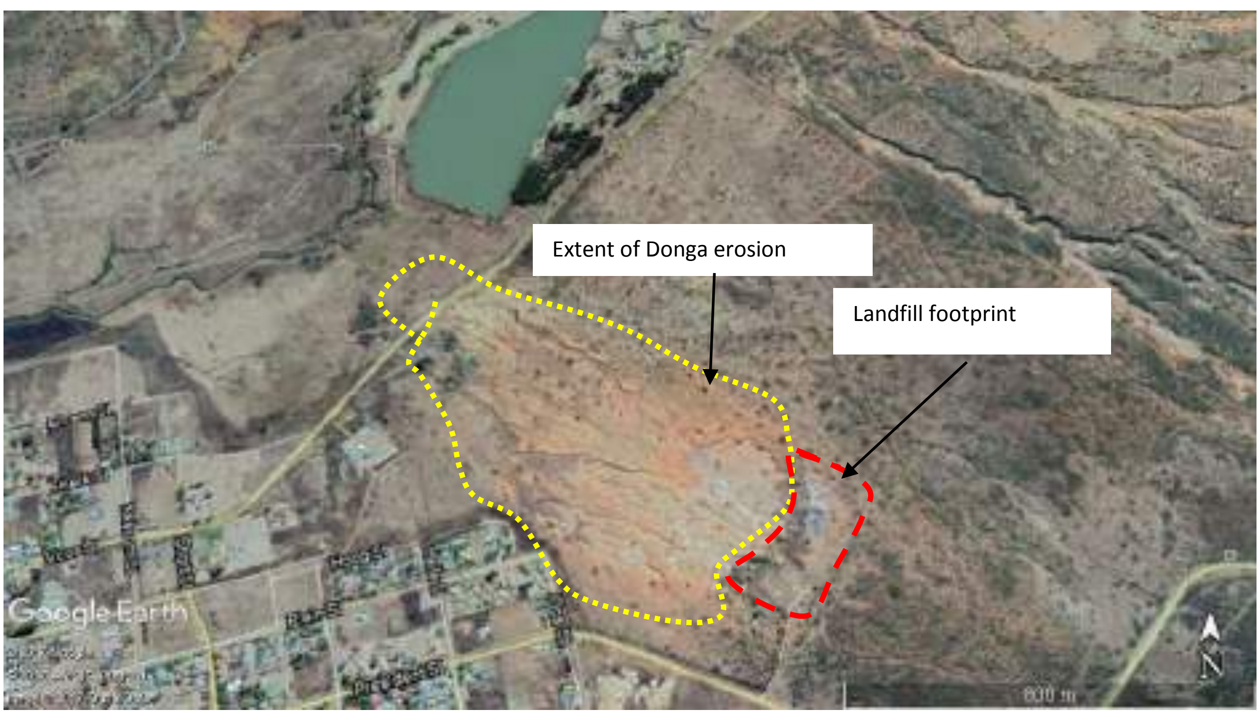

Figure 2: Extent of donga erosion with direction of water and sediment flow in the NW direction. Location of surface water bodies in the area (river and dam).

4.1.1.3 **Climate**

The climate in this area is mild and characterised by warm, moist summers and cool dry winters. Most rainfall occurs from October to March, with a mean annual precipitation of about 680mm. Climate determines the mode and rate of weathering. The effect of climate on the weathering process (i.e. soil formation) is determined by the climatic N-value defined by Weinert. The N-value at the site is between 3 and 4, which implies that the climate is still moderate to dry, and that both chemical decomposition as well as mechanical disintegration, are the modes of rock weathering at the site. It would seem though that chemical decomposition predominates. No flood line studies have been carried out, but the site could be within or on the edge of a 1:50 year floodline considering proximity to the dam and river some 1.5km to the northwest.

4.1.1.3.1 **Precipitation and evaporation**

Figure 3 below shows the average rainfall values for Utrecht per month. Generally, the weather patterns follow a high summer and low winter rainfall. It receives the lowest rainfall in July and the highest in January. The landfill site receives an annual rainfall ranging from 680 to 898 mm and evaporation rates of 1362 to 2224 mm/annum (

Table 1) meaning site has a negative water balance and a relatively dry site. This negative water balance classifies the landfill site to be a B- in terms of previous Guidelines of Landfill Classification, suggesting no significant leachate is generated.

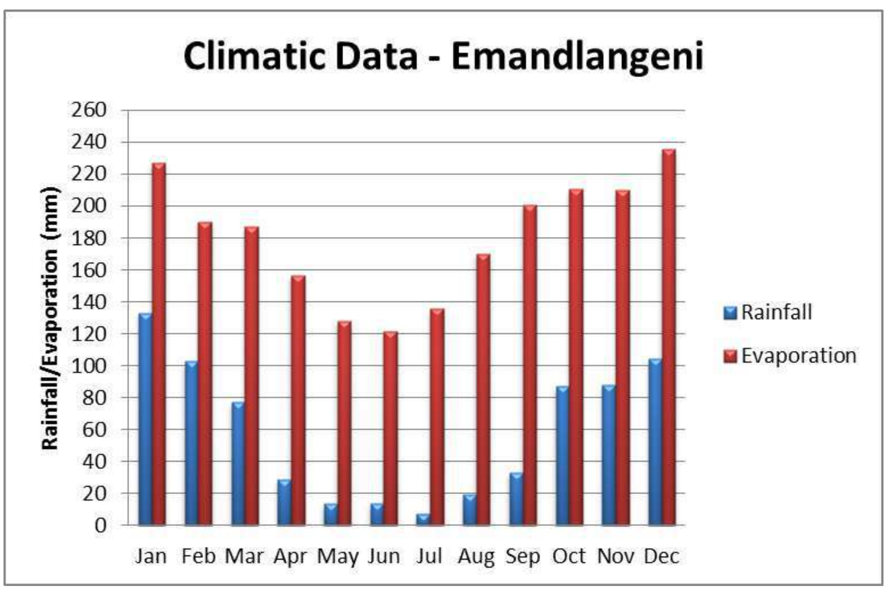

Figure 3: Climatic data from station V3E004.

Table 1: Summary of climatic data

Area (station)	Average Rainfall (mm/annum)	Average Evaporation (mm/annum)
Emadlangeni (V3E004)	679.6	2223.9

4.1.1.3.2 **Temperature**

The monthly distribution of average daily maximum temperatures shows that the average midday temperatures for Utrecht range from 18.7°C in June to 26.1°C in January. The region is the coldest during July when the mercury drops to 2.9°C on average during the night.

4.1.1.3.3 **Wind**

At a sub-regional scale, cool mountain-plain winds blow at night, whereas in the day, a warm up-valley wind blows towards the escarpment. Strong westerly pressure winds (known as “berg winds”) are prevalent in spring between August and September. They occur ahead of frontal disturbances and are of considerable significance regarding the spread of wildfire, and for the selection of sites for development infrastructure.

4.1.1.3.4 **Fauna and Flora**

The area is largely natural grassland (Figure 4), which could support natural populations of various faunal groups. Some small antelope still occur naturally and some roaming at the landfill site on the day of the site walkover. Groves of mature acacia and aloe and other trees are, however, present over parts of the landfill and outside.

Figure 4: Typical vegetation covering the ‘not yet dumped’ portion of the landfill.

4.1.1.4 **Regional and Local Geology and Structural Conditions**

The eMadlangeni Landfill is underlain by sedimentary sandstone, shale (of the Ecca Group) which are overlain by post Karoo dolerite (of the Drakensburg Group). The site is located inside a valley covered on northwest and southeast sides by resistive dolerite plateaus (Figure 5) which form the topography of the area escarpment consisting of hills and cliffs. Where dolerite has weathered it tends to form deep red residual soils. The runoff from the landfill site washes the sediments into a stream and a dam located approximately 1.5km downhill. There are no major geological lineaments visible from the geological map.

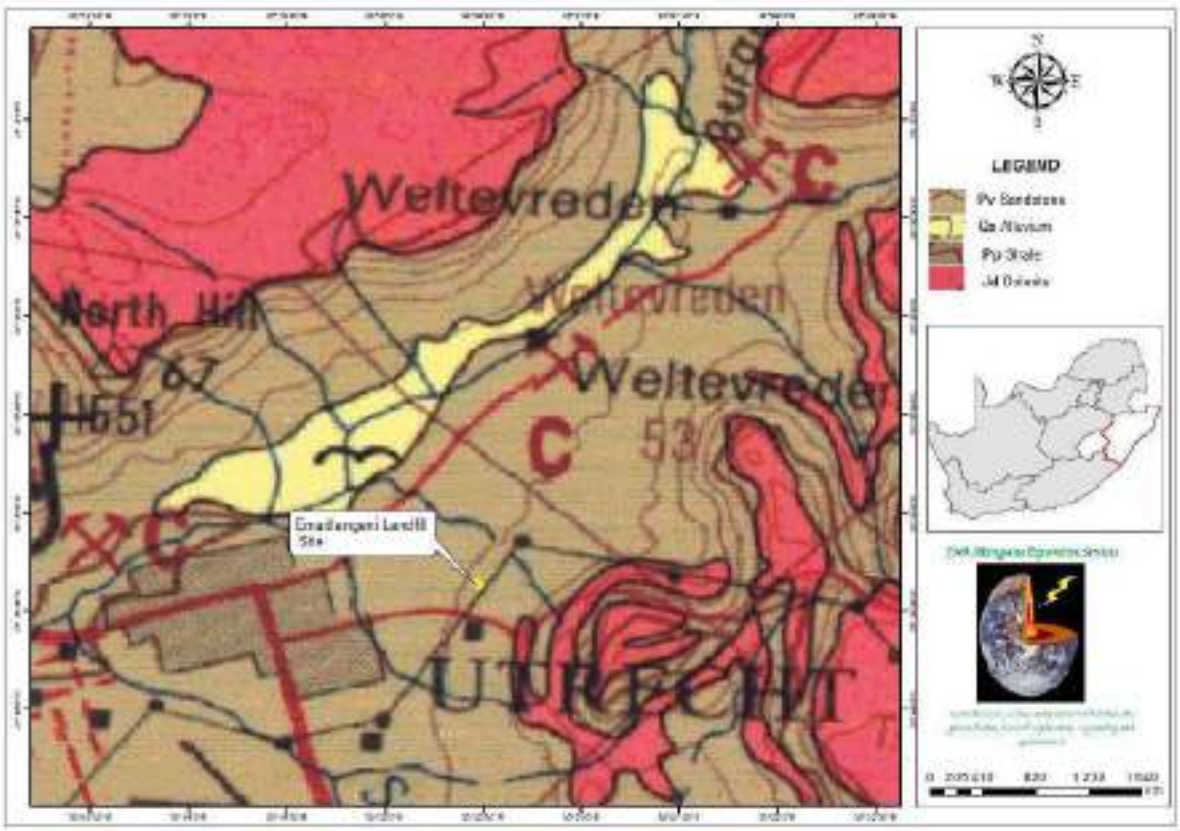

Figure 5: Geology Map of Vryheid showing eMadlangeni Landfill site. Source (FNA Exploration).

4.1.1.5 **Seismic Zoning**

The two main geohazards (*sensu stricto*) under consideration in the Amajuba region are (1) earthquakes, and (2) catastrophic slope failures or other kinds of ground instability. The latter hazard may frequently be associated with or triggered by the first, although slope failure is more commonly triggered by hydro-meteorological factors, such as rainstorm or flood.

4.1.1.5.1 **Earthquakes**

The Amajuba municipal area is close to an apparent junction between two seismically active belts:

- A N/S-trending belt along the escarpment zone between Limpopo, Mpumalanga, Swaziland and northern KZN;

- An offshore NE/SW-trending belt crossing the KZN-Mozambique continental margin in the Mozambique Channel, within which occurred South Africa's largest historical earthquake (Cape St Lucia, 1932).

Figure 6 shows a seismic hazard map of Southern Africa and the location of the site relative to seismic activity.

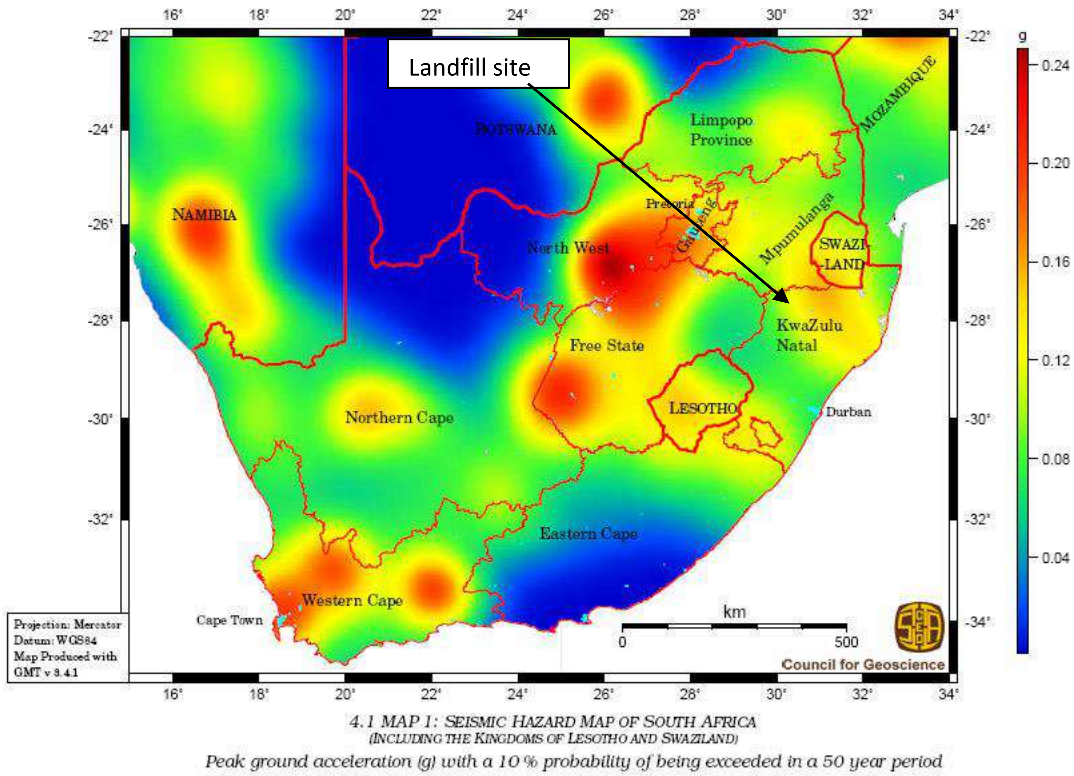

Figure 6: Seismic hazard map of South Africa. Source (CGS).

4.1.1.5.2 **Slope instability**

The KwaZulu-Natal Geohazards Database (Richards and Grow, 2003) currently identifies no record (Figure 7) of slope failures of whatever type within the Amajuba area. The absence of an historical record for a particular type of geohazard is a significant disadvantage to analysis and assessment. The potential for slope instability – which could be either earthquake-, rainstorm- or flood-triggered – could exist in parts of Amajuba because of the deep incision of the major rivers or stream, and local steep slopes between the flood plains and the surrounding plateau areas. Locally at Utrecht at the landfill site, the area has active donga erosion as can be seen on Figure 2 and Figure 8.

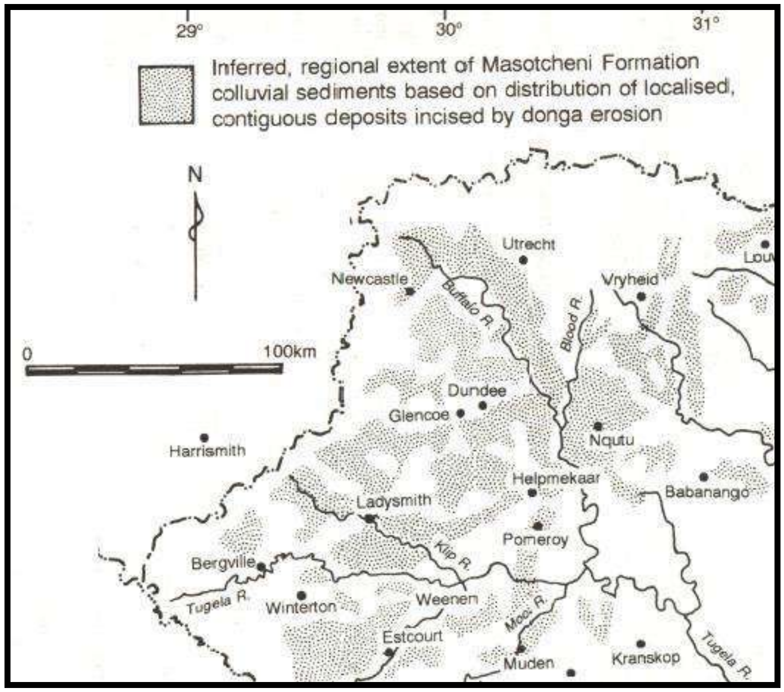

Figure 7: Distribution of colluvial sediments in the Amajuba (Newcastle-Utrecht) area and surrounding districts.

Figure 8: Active erosion of the residual soil as shown by erosion of the western boundary fence post foundation.

4.1.1.6 **Geophysics**

Freely available 1 km resolution airborne magnetic data was interpreted to identify the possibility of any structural geological features which can act as preferential pathways for pollution from landfill into groundwater. The interpreted lineaments (black lines) are plotted as black lines on Figure 9. Predominantly NNW-SSE tending lineaments were interpreted on the area surrounding the eMadlangeni site. Should these structures be water-bearing, the direction of the water flow could be NNW-wards down gradient towards the dam and river. Any plume of polluted groundwater will also follow this similar path.

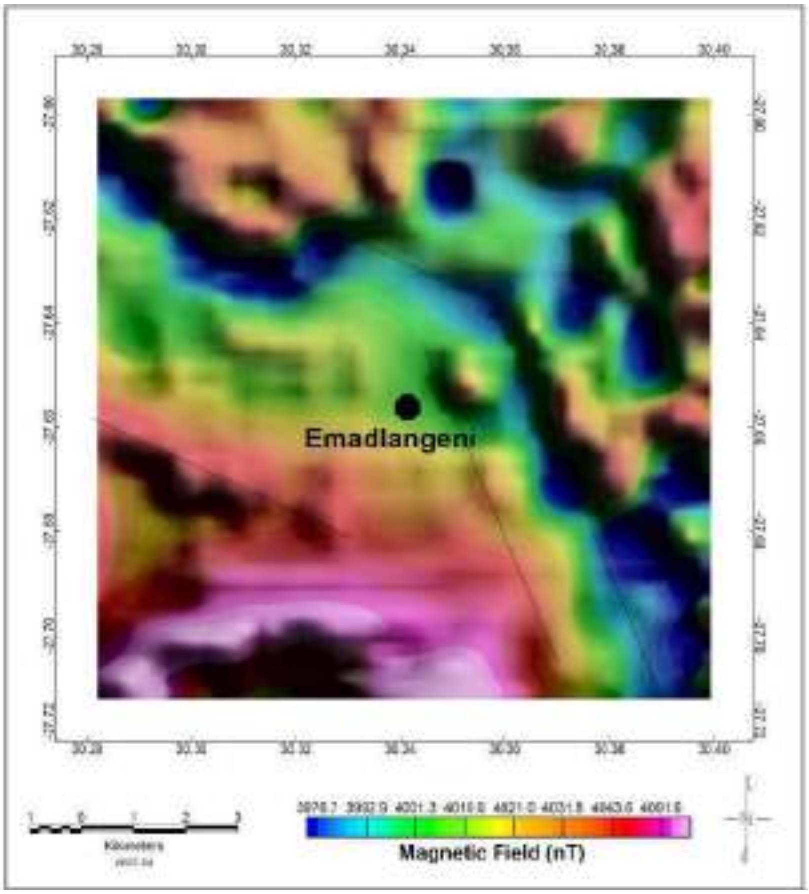

Figure 9: Airborne magnetic data surrounding the eMadlangeni Landfill site.

4.1.1.7 **Regional and Local Geohydrological Conditions**

The country rock around the landfill area is sandstone, shale and dolerite. In undisturbed and unweathered form, the sandstone and shale rocks are hard and tight and their potential as water bearing aquifers is low. Where affected by faulting and fracturing, they form secondary aquifers of limited storativity but potentially high transmissivity particularly in the sandstones. Contact between dolerite intrusions and surrounding country rock often tends to act as water conduits. The landfill site is located in an area where faults and fracture zones seem not so prominent and therefore the likelihood of encountering groundwater is potentially low. This is subject to detailed follow-up ground geophysics surveys at closer spacing being done to verify this postulation.

4.1.1.7.1 **Surface water**

As per Figure 2, showing the high level of donga and sheet erosion on the landfill site with direction of water and sediment flow downslope towards the river and dam, there is high potential for silting of the river and dam as well as contamination by leachate emanating from the landfill. There is probability of flood occurrence on the landfill originating from the dam or river considering the close proximity of the landfill to these water resources.

4.1.1.7.2 **Aquifer Type**

The Aquifer Classification Map of South Africa classifies the aquifer as a minor aquifer. The explanatory notes for the Aquifer Classification Map (Parsons and Conrad, 1998) describe a minor aquifer as a moderately yielding aquifer system of variable water quality. The Hydrogeological Map of Vryheid (2730) classifies the aquifer type as Intergranular and Fractured with the lithology of predominantly arenaceous rocks such as sandstone and conglomerate with typical borehole yield ranging from 0.5 to 2 L/s. The lithology of the site is confirmed by the national groundwater archive database were three boreholes recorded show shale and sandstone as rock type found and the borehole yields range from 0.47 to 2.29 L/s. The water strikes are expected on the contact between the shale and sandstone and possibly on the dolerite intrusion contacts. A summary of borehole information from NGA is given on **Error! Reference source not found.** and the borehole locations relative to the 5km radius from zone of landfill site are shown on Figure 10.

Table 2: Groundwater data from NGA (5km radius of eMadlangeni landfill site)

Name	**Latitude**	**Longitude**	**Geology**	**Water Strike (mbgl)**	**Yield (L/s)**	**Water Level (mbgl)**
2730CB00063	-27.69365	30.33984	Shale Sandstone	21, 37	0.47	12
8042	-27.62774	30.36531	Shale Sandstone	44	1.13	32
2730CB00047	-27.68051	30.35336	Shale Sandstone	28	2.29	10

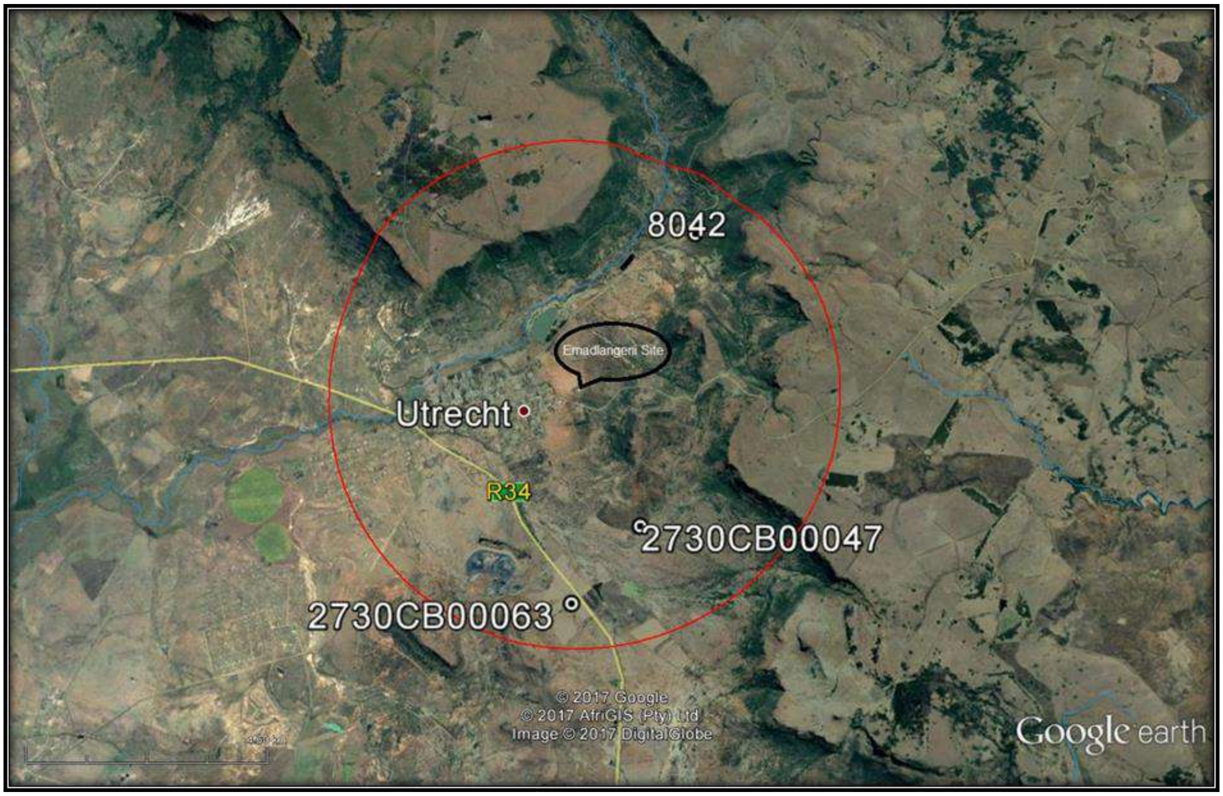

Figure 10: NGA boreholes relative to eMadlangeni 5km radius.

Geohydrologically the site is in a minor aquifer with moderately yielding aquifers of variable water quality. The landfill site is suitable for borehole siting. Groundwater is expected to be in the Intergranular and Fractured rock were water strikes are mainly found in the contact zone between the two rocks. The interpreted lineaments can be targeted by ground geophysical surveys to ascertain and resolve the interpretation.

4.1.1.7.3 **Groundwater Level and Recharge**

The Department of Water and Sanitation, the Department of Water Affairs and Forestry, embarked on a project aimed at the quantification of groundwater resources of South Africa on a national scale. Algorithms were developed for the estimation of storage, recharge, and baseflow. The recharge and groundwater level depth maps were used to predict the expected values at each landfill site. The eMandlangeni landfill site is expected to have recharge values of between 37 and 50 mm/annum. The mean groundwater level depth ranges between 11 to 15m below ground level.

4.1.1.7.4 **Groundwater Use and Quality**

Groundwater use in the area does not seem to be of large scale but could be very beneficial to local users where bulk infrastructure is not available. It is recommended to do detailed hydrocensus to verify and supplement the available information from this initial 5km radius exercise. There was no access to the boreholes nor sampling (no information on quality of the water) of the boreholes was carried out for this investigation.

4.2 **Site Investigations**

Based on the outcomes of the Desk Study phase of the investigation, the information discussed below was obtained as part of the site walkover and follow-up investigations. To assess the requirements for the licensing of the sites, it is essential to gain perspective on the status of the site. A site visit was undertaken on 31 October 2017 during which it was assessed as well as to gather facts to corroborate with scope of activities described below. While on site the following were carried out:

- Site walkover - description of the site and waste body. The following aspects were noted and considered (as per Table 9):
    - Potential Problem soils
    - Seepage
    - Construction material
    - Permeability
    - Excavation
    - Undermined ground
    - Instability in areas of soluble rock
    - Steep slopes
    - Areas of unstable natural slopes
    - Areas subject to seismic activity
    - Areas subject to flooding
    - Application of on-site soils for designed base and capping layers in landfills.
    - Identification of potential geotechnical significant features such as tension cracks, slope failures and bulging of faces.
- Field mapping to confirm the geology where there are outcrops and the nature of the soils.
- A hydrocensus to locate any groundwater monitoring boreholes on or near the site.
- Despite this being a Desk top study phase, limited excavation of test pits for soil profiling and collection of samples for description and for laboratory testing for suitability of soils was undertaken in order to obtain some information that would ordinarily be obtained only at the Preliminary Design stage.

4.2.1 **Site Classification and Description**

This existing landfill site located on co-ordinates -27,654651 (S), 30,34198003 (E), 1258 (m), 4km east of Utrecht, occupies an area of ~63,000 m2 (~6ha). It is located on the foot of a koppie, with the topography gently sloping northwards towards a river and dam (Figure 2) both located ~1.5km away. According to previous studies carried out by SiVest (2004), the site received an average of 72 tonnes of waste per month. This volume translates to 3 tonnes per day.

The waste disposal site is listed as having an indefinite lifespan; this is because the municipality has selected dongas in the area to be used for waste disposal. It is not possible to determine what future capacity is available as these are developed as and when required it would seem. The site seems to still has some capacity in terms of the life span of the waste disposal site even though it is earmarked for closure.

Table 3: Landfill information. Source (SiVEST, 2004)

Local Municipality	DWAF permit status	Monthly waste disposed (tons)	Description of wastes disposed	Expected lifespan
eMadlangeni	Permitted (Class 2)	~72	Domestic and garden refuse	Indefinite

4.2.1.1 **The Nature of the Waste Body**

The inception date of the landfill is unknown, but it seems to be at least 10-15 years old. The topographic landscape (Figure 11) of low-lying donga compartments (in between the remaining ridges of red soil) seems to have been the natural attraction for this to have been used as a dumping site since inception. The municipality makes use of the existing dongas caused by soil erosion in the area. These are backfilled and banked to minimise storm water runoff. The use of dongas for waste disposal needs to be carefully considered. This is especially true when considering ground and surface water pollution, as runoff from the donga contaminated with leachate could be a source of pollution.

The landfill receives general waste from the areas of the municipality as well as being used as a transfer site. No records of waste received since inception are available or known to have been ever kept. There is limited reclaiming of waste on site. On site, there is a fence, a gatehouse, manholes, a water tap, a toilet, a shipping container and a prefabricated building. There is no weighbridge no compacting equipment. No record-keeping takes place on site even though there is a fulltime attendant.

Figure 11: Waste material being deposited between the donga valleys (left). On the right is donga erosion exposing deeply (3-4m deep) incised and weathered in-situ soil. Donga erosion is on the southern fence boundary portion of the landfill where dumping is yet to reach.

The landfill waste body comprises two parts (cells), a garden refuse/builders' rubble section and a general waste (domestic) section (Figure 13). Some medical waste (bottles) were seen scattered around, worryingly suggesting that hazardous waste could have been dumped in the past. The landfill does not have a basal liner. There is no leachate management system other than a shallow earth stormwater channel that seems to have been dug outside the eastern boundary fence. No concrete stormwater cut-off channels are present. A small portion within the landfill remains unfilled and is still covered in pristine local vegetation where no dumping is currently undertaken. Visual problems noted on this site include windblown litter and air quality problems from the burning of waste.

Even though there is no waste permit in terms of the Environmental Conservation Act (Act 73 of 1989) dumping seems to be in a more controlled manner, although still not up to acceptable standards. General management of the waste disposal sites needs to take into account frequent covering of waste and avoiding making fires. This will reduce the incidents of wind scatter and air pollution in the area. There is regular burning, limited compaction and covering of waste. The rehabilitation of the site is somewhat being done in a well-planned and systematic manner. The waste is intermittently covered with cover soil of varying composition and thickness, particularly the old section to the east.

The frequency of capping (to prevent / reduce the nuisance of windblown litter and odours) is unknown. Some parts of the waste body are still exposed (see Figure 12). Vegetation (seasonal grasses and weeds) covers portions of the landfill's crest and side slopes. The current poor application of cover material has created areas with exposed waste leading to the possibility of horizontal leachate seepage or run-off downslope towards the river and dam.

Figure 12: View towards the northwest direction of surface water (and possible leachate run-off)) flow through the donga valleys and non-perennial streams. On left (foreground) is evidence of waste cover with top soil, while on right is uncompacted and uncovered waste next to a vegetated section of the landfill yet to be dumped.

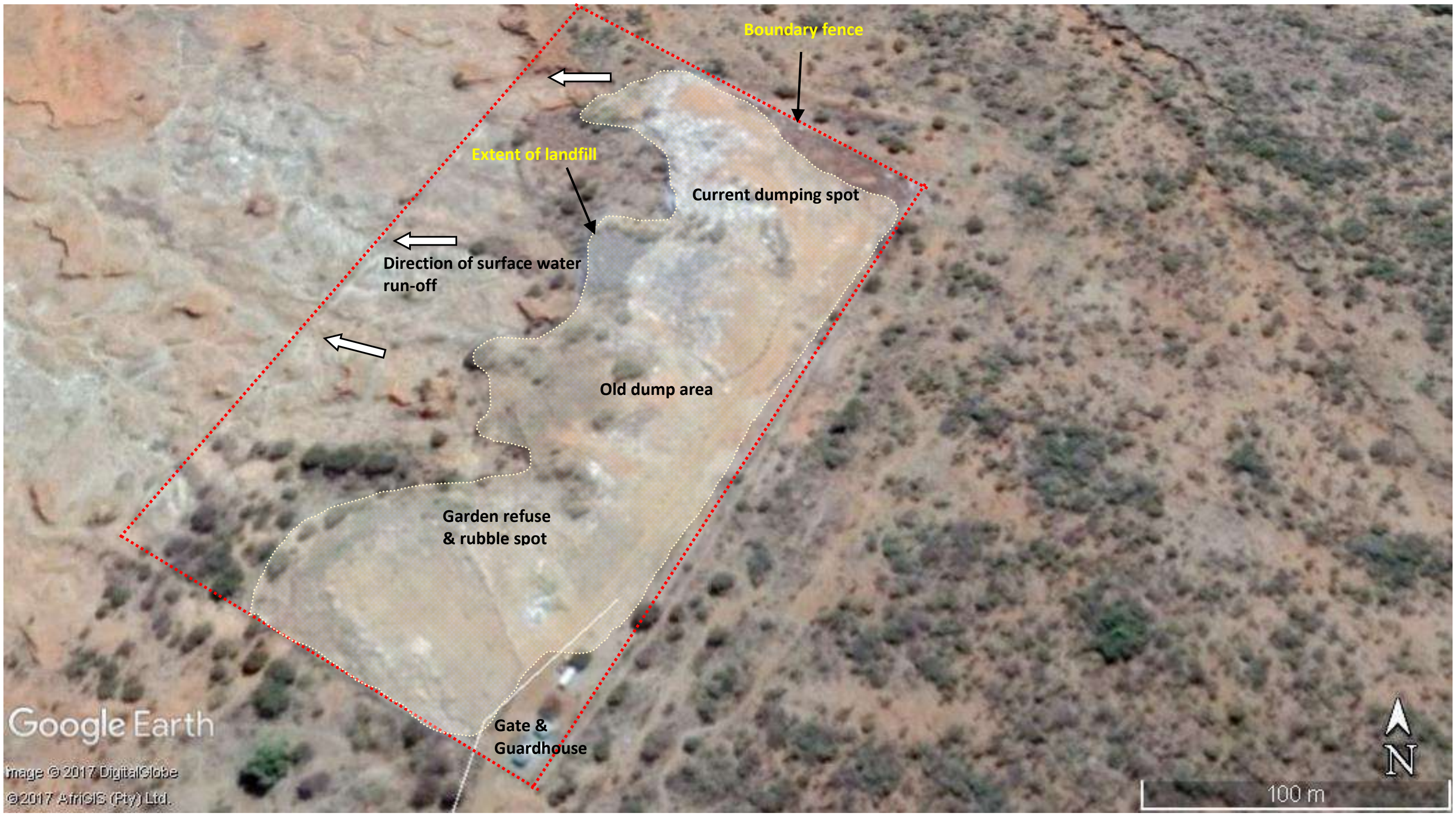

Figure 13: Planview showing fenced area of the landfill, extent of landfill deposition to date and direction of drainage water flow.

4.2.1.1.1 **Current Slope Stability**

From the site walkover and investigations, the side slopes of the landfill currently appear stable even though not covered (Figure 14). No other warning signs of local or larger scale slope failures such as tension cracks or bulging of slope faces were observed at the site. No notable erosion channels were observed on the landfill itself other than as reflected on the western portion of the landfill where waste filling has not occurred yet. There is general absence of vegetation as part of rehabilitation on the vertical slopes other than overgrown alien vegetation in some places. In the unlikely event that the waste body is deeply saturated, the risk of internal slope failure may present itself.

Figure 14: An example of waste side slope which has not been capped nor rehabilitated by vegetation.

4.2.1.1.2 **Occurrence of Leachate**

The potential for significant leachate production is based on whether the landfill is able to produce a significant amount of leachate. Leachate production is the main source of pollution of a landfill. No visible perched leachate was encountered in any of the test pits subsequently excavated. Buried waste seems to be relatively moist but not wet. Also, no flow (seepage) could be observed from the sidewalls. The precipitation and evaporation data show that the landfill is in a water deficit area. A landfill in such an area would be expected to produce little leachate. However, due to the enclosed designs of most of these facilities climatic factors are expected to have little influence on the waste deposited/treated at the facility. Any leachate that may be generated would be the result of the moisture content of the incoming waste.

4.2.1.1.3 **Potential for Landfill Gas and Air Quality Problems**

Since some of the landfill comprises rubble and general builders waste the potential for the significant development of gasses is unlikely as is that of air pollution except when burning of the other general waste occurs or there is wind and litter is blown away.

4.2.1.1.4 **Settlement of waste**

It is not known how much settlement has occurred on this landfill. Settlement of solid waste is typically taken as 5-10% of the ultimate fill thickness. Some of the settlement occurs in the short term which is generally due to self-weight of overlying waste. Long term settlement comprising mechanical creep, chemical/corrosion and biodegradation-related effects dominate, which may continue over a period of 30 years or more.

It is surmised that most of the above-described settlement has already taken place over the last 10-15 years of operation of the landfill and that a smaller magnitude of settlement is anticipated to yet occur (possibly up to 0,5m of settlement). It should however be noted that settlement of waste will be an on-going process. Long term settlement which exceeds tolerable limits can affect any closure infrastructure Settlement may also increase because of water ingress causing saturation of waste. Settlement may cause subsidence and resultant in cracking/tearing of the liner or ponding of water. Ponding of water and subsequent saturation of waste may, in turn, increase the risk of local sloughing or slope failures.

4.2.2 **Surveys**

The site was surveyed to determine the general sloping of the ground within the shape of the waste body and the location of any site infrastructure. To quantify the amount of waste within the landfill needs to be done as part of a detailed survey by a professional land surveyor. The following surveys (see Figure 15 for the planview map and Appendix A for the GPS metadata) were conducted (using a hand-held Garmin GPS 64s) to measure locations and elevations for:

- Mapping the boundary fence corners
- Determine the extent of the landfill - edges (crest and toe) of the benches/slopes
- Mapping of geological outcrops
- Location of test pit excavations
- Any other feature worth locating for geo-referencing purposes

This preliminary information where relevant were passed on to the conceptual design engineer to enable preliminary geometric designs. This forms an important part of the geotechnical evaluation of sites, since ground elevations will be altered, due to the cut/fill construction activities for closure.

Figure 15: Example of locations of survey points (fence boundary corners – green) and landfill surface extent and slope elevations (blue).

4.2.3 Geological and Geotechnical Investigations

4.2.3.1 Geological Mapping

According to the 1:250 000 scale geological map Vryheid 2326, the landfill site is underlain by a sequence of sandstone (Figure 18 and Figure 19) and shale rocks which are overlain by deep red residual sandy soil (Figure 17) derived from dolerite which extends to depths of 3-4m below surface level based on the deep levels of donga erosion observed. Outcrops of sandstones are seen on the western boundary fence where waste dumping has not taken place yet. In essence, this geology has given rise to many of the in - situ characteristics of soils that are found in the area. Erosion has exposed and cut into the sandstone to reveal these outcrops. However, no significant layer of residual sandstone soils have been observed and it would seem it has all been eroded away due to its inherent low clay content and sandy loam textural class. Dolerite boulders ranging from fresh, to partly weathered and to completely weathered soils have been observed and mapped as per Figure 16 below.

4.2.3.2 Test Pit Excavations

Test pits were excavated in order to assess the local soils for suitability as top capping material for the landfill as well as study the profile of the waste body. The test pits were excavated randomly concentrating along the older parts of the landfill. The test pits were excavated to a maximum depth of 2,0m below surface ending in either waste or deep red clayey sandy soil. The descriptions of the soil profiles encountered in the test pits are presented in Table 4 and the subsoil conditions discussed summarised below. Each pit was profiled in-situ in accordance with the standard methods prescribed in the document Guidelines for Soil and Rock Logging in South Africa (1990)(2) prepared by the Geotechnical Division of the South African Institute of Civil Engineers and the Association of Engineering Geologist of South Africa.

Six (6) test pits (UTP1 to UTP6) were randomly excavated using a Tractor Loader Backhoe (Bell) on 31 October 2017 (Figure 16). The test pit GPS coordinates and related information are presented in Table 4. Test pits UTP1 and UTP4 were excavated and ended in deep red clayey sand while the others (UTP2,3,5 and 6) exposed layers of top soil cover (ranging from 0.5m to 1m depth) underlain by waste. The cover soil typically comprises structureless or intact clayey sand, sandy silt or slightly silty sand over the waste material. The relative density/consistency of the cover soil varies between loose and medium dense/soft and stiff. The waste layers comprise varying quantities of plastics, textiles, bottles and containers, wood, bricks, PVC pipes, tin cans, woven bags, shoes, cardboard, wool, organic matter, glass bottles, ceramic tiles, paper and boulders, etc.

Figure 16: Location of test pits (brown), sandstone (green) rock in-situ exposure and positions of dolerite (blue) boulders mapped against the landfill boundary fence (yellow).

Figure 17: Dolerite boulder outcrops (left), weathered (middle) and completely altered dolerite into friable soil (right).

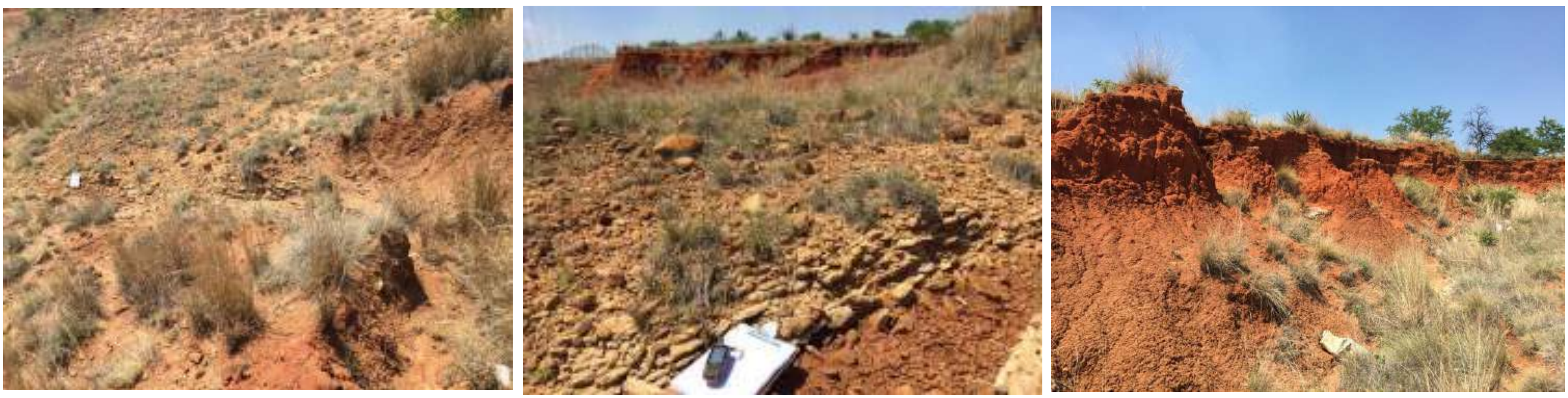

Figure 18: Left and middle - Sandstone exposure along which rivulets or water erosion channels (flowing to the south) have developed. Right - Donga weathering profile showing red residual soil from natural ground level to approximately 3-4m below surface.

Figure 19: Massive sandstone rock exposures (blue pins) mapped south of the dam as well as at landfill. Direction is looking eastwards upslope towards the landfill.

Table 4: Summary of test pit profiles.

Test Pit ID	Co-ordinate			Depth From (m)	Depth To (m)	Description	Sample collected	Reference to pictures	TLB Equipment used	Date Excavated
	Latitude (S)	Longitude (E)	Elevation (m)							
UTP1	-27,65408	30,34176604	1260	0	2	Moist, deep red fine silty to clayey loosely consolidated residual soil. Top 30cm dry and compacted.	SUTP001	Figure 20	Bell 3189K 4x4	31/10/17
UTP2	-27,654513	30,34235604	1261	0	1	Waste dump material full of textiles and plastic. Some smell, evidence of decomposition taking place.	No sample collected	Figure 21	Bell 3189K 4x4	31/10/17
				1	2	Waste dump material with dark grey colour and less reddish soil				
UTP3	-27,654835	30,342406	1263	0	0.5	Deep red soil cover, up to 1m deep in places	No sample collected	Figure 22	Bell 3189K 4x4	31/10/17
				0.5	2	Waste dump material				
UTP4	-27,655431	30,342004	1265	0	2	Moist, deep red fine silty to clayey loosely consolidated soil. Top 30cm dry and compacted	No sample collected	Figure 23	Bell 3189K 4x4	31/10/17
UTP5	-27,655172	30,34218103	1265	0	0.8	Deep red soil cover	No sample collected	Figure 24	Bell 3189K 4x4	31/10/17
				0.8	2	Waste dump material				
UTP6	-27,656121	30,34152204	1264	0	0.9	Deep red soil cover	No sample collected	Figure 25	Bell 3189K 4x4	31/10/17
				0.9	2	Waste dump material				

Figure 20: UTP1 test pit profile.

Figure 21: UTP3 test pit profile.

Figure 22: UTP2 test pit profile.

Figure 23: UTP5 test pit profile.

Figure 24: UTP4 test pit profile.

Figure 25: UTP6 test pit profile.

4.2.3.2.1 **Capping soil material availability**

Based on the depth of exposed soil profiles from donga erosion (Figure 26), a substantial thickness of the deep red dolerite residual sandy soil underlies the site and vicinity. Assuming a 100mx100m (1ha) surface extent of the soil body, the estimated quantity of potentially available soil to use as capping material is listed in Table 5 below. This material can be sourced via a borrow pit that can be excavated around the valley to the east of the landfill. This material should be adequate to cover an area of approximately 4 ha.

Table 5: estimated capping cover material quantity.

Soil type	**Depth (m) below surface**	**Length (m)**	**Breadth (m)**	**Volume (m^3)**
Sandstone soils	N/A	N/A	N/A	N/A
Deep red dolerite residual soil	3-4	100	100	40,000

Figure 26: Example of exposed residual soil profile, showing depth extent below surface.

4.2.3.3 **Ground water**

No water seepage was encountered in any of the trial holes excavated, however, moist conditions of the red sandy soil were noted in the test pits and some parts of the waste layers. Given the dry climate, shallow groundwater seepage is not expected to be problematic for most of the year. However, a shallow, perched water table may be encountered on site during the rainy seasons.

4.2.4 **Integrated water and waste management**

4.2.4.1 **Surface water**

Hydrologically, and considering the dry nature of the area, there are no perennial drainage systems at or in the immediate vicinity of the site. There is no evidence of ponding water bodies on the landfill waste body as well as to the west of the fence boundary. There is also no evidence of any present monitoring (for potential pollution) of the dam and river water resources due to the landfill located up slope.

Figure 27: Sheet erosion valley created by donga erosion looking west of the boundary fence (left). Waterflow channels cutting through in-situ exposed sandstones (right).

4.2.4.2 **Groundwater**

There are no monitoring boreholes present on the landfill site. The static groundwater level at or near the site could be in the order of 10-30m below surface judging by the nearby 3 boreholes within the 5km radius of the landfill site. The aquifers present in the area can be described as being of low significance, deep and generally low yield, except for in the low-lying areas along the drainage lines.

According to the desktop studies carried out, the groundwater flow appears to be northwestwards. This means that the liquids and leachates potentially originating from material dumped at the existing site could also be flowing in a similar direction.

4.3 **Laboratory Testing**

Disturbed samples (Table 2) of approximately 70kg each were collected from the test pits at distinct soil horizons. The samples were submitted to Civilab in Centurion, Gauteng where tests were carried out in a controlled certified (SANAS or ISO) laboratory environment, using standardized equipment and procedures to provide quantitative and qualitative data for material classification, as well as characteristic parameters for design purposes. Table 6 below shows the type of tests carried out, quantities of samples and objective of each test.

Table 6: Summary of laboratory tests conducted for the samples collected.

Test Type	**Number of samples**	**Type & Objective**
Foundation Indicator: • Atterberg limits, • Sieve analysis (grading to 0,075mm)	1	Classification tests to confirm field soil descriptions and quantify variations in the ground profile laterally and vertically and to determine basic engineering properties.
• Permeability	1	• stability analysis of slopes, earth dams, and earth retaining structures • estimation of quantity of underground seepage water under various hydraulic conditions • design of the clay layer for a landfill liner.

4.3.1 **Laboratory Results**

4.3.1.1 **Indicator Tests**

The detailed laboratory test results per sample are given in Appendix B and summarized in Table 7 below. The sieving results indicate that in general the soils tested comprise of silt (15%) clay (21%) and sand (64%). In terms of the Unified Soil Classification system the soil classifies mainly as a "SC" soil type, these clayey sand and poorly graded sand-clay mixtures. The Grading Modulus of 0.72 seems to reflects its fairly fine nature as corroborated with the sieving analysis results. Based on the indicator tests, the sand is considered to be of fair workability as a cover material, semi pervious.

The plasticity indices (a measure of the plasticity of the clay) recorded show low values (< 12) which are indicative of fairly low activity (low expansiveness) for the soils. These should therefore not constitute any serious problems under conditions of moisture migration.

4.3.1.2 **Permeability Tests**

Capping of the waste is to minimise water ingress into the waste underneath. Permeability (also known as hydraulic conductivity) tests were carried out on disturbed samples in the laboratory using the constant head method to arrive at an order of magnitude of coefficient permeability of 1.3 x10^{-9} m/s for the soil tested (Table 8). To put this value in perspective, the liner requirements at waste disposal sites specified in the DWAF Minimum Requirements for Waste Disposal by Landfill (1998), specify permeability of 1 x 10^{-6} cm/s for the geosynthetic layer system.

Table 7: Summary of results of laboratory results (Also refer to Appendix B).

Pit ID	Sample ID	Sample Interval (m)	Field Sample Description	Sieving Analysis				Atterberg Limits					Mod AASHTO		% CBR				
				% gravel	% sand	% silt	% clay	LL%	PI	LS	Overall PI	GM	MDD (Kg/m3)	OMC %	90%	93%	95%	98%	100 %
UTP1	SUTP001	0-2m	Moist, deep red fine silty to clayey loosely consolidated sandy soil	0	64	15	21	26	11	4.5	10	0.72	N/A	N/A	N/A	N/A	N/A	N/A	N/A

LL - Liquid Limit. OMC - Optimum Moisture Content. PI - Plasticity Index. LS - Linear Shrinkage. GM - Grading Modulus. MDD - Maximum dry density. CBR – California Bearing Ratio. AASHTO-American Association of State Highway and Transportation Officials. Unified- Unified soil classification;

Table 8: Summary of permeability test results.

Test Pit ID	Sample No	Depth To-From (m)	USCS	Dry Density (kg/m3)	Optimum Moisture Content (%)	Coefficient of Permeability (m/s)
UTP1	SUTP001	0-2	SC	1433	N/A	1.3×10^{-9}

4.4 **Geotechnical and Geohydrological Appraisal**

Table 9 below summarizes the findings from the site investigations of the waste body and surrounding geology. In general, the following comments are made:

- Soil quality - reflects the suitability of the available material for use as cover. The available soil classifies as a fine silty clayey sand. It is of fair workability as a cover material and its permeability coefficient indicates that it is semi pervious.
- Soil depth and availability - is the thickness of soil available for use as cover material at closure. There could be approximately 40,000 m^3 of soil available potentially down to 4m depth. This should be sufficient to use as cover and cut and fill material as part of the rehabilitation. In the vicinity, borrow pits will need to be identified and excavated to obtain this volume of material.
- In-situ permeability - is the ease with which water seeps through the underlying surface soil and bedrock and into the ground water. Permeability (hydraulic conductivity) tests conducted in the laboratory on a disturbed sample indicates a value of 1.3x10-9 m/s. The residual deep red soil is suitable to use as capping material subject to further consolidation at optimum density and moisture content. An additional capping system is however still suggested. Before final capping, the waste must be compacted and shaped in such a way as to promote run-off and to prevent any ponding of water on the landfill site. A cut to fill operation of the waste and landscaping will be necessary to achieve this. This is very important in order to prevent any pooled water from seeping through the capping layer and into the waste below.
- The close proximity of the landfill to the river and dam 1.5km down slope presents a leachate pollution risk to surface water and possibly ground water. A leachate collection and cut-off drain is required at the toe of the landfill. Should the water monitoring results show signs of any contamination of the stream or river, a deeper, more sophisticated and expensive leachate cut-off wall solution will be required.
- The plateau of the final landfill must be graded to encourage flow of water and discouraging ponding at the top of the landfill. Side slopes of a minimum of 1:3 can be adopted to ensure stability of the landfill. This gentle slope also encourages the growth of vegetation which will act as a cover, improving the aesthetics of the site in the post closure period. The growth of vegetation will also reduce erosion of the side slopes. However, the final shape must be approved by the regulating authority.

Table 9: Summary of geotechnical and geohydrology appraisal.

Aspect	Description of findings
1. Problem soils	There are no potentially problematic soils observed
2. Erodable soils	During the site walkover small erosion channels were noted. The erosion channels observed were created by surface runoff dislodging and transporting soils and waste particles downslope into the lower slopes of the waste body. Lots of continuing gulley and hillwash erosion as can be seen on the western boundary fence
3. Seepage	Potential basal seepage downslope to river and dam to the northwest of the site. The moist soil is perhaps a sign of groundwater seepage occurring below 0.50m as observed in the trial pits and provision must be made for dewatering of excavations, particularly during the summer rainy season. The risk of groundwater seepage will be significantly reduced should construction take place during the drier winter season.
4. Construction material	The in-situ residual soil down to 2m depth across the test pits is generally moist and should allow for compaction to indicated 95% Mod AASHTO Maximum Dry Density and Optimum Moisture Content (OMC). As discussed before, the residual shale and sandstone soils encountered at the test pit depths are considered good for founding due to low P.I and shrinkage value. It seems reasonable that site buildings can be founded on an engineered soil raft (900mm thickness below base of footing, G5 material specification).
5. Permeability	The residual soil has been tested to permeability coefficient of $1.3x\ 10^{-9}$ m/s which is impervious enough to meet minimum capping requirements
6. Excavation	**Ease of excavation (Excavation Plant) - Excavatability and Rippability** - According to the criteria published in SANS 1200D Earthworks, as specified for restricted excavation, soft excavation conditions are expected to depths of approximately 2m below ground level. As evidenced during test pit excavations, a tractor with a backhoe to rip loose from surface down to 2m and deeper depth should enable easy removal of materials (classified as SOFT to INTERMEDIATE in terms of SABS 1200DA) from surface down to 2m depth or deeper. Notwithstanding the above comments, hard rock (hard and competent dolerite and sandstone) could be encountered at deeper depths and random depths within the residual soils (should there be deep cut excavations greater than 1-2m depth) in the form of core stones. No sidewall collapse was observed during the excavation of the trial pits. However, the sidewalls of deeper excavations, may become unstable. The risk of sidewall collapse will increase with increasing soil moisture content. Excavations deeper than 2m depth below existing ground level in very soft to soft residual dolerite soil are not expected to be unstable but caution must be exercised. The risk of collapse will have to be assessed on site during construction and shoring must be implemented if considered necessary.
7. Open-cast or underground mines	There are no mines in the vicinity of the site. No coal or other mineral reserves underlie the site and so the potential for future mining in this area is remote.
8. Undermined ground	There are no undermined areas nor coal mining activity nearby
9. Instability in areas of soluble rock	The site does not reflect any risk for the formation of sinkholes or subsidence caused by the presence of water-soluble rocks (dolomite or limestone) and no evidence of mining activity beneath the site. The geological conditions underlying the site do not lend themselves to the formation of sinkholes or surface subsidences such as dolines
10. Steep slopes	There is donga erosion which has left erosion gulleys and steep ridges of soil. The waste slope are not covered.
11. Areas of unstable natural slopes	There is donga erosion which has left erosion gulleys and steep ridges of soil
12. Areas subject to seismic activity	Even though the site is located in a region located in an apparent junction between two seismically active belts., the probability of a seismic event occurring is low
13. Areas subject to flooding	There is a river and dam to the northwest downslope of site which sits on the foot slopes of a koppie. The site could be situated within or on the edge of a 50-year floodline
14. Application of on-site soils for designed base and capping layers in landfills	There is potentially >4m deeply weathered red silty residual clay soil exposed by deep donga erosion is appropriate material to use as a capping material over the waste. The base of the landfill has not been lined so the prevention of water ingress has to be done from the top of the waste. Basal rock underlying the residual soil is sandstone rock (could be porous and permeable) and fresh and weathered dolerite boulders in places.

5. IMPACT ASSESSMENT

Typical impacts which need to be considered as part of the closure of the landfill site are tabulated in the Table 10 and Table 11 below together with mitigating measures. The identified combined risks can typically be mitigated to a large degree by the implementation of an appropriate and effective Environmental Management Plan (EMP). The mitigation measures should be implemented to avoid or reduce negative impacts during the closure phase.

The potential future developments are only conceptual and thus there was limited information available to facilitate the geotechnical and geohydrological assessment at the time of report compilation. The following assumptions and limitations are stated pertaining to the investigations:

- The current assessment is broad in nature and detailed analyses are to be conducted by the closure engineers.
- It is understood that no investigations had been undertaken at the site prior to the establishment of this landfill and therefore the nature and engineering properties of the subgrade material (in-situ soil and rock below the waste bodies) were unknown until this preliminary investigation.
- No detailed records of the waste dumped during the operational life of the site have been kept and therefore the engineering properties and exact nature of the waste is limited.
- It is recognised internationally that the geotechnical properties of waste (shear strength, potential settlement etc.) in general are difficult to measure accurately. This is related to the heterogeneity of waste and limited research carried out on the subject of geotechnical properties of the landfilled waste.
- A limited number of test pits has been dug, however this is considered sufficient to provide suitable recommendations with regards to conceptual engineering designs and basis for next phases of work.
- Potential dust and air pollution, siltation of adjacent streams/rivers/dams and leachate pollution did not form part of this assessment even though some minor comments in this respect are made.

Table 10: Impact assessment during decommissioning phase.

Activity/Aspect	**Potential Impact**	**Nature**	**Status**	**Extent**	**Duration**	**Probability**	**Severity/Beneficial scale**		**Significance**
							Before mitigation	**After mitigation**	
Slope stability	Failure (by landslide) of landfill slopes – slope angles steeper than shear strength of material	Because of quality of waste and cover material composition and quality, external inducing factures (climate, seismic activity) or engineering design	Negative	Local	Short-term	Probable	Moderate	Slight	Medium
Settlement of waste	Subsidence and ponding of water which, in turn, may cause saturation of waste and subsequent slope failures	Saturation of waste and subsequent slope failures.	Negative	Local	Long-term	Highly Probable	Moderate	Slight	Very low
Soil erosion	Exposure of upper capping layer, siltation of water courses, and pollution of water courses and safety of workers/public.	Soil and waste particles will continue to be washed downslope into the lower slopes of the waste body, as well as the surrounding drainage channel situated at the toe of the waste body. The erosion of these slopes will be exacerbated during periods of heavy rainfall.	Negative	Regional	Long term	Probable	Medium	Slight	Medium
Seismic activity	Damage to a building, system, or other entity on the landfill structure.	Side slopes of the landfill may become unstable resulting in local or large-scale slope failures and damage to structures. This may cause exposure of soil and waste which, in turn, may increase soil erosion.	Negative	Regional	Short-term	Improbable	Moderate	Slight	Medium

Activity/Aspect	Potential Impact	Nature	Status	Extent	Duration	Probability	Severity/Beneficial scale		Significance
							Before mitigation	**After mitigation**	
Closure/capping of waste disposal cells	Uncontrolled leachate generation and build-up of leachate level	Insufficient/inappropriate cover construction resulting in rainwater infiltration, leachate generation and eventually leachate seepage from disposal cells	Negative	Local	Medium term	Probable	Moderately severe	Slight	Medium
Treating/disposal of surplus leachate and storm water in the holding dams at final closure	Contamination of ground and surface water resources	Poor leachate management resulting in surplus at closure	Negative	Local	Medium	Probable	Moderately severe	No effect	Medium
Maintenance of storm water control systems	Soil erosion at closed disposal cells	Erosion of cells resulting in collapse and exposure of waste material	Negative	Local	Medium	Probable	Moderately severe	Slight	Medium
Maintenance of capping	Uncontrolled leachate generation	Capping losing its low permeability character resulting in rainwater infiltration and leachate generation	Negative	Local	Medium	Probable	Moderately severe	Slight	Medium
Maintenance of water monitoring systems (boreholes) and surface water and maintaining a sampling and analysis programme after closure according to permit conditions	Quality deterioration of water resources	Poor maintenance and control of groundwater and surface water monitoring points and boreholes, as well as neglecting regular sampling and analyses as stipulated in permit conditions	Negative	Local	Medium	Probable	Moderately severe	Slight	High

Table 11: Proposed mitigating actions during the Closure stage.

Phase	Activity	Impact Description	Proposed Mitigation
Decommissioning	Slope Stability	Failure (by landslide) of landfill slopes – slope angles steeper than shear strength of material	• Maximum slope angle of 1v:3h implemented across the landfill. • Shaping of waste bodies and construction of capping system to avoid infiltration or ponding of water and subsequent saturation of waste; which may influence stability of waste. • Allowing for factors such as interface friction, slope angles and soil/material shear strength during design of capping layer to prevent instability of liner. That is, the liner to be suitably designed. • Implementation of safe slope angles based on seismic risk.
	Soil erosion	Exposure of upper capping layer, siltation of water courses, and pollution of water courses and safety of workers/public	• Maximum slope angle of 1v:3h implemented across the landfill. • Complete vegetative covering of waste bodies (ideally indigenous flora). • Selection of non-erodible and non-dispersive topsoil to avoid erosion. • Creation of sufficient horizontal channels along outer slopes of waste bodies to decrease flow rate of surface runoff and minimise erosion. • Concrete drainage channels surrounding cells to be maintained to avoid clogging and possible overflowing of stormwater and leachate resulting in continued erosion along base of waste bodies.
	Seismic Activity	Damage to a building, system, or other entity on the landfill structure.	• Implement safe slope angles
	Settlement of waste	Subsidence and ponding of water which, in turn, may cause saturation of waste and subsequent slope failtures	• By taking into consideration the total predicted magnitude and rate of settlement and related potential adverse effects when designing the elements of the closure and rehabilitation. • Stormwater channels situated upon the waste bodies should be designed to be relatively flexible so as to allow for settlement in the long term, as well as to allow for easy maintenance and repairs. • Designing the level crest area to accommodate the estimated settlements such that no low areas are formed causing ponding of storm water. Ponding of stormwater increases the risk of saturation of the waste which may accelerate settlement of the waste.
	Closure/capping of the landfill	Uncontrolled leachate generation and seepage, build-up of leachate level	Proper capping of each landfill and regular maintenance of capping according to permit conditions to avoid infiltration of rainwater and thus leachate generation within the waste pile. Installation of leachate level monitoring facility or each cell monitoring point
	Treating/disposal of surplus leachate and storm water in holding dams at final closure	Contamination of ground land surface water resources	Treating and/or disposal of final leachate volumes and draining of holding dams
	Maintenance of storm water control systems	Soil and waste pile erosion after closure	Development and implementation of a stormwater management plan as well as the proper maintenance of storm water control systems on site after closure according to permits and regulations issued from time to time by the relevant authorities. Regular inspections by authorities
	Maintenance of water monitoring systems (borehole and surface water) and programme	Quality deterioration of water resources	Regular water quality monitoring according to permit conditions and in compliance to Minimum Requirement documents of DWAF. Reporting of results to authorities on a six-monthly basis

6. MONITORING SYSTEMS

As part of the closure, a monitoring programme is suggested to be in place. Monitoring can be described as the repetitive and continued observation, measurement and evaluation of geohydrological information such as water level and groundwater quality to follow changes over a period of time to assess the efficiency of control measures. In essence, monitoring serves as an early warning system so that any corrective actions required can be taken promptly. The objectives of water quality monitoring will be to:

- comply with the relevant Licence conditions and legislation;
- detect any pollution emanating from the landfill;
- serve as an early warning system, so that any pollution problems that arise can be identified and rectified; and
- quantify any effect that the landfill has on the water regime.

The development of a groundwater monitoring programme will be important for assessing the impacts of the decommissioned Landfill on groundwater and the environment. It is recommended that groundwater monitoring be undertaken in accordance with guidelines set out in the documents Minimum Requirements for Waste Disposal by Landfill (DWAF, 2nd edition, 1998 and draft 3rd edition, 2005a) and the Minimum Requirements for Water Monitoring at Waste management Facilities (DWAF, 2005b, 3rd edition) issued by the Department of Water Affairs and Forestry, specifications for the monitoring of groundwater at waste disposal facilities. The various aspects of the monitoring are presented in this section, along with relevant recommendations.

Table 12: Monitoring borehole recommendations.

General Waste	No. Holes	Distance (m) from waste site	Monitoring Frequency
Communal to Small (<25 tonnes per day)	2-4	20-200 downstream and upstream	• Samples from boreholes every 6 months or as specified in the permit • Sample boreholes 1-5km radius initially when problems are expected • Sample surface water as specified in the permit. • Sample monthly for leachate, if any

6.1 Surface water or run-off monitoring

Water sources around the landfill within a radius as suggested by the risk assessment must be sampled and water preserved for chemical analysis. To establish a potential pollution baseline, continuous recording of water flow and possible waste run-off (quantities) and quality is necessary. Similarly, rainfall levels at the landfill must be recorded for the past 24 hours at a set time every day. This includes leachate collection and toe seepage.

6.2 Ground water monitoring

Currently there are no monitoring boreholes on the site. According to the 3rd edition draft of the Minimum Requirements for Water Monitoring at Waste Management Facilities (2005), between 1-2 boreholes would typically be required for a small general waste site. Each borehole should have a cover (e.g. lockable cap) to prevent it from being polluted and damaged. Boreholes must be kept accessible to allow for continual monitoring of water levels and chemistry of groundwater.

Based on the geohydrological data available from the existing reports and from follow-up ground geophysical survey outcomes, boreholes should be drilled at strategic locations (within the sandstones and the contact between shale and sandstone and dolerite) where fracture zones and zones of deep weathering that may be indicative of groundwater flow and represent potential aquifers have been identified. The boreholes should be used to establish a groundwater monitoring system for the waste site as well as obtaining additional geological and geohydrological information.

It is recommended that ground geophysical surveys be carried out designed to cover the site surrounding the existing waste site and surrounds as per the airborne geophysics results. Yield tests to determine the aquifer properties and water quality tests should be carried out at each borehole that has struck water.

6.2.1 Monitoring Frequency

DWAF (1998b) only prescribes annual water level measurements, but to best understand and monitor the site it is recommended that monthly water level measurements be taken. Boreholes should be sampled bi-annually (i.e. once in summer and once in winter), while groundwater levels should be measured on a monthly basis and accurately recorded. If contamination is picked up then more regular monitoring will be required to determine the source, movement and extent of contamination.

According to the Department of Water Affairs and Forestry (DWAF) (1998b) an assessment of groundwater usage and borehole yields should be undertaken on an annual basis. A detailed hydrocensus should focus on an area within 1 km of the landfill.

Post-closure monitoring is to continue for 30 years following closure of the site, unless otherwise motivated, and authorised by the authorities.

6.2.2 Sampling Method

6.2.2.1 Sampling Process

The monitoring boreholes should be assessed whether they are low or high yielding before sampling. Should the monitoring borehole be of low yield and unable to be pumped with a conventional pump (until field parameters stabilize and a sample collected), a bailer (grab) sample can be collected. It is preferable to use a low volume sampling pump though (also known as a bladder pump). For a high yielding borehole, it is recommended that the pump be installed either half a meter above the bottom of the borehole or at the highest yielding water-strike depth. The groundwater should be pumped into a flow-through cell, and an EC and pH probe should be placed into the flow-through cell. The borehole must be pumped until field chemistry parameters stabilise prior to sampling.

6.2.2.2 Sample Collection, Preservation and Submission

Sample bottles must be labelled with the borehole name, site name and date. At the time of sampling field chemistry parameters must be measured and recorded. These include electrical conductivity (EC), oxidation reduction potential (ORP), pH, temperature and dissolved oxygen (DO). Samples must be taken in their correct sampling container and preserved (if necessary) in the correct manner (Table 13) prior to submission to an accredited laboratory for the analysis of selected parameters.

The sample method and preservation must be discussed with the laboratory prior to sampling. The different preservation requirements for the different types of sample are discussed below. This table lists the correct sampling methods and preservation thereof for a range of parameters. The parameters that should be analysed for will be stipulated in the initial permit granted during the application for the closure permit.

6.2.2.3 **Groundwater levels**

Groundwater level measurements are prescribed for the monitoring boreholes to be drilled as part of the closure. A dip meter can be used to measure the water level below the top of the borehole collar / casing height, however, the height of the collar / casing must also be measured. The water level is then calculated by subtracting the collar / casing height from the water level. All three values must be recorded along with the date and time that the measurement was taken. An interface meter can be used during monitoring to detect the presence of non-aqueous phase liquids (if present). Monthly recording of groundwater levels is recommended.

6.2.2.4 **Inorganic analysis**

Plastic sample bottles with a plastic cap (with no liner within the cap) can be used for the inorganic sampling. The bottle must be clean and should be rinsed along with the cap prior to sample collection. The sample bottle should be filled entirely to ensure there is no air in the sample. The samples must be put into an ice box immediately following sampling and stored/transported at temperatures of approximately 4 °C. No preservation of the sample is generally required if the sample is to be submitted within 6 hours of sampling. If not the minimum sample preservation requirements (DWAF, 1998b) must be adhered to.

6.2.2.5 **Microbiological analysis**

The microbiological samples must be taken in designated sterilized sample bottles obtained from the microbiological laboratory. Care must be taken not to touch inside the bottle or the bottle lid in any way. The sample bottle must be filled carefully not allowing water to wash over the side of the bottle. The bottle can be filled ¾ of the way and then closed and then refrigerated (at 4 °C). The samples must be delivered to the laboratory within 24 hours of the sampling. Ideally the samples should be submitted within 6 hours of sampling.

6.2.3 **Water Quality Variables to be Analyzed**

For first time monitoring, a comprehensive analysis must be undertaken to obtain a baseline of groundwater conditions. Such an analysis should include a complete macro analysis and an analysis for trace elements that can be expected from the site (note that the closure permit for the existing landfill will provide a list of water quality variables to be tested for background monitoring). Once this has been undertaken, an indicator analysis can be continued with for further monitoring. A list (Table 13 below) of these parameters will be available in the permit that that will be applied for. After a comprehensive analysis has been completed, an **indicator analysis** can be continued with, to save on costs. This will still provide enough data to determine whether further action is required. For general waste the “pollution indicators” are COD, Cl, K, NO_3 and NH_4. As a standard, pH, EC, alkalinity and acidity should be analysed.

Table 13: Minimum requirements for water sample preservation from DWAF (1998b).

Variable	**Action**
Carbon dioxide	Analyse immediately
Chloride – residual	
pH	
Electrical Conductivity	No additives. Refrigerate. Analyse as soon as reasonably be achieved
Acidity	
Alkalinity	
BOD	
Colour	
Chromium (VI)	
Nitrite	
Silica	
Sulphate	
Boron	Analyse when convenient
Bromide	
Chloride	
Fluoride	
Potassium	
Sodium	
Hardness	Filter in field. Add NHO_3 to pH<2
Metals (general)	
COD	Add H_2SO_4 to pH>2
Grease and oil	
Nitrogen – NH_4	
Nitrogen – NO_3	
Nitrogen-organic	
Phenols	
TOC	
Cyanide	Add NAOH to pH>12
Sulphide	Add 4 drops 2N zinc acetate/100ml
No preservatives are required if the sample is to be analysed within 6hours. Samples should always be stored or transported at temperatures around 6 degrees centigrade	

6.2.4 **Data storage and collation**

All collected data, field measurements and laboratory results must be captured into an appropriate database for ease of reference and meaningful interpretations and reporting. This must be kept up to date and the data assessed regularly.

6.2.5 **Documentation and Record Keeping**

The following is a list of documentation that shall be retained with the responsible person in charge of the decommissioned Landfill site and must be made available on request:

- Borehole monitoring results;
- Monthly groundwater levels

6.2.6 **Monitoring and Auditing**

Quarterly internal environmental audits and annual external audit reports must be conducted. The audits are to verify the projects compliance with the conditions of the Waste Management Licence. In this regard a checklist shall be compiled using the CEMP and the Waste Management Licence and with each audit the compliance can be verified against this.

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the desktop study, site investigations and profiling of six (6) test pits excavated within the general landfill facility on 31 October 2017 together with results from laboratory tests, the following can be concluded:

- The landfill is estimated to be 70 tonnes per annum receiver of waste with leachate generation as possibly sporadic due to the negative climatic balance of the area.
- The landfill site has active serious sheet erosion resulting in the formation of dongas (gulleys) where there are large bare patches of veld with a hard surface and low amounts of organic material, making plant growth virtually impossible. The water and soil run-off direction is downslope to the northwest direction towards the nearby river and dam water resources.
- The Landfill site is underlain by sedimentary sandstone and shale (of the Ecca Group) which are overlain by post Karoo dolerite (of the Drakensburg Group). The site is located inside a valley covered on northwest and southeast sides by resistive dolerite plateaus which form the topography of the area escarpment consisting of hills and cliffs. Where dolerite has weathered it tends to form deep red residual soils. The runoff from the landfill site washes the sediments into a stream and a dam located approximately 1.5km downhill. There are no major geological lineaments visible from the geological map.
- Predominantly NNW-SSE tending lineaments were interpreted in the area surrounding the eMadlangeni landfill site. Should these structures be water-bearing, the direction of the water flow will be NNW-wards down gradient towards the dam and river. Any plume of polluted groundwater will also follow this similar path.
- Geohydrologically the site is in a minor aquifer with potentially low to moderately yielding aquifers of variable water quality. The country rock below the landfill is sandstone, shale and dolerite. In undisturbed and unweathered form the sandstone and shale rocks are hard and tight and their potential as water bearing aquifers is low. Where affected by faulting and fracturing, they form secondary aquifers of limited storativity but potentially high transmissivity particularly in the sandstones. Contact between dolerite intrusions and surrounding country rock often tend to act as water conduits. The landfill site is located in an area where faults and fracture zones are not so prominent and therefore the likelihood of encountering groundwater potentially is low. This is subject to detailed ground geophysics at closer spacing being done to verify this postulation.
- Exposure of sandstone rock and boulders of dolerite were observed as part of the site walkover. Where dolerite has weathered it tends to form deep red residual clayey sandy soils. Donga erosion has incised these soils down to some 3-4m depth below ground surface.
- The exposed test pit profiles in the waste body generally comprise layers of cover soil (thickness ranging from 0.5m to 1m) underlying the landfill waste. No groundwater or perched leachate tables were encountered within the test pits.
- Laboratory sieving results indicate that in general the soils tested comprise of silty (15%) clayey (21%) sand (64%). In terms of the Unified Soil Classification system the soil classifies mainly as a “SC” soil type, these clayey sand and poorly graded sand-clay mixtures. The Grading Modulus of 0.72 seems to reflect the soils fairly fine nature as corroborated with the sieving analysis results. The soil is considered suitable to use as cover material for the facility.

- Special foundation precautions such as further compaction or consolidation must be implemented to address the possibility of settlement occurring to buildings founded within the soil.
- The tested soil indicates coefficient permeability of $1.3x10^{-9}$m/s. Due to the fact that there is no basal lining, an additional lining system needs to be installed to complement the soil capping. A leachate collection system to prevent seepage of leachate into the regional ground water should also be in place.

In view of the initial objectives set by the client it is believed that during the desk study, site walkover and investigations, it is believed that sufficient information at this stage of the project was obtained to enable a reasonable geotechnical and geohydrological assessment which will provide reasonable and appropriate information for the Conceptual engineering design for the planned decommissioning (closure) and rehabilitation of the landfill site.

7.1 **Further Work**

Additional studies should be carried out to ascertain the potential for pollution originating from the existing waste site. The additional work entails further detailed studies of the existing geological and geohydrological information available for the site and the surrounding areas. The aim of the additional work to support the Detailed engineering phase of the project will be three-fold:

- Clarify the groundwater flow and the likely migration of a pollution plume around landfill and determine the groundwater conditions to the northwest of the existing site towards the dam and river.
- Establish a more comprehensive groundwater monitoring system around the entire.
- Further determine the geotechnical and geohydrological properties of the soils and underlying bedrock.

The scope of the work (also see Table 15) and associated costs (Table 16) below envisaged is as follows:

7.1.1 **Surveys**

- Undertake detailed topographic surveys to map out the terrain of the site which would ensure accurate detailed closure engineering designs.

7.1.2 **Geotechnical Assessment**

- Review of Desktop and limited preliminary stage data acquired from the work done as documented in this report.
- Further test pit excavations and mapping of identified areas to confirm capping material availability and volumes. Perform in-situ tests such as permeability and DCP's (determine the variation in in-situ stiffness). Sampling and laboratory testing.
- Soil samples from the test pits will be tested for classification, density, compaction characteristics and strength/stiffness properties. Problem soils, if presents, will be tested to quantify the degree of the problem condition (e.g. collapse potential).
- Compiling a geological/geotechnical map indicating features observed;
- Identifying and assessing significance of potential geotechnical constraints to the proposed development.

- Proposing mitigation measures that could reduce or eliminate the identified constraints; and
- Compiling a report that will be based on the findings of the study.

7.1.3 **Geohydrology Assessment**

- A review of all existing groundwater information available to date the baseline status;
- A follow-up detailed hydrocensus within an identified buffer zone;
- Perform follow-up ground geophysics (magnetics, resistivity) from current airborne magnetics data (identify local deep fracture zones and structures which could be water-bearing and act as groundwater aquifers and electrical resistivity (to determine presence of water in the fractures). Results will be the basis for sighting locations of geohydrology monitoring boreholes which will be drilled. Pump testing and borehole equipping. Subcontractors will carry out the work.
- Carry out a rotary percussion-drilling (Monitoring Boreholes) programme to verify the presence of any aquifer(s). Subcontractors will carry out the fieldwork.
- Aquifer Tests - to test the yield, storativity and transmissivity of the aquifer(s). Subcontractors will carry out the fieldwork.
- Hydrochemical sampling and analysis
- The development of a Flow and Mass Transport Models; and Pollution plume simulation.
- Establish a groundwater monitoring system for the site that is based on the information obtained from outcomes of activities as listed above.
- Data analyses of information collected during the field investigations.
- Discuss preliminary findings with other relevant team members during progress meetings.
- Present data on maps and compile a report on each of the three sites.
- Present data at meeting and finalise report.

Leading to or as part of the closure the following sequence of events listed in Table 15 below are recommended.

Table 14: Suggested closure sequence of events.

Activity	**Status at the time of the writing of this report**
(i) Obtain information on disposal practices, volumes and type of waste.	This document serves the purpose
(ii) Obtain available information on the topography, stream flow, fountains, dams, geology, existing boreholes, wells and excavations (see Chapter 6 of the Minimum Requirements for Waste Disposal by Landfill).	This document serves the purpose. Desktop and some Preliminary stage data obtained to ensure conclusion of Conceptual designs.
Sample surface and groundwater for chemical analyses to determine the presence of pollutants, if any, at existing points. Obtain information on other human activities that could be affected by the disposal of the waste. Delineate possible pollution plumes at existing waste sites.	Proposed as part of next phase scoped activities
(iii) Perform a risk assessment and decide on the level of the impact study and the monitoring facilities that will be required (see Chapter 5 and Appendix A).	This document serves the purpose
(iv) Perform geophysical investigations to locate groundwater barriers and aquifers (see Chapter 6 of the Minimum Requirements for Waste Disposal by Landfill).	Proposed as part of next phase scoped activities
(v) Drill boreholes at positions as determined by (i), (ii), (iii) and (iv). Record geological and geohydrological information from boreholes. If necessary, perform tests such as hydraulic	Proposed as part of next phase scoped activities

conductivity, aquifer yield and water quality profiling in boreholes. Study characteristics of rainwater penetration into waste. Install, if required, early warning devices underneath new disposal sites (see Chapter 6).	
(vi) Perform water sampling from holes. Analyse for elements typically found within the natural and waste environments	Proposed as part of next phase scoped activities
(vii) Document data or enter it into the computerized database, Waste Manager, for processing and interpretation. Interpret data, extract tables and graphs, identify and investigate anomalies	Proposed as part of next phase scoped activities
(viii) Present report, database and recommend methods and frequency of sampling to the client. Specify equipment to sample water from boreholes.	Proposed as part of next phase scoped activities & the closure plans
(ix) Include information in the application for a waste management permit in the case of general	Proposed as part of next phase scoped activities
(x) Train on-site personnel in the use of the database, the sampling equipment and in the interpretation of the data. Provide facilities for the client to report to the Department in terms of their permit conditions.	Proposed as part of closure plans

Table 15: Cost estimate (Class 0 +-45% accuracy & level of estimation) for recommended further work.

ACTIVITY	**COST (Rand)**
Land Survey	100,000
Geotechnical Assessment	
• *Site Investigations*	*100,000*
• *Laboratory testing*	*R50,000*
• *Data analyses and final reporting*	*R150,000*
Geohydrological Assessment	
• *Ground geophysics*	*100,000*
• *Detailed Hydrocensus*	*50,000*
• *X4 holes - Percussion Drilling, borehole equipping & supervision*	*500,000*
• *Aquifer testing*	*200,000*
• *Geohydrological modelling (pollution plume simulation, etc)*	*100,000*
• *Water quality analyses*	*50,000*
• *Data Analysis and final reporting*	*150,000*
Sub-total	1,550,000
Contingency 10%	155,000
Vat 14%	217,000
Total	**1,922,000**

8. DISCLAIMER - LIMITATIONS AND USE OF THIS REPORT

This report has been prepared for the exclusive use of the client for specific application to the project discussed and has been prepared in accordance with generally accepted engineering geology practices.

This report has been based on a desktop study followed by a site visit and limited penetrative investigations where sub-surface soils were examined through test pit excavations, soil profiling and laboratory analyses. The nature of geotechnical engineering is such that variations in what is reported here may become evident during construction and it is thus imperative that a Competent Person inspects all excavations to ensure that conditions at variance with those predicted do not occur and to undertake an interpretation of the facts supplied in this report.

Although every effort has been made to ensure the integrity of the data and information on which this report is based, conditions at variance with those encountered during construction may occur and the shortcomings of a limited penetrative investigations should be noted. In the event that changes in the nature, design, or location of the project as outlined in this report are planned, the conclusions and recommendations contained in this report shall not be considered unless the Consultant reviews the changes and either verifies or modifies the conclusions of this report in writing.

9. REFERENCES

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10. APPENDICES

- APPENDIX A – GPS Survey data
- APPENDIX B – Laboratory test results
- APPENDIX C– Criteria and Definitions used in Impact Assessment Tables

APPENDIX A - GPS Survey data

APPENDIX B - Laboratory test results

APPENDIX C - CRITERIA AND DEFINITIONS USED IN IMPACT ASSESSMENT TABLES

Impact Assessment Criteria and Definitions

In order to evaluate the significance of potential impacts, the following criteria and terminology is used to identify and describe the characteristics of each potential impact:

- the ***nature*,** which shall include a description of what causes the effect, what will be affected and how it will be affected;
- the ***status***, which will be described as either a **positive** impact or a **negative** impact.
- the ***extent***, wherein it will be indicated whether the impact will be **local** (limited to the immediate area or site of development) or **regional**;
- the ***duration***, wherein it will be indicated whether the lifetime of the impact will be of a **short duration (0–5 years**), **medium-term (5–15 years**), **long term (> 15 years)** or **permanent;**
- the ***probability***, which shall describe the likelihood of the impact actually occurring, indicated as **improbable** (low likelihood), **probable** (distinct possibility), **highly probable** (most likely), or **definite** (impact will occur regardless of any preventative measures);
- the ***severity/beneficial scale****:* indicating whether the impact will be **very severe/beneficial** (a permanent change which cannot be mitigated/permanent and significant benefit, with no real alternative to achieving this benefit), **severe/beneficial** (long-term impact that could be mitigated/long-term benefit), **moderately severe/beneficial** (medium- to long-term impact that could be mitigated/ medium- to longterm benefit), **slight or have no effect**; and
- the ***significance***, which shall be determined through a synthesis of the characteristics described above and can be assessed as **low**, **medium** or **high**.