REPORT

HYDROPEDOLOGY WETLAND IMPACT ASSESSMENT AND MANAGEMENT REPORT:

SPEED EVENTS, HAKSKEENPAN, NORTHERN CAPE PROVINCE

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Declaration

I, Johan Hilgard van der Waals, declare that:

- I act as the independent specialist in this application
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, regulations and all other applicable legislation;
- I have 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;
- all the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of Section 24F of the Act.

J.H. VAN DER WAALS
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TABLE OF CONTENTS

HYDROPEDOLOGY WETLAND IMPACT ASSESSMENT AND MANAGEMENT REPORT: SPEED EVENTS, HAKSKEENPAN, NORTHERN CAPE PROVINCE

1. INTRODUCTION

1.1 TERMS OF REFERENCE

Terra Soil Science was appointed by the **Northern Cape Provincial Government** (NCPG) and **Bloodhound SSC** to conduct a hydropedology based assessment of Hakskeenpan and the impacts of the proposed activities associated with the Bloodhound SSC land speed record attempt as well as the yearly Speedweek events. The focus of the investigation is to address aspects that include wetland distribution and functioning, landscape hydropedology and impacts of the proposed activities on the hydrological functioning of the pan wetland system.

1.2 AIM OF THIS REPORT

The aim of this report is to provide a perspective on the extent, distribution and functioning of the pan wetland system of Hakskeenpan, to provide a description of the hydropedology of the site and to provide specific management recommendations regarding the hydrology of the wetland and site during the activities/events as well as post activity/event recovery. In conclusion the aim of this report is to provide dedicated recommendations regarding the management of the soils on the site in terms of the above aspects as well as the management and mitigation of erosion and pan crust restoration.

1.3 DISCLAIMER

This report was generated under the regulations of NEMA (National Environmental Management Act) that guides the appointment of specialists. The essence of the regulations is 1) independence, 2) specialisation and 3) duty to the regulator. The independent specialist has, in accordance with the regulations, a duty to the competent authority to disclose all matters related to the specific investigation should he be requested to do such (refer to declaration above).

1.4 METHODOLOGY

The report was generated through:

1. The collection and presentation of baseline land type and topographic data for the site;
2. The thorough consideration of the statutory context of wetlands and the process of wetland delineation as well as agricultural potential;
3. The identification of water related landscape parameters (conceptual and real) for the site;
4. Aerial photograph interpretation of the site;
5. Reconnaissance soil investigation and sampling and analysis of selected areas for a range of soil physical, chemical, morphological and mineralogical parameters;
6. Focused site survey in terms of speed event related impacts; and

7. Presentation of the findings of the various components of the investigation.

2. SITE LOCALITY AND DESCRIPTION

2.1 SURVEY AREA BOUNDARY

Hakskeenpan lies between 26° 42' 32'' and 26° 55' 27'' south and 20° 05' 39'' and 20° 21' 24'' east about 10 km east and south of the town of Rietfontein in the Northern Cape Province (**Figure 1**).

2.2 LAND TYPE DATA

Land type data for the site was obtained from the Institute for Soil Climate and Water (ISCW) of the Agricultural Research Council (ARC). The land type data is presented at a scale of 1:250 000 and entails the division of land into land types, typical terrain cross sections for the land type and the presentation of dominant soil types for each of the identified terrain units (in the cross section). The soil data is classified according to the Binomial System (MacVicar et al., 1977). The soil data was interpreted and re-classified according to the Taxonomic System (Soil Classification Working Group, 1991).

The pan and western edge of Hakskeenpan falls into the **Ae112** land type and the dunes to the east into the **Af3** (Land Type Survey Staff, 1972 - 2006) with F**igure 2** providing the land type distribution for the site. **Ae** land types denote areas that are dominated by shallow red soils of high base status with no dunes and **Af** land types the same types of soils but with dunes present.

2.3 TOPOGRAPHY

The topography of the pan and surrounding landscape is predominantly flat but with distinct longitudinal dunes on the eastern and northern side. The pan itself is very flat and lies at al altitude of between 795 and 800 m above mean sea level. The contour map for the site is provided in **Figure 3**. From the contour data a digital elevation model (DEM) (**Figure 4**) was generated.

2.4 DRAINAGE SYSTEMS

The Mier rural area forms part of the lower Molopo River sub-drainage area (D42). Present-day drainage in the Kalahari is dominated by the Auob, Nossob, Kuruman and Molopo Rivers. With the exception of the dry Nossob River course in the east, the area generally lacks surface drainage. Minor streams drain the area in the vicinity of Rietfontein and flow towards the larger pans.After heavy thunderstorms the water flows in the so-called "streets" between the dunes. The main volume of the rainwater usually, shortly after a rainfall event, either evaporate or is retained in the sand cover with no water reaching the Nossob River which is the main receiving stream. Only a small fraction of infiltrating water will, under favourable conditions, reach the groundwater table (Kramer, 1985).

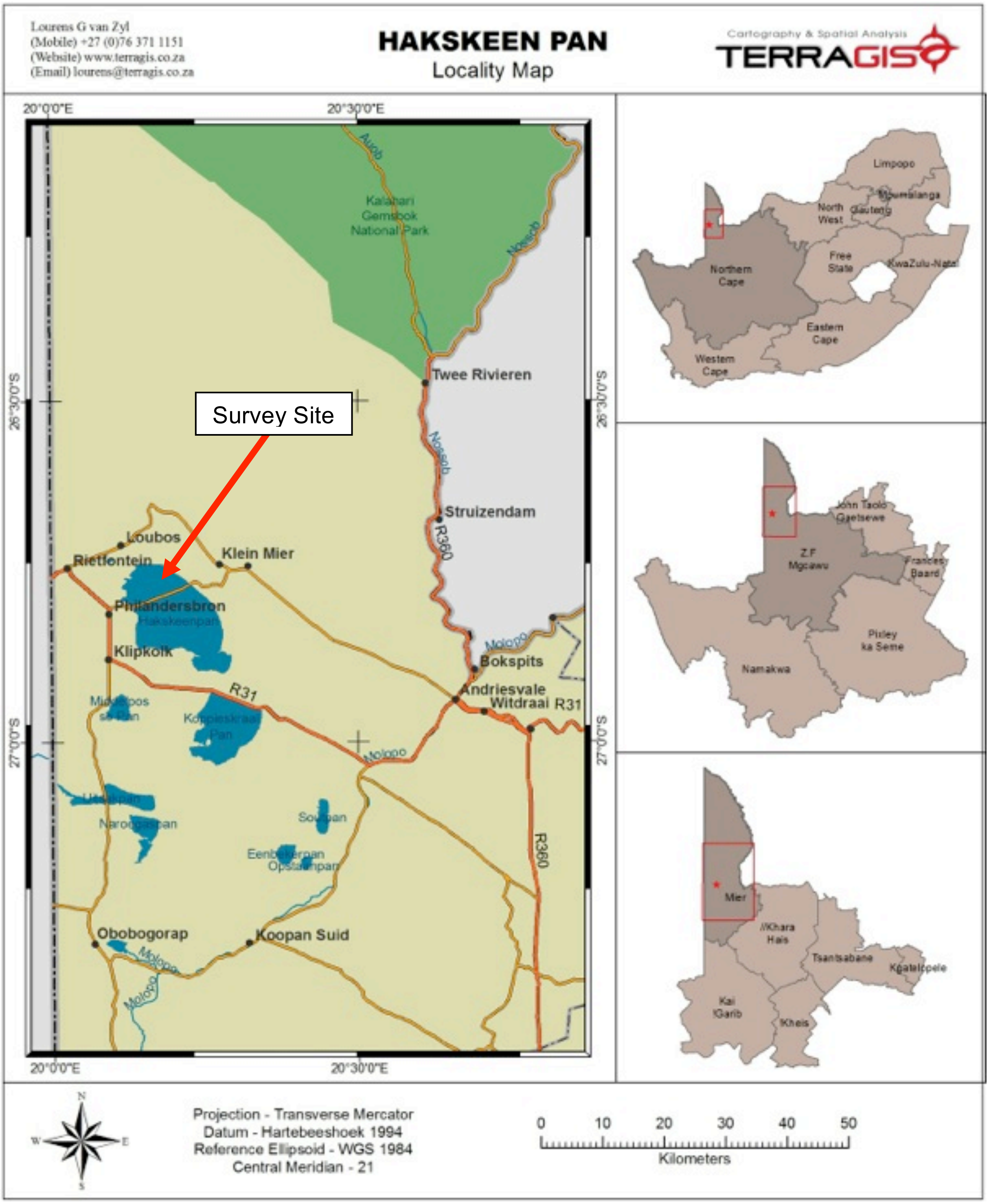

Figure 1 Locality of the survey site

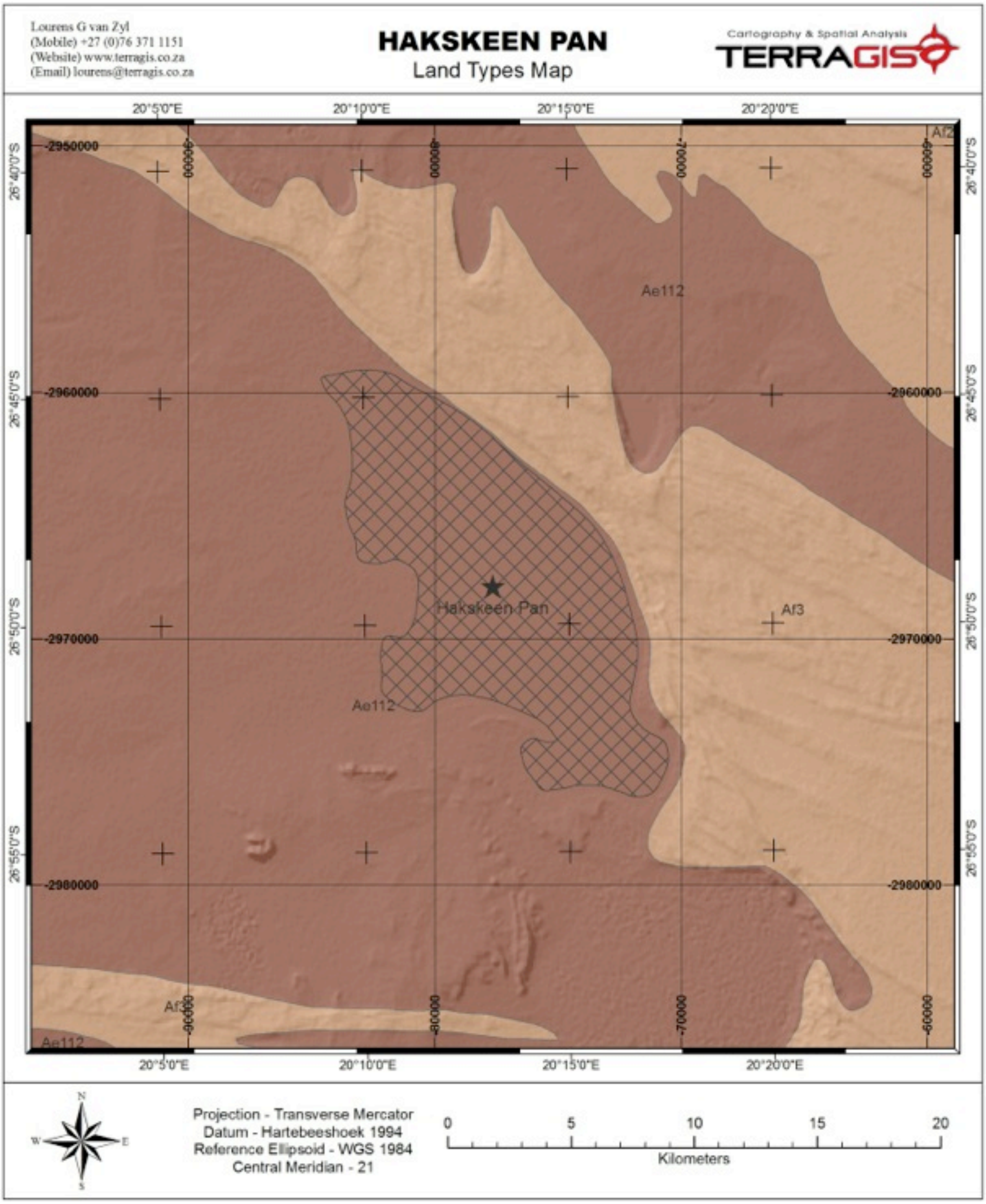

Figure 2 Land type map of the survey site and surrounding area

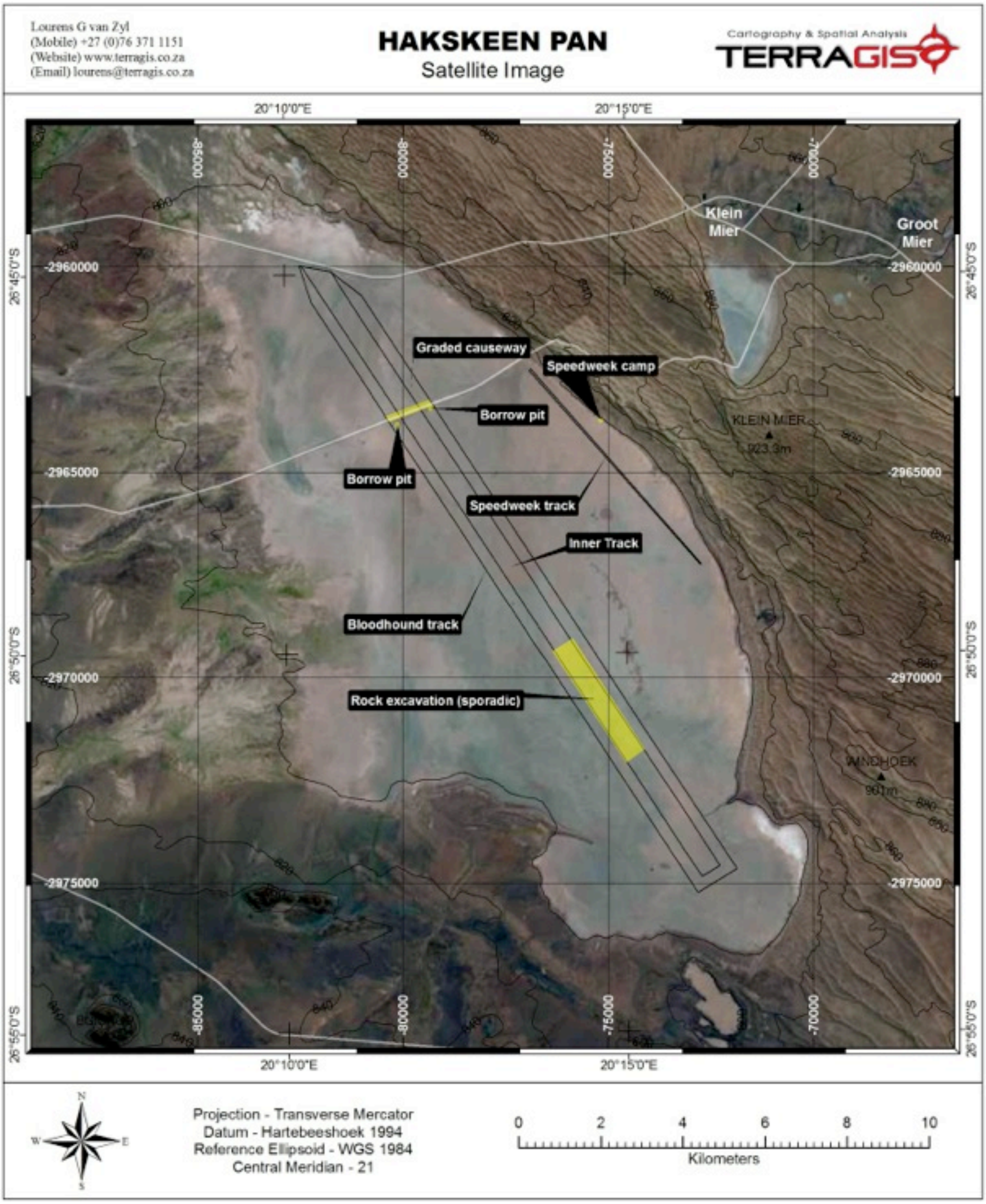

Figure 3 Contours of the survey area superimposed on an aerial photograph

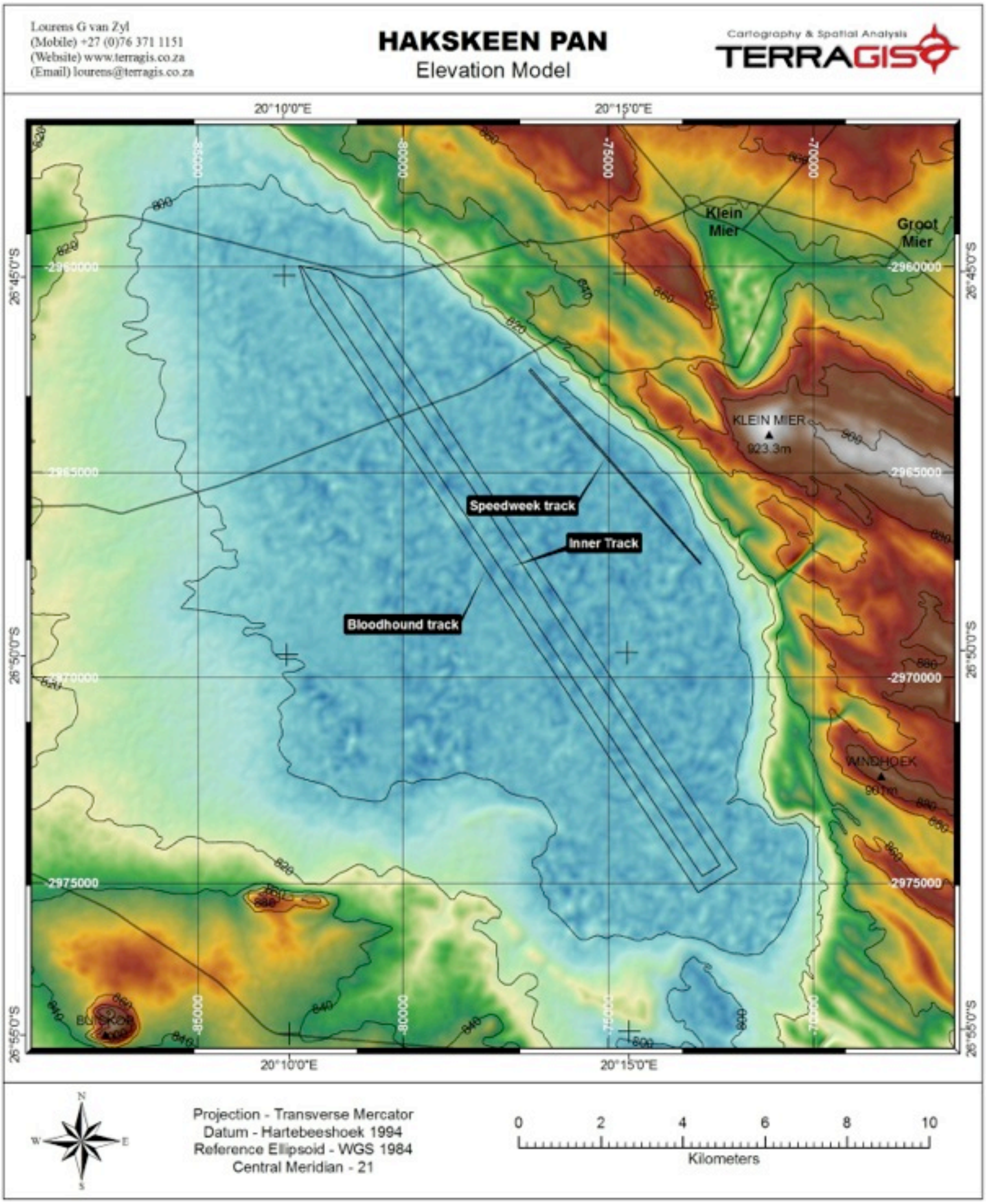

Figure 4 DEM of the survey site

2.5 GEOLOGY

The geological map of the pan area is indicated in **Figure 5** as an excerpt of the 2520 and 2620 sheets as generated by the Geological Survey (Thomas et al., 1988). Information from various geological maps was used to compile a simplified geological map over the Molopo-Nossob Basin (Carlsson et al., 2009). The main lithostratigraphy units present over the Molopo-Nossob Basin comprise the (from oldest to youngest): The Archaean Basement rocks (>2 500 M years), Proterozoic rocks (2 500 to 552 M years), Nama rocks (552 to 490 M years), Karoo rocks (360 to 65 M years) and Kalahari sediments (< 85 M years). The lithological sequences (Thomas et al., 1988) in the vicinity of and on Hakskeen Pan are described below.

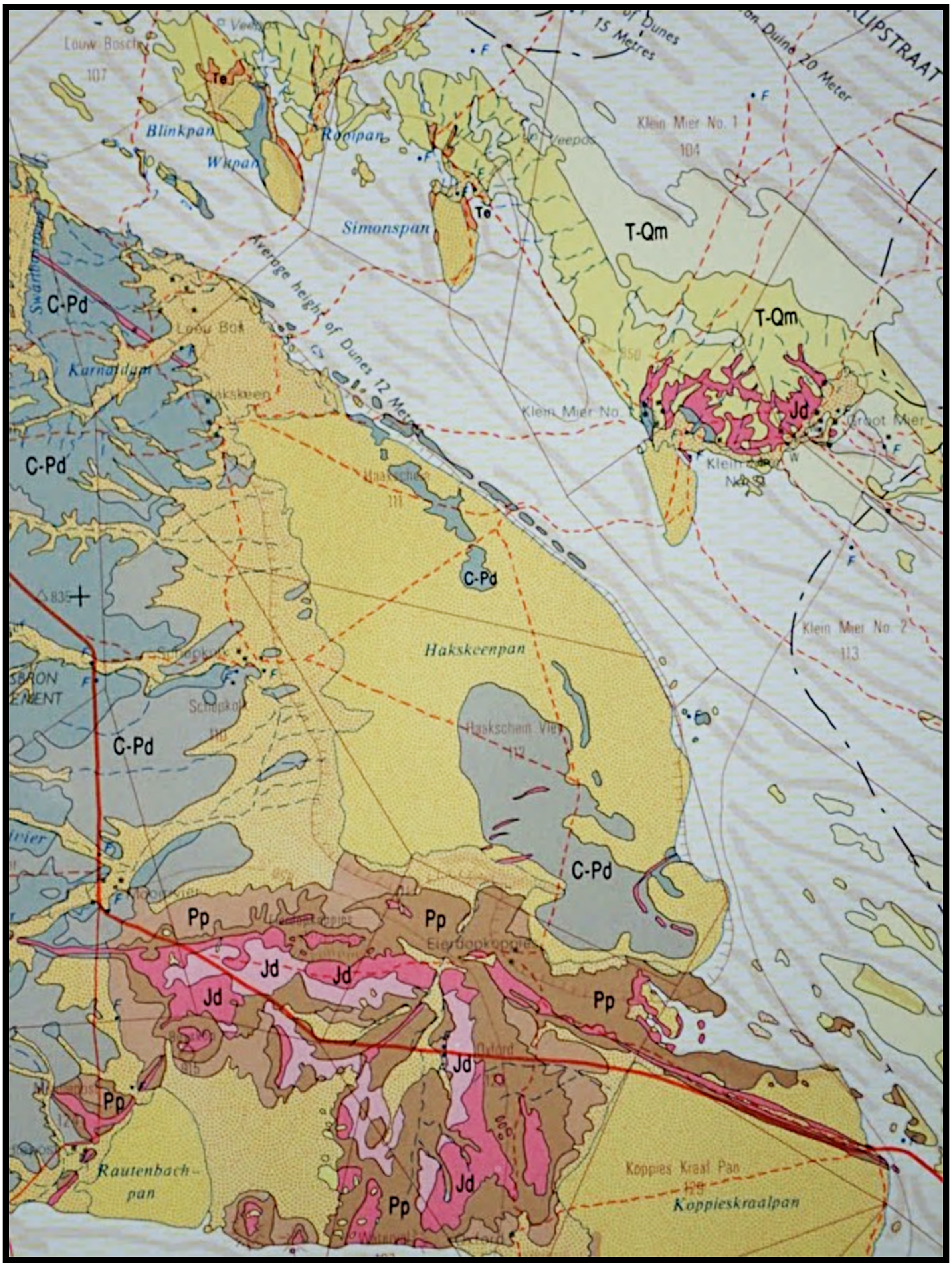

Figure 5 Excerpt of the 2520 and 2620 sheets as generated by the Geological Survey (Thomas et al., 1988)

2.5.1 Nama Group

The oldest outcropping rocks within the Mier rural area are Nama Group sediments, north-west of Rietfontein, specifically rocks belonging to the Breckhorn Formation of the Fish River Subgroup consisting of brown and purplish sandstone and subordinate brown micaceous shales with clay-pellet horizons (Thomas, 1982).

2.5.2 Karoo Sequence

Rocks of the Dwyka and Prince Albert Formations occur extensively beneath the Kalahari sediments and outcrop at a few localities, especially to the west and south of Hakskeen Pan respectively. Sub-outcrops of the Dwyka formation occur on Hakskeen Pan.

2.5.2.1 Dwyka Formation

Rocks of the Dwyka Formation unconformably overlay the rocks of the Nama Group and outcrop in a large area in the vicinity of, as well as south of, the town of Rietfontein (Thomas et al., 1988). The Dwyka sequence is predominantly described as arenaceous rocks with tillite in the lower portions. The sequence shows both lateral and vertical facies changes. The thickness of the Dwyka Formation, in the vicinity of Rietfontein, is estimated to be more than 50m increasing in thickness eastwards away from the Nama basement.

North of Rietfontein outcrops of coarse, brown, immature conglomerates, cross-bedded grits and sandstones, flagstones, calcarenites and nodules of impure, brown ferruginous limestones overlie tillite and grey-green shales with occasional dropstones. The tillite contains sub-rounded clasts up to 750mm in diameter comprising of vesicular basalt, granite, gneiss, dolomite, quartzite and red sandstones.

Extensive outcrops of the uppermost sediments of the Dwyka Formation comprising of ferrigunous, brown and grey, flaggy sandstones occur on the north-west side of Hakskeen Pan. These rocks are conformably overlain by rocks of the Prince Albert Formation on the southern margin of the pan.

South of Rietfontein both outcrops and sub-outcrops of the Dwyka rocks occur. The outcrops comprise of sandy tillite and hard, grey limestones. Gravel strewn areas covered by clasts derived from the erosion of the Dwyka tillite occur commonly.

South of Philandersbron, 2-4m thick sandstones overlie sandy tillite.

The diamicitite is interpreted as being of glacial marine origin while the arenaceous rocks are indicative of near-shore, possibly deltaic conditions.

2.5.2.2 Prince Albert Formation

Sedimentary rocks of the Prince Albert Formation, with thicknesses varying between 30m to 50m, occur over a large area to the southwest of Hakskeen Pan and to the northwest of Koppieskraal Pan (Thomas et al., 1988). The basal part of the Prince Albert Formation consists of brown, ferruginous sandstones overlain by dark-grey and green, carbonaceous, thinly bedded micaceous shales. The shales are typically broken up into small, lenticular fragments. The shales show extreme hardening to a dark-grey, flinty hornfels when in contact with the many dolerite sills and dykes occurring in the area. The thickness of the shales varies between 10m to 12m.

The shales are overlain by a 10m to 15m thick unit of hard and compact arenaceous rocks. The rocks are light-grey, pure sandstones and quartzitic sandstones with darker ferruginous and micaceous bands and lenses. The rocks have been extensively hardened by the ubiquitous dolerite intrusions.

The arenaceous rocks are overlain by a 10m to 20m thick sequence of mixed arenaceous and argillaceous sediments. The shales are blue-grey while the sandstones are grey and micaceous with prominent arkosic sandstones and grits.

The Prince Albert Formation represents a marine environment with slow deposition periodically interrupted by periods of rapid influx of coarser clastic material.

2.5.3 Kalahari Group

The deposits of the Kalahari Group cover the entire area (except arounds Rietfontein) and consist of sand, calcrete, silcrete, limestone, grit, conglomerate, sandstone, clay and gravel (Thomas, 1982). The Group is subdivided into four Formations as follows (from top to bottom):

- Gordonia Formation - Sand (12m to 30m building dunes)
- Eden Formation - Gravel and sand, mostly clayey, locally calcified and silicified
- Budin Formation - Clay, gravel
- Wessels Formation - Gravel, clayey gravel; sandstone, partly or entirely calcified.

The age of this succession ranges from the late Palaeocene to the upper Pleistocene (SACS, 1980).

According to the borehole logs the Kalahari Group reaches a maximum thickness of approximately 130m in the north-west while the thickness gradually diminishes towards the south-eastward to a constant of about 100m. Towards the south-west, south and further south east, the thickness diminishes further.

The formations of the Kalahari Group that is present in the vicinity of Hakskeen Pan are described below. The south-easterly trending, unconsolidated longitudinal dunes (Gordonia Formation) clearly demarcate the north-western boundary of Hakskeen Pan while the pan itself is covered with young, brown to white fine-grained sediment (Quaternary sediments) and a white salt crust with distinct mud cracks forming during dry periods.

2.5.3.1 Gordonia Formation

The formation is a vast accumulation of unconsolidated, red aeolian sand in the form of longitudinal dunes (Thomas et al., 1988). The average thickness of the sand is 10m to 20m with a maximum thickness of 40m in the north-west where the dunes are 30m in height. The sand comprise of well-rounded quartz grains (approximately 0.5mm in size) with the red colouration caused by a thin coating of hematite.

The unconsolidated longitudinal dunes trend in a south-easterly direction and has been fixed by vegetation over most of the area. However, aeolian migration of the dunes does occur in some places where the dune sand has been exposed due to over-grazing.

2.5.3.2 Quaternary Pan Sediments

A dedicated investigation into the selected physical and chemical parameters of the pan sediments (soils) was conducted as part of this report. The results are provided in the relevant section later in the report.

2.5.4 Karoo Dolerite

Dykes and sills of Karoo dolerites have intruded rocks of the Nama Group as well as rocks of the Dwyka and Prince Albert formations (Thomas et al., 1988). The intrusive nature of the Karoo dolerites dykes and sills are visible in these rocks outcropping in the vicinity of Hakskeen Pan. The dolerite is generally fine-grained and the sills attain thicknesses in excess of 100m.

Extensive dolerite dykes and major sills have intruded rocks of the Prince Albert Formation to the south of Hakskeen Pan and into rocks of the Dwyka Formation in the vicinity of Klein and Groot Mier. Small en-echelon dykes have intruded sub-outcrops of the upper sandy units of the Dwyka Formation in the southern parts of Hakskeen Pan.

2.6 Hydrogeology

2.6.1 Molopo-Nossob Basin

A comprehensive study was conducted to evaluate the groundwater resources of the larger Molopo-Nossob basin (Carlsson et al., 2009). The Molopo-Nossob Basin covers an area of 367 201km^2 (based on surface water catchment), including Botswana (37% of area), Namibia (33%) and South Africa (30%). The basin contains the catchment areas of four main rivers – the Molopo, Kuruman, Nossob and Auob rivers.

The long-term average annual precipitation varies from 100 mm/a in the SW part of the basin to over 500 mm/a in the E of the basin. Evaporation and potential evapotranspiration highly exceed the average rainfall. UNEP classification – basin is arid to semi-arid.

The population in the Molopo-Nossob Basin is approximately 1 million while the livestock units (ELSU) is about 1.6 million including wildlife. Average population density is 2.7 persons per km^2 and the livestock unit (ELSU) density is 4.2 to 4.6 per km^2 (ELSU per km^2).

Water requirement in the Molopo-Nossob Basin: The total requirement is 128 Mm^3/a (year 2000) with 37% of water for livestock watering, 27% for domestic purposes, 27% for irrigation, 9% for industry (mining) and only 0.1% for tourism. Approximately 69% of this water is required in South Africa, 18% in Namibia and 13% in Botswana. The future water requirement for the 3 countries will increase (year 2015) to approximately 160Mm^3/a. It is proposed that the average annual increase in the water requirement for the Molopo-Nossob Basin is approximately 1.5%.

Geological formations ranging in age from Archean to Recent, a time-span of more than 2 500 million years, covers the basin. The formations host a variety of aquifers including intergranular, fractured intergranular, fractured and karstic aquifers. Aquifer potential is based on mean borehole yields and three classes are recognised – high, medium and low potential. Yields in South Africa vary between 1.8 to > 7.2m^3/hr.

- Saturated Kalahari Beds contains local groundwater resources over large areas (especially in Namibia). Perched aquifers also occur locally in the Kalahari beds.
- Fractured integranular Ecca aquifer (Auob aquifer) & intergranular Kalahari Bed aquifer. Extensive aquifer systems in contact with each other and classified generally as a medium potential aquifer with areas of high potential (> 7.2m^3/hr).
- Dolomitic (karst systems) formations in SA and Botswana – Represent the aquifers with the highest potential classed as medium potential aquifers.
- Crystalline bedrock is classified as low potential aquifers. Groundwater occurrence is limited to fractures and fissures while good yielding local aquifers occur where extensive fracture systems occur.

The quality of groundwater varies within the basin. The groundwater quality with respect to total dissolved solids (TDS) and fluoride (F) generally exceeds the water quality guideline limits for domestic use over large areas. Areas of site specific, high nitrate (NO_3) concentrations point to local groundwater pollution.

Monitoring of groundwater level (at various time intervals and utilising different methods) is conducted in more than 600 boreholes (mostly in South Africa) in the Molopo-Nossob Basin. The regional groundwater map for the Molopo-Nossob Basin was constructed based on groundwater level data, comprising 34 000 boreholes, archived in databases in South Africa, Namibia and Botswana. The regional groundwater map indicates that groundwater flow is directed from northern Namibia southeast into Botswana and then south into South Africa. Higher groundwater levels are also encountered in the south-eastern part of the basin in South Africa. The groundwater level and flow indicate that the Molopo-Nossob Basin is drained along the Molopo River.

The chloride mass balance method shows that large areas of the basin receive less than 1 mm/a recharge as a long-term average. Recharge of more than 10 mm/a is indicated for the northern part of Namibia and the south-eastern parts (Mmabatho and Kuruman areas) of the basin in South Africa. Extremely low recharge values (< 0.1 mm/a as an average annual value) is indicated for the central part of the Molopo-Nossob Basin. The areas of low recharge in the basin generally correspond to areas of poor groundwater quality.

2.6.2 Mier Villages and Rural Area

The villages of Philandersbron and Loubos, situated in the Mier Rural Area, are totally dependent on groundwater for all their water requirements (Toens & Associates, 1992). The water supply to these villages was found to be highly contaminated by faecal organisms as well as with naturally high nitrate concentrations in the groundwater. The faecal contamination can be attributed to a combination of a number of factors, namely (Toens & Associates, 1992):-

- A relatively shallow water table,
- The location of pit latrines close to wells and boreholes,
- The presence of large numbers of animals in the area and especially around the wells and boreholes, and
- Fairly rapid recharge of the aquifers after rains.

The water requirements for Philandersbron were calculated as 65 kl per day (0.75 L/s), and for Loubos 51 kl per day (0.60 L/s) respectively calculated on a basis of 100 litres per person per day (Toens & Associates, 1992). The planned (at the time) sewerage systems increased the total water requirements to an estimated 175 kl per day or 2 L/s of water for each of the village.

The area is covered by Kalahari sediments that are underlain by the sediments of the Dwyka formation comprising predominantly of tillite with minor amounts of limestone, gritstone and conglomerates.

The sediments of the Kalahari constitute a primary aquifer system with some boreholes targeting this aquifer (Toens & Associates, 1992). The secondary aquifer occurs predominantly in the tillites of the Dwyka Formation representing the most important aquifer for the supply of water to the villages. Groundwater is generally intersected directly below the weathered tillite layer within a fractured and/or jointed zone. However, boreholes yields differ significantly and boreholes within 10 metres of each other produced substantially different yields at a number of localities in the area due to lateral facies variations. Recharge into the aquifers is fairly rapid after rainfall events as indicated by the rise in the groundwater levels in the boreholes.

A groundwater exploration programme (i.e. drilling of four boreholes and pumping tests) was conducted in the vicinity of the villages of Philandersbron and Loubos by Toens & Associates during the latter half of 1991. The results of the exploration programme were as follows:

- Boreholes were drilled to depths of approximately 30m below surface,
- Groundwater levels varied between 4m to 8m below surface,
- Water intersections occurred over a vertical depth of 9m to 20m below surface within the tillites (directly below a layer of weathered tillites), and
- The estimated, conservative (i.e. dry season) safe yields varied between 64 KL/day (= 0.75 L/s) to 215 Kl/day (= 2.5 L/s).

The results based, based on the groundwater exploration programme conducted in 1991, indicated that sufficient water, satisfying the SABS standards, is available to accommodate the needs of both villages (Toens & Associates, 1992).

The geohydrological characteristics of the various lithological units (in the Mier rural area) was briefly described as follows (Kramer, 1985):

2.6.2.1 Groundwater in Nama Group

Very little information on the Nama's water bearing properties is available. There is limited outcrop in areas west and north-west of Rietfontein while further north and east of Rietfontein the Nama is covered with thick sediments of the Kalahari Group and possibly Dwyka Formation as well. Artesian or sub-artesian aquifer conditions might occur in localities associated with the Nama rocks under the impermeable Dwyka cover. The groundwater level contours are between 880 and 850 m.a.m.s.l.

2.6.2.2 Groundwater in the Dwyka Formation

At the time, the Dwyka Formation was not considered to be an aquifer. The groundwater elevation ranges between 840 and 820 m.a.m.s.l and the groundwater level is less than 10m below surface.

2.6.2.3 Groundwater in the Kalahari Group

The Kalahari Group was considered to be the main aquifer in the Mier rural area. The groundwater level contours vary from 890 m.a.m.s.l. in the north-west to 810 m.a.m.s.l. in the south-east. The depth to groundwater is ranging from less than 10m to as deep as 80m in places.

2.6.2.4 Groundwater Flow

The groundwater flows from the north-west, possibly recharged by the Auob River, in a south-easterly and southerly direction towards Rietfontein and Hakskeen Pan. The Dwyka (tillite) aquifer appears to receive substantial, direct rain recharge at Rietfontein due to the absence of the sandy cover.

2.6.2.5 Groundwater Quality

The groundwater quality of the Mier rural area is poor. Values higher than 2000 mS/m (or approximately 13 000 mg/l TDS) occur towards the north of the area and along the Nossob River course. The only reasonable groundwater quality (EC = 300 mS/m), which could also be used by humans, occur in the Rietfontein area.

Four groundwater types can be distinguished:

(1) HCO_3 type
(2) HCO_3-Cl type
(3) Cl-SO_4 type
(4) Cl-type

The HCO_3-Cl type is the dominant groundwater type. The nitrate concentrations in groundwater gradually decrease from north to south ranging from 250 mg/l to less than 45 mg/l respectively. The origin of the nitrates in concentration up to 250 mg/l NO_3 may be explained by the physical and chemical soil processes when rainwater is available. Values higher than this concentration are recorded as pollution derived from livestock waste (Heaton, 1984). The fluoride concentration in several groundwater samples exceeds a critical WHO limit of 3.0 mg/l. The origin of the high fluoride concentrations in groundwater of the Mier area remains unknown (Kramer, 1985).

The groundwater quality (BVI, 2007 & 2011) in the Mier region is very poor and conductivity (EC), as an indication of the quality of the groundwater, vary as follows (Table 1):

Table 1 Conductivity (EC) ranges for the Mier area (BVI, 2007 & 2011)

Conductivity (mS/m)	% of target area
70 to 300 ms/m *(448 to 1920 ppm)*	10
300 to 1000 ms/m *(1920 to 6400 ppm)*	60
Larger than 1000 ms/m *(>6400 ppm)*	30

A conductivity of 370ms/m is the maximum allowable conductivity suitable for drinking water (SANS 241). Only a small percentage of water is suitable for human consumption (Table 1)

The borehole yield within the Mier area ranges as follows (Table 2):

Table 2 Borehole yield variation for the Mier area (BVI, 2007 & 2011)

Borehole yield (liters per second)	% of target area
0.1 to 0.5 l/s	50
0.5 to 2.0 l/s	40
2.0 to 5.0 l/s	10

3. PROBLEM STATEMENT

The assessment of a dry pan system, with human impacts intended for the dry-state use of the pan, in a wetland context poses some challenges. This investigation will focus on the description and delineation of the wetland features based on soil hydromorphy and landscape hydrology as well as to provide a relatively detailed description of the pan soil environment to elucidate the statutory context of the project and impacts.

4. STATUTORY CONTEXT

4.1 WETLAND DEFINITION

Wetlands are defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

"Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."

4.2 WATERCOURSE DEFINITION

"Catchment" is defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

"…, in relation to a watercourse or watercourses or part of a watercourse, means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points;"

"Watercourse" is defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

"*(a)* a river or spring;
(b) a natural channel in which water flows regularly or intermittently;
(c) a wetland, lake or dam into which, or from which, water flows; and
(d) any collection of water which the Minister may, by notice in the *Gazette*, declare to be a water course,
and a reference to a watercourse includes, where relevant, its bed and banks;"

4.3 THE WETLAND DELINEATION GUIDELINES

In 2005 the Department of Water Affairs and Forestry published a manual entitled "A practical field procedure for identification and delineation of wetland and riparian areas" (DWAF, 2005). The "…manual describes field indicators and methods for determining whether an area is a wetland or riparian area, and for finding its boundaries." The definition of a wetland in the guidelines is that of the NWA and it states that wetlands must have one or more of the following attributes:

- "**Wetland (hydromorphic) soils** that display characteristics resulting from prolonged saturation"
- "The presence, at least occasionally, of **water loving plants (hydrophytes)**"

- “A **high water table** that results in saturation at or near the surface, leading to anaerobic conditions developing in the top 50cm of the soil.”

The guidelines further list four indicators to be used for the finding of the outer edge of a wetland. These are:

- Terrain Unit Indicator. The terrain unit indicator does not only identify valley bottom wetlands but also wetlands on steep and mild slopes in crest, midslope and footslope positions.
- Soil Form Indicator. A number of soil forms (as defined by MacVicar et al., 1991) are listed as indicative of permanent, seasonal and temporary wetland zones.
- Soil Wetness Indicator. Certain soil colours and mottles are indicated as colours of wet soils. The guidelines stipulate that this is the primary indicator for wetland soils. (Refer to the guidelines for a detailed description of the colour indicators.) In essence, the reduction and removal of Fe in the form of “bleaching” and the accumulation of Fe in the form of mottles are the two main criteria for the identification of soils that are periodically or permanently wet.
- Vegetation Indicator. This is a key component of the definition of a wetland in the NWA. It often happens though that vegetation is disturbed and the guidelines therefore place greater emphasis on the soil form and soil wetness indicators as these are more permanent whereas vegetation communities are dynamic and react rapidly to external factors such as climate and human activities.

The main emphasis of the guidelines is therefore the use soils (soil form and wetness) as the criteria for the delineation of wetlands. The applicability of these guidelines in the context of the survey site will be discussed in further detail later in the report.

Due to numerous problems with the delineation of wetlands there are a plethora of courses being presented to teach wetland practitioners and laymen the required techniques. Most of the courses and practitioners focus on ecological or vegetation characteristics of landscapes and soil characteristics are often interpreted incorrectly due to a lacking soil science background of these practitioners. As such this author regularly presents, in conjunction with a colleague (Prof Cornie van Huyssteen) from the University of the Free Sate, a course on the aspects related to soil classification and wetland delineation.

4.4 THE RESOURCE DIRECTED MEASURES FOR PROTECTION OF WATER RESOURCES.

The following are specific quotes from the different sections of the “Resource Directed Measures for Protection of Water Resources.” as published by DWAF (1999).

4.4.1 The Resource Directed Measures for Protection of Water Resources: Volume 4: Wetland Ecosystems.

<u>From the Introduction:</u>

"This set of documents on Resource Directed Measures (RDM) for protection of water resources, issued in September 1999 in Version 1.0, presents the procedures to be followed in undertaking **preliminary determinations of the class, Reserve and resource quality objectives for water resources**, as specified in sections 14 and 17 of the South African National Water Act (Act 36 of 1998).

The development of procedures to determine RDM was initiated by the Department of Water Affairs and Forestry in July 1997. Phase 3 of this project will end in March 2000. Additional refinement and development of the procedures, and development of the full water resource classification system, will continue in Phase 4, until such time as the detailed procedures and full classification system are ready for publication in the Government Gazette.

It should be noted that until the final RDM procedures are published in the Gazette, and prescribed according to section 12 of the National Water Act, all determinations of RDM, whether at the rapid, the intermediate or the comprehensive level, will be considered to be preliminary determinations."

4.4.2 The Resource Directed Measures for Protection of Water Resources: Generic Section "A" for Specialist Manuals – Water Resource Protection Policy Implementation Process

"Step 3: Determine the reference conditions of each resource unit"

"What are reference conditions?"

"The determination of reference conditions is a very important aspect of the overall Reserve determination methodology. Reference conditions describe the natural unimpacted characteristics of a water resource. Reference conditions quantitatively describe the ecoregional type, specific to a particular water resource."

4.4.3 The Resource Directed Measures for Protection of Water Resources: Appendix W1 (Ecoregional Typing for Wetland Ecosystems)

<u>Pan systems are explained:</u>

"6. Endorheic System

<u>Definition</u>

The Endorheic System comprises wetlands that would otherwise be classified as Palustrine or Lacustrine, but which possess **all** of the following additional characteristics:

1. circular to oval in shape, sometimes kidney-shaped or lobed;
2. flat basin floor;
3. less than 3 m deep when fully inundated; and
4. closed drainage (lacking any outlet).

<u>Description</u>

Wetlands of the Endorheic System are commonly referred to as pans in South Africa, and as small closed basins or playas in geomorphological literature. The majority of pans in the country occur in the area with a mean annual rainfall of less than 500 mm and an average net evaporation loss greater than 1000 mm per annum (Shaw 1988). Being located largely in dry regions, pans display characteristic patterns of ephemeral and irregular inundation. Pans in the arid western regions of South Africa may remain dry for years between temporary flooding, while those in the higher rainfall regions display seasonal inundation regimes, and may remain flooded over a number of seasons. Some of the larger pans on the Mpumalanga highveld are permanently inundated, large, deep and have rooted vegetation (Allan *et al* 1995). As such, these pans would be classified as Lacustrine if their water depth exceeds 3 m. Being endorheic, pans lose water largely by evaporation, which also contributes to the high salinity observed in many of these systems."

Artificial modifiers are explained namely:

"Many wetlands are man-made, while others have been modified from a natural state to some degree by the activities of humans. Since the nature of these alterations often greatly influences the character of such habitats, the inclusion of modifying terms to accommodate human influence is important. In addition, many human modifications, such as dam walls and drainage ditches, are visible in aerial photographs and can be easily mapped. The following Artificial Modifiers are defined and can be used singly or in combination wherever they apply to wetlands:

Farmed: the soil surface has been physically altered for crop production, but hydrophytes will become re-established if farming is discontinued

Artificial: substrates placed by humans, using either natural materials such as dredge spoils or synthetic materials such as concrete. Jetties and breakwaters are examples of Non-vegetated Artificial habitats

Excavated: habitat lies within an excavated basin or channel

Diked/Impounded: created or modified by an artificial barrier which obstructs the inflow or outflow of water

Partially Drained: the water level has been artificially lowered, usually by means of ditches, but the area is still classified as wetland because soil moisture is sufficient to support hydrophytes."

4.4.4 The Resource Directed Measures for Protection of Water Resources: Appendix W4 IER (Floodplain Wetlands) Present Ecological Status (PES) Method

In Appendix W4 the methodology is provided for the determination of the present ecological status (PES) of a palustrine wetland.

The present ecological state (PES) of the wetland was determined according to the method described in "APPENDIX W4: IER (FLOODPLAIN WETLANDS) PRESENT ECOLOGICAL STATUS (PES) METHOD" of the "Resource Directed Measures for Protection of Water Resources.

Volume 4: Wetland Ecosystems" as published by DWAF (1999). However, the PES methodology already forms an adaptation from the methodology to assess palustrine wetlands. Hillslope seepage wetlands have a range of different drivers and as such some modification of the criteria has been made by this author to accommodate the specific hydropedology drivers of hillslope seepage wetlands.

The criteria as described in Appendix 4 is provided below with the relevant modification or comment provided as well.

The summarised tasks in the PES methodology are (for detailed descriptions refer to the relevant documentation):

1. Conduct a literature review (review of available literature and maps) on the following:
    a. Determine types of development and land use (in the catchment in question).
    b. Gather hydrological data to determine the degree to which the flow regime has been modified (with the "virgin flow regime" as baseline). The emphasis is predominantly on surface hydrology and hydrology of surface water features as well as the land uses, such as agriculture and forestry, that lead to flow modifications. <u>Important Note</u>: The hydropedology of landscapes is not explicitly mentioned in the RDM documentation and this author will make a case for its consideration as probably the most important component of investigating headwater systems and seepage wetlands and areas.
    c. Assessment of the water quality as is documented in catchment study reports and water quality databases.
    d. Investigate erosion and sedimentation parameters that address aspects such as bank erosion and bed modification. <u>Important Note</u>: The emphasis in the RDM documentation is again on river and stream systems with little mention of erosion of headwater and seepage zone systems. Again a case will be made for the emphasis of such information generation.
    e. Description of exotic species (flora and fauna) in the specific catchment in question.
2. Conduct and aerial photographic assessment in terms of the parameters listed above.
3. Conduct a site visit and make use of local knowledge.
4. Assess the criteria and generate preliminary PES scores.
5. Generation of report.

Table 3 presents the score sheet with criteria for the assessment of habitat integrity of palustrine wetlands (as provided in the RDM documentation).

Table 3 "Table W4-1: Score sheet with criteria for assessing Habitat Integrity of Palustrine Wetlands (adapted from Kleynhans 1996)"

Criteria and attributes	**Relevance**	**Score**	**Confidence**
Hydrologic			
Flow modification	Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland.		
Permanent Inundation	Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota.		
Water Quality			
Water Quality Modification	From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland		
Sediment load modification	Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats.		
Hydraulic/Geomorphic			
Canalisation	Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage.		
Topographic Alteration	Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railwaylines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns.		
Biota			
Terrestrial Encroachment	Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions.		
Indigenous Vegetation Removal	Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion.		
Invasive plant encroachment	Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading).		
Alien fauna	Presence of alien fauna affecting faunal community structure.		
Overutilisation of biota	Overgrazing, Over-fishing, etc		
TOTAL MEAN			

Scoring guidelines per attribute:
natural, unmodified = 5; Largely natural = 4, Moderately modified = 3; largely modified = 2; seriously modified = 1; Critically modified = 0.
Relative confidence of score:
Very high confidence = 4; High confidence = 3; Moderate confidence = 2; Marginal/low confidence = 1.

Important Note: The present ecological state (PES) determination is, as discussed earlier in the report, based on criteria originally generated for palustrine and floodplain wetlands. Pan (or endorheic) wetlands in dry environments very rarely have the same degree of saturation or free water and consequently often do not have permanent wetland zones. These wetlands are therefore often characterised at best by seasonal or temporary properties or high salt content soils and crusts. As such a standard PES approach is flawed as it rests on a range of ecological parameters that do not apply to predominantly dry pan systems. The existing criteria is provided below as is a comment on the applicability as well as proposed improvements.

Criteria

Hydrological Criteria

- "Flow modification: Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland." Comment: Although the description is wide it is very evident that it does not cater adequately for dry pan environments. The main criterion should therefore be the surface and subsurface hydrological linkages expressed as a degree of alteration in terms of the surface, hydropedology and groundwater hydrology.
- "Permanent inundation: Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota." Comment: Mostly not applicable to dry pan wetlands.

Water Quality Criteria

- "Water quality modification: From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland." Comment: Water quality in this context applies generally but cognisance should be taken of very high salt content of the ephemeral water in the pan. The pan system and function generally renders the water unsuitable for human or animal consumption due to very hig salt loads.
- "Sediment load modification: Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats." Comment: This is a very relevant concept but on very large pan systems become almost

irrelevant due to scale. In many dry pan systems the process of sedimentation and addition of salts is a natural and continuous process.

Hydraulic / Geomorphic Criteria

- “Canalisation: Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage.” Comment: Again this is a very relevant concept but in large dry pan systems the impacts are often dwarfed or negated by constant variation in rainfall over the area.
- “Topographic Alteration: Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railwaylines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns.” Comment: Again this is a very relevant concept but in large dry pan systems the impacts are often dwarfed or negated by constant variation in rainfall over the area. These aspects should be elucidated and contextualised.

Biological Criteria

- “Terrestrial encroachment: Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions.” Comment: Again this is a very relevant concept but in large dry pan systems the impacts are not distinguishable from naturally prolonged dry cycles.
- “Indigenous vegetation removal: Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion.” Comment: This aspect is almost irrelevant in dry pan systems as the vegetation is very sparse or even absent within the pan.
- “Invasive plant encroachment: Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading).” Comment: This aspect is almost irrelevant in dry pan systems as the vegetation is very sparse or even absent within the pan.
- “Alien fauna: Presence of alien fauna affecting faunal community structure.” Comment: This aspect is almost irrelevant in dry pan systems as the vegetation is very sparse or even absent within the pan.
- “Overutilisation of biota: Overgrazing, Over-fishing, etc.” Comment: This aspect is almost irrelevant in dry pan systems as the biota is very sparse or even absent within the pan during dry years. In wet years the variable occurrence of biota influences short bursts of activity as in the form of migrating birds feeding on short life-span invertebrates.

Scoring Guidelines

Scoring guidelines per attribute:

Natural, unmodified = 5

Largely natural = 4

Moderately modified = 3

Largely modified = 2

Seriously modified = 1

Critically modified = 0

Relative confidence of score:
Very high confidence = 4
High confidence = 3
Moderate confidence = 2
Marginal/low confidence = 1

4.4.5 The Resource Directed Measures for Protection of Water Resources: Appendix W5 IER (Floodplain Wetlands) Determining the Ecological Importance and Sensitivity (EIS) and the Ecological Management Class (EMC)

In Appendix W5 the methodology is provided for the determination of the ecological importance and sensitivity (EIS) and ecological management class (EMC) of floodplain wetlands.

"Ecological importance" of a water resource is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales. "Ecological sensitivity" refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred. The Ecological Importance and Sensitivity (EIS) provides a guideline for determination of the Ecological Management Class (EMC)." Please refer to the specific document for more detailed information.

The following primary determinants are listed as determining the EIS:

1. Rare and endangered species
2. Populations of unique species
3. Species / taxon richness
4. Diversity of habitat types or features
5. Migration route / breeding and feeding site for wetland species
6. Sensitivity to changes in the natural hydrological regime
7. Sensitivity to water quality changes
8. Flood storage, energy dissipation and particulate / element removal

The following modifying determinants are listed as determining the EIS:

1. Protected status
2. Ecological integrity

Comment: This entire concept is almost irrelevant in dry pan systems as the ecology is intimately linked to the presence of water, which is sporadic at best. The EIS and EMC can therefore only be viewed in the context of a system that has very little expression of ecological activity during dry periods and has bursts of activity during short and often sporadic wet spells.

4.5 SUMMARY AND PROPOSED APPROACH

When working in dry pan environments where water and ecological aspects are only expressed for short periods during most years it is important to answer the following critical questions regarding the assessment and management planning for wetlands:

1. What is the reference condition?
2. What is the difference between the reference condition in terms of dry vs wet cycles and how long do these cycles last?
3. What will the impact on the reference condition be if dry cycles become longer and more pronounced for certain long-term rainfall cycles?
4. What are the hydrological drivers (as a function of geology, topography, rainfall and soils) and what are the relative contributions of these drivers to the functioning of the wetland system?
5. What is the intended or planned land use in the wetland as well as terrestrial area and how will these developments impact on the hydrology of the landscape and wetlands?
6. How can the intended land use be plied to secure the best possible hydrological functioning of the landscape in terms of storm water attenuation, erosion mitigation and water quality?

The key to the generation of adequate information lies in the approach that is to be followed. In the next section an explanation about and motivation in favour of will be provided for a hydropedology assessment approach. Due to the detailed nature of the information that can be generated through such an approach it is motivated that all wetland assessments be conducted with the requirements of criminal law in mind. The main reason for this is the fact that many well-meaning administrative exercises often yield no tangible results due to the gap in terms of information that is required should there be a compliance process followed.

To Summarise:

During wetland assessments and delineations it is important to provide a perspective on assessment tools, the original or reference state of the wetland, the assessment process and outcome as well as the intended or possible state of the wetland and site post development or impact. Urban and mining developments are good examples of cases where surrounding developments and land use changes have significant effects on wetland integrity and water quality emanating from the site.

5. CHALLENGES REGARDING WETLAND DELINEATION IN ARID ENVIRONMENTS

Disclaimer: The following section represents a discussion that I use as standard in describing the challenges regarding wetland delineation and management in arid environments. This implies that the section is verbatim the same as in other reports provided to clients and the authorities. Copyright is strictly reserved.

In order to discuss the procedures followed and the results of the wetland identification and impact assessment exercise it is necessary at the outset to provide some theoretical background on soil forming processes, soil wetness indicators, water movement in soils and topographical sequences of soil forms (catena).

5.1 PEDOGENESIS

Pedogenesis is the process of soil formation. Soil formation is a function of five (5) factors namely (Jenny, 1941):

- Parent material;
- Climate;
- Topography;
- Living Organisms; and
- Time.

These factors interact to lead to a range of different soil forming processes that ultimately determine the specific soil formed in a specific location. Central to all soil forming processes is water and all the reactions (physical and chemical) associated with it. The physical processes include water movement onto, into, through and out of a soil unit. The movement can be vertically downwards, lateral or vertically upwards through capillary forces and evapotranspiration. The chemical processes are numerous and include dissolution, precipitation (of salts or other elements) and alteration through pH and reduction and oxidation (redox) changes. In many cases the reactions are promoted through the presence of organic material that is broken down through aerobic or anaerobic respiration by microorganisms. Both these processes alter the redox conditions of the soil and influence the oxidation state of elements such as Fe and Mn. Under reducing conditions Fe and Mn are reduced and become more mobile in the soil environment. Oxidizing conditions, in turn, lead to the precipitation of Fe and Mn and therefore lead to their immobilization. The dynamics of Fe and Mn in soil, their zones of depletion through mobilization and accumulation through precipitation, play an important role in the identification of the dominant water regime of a soil and could therefore be used to identify wetlands and wetland conditions.

5.2 WATER MOVEMENT IN THE SOIL PROFILE

In a specific soil profile, water can move upwards (through capillary movement), horizontally (owing to matric suction) and downwards under the influence of gravity.

The following needs to be highlighted in order to discuss water movement in soil:

- Capillary rise refers to the process where water rises from a deeper lying section of the soil profile to the soil surface or to a section closer to the soil surface. Soil pores can be regarded as miniature tubes. Water rises into these tubes owing to the adhesion (adsorption) of water molecules onto solid mineral surfaces and the surface tension of water.

  The height of the rise is inversely proportional to the radius of the soil pore and the density of the liquid (water). It is also directly proportional to the liquid's surface tension and the degree of its adhesive attraction. In a soil-water system the following simplified equation can be used to calculate this rise:

  $$\text{Height} = 0.15/\text{radius}$$

  Usually the eventual height of rise is greater in fine textured soil, but the rate of flow may be slower (Brady and Weil, 1999; Hillel, 1983).

- Matric potential or suction refers to the attraction of water to solid surfaces. Matric potential is operational in unsaturated soil above the water table while pressure potential refers to water in saturated soil or below the water table. Matric potential is always expressed as a negative value and pressure potential as a positive value.

  Matric potential influences soil moisture retention and soil water movement. Differences in the matric potential of adjoining zones of a soil results in the movement of water from the moist zone (high state of energy) to the dry zone (low state of energy) or from large pores to small pores.

  The maximum amount of water that a soil profile can hold before leaching occurs is called the field capacity of the soil. At a point of water saturation, a soil exhibits an energy state of 0 $J.kg^{-1}$. Field capacity usually falls within a range of -15 to -30 $J.kg^{-1}$ with fine textured soils storing larger amounts of water (Brady and Weil, 1999; Hillel, 1983).

- Gravity acts on water in the soil profile in the same way as it acts on any other body; it attracts towards earth's centre. The gravitational potential of soil water can be expressed as:

  $$\text{Gravitational potential} = \text{Gravity} \times \text{Height}$$

  Following heavy rainfall, gravity plays an important part in the removal of excess water from the upper horizons of the soil profile and recharging groundwater sources below.

  Excess water, or water subject to leaching, is the amount of water that falls between soil saturation (0 $J.kg^{-1}$) or oversaturation (> 0 $J.kg^{-1}$), in the case of heavy rainfall resulting in a pressure potential, and field capacity (-15 to -30 $J.kg^{-1}$). This amount of water differs according to soil type, structure and texture (Brady and Weil, 1999; Hillel, 1983).

- Under some conditions, at least part of the soil profile may be saturated with water, resulting in so-called saturated flow of water. The lower portions of poorly drained soils are often saturated, as are well-drained soils above stratified (layers differing in soil texture) or impermeable layers after rainfall.

The quantity of water that flows through a saturated column of soil can be calculated using Darcy's law:

$$Q = Ksat.A.\Delta P/L$$

Where Q represents the quantity of water per unit time, Ksat is the saturated hydraulic conductivity, A is the cross sectional area of the column through which the water flows, ΔP is the hydrostatic pressure difference from the top to the bottom of the column, and L is the length of the column.

Saturated flow of water does not only occur downwards, but also horizontally and upwards. Horizontal and upward flows are not quite as rapid as downward flow. The latter is aided by gravity (Brady and Weil, 1999; Hillel, 1983).

- Mostly, water movement in soil is ascribed to the unsaturated flow of water. This is a much more complex scenario than water flow under saturated conditions. Under unsaturated conditions only the fine micropores are filled with water whereas the macropores are filled with air. The water content, and the force with which water molecules are held by soil surfaces, can also vary considerably. The latter makes it difficult to assess the rate and direction of water flow. The driving force behind unsaturated water flow is matric potential. Water movement will be from a moist to a drier zone (Brady and Weil, 1999; Hillel, 1983).

The following processes influence the amount of water to be leached from a soil profile:

- Infiltration is the process by which water enters the soil pores and becomes soil water. The rate at which water can enter the soil is termed infiltration tempo and is calculated as follows:

  $$I = Q/A.t$$

  Where I represents infiltration tempo ($m.s^{-1}$), Q is the volume quantity of infiltrating water (m^3), A is the area of the soil surface exposed to infiltration (m^2), and t is time (s).

  If the soil is quite dry when exposed to water, the macropores will be open to conduct water into the soil profile. Soils that exhibit a high 2:1 clay content (swelling-shrinking clays) will exhibit a high rate of infiltration initially. However, as infiltration proceeds, the macropores will become saturated and cracks, caused by dried out 2:1 clay, will swell and close, thus leading to a decline in infiltration (Brady and Weil, 1999; Hillel, 1983).

- Percolation is the process by which water moves downward in the soil profile. Saturated and unsaturated water flow is involved in the process of percolation, while the rate of percolation is determined by the hydraulic conductivity of the soil.

  During a rain storm, especially the down pouring of heavy rain, water movement near the soil surface mainly occurs in the form of saturated flow in response to gravity. A sharp boundary, referred to as the wetting front, usually appears between the wet soil and the underlying dry soil. At the wetting front, water is moving into the underlying soil in response to both matric and gravitational potential. During light rain, water movement at the soil surface may be ascribed to unsaturated flow (Brady and Weil, 1999; Hillel, 1983).

The fact that water percolates through the soil profile by unsaturated flow has certain ramifications when an abrupt change in soil texture occurs (Brady and Weil, 1999; Hillel, 1983). A layer of course sand, underlying a fine textured soil, will impede downward movement of water. The macropores of the coarse textured sand offer less attraction to the water molecules than the macropores of the fine textured soil. When the unsaturated wetting front reaches the coarse sand, the matric potential is lower in the sand than in the overlying material. Water always moves from a higher to a lower state of energy. The water can, therefore, not move into the coarse textured sand. Eventually, the downward moving water will accumulate above the sand layer and nearly saturate the fine textured soil. Once this occurs, the water will be held so loosely that gravitational forces will be able to drag the water into the sand layer (Brady and Weil, 1999; Hillel, 1983).

A coarse layer of sand in an otherwise fine textured soil profile will also inhibit the rise of water by capillary movement (Brady and Weil, 1999; Hillel, 1983).

Field observations and laboratory based analysis can aid in assessing the soil-water relations of an area. The South African soil classification system (Soil Classification Working Group, 1991.) comments on certain field observable characteristics that shed light on water movement in soil. The more important of these are:

- Soil horizons that show clear signs of leaching such as the E-horizon – an horizon where predominantly lateral water movement has led to the mobilisation and transport of sesquioxide minerals and the removal of clay material;
- Soil horizons that show clear signs of a fluctuating water table where Fe and Mn mottles, amongst other characteristics, indicate alternating conditions of reduction and oxidation (soft plinthic B-horizon);
- Soil horizons where grey colouration (Fe reduction and redox depletion), in an otherwise yellowish or reddish matrix, indicate saturated (or close to saturated) water flow for at least three months of the year (Unconsolidated/Unspecified material with signs of wetness);
- Soil horizons that are uniform in colouration and indicative of well-drained and aerated (oxidising) conditions (e.g. yellow brown apedal B-horizon).

5.3 WATER MOVEMENT IN THE LANDSCAPE

Water movement in a landscape is a combination of the different flow paths in the soils and geological materials. The movement of water in these materials is dominantly subject to gravity and as such it will follow the path of least resistance towards the lowest point. In the landscape there are a number of factors determining the paths along which this water moves. **Figure 6** provides a simplified schematic representation of an idealised landscape (in "profile curvature". The total precipitation (rainfall) on the landscape from the crest to the lowest part or valley bottom is taken as 100 %. Most geohydrologists agree that total recharge, the water that seeps into the underlying geological strata, is less than 4 % of total precipitation for most geological settings. Surface runoff varies considerably according to rainfall intensity and distribution, plant cover and soil characteristics but is taken as a realistic 6 % of total precipitation for our idealised landscape. The total for surface runoff and recharge is therefore calculated as 10 % of total precipitation. If evapotranspiration (from plants as well as the soil surface) is taken as a very high 30 % of total precipitation it leaves 60 % of the total that has to move through the soil and/or geological strata from higher lying to lower lying areas. In the event of an average rainfall of 750 mm per year it results in 450 mm per year having to move laterally through the soil and geological strata. In a landscape there is an accumulation of water down the slope as water from higher lying areas flow to lower lying areas.

To illustrate: If the assumption is made that the area of interest is 100 m wide it follows that the first 100 m from the crest downwards has 4 500 m^3 (or 4 500 000 litres) of water moving laterally through the soil (100 m X 100 m X 0.45 m) per rain season. The next section of 100 m down the slope has its own 4 500 m^3 of water as well as the added 4 500 m^3 from the upslope section to contend with, therefore 9 000 m^3. The next section has 13 500 m^3 to contend with and the following one 18 000 m^3. It is therefore clear that, the longer the slope, the larger the volume of water that will move laterally through the soil profile.

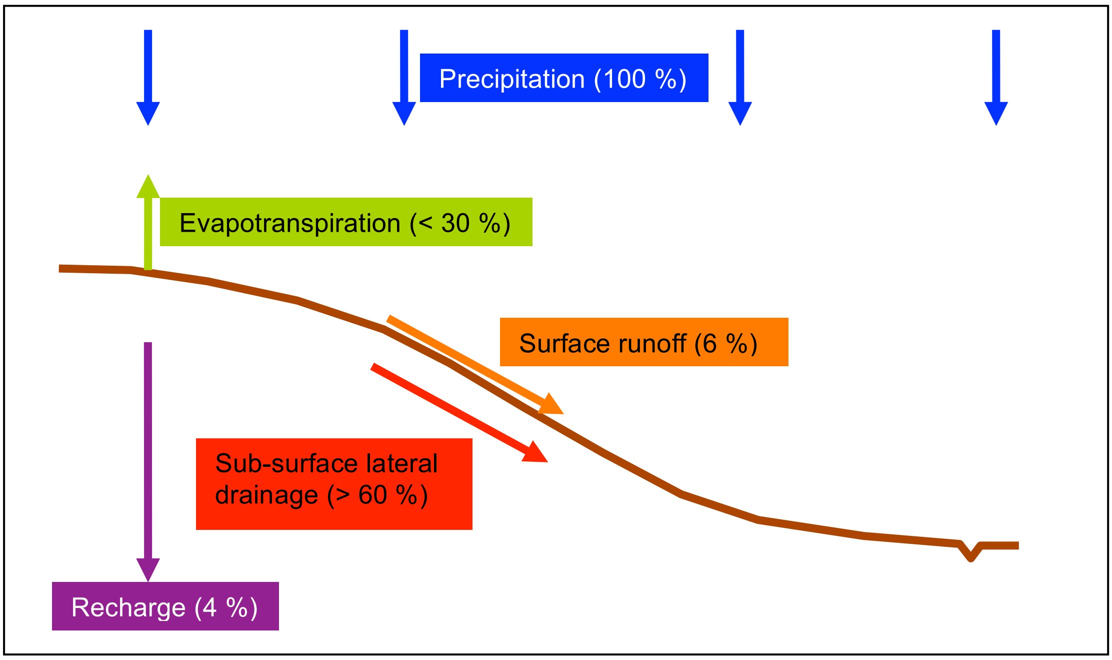

Figure 6 Idealised landscape with assumed quantities of water moving through the landscape expressed as a percentage of total precipitation (100 %).

Flow paths through soil and geological strata, referred to as “interflow” or “hillslope water”, are very varied and often complex due to difficulty in measurement and identification. The difficulty in identification stems more from the challenges related to the physical determination of these in soil profile pits, soil auger samples and core drilling samples for geological strata. The identification of the morphological signs of water movement in permeable materials or along planes of weakness (cracks and seams) is a well-established science and the expression is mostly referred to as “redox morphology”. In terms of the flow paths of water large variation exists but these can be grouped into a few simple categories. **Figure 7** provides a schematic representation of the different flow regimes that are usually encountered. The main types of water flow can be grouped as 1) recharge (vertically downwards) of groundwater; 2) lateral flow of water through the landscape along the hillslope (interflow or hillslope water); 3) return flow water that intercepts the soil/landscape surface; and 4) surface runoff. Significant variation exists with these flow paths and numerous combinations are often found. The main wetland types associated with the flow paths are: a) valley bottom wetlands (fed by groundwater, hillslope processes, surface runoff, and/or in-stream water); b) hillslope seepage wetlands (fed by interflow water and/or return flow water); and wetlands associated with surface runoff, ponding and surface ingress of water anywhere in the landscape.

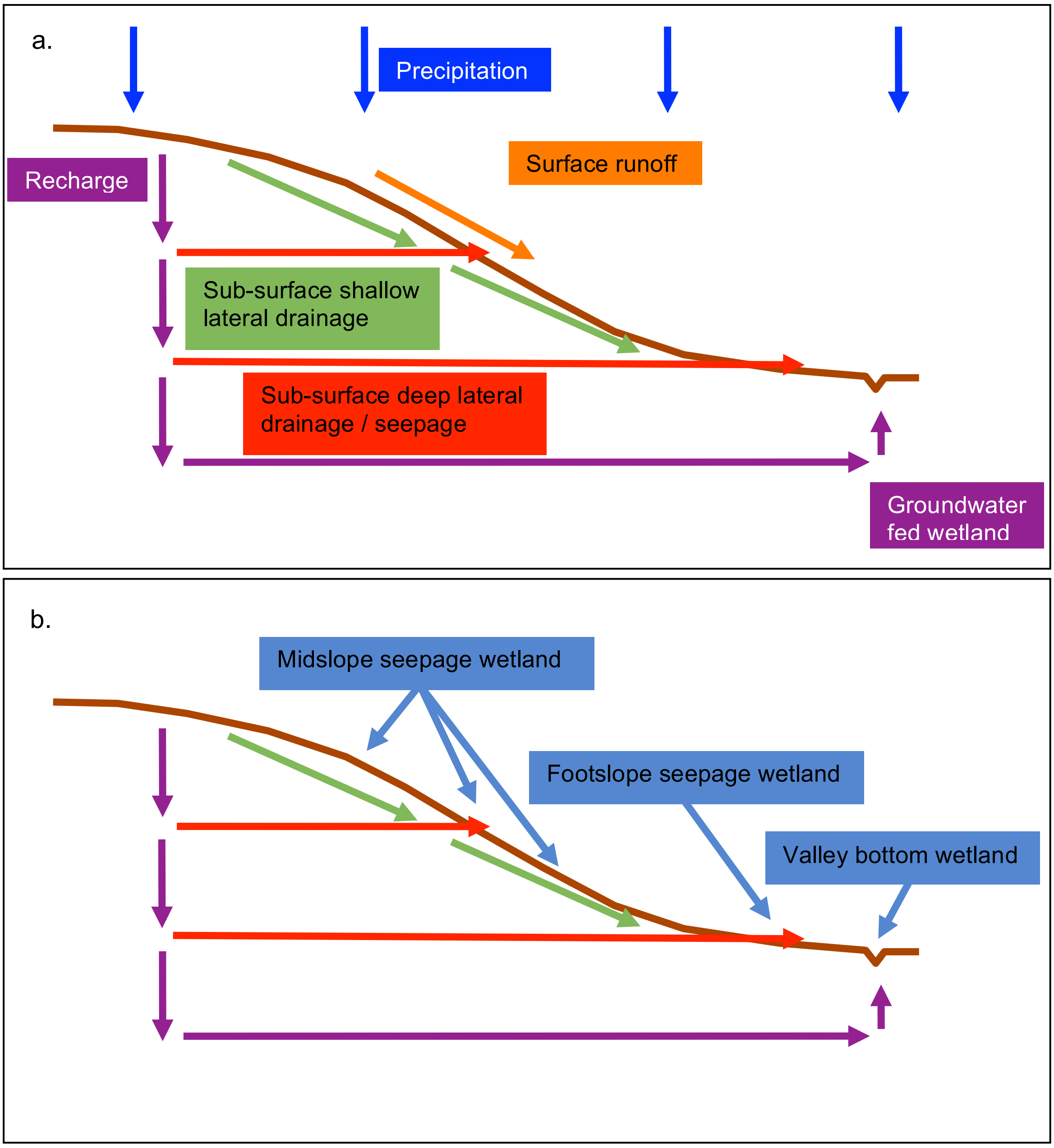

Figure 7 Different flow paths of water through a landscape (a) and typical wetland types associated with the water regime (b)

Amongst other factors, the thickness of the soil profile at a specific point will influence the intensity of the physical and chemical reactions taking place in that soil. **Figure 8** illustrates the difference between a dominantly thick and a dominantly thin soil profile. If all factors are kept the same except for the soil profile thickness it can be assumed with confidence that the chemical and physical reactions associated with water in the landscape will be much more intense for the thin soil profile than for the thick soil profile. Stated differently: The volume of water moving through the soil per surface area of an imaginary plane perpendicular to the direction of water flow is much higher for the thin soil profile than for the thick soil profile. This aspect has a significant influence on the expression of redox morphology in different landscapes of varying soil/geology/climate composition.

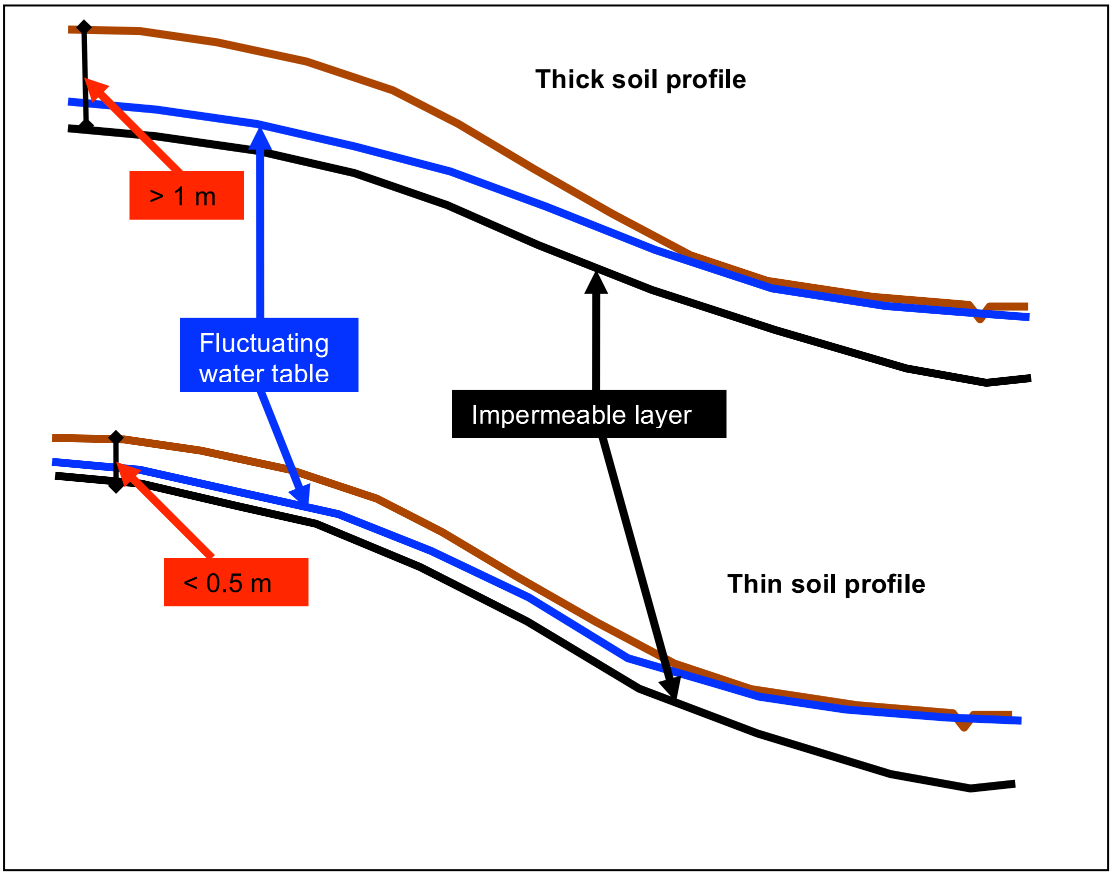

Figure 8 The difference in water flow between a dominantly thick and dominantly thin soil profile.

5.4 THE CATENA CONCEPT

Here it is important to take note of the "catena" concept. This concept is one of a topographic sequence of soils in a homogenous geological setting where the water movement and presence in the soils determine the specific characteristics of the soils from the top to the bottom of the topography. **Figure 9** illustrates an idealised topographical sequence of soils in a catena for a quartz rich parent material. Soils at the top of the topographical sequence are typically red in colour (Hutton and Bainsvlei soil forms) and systematically grade to yellow further down the slope (Avalon soil form). As the volume of water that moves through the soil increases, typically in midslope areas, periodic saturated conditions are experienced and consequently Fe is reduced and removed in the laterally flowing water. In the event that the soils in the midslope positions are relatively sandy the resultant soil colour will be bleached or white due to the colour dominance of the sand quartz particles. The soils in these positions are typically of the Longlands and Kroonstad forms. Further down the slope there is an accumulation of clays and leaching products from higher lying soils and this leads to typical illuvial and clay rich horizons. Due to the regular presence of water the dominant conditions are anaerobic and reducing and the soils exhibit grey colours often with bright yellow and grey mottles (Katspruit soil form). In the event that there is a large depositional environment with prolonged saturation soils of the Champagne form may develop (typical peat land). Variations on this sequence (as is often found on the Mpumalanga Highveld) may include the presence of hard plinthic materials instead of soft plinthite with a consequent increase in the occurrence of bleached soil profiles. Extreme examples of such landscapes are discussed below.

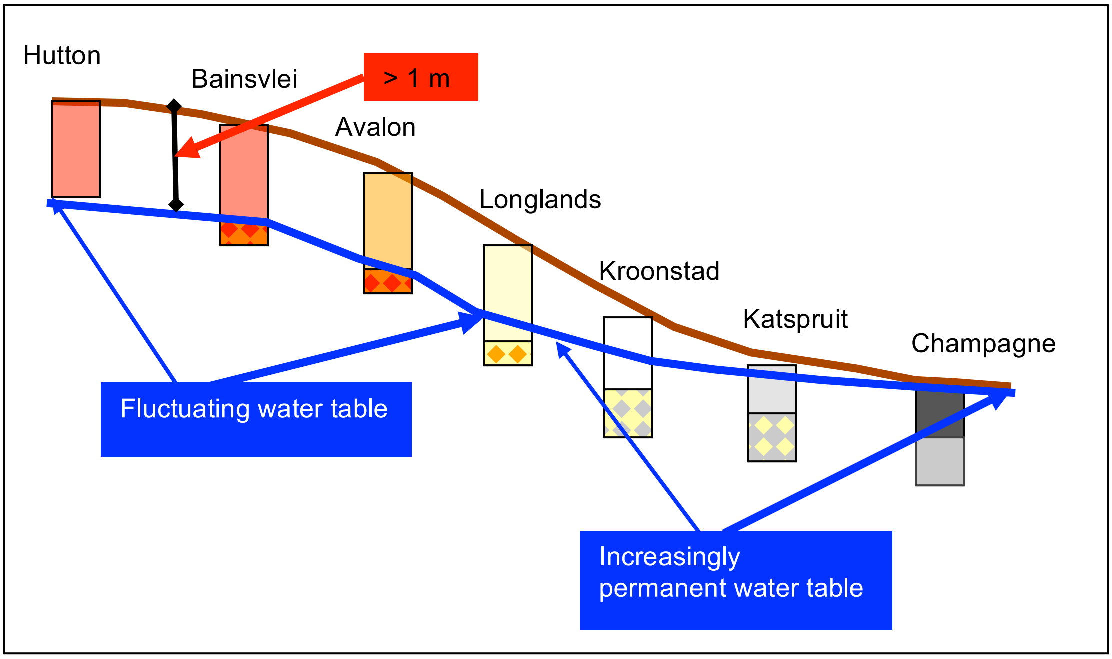

Figure 9 Idealised catena on a quartz rich parent material.

5.5 THE ARID KALAHARI PAN SYSTEM "CATENA"

The soils of the arid Kalahari pan systems range from dunes and/or shallow soils with rock subsoils or exposed rock sheets outside of the pan to soils with very distinct crusting and thin subsoil sodium affected horizons. **Figure 10** provides a schematic representation of the system. The dune soils are classified as of the Namib (orthic A horizon / regic sand / unspecified – often soft or hardpan carbonate) form, the shallow soils as of the Mispah (orthic A horizon / hard rock) or Glenrosa (orthic A horizon / lithocutanic B horizon) forms and the pan soils as Sterkspruit (orthic A horizon / prismacutanic B horizon) forms. In the latter the A horizon is reduced to a thin flaky crust overlying a thin, but very well developed and dense prismatic and high sodium content subsoil horizon. Invariably the prismacutanic B horizon does not exhibit any redox morphology due to the dry state of the environment but the contact to the underlying shale may exhibit some signs of Fe translocation in the form of slight colour variation.

The hydrological functioning (**Figure 11**) is rather simple in that the sandy dunes act as recharge areas with much of the water seeping out in low points into the pan depression. The pan soils receive precipitation but the water does not percolate downwards through the soil due to the high sodium levels and subsequent Na-induced swelling of clay and silt particles. It is therefore found that the water is "perched" in the top few centimetres of the pan crust with a subsequent volume variation that manifests as distinct cracks upon drying. The evaporation in the area exceeds the rainfall by several orders of magnitude leading to the rapid loss of water from the pan surface.

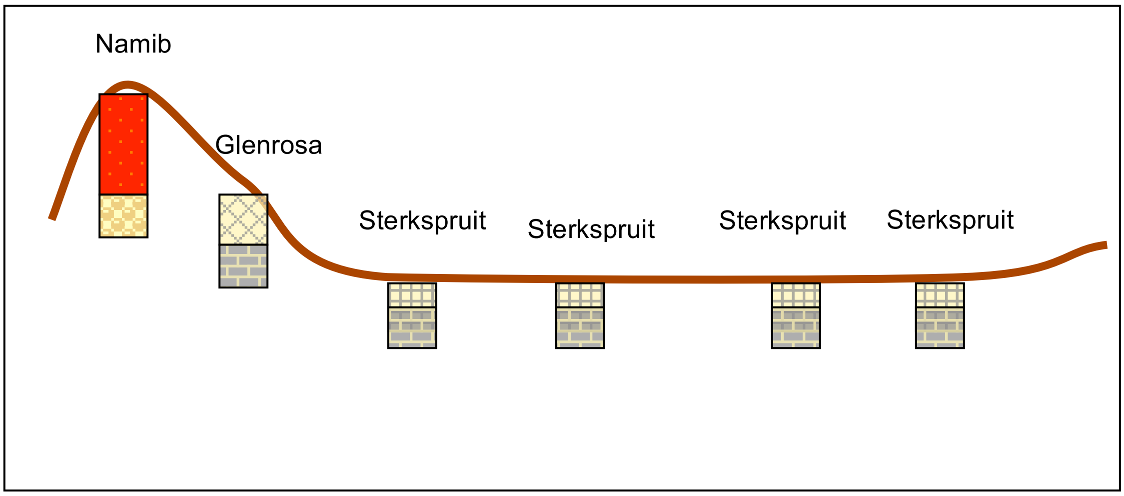

Figure 10 Conceptual cross section of a dune an pan system in the Kalahari

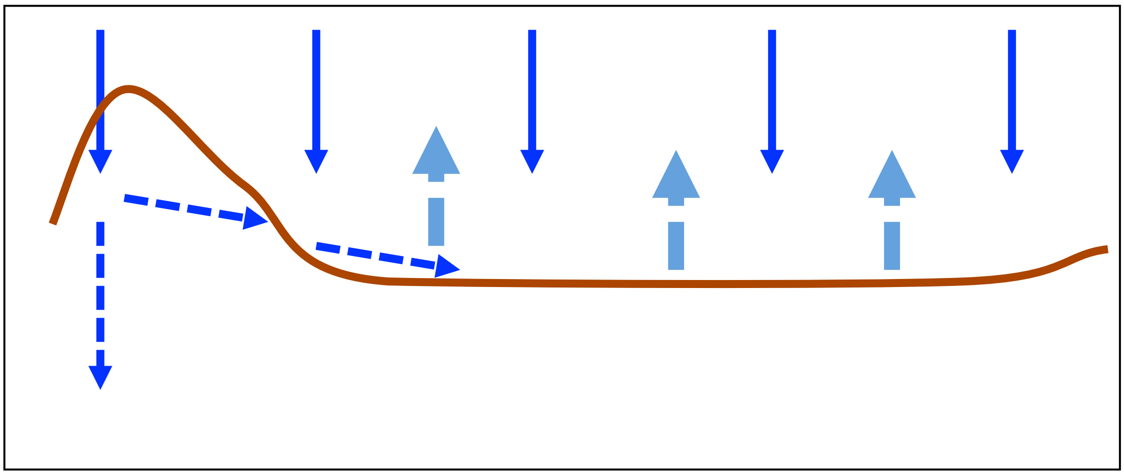

Figure 11 Conceptual hydropedology of a dune and pan system in the Kalahari

Salts are typically sequestered in shallow layers immediately below crust surface and along vertical faces of cracks on polygon surfaces with a manifestation of white salt layers immediately below the crust surface and not on the surface itself. The fact that the salts are sequestered near the surface in the soil profile indicates that the pan system is not a leaking one and it can therefore be stated with confidence that such pans do not contribute significantly to groundwater recharge. The major difference in salt content between the pan soils and the groundwater found in these areas is a further confirmation of this statement.

5.6 Redox Morphology in Arid Alkaline Soils

Wetland delineation, based on common generalisations regarding hydromorphy, is a very challenging exercise in areas dominated by arid alkaline soils such as pan depressions in the Kalahari. This is mainly due to the almost complete absence of Fe-mottles in the soils that grade from the terrestrial to the "wetland" areas. There are a number of reasons that will be explained in more detail below.

In order to illustrate the stability and distribution of Fe minerals in soils the figure provided below (**Figure 12**) was copied from page 124 of a book entitled "Soil Chemistry" by Bohn, et al., (1990). The essence is that when reduction and oxidation reactions of Fe (in this case) are considered in soils both the electron activity (driver of reducing conditions) and pH have to be considered as they are intimately linked and dependent on each other. Suffice to say that for redox and mineral stability purposes they are indicated on the same graph. From Figure 4.6 (**Figure 12**) it is clear that as the Eh decreases (increasing reducing conditions) the dominant Fe species in solution changes from Fe^{3+} (insoluble and forming brightly coloured minerals) to Fe^{2+} (soluble and essentially colourless). Once pH is included in the observation it is clear that distinct Fe minerals come into play. Applying the decreasing Eh values to Fe minerals at high pH it is clear that the dominant Fe mineral under oxidizing conditions is FeOOH (Goethite – predominantly yellow). As the conditions become more reducing the equilibrium shifts to $FeCO_3$ (Siderite – white) and thereafter to FeS_2 (Pyrite). Whereas goethite has a distinct colour in soil, siderite and pyrite are less conspicuous in small quantities. It follows therefore that Fe minerals are much less visible in high pH reduced soils than in oxidised soils. In addition, arid environments often lack prolonged saturation that would lead to the reduction of Fe.

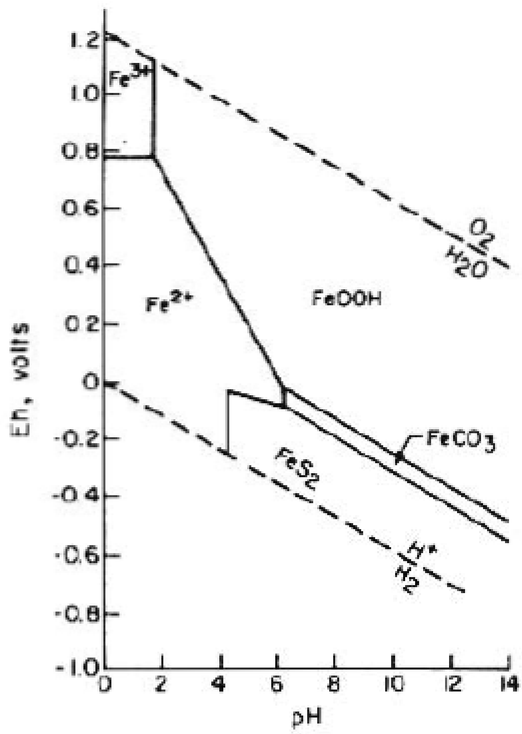

FIGURE 4.6. The *Eh*–pH diagram of various iron ions and compounds.

Figure 12 Eh pH diagram as sourced from Bohn, et al., (1990) p124

Another factor related to pH is the degree of reduction that is required to reduce Fe from its oxidised to its reduced state. From the graph it is clear that there is a steep decreasing gradient as the pH of the soil increases. This implies that much more intensive reducing conditions are required for the same degree of Fe reduction when high pH conditions (as those experienced in sodic soils) are compared to low pH conditions. The fact that the soils are also not subjected to prolonged inundation and saturation means that Fe redox morphology is often not observed as conditions are not conducive.

In essence therefore, a number of factors, including aridity, degree of reduction, soil pH and dominant Fe minerals, conspire against the use of Fe indicators in arid pan and sodic soils for the delineation of wetlands. There is no quick solution to this problem and delineators should use as many other indicators of wetland conditions in such soils as they can. The most obvious in this case is the rather arbitrary definition of all endorheic systems as wetlands.

5.7 IMPLICATIONS FOR WETLAND DELINEATION AND APPLICATION OF THE GUIDELINES

The main implication for the delineation of wetlands and the application of the guidelines in arid environments is the fact that none of the generally accepted indicators are applicable. The only indicator that can be used with confidence is the terrain unit indicator. In most arid environments vegetation indicators, adapted to the arid environment, can be used. However, in arid pan systems the salt contents and osmotic stresses are often too high for plants to colonise pan environments, therefore making vegetation indicators redundant. The soil form and soil wetness indicators are also not supportive of wetland character as there is a general lack of grey colours (due to Fe reduction and depletion) as well as Fe mottles (indicative of redox accumulations). The wetland delineation guidelines can therefore not be applied to arid pan systems with confidence and the only way to describe such systems as wetlands is to define them as such arbitrarily.

6. METHOD OF SITE INVESTIGATION

6.1 DETAILED SOIL INVESTIGATION

A detailed soil investigation was conducted for the pan area for the purpose of providing background to and input into a range of activities and impact assessments for the proposed activities. Additionally, due to the dearth of information on the soils of such arid pan systems it was decided to generate as much soil data as possible within a limited budget in order to contribute to the body of knowledge on such systems.

The soil investigation consisted of the following (details regarding methods and procedures are provided in the results section of the report):

1. Soil profile description through the localised digging of two shallow (less than 30 cm deep) pits as well as soil description through soil auger investigations in more than 90 localities throughout the pan;
2. Soil strength and consistence investigation through a detailed penetrometer assessment of the pan soils in more than 90 localities;
3. Analysis of 18 soil samples collected throughout the pan for extractable cations, anions, EC and pH;
4. Analysis of 11 samples for texture parameters (sand, silt and clay content);
5. Mineralogical analysis of 7 samples;
6. Collection of 36 surface core samples with wet sieving and gravel fraction determination; and
7. Visual assessment of the dispersivity of the pan crust and subsoil.

6.2 HYDROPEDOLOGY INVESTIGATION

6.2.1 Hydropedology Background

The identification and delineation of wetlands rest on several parameters that include topographic, vegetation and soil indicators. Apart from the inherent flaws in the wetland delineation process, as discussed earlier in this report, the concept of wetland delineation implies an emphasis on the wetlands themselves and very little consideration of the processes driving the functioning and presence of the wetlands. One discipline that encompasses a number of tools to elucidate landscape hydrological processes is “hydropedology” (Lin, 2012). The crux of the understanding of hydropedology lies in the fact that pedology is the description and classification of soil on the basis of morphology that is the result of soil and landscape hydrological, physical and chemical processes. But, the soils of which the morphology is described also take part in and intimately influence the hydrology of the landscape. Soil is therefore both an indicator as well as a participator in the processes that require elucidation.

Wetlands are merely those areas in a landscape where the morphological indicators point to prolonged or intensive saturation near the surface to influence the distribution of wetland vegetation. Wetlands therefore form part of a larger hydrological entity that they cannot be separated from.

6.2.2 Hydropedology – Proposed Approach

In order to provide detailed pedohydrological information both detailed soil surveys and hydrological investigations are needed. In practice these intensive surveys are expensive and very seldom conducted. However, with the understanding of soil morphology, pedology and basic soil physics parameters as well as the collection and interpretation of existing soil survey information, assessments at different levels of detail and confidence can be conducted. In this sense four levels of investigation are proposed namely:

1. Level 1 Assessment: This level includes the collection and generation of all applicable remote sensing, topographic and land type parameters to provide a "desktop" product. This level of investigation rests on adequate experience in conducting such information collection and interpretation exercises and will provide a broad overview of dominant hydropedological parameters of a site. Within this context the presence, distribution and functioning of wetlands will be better understood than without such information.
2. Level 2 Assessment: This level of assessment will make use of the data generated during the Level 1 assessment and will include a reconnaissance soil and site survey to verify the information as well as elucidate many of the unknowns identified during the Level 1 assessment.
3. Level 3 Assessment: This level of assessment will build on the Level 1 and 2 assessments and will consist of a detailed soil survey with sampling and analysis of representative soils. The parameters to be analysed include soil physical, chemical and mineralogical parameters that elucidate and confirm the morphological parameters identified during the field survey.
4. Level 4 Assessment: This level of assessment will make use of the data generated during the previous three levels and will include the installation of adequate monitoring equipment and measurement of soil and landscape hydrological parameters for an adequate time period. The data generated can be used for the building of detailed hydrological models (in conjunction with groundwater and surface hydrologists) for the detailed water management on specific sites.

For most wetland delineation exercises a Level 2 or Level 3 assessment should be adequate. For this investigation a Level 3 assessment was conducted with extensive field work. Analysis of soils was conducted but data from other sites with highly similar soils was also used to illustrate the challenges faced on the site and in the broader area.

The process of the hydropedology assessment entails the aspects listed below. The results of the assessment will therefore be structured under the headings as provided below.

6.3. AERIAL PHOTOGRAPH INTERPRETATION

An aerial photograph interpretation exercise was conducted through the use of Google Earth images and historical aerial photographs of the site. This data was used to obtain an indication of the extent of the wetlands on the site as well as to provide an indication of the artificial modifiers evident on the site and in the catchment.

6.4 TERRAIN UNIT INDICATOR

Detailed contours of the site (filtered to 5 m intervals for the purpose of map production) were used to provide an indication of drainage depression and drainage lines. From this data the terrain unit indicator was deduced.

6.5 SOIL FORM AND SOIL WETNESS INDICATORS

The soil form and wetness indicators were assessed on the site through a dedicated soil survey within the context of the description of the arid and alkaline Kalahari pan “catena” as provided in sections 5.5 and 5.6. The data generated during the detailed soil investigation was used for the interpretation of the wetness indicators and their context.

Historical impacts were identified as the impacts on the soils are very distinct. Soil characteristics could therefore be used to provide a good indication of the historical impacts on the grounds of a forensic approach. In areas where soil impacts are limited the standard approach in terms of identification of soil form and soil wetness indicators was used.

6.6 VEGETATION INDICATOR

Due to the extent of the historical impacts as well as the timing of the investigation a dedicated vegetation survey for the purpose of wetland delineation was not conducted. These parameters were generated in a wetland report by different workers and will not be repeated here as this report focuses primarily on hydropedology and soil indicators. Relevant vegetation parameters were noted and these are addressed in the report where applicable.

6.7 ARTIFICIAL MODIFIERS

Artificial modifiers of the landscape and wetland area were identified during the different components of the investigation and are addressed in the context of the wetland management plan.

7. SITE SURVEY RESULTS AND DISCUSSION

7.1 DETAILED SOIL AND PAN SURFACE INVESTIGATION

7.1.1 Soil Profile Description

The soils within the pan can be divided into three main groups as based on surface characteristics. The surface characteristics have a significant influence on the trafficability of the pan surface as well as the measurement of penetration resistance. A brief description follows below.

7.1.1.1 Soils with Rocks and Rock Outcrops

These soils occur mainly on the edge of the pan and are characterised by significant occurrences of loose rock and rock outcrops (**Figures 13** and **14**). Due to the presence of the rock as well as the fact that these areas do not form part of the track these areas were not sampled or assessed in terms of physical and chemical parameters.

Figure 13 Rock and rock outcrops on the edge of the pan

Figure 14 Rock and rock outcrops on the edge of the pan

7.1.1.2 Soils with a Hard or Thin Surface Crust

Soils with a hard or thin surface crust dominate in the pan and typically exhibit prisms with some cracks that extend downwards for a centimetre or two (**Figures 15** and **16**). These soils appear to not have significant salt accumulation at the surface and are considered to form part of the dryer parts of the pan (**Figures 17** and **18**). As a consequence, vehicle and tyre track impacts are limited to the surface and without indentations (**Figure 19**).

Figure 15 Hard pan surface with prisms and cracks dominating on the pan

Figure 156Hard pan surface with prisms and cracks

Figure 17 Exposed soil profile (20 cm) of hard pan soil without a puffy salt crust


Figure 18 Hard pan crust without visible salt accumulation


Figure 19 Vehicle tyre tracks leaving barely a mark

7.1.1.3 Soils with a Soft and Puffy Surface Crust

Soils with puffy surface crusts are considered to occur in locally wetter areas of the pan. The distribution of these soils is erratic for most of the pan but they also occur in concentrated areas throughout the pan. The soil surface consists of a thin and very brittle soil crust with precipitated salts underneath (**Figures 20** to **21**). Vehicle tracks are distinctly more visible as the surface crusts are crushed (**Figure 24**).

Figure 20 Puffy and brittle surface crust

Figure 21 Puffy and brittle surface crust broken by hand

Figure 22 Salt crystals as precipitated underneath the puffy crust

Figure 23 Exposed soil profile (10 cm) with a visibly brittle and puffy surface crust with salt crystals at the contact between the subsoil and the crust

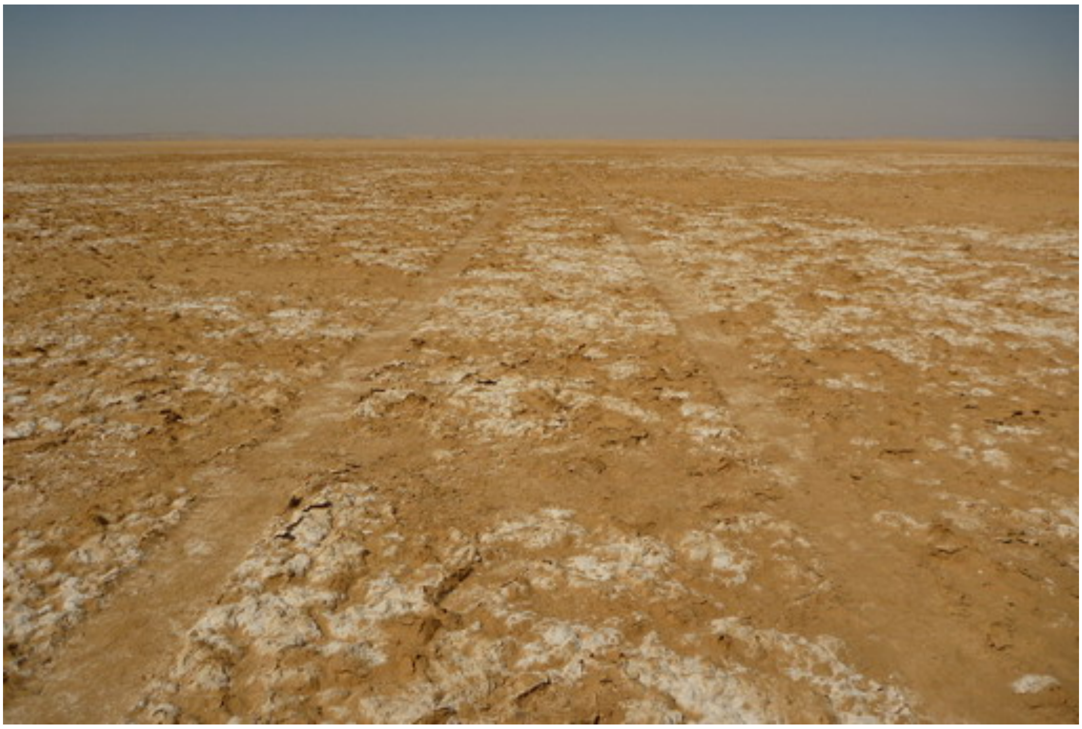

Figure 24 Vehicle tyre tracks leaving a distinctly visible mark as the puffy crusts have been broken

7.1.2 Penetrometer Data

7.1.2.1 Background

Penetration resistance data can be used to provide an indication of the bulk density of a soil and is often used to identify layers or horizons in soil that could pose a restriction (due to excessive density) regarding plant root growth and development. The correlation between bulk density parameters and penetration resistance data is only realistic for soils with a water content at field capacity (immediately after a wetting event and the removal of excess water by gravity). Penetration resistance data generated in dry soils can only be correlated with physical parameters such as consistence/consistency. The difference between consistence and consistency is rather semantic (engineering vs soil science application) and both refer to the hardness or firmness of a soil clod or ped. As this investigation's focus is the hardness of the surface of the pan in the dry state the correlation of the penetrometer data with consistence/consistency parameters is therefore deemed adequate. On the specific site the data was used to provide an indication of the hardness of the soils on the pan floor and to draw conclusions on their suitability for land speed record purposes.

7.1.2.2 Methodology

A hand penetrometer (Model P5; manufactured by Geotron, Potchefstroom, South Africa – **Figures 25** and **26**) was used to generate penetration resistance data (measured in kPa per cm depth penetration) for soils on the Bloodhound SSC track perimeter. In addition, a transect perpendicular to the track was also sampled. (Refer to **Figure 27** for the sample locations.) For each of the sample points two penetration resistance readings were generated a distance of 1 m apart. The maximum penetration resistance for the apparatus was set at 5000 kPa. At this pressure the resistance was such that the weight of two fully-grown men was not enough to keep the apparatus from lifting off the ground. The resultant data was logged and statistically analysed, per depth increment, for the following parameters: average (mean), maximum value, minimum value, median, standard deviation and coefficient of variation. The data set was split into two due to the significant difference between the bulk of the samples and those sampled at point H5.

Figure 25 Hand penetrometer Model P5

Figure 26 Generation of data on the salt pan

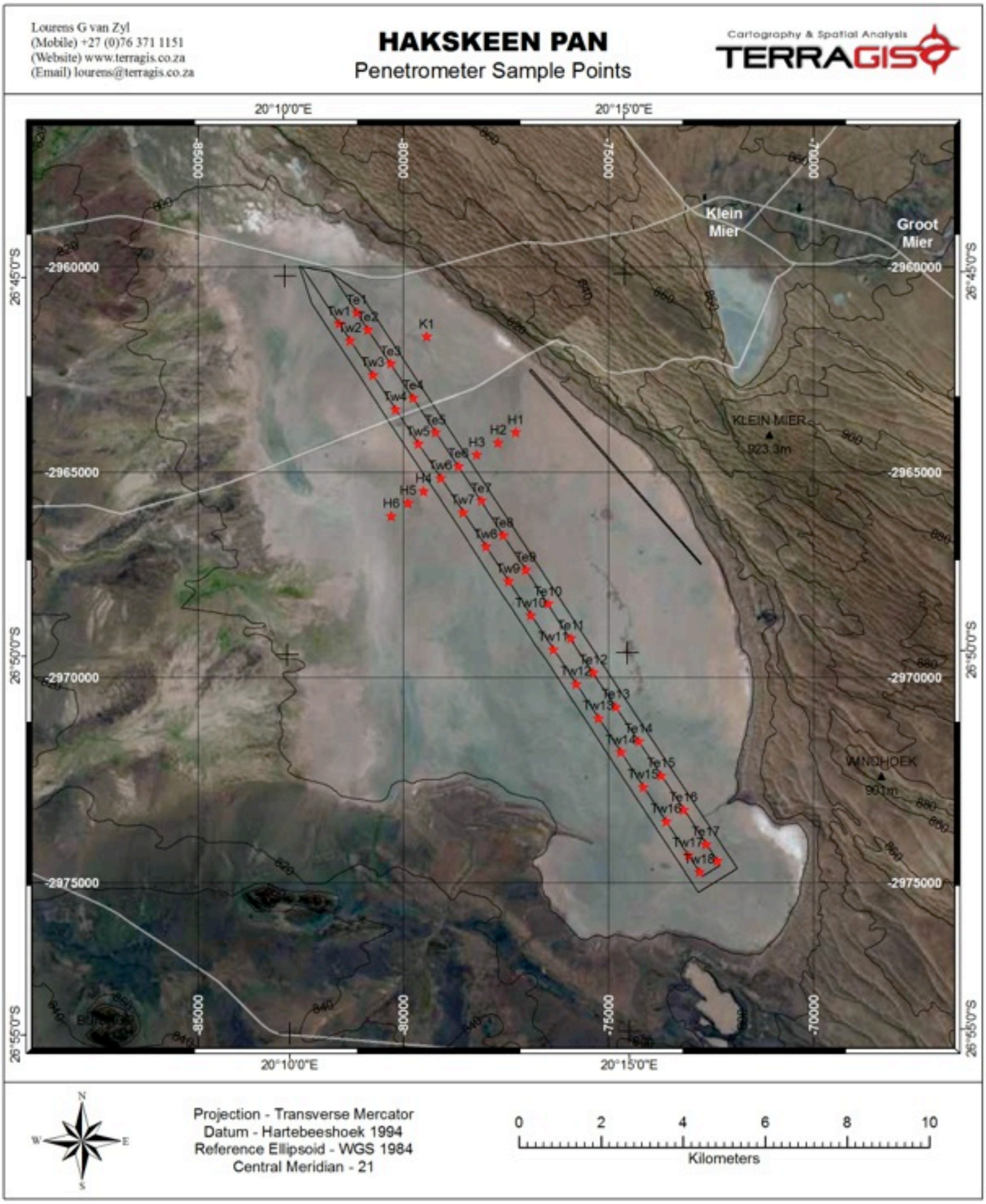

Figure 27 Penetrometer sample points on Hakskeenpan

7.1.2.3 Results

The data as generated for the track is summarised in **Table 4** and is split into two sets namely 1) the bulk of the samples and 2) four points sampled around point H5. The penetration resistance values for the bulk of the sample sites indicate that the soils increase in hardness rapidly within 1 to 2 cm depth (**Figure 28**). At a depth of 3 cm the average value exceeds 4000 kPa and at a depth of 5 cm all the samples exceeded values of 5000 kPa. In comparison, the values generated for

Point H5 differed markedly as the maximum penetration resistance was only encountered at a depth of 11 to 12 cm (**Figure 28**). The bulk of the samples correspond to areas described under Section 7.1.1.2 (hard or thin surface crusts) and the samples generated at Point H5 correlate with those described under Section 7.1.1.3 (soft and puffy surface crusts).

Table 4 Penetrometer data generated for track points on Hakskeenpan

Depth (cm)	Penetration Resistance (kPa)			
	All Points Average (mean)	n	Point H5 Average (mean)	n
1	181	82	0	4
2	1776	82	13	4
3	4143	80	253	4
4	4777	35	753	4
5	5233	9	1141	4
6	-	-	1275	4
7	-	-	1481	4
8	-	-	1769	4
9	-	-	2213	4
10	-	-	2628	4
11	-	-	4322	4
12	-	-	5462	1

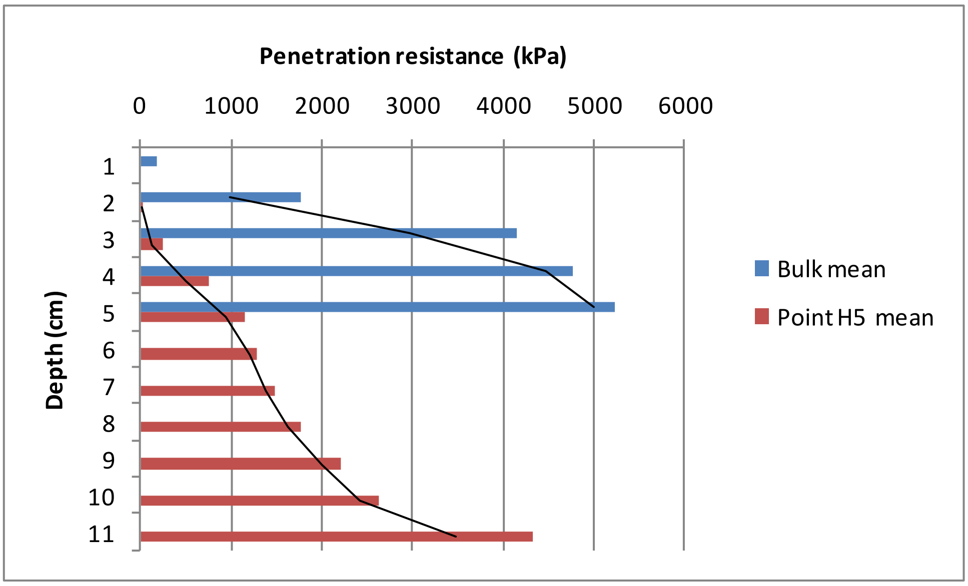

Figure 28 Comparison of the penetration resistance values for the bulk of the samples and those from point H5

The variability in the top 2 cm of the bulk of the samples is ascribed to a number of factors. These are:

1. Presence of Salt Crusts: The presence of the salt crusts leads to thin and soft surfaces through which the cone tip penetrated without significant resistance.

2. Presence of Cracks: Cracks represent areas of low penetration resistance. The depth of these cracks is limited and maximal penetration resistance was encountered once the bottom of the cracks was reached.
3. Uneven Local Surface: The uneven surfaces (at a local and micro scale) led to an uneven surface on which the penetrometer base was placed.

7.1.3. Chemical Analysis Data

7.1.3.1 Background

For agricultural soils in South Africa the typical analysis of cations is conducted using a solution of ammonium acetate buffered at a pH of 7. This procedure provides an accurate indication of the soluble and exchangeable fractions contained in soils of which the pH values are not too acid. For the determination of soluble salts (cations and anions) a saturated paste extract is used in which the soil is left to incubate for 24 hours and the solution extracted under vacuum in Buchner funnels. In all the cases the ions are determined using atomic adsorption spectrometry (flame emission or inductively coupled plasma).

In most cases for agricultural soils the salt levels are low to very low – depending on climate and drainage properties of the soils. In arid evaporative environments the salt contents of soils increase drastically and saturated paste extracts become ineffective due to suppression of solubility of certain salts due to the high ionic concentration of the solution. From the investigations and observations made on Hakskeenpan it was decided to conduct a non-standard procedure where the soil to solution ration would be very small, therefore ensuring the solubilisation of a larger fraction of salts than would have been the case with a saturated paste extract. This decision was confirmed when the initial saturated paste extract for the soils yielded a number of artefacts that could not be explained. This initial data set will not be discussed here.

7.1.3.2 Methodology

A total of 18 samples were collected from 10 localities for chemical analysis (**Figure 29**). Most of these samples were made up of a crust sample collected separately from a subsoil sample. The selected pan samples were subjected to a 1:20 water extract through shaking of the sample for 60 minutes on a reciprocal shaker. The resultant solution was filtered and the cations determined on an atomic absorption spectrometer (AA). The anions were determine on an ion chromatograph (IC). Bicarbonate was not determined.

For each of the samples the electrical conductivity (EC) was determined in the solution obtained from the 1:20 water extract. Although the standard approach is to determine EC in a saturated paste extract it was decided to rather conduct the determination on the 1:20 extract solution for reasons that are discussed under the background section above.

The pH of the samples was determined separately during initial analysis of the samples in a 1:2.5 water suspension. Again, the high salt content of the soils was considered to be problematic as such high ionic concentration solutions often lead to an under reporting of pH values. The main reason for under-reporting is junction potential induced artefacts related to the charge influences on the surface of the glass electrode.

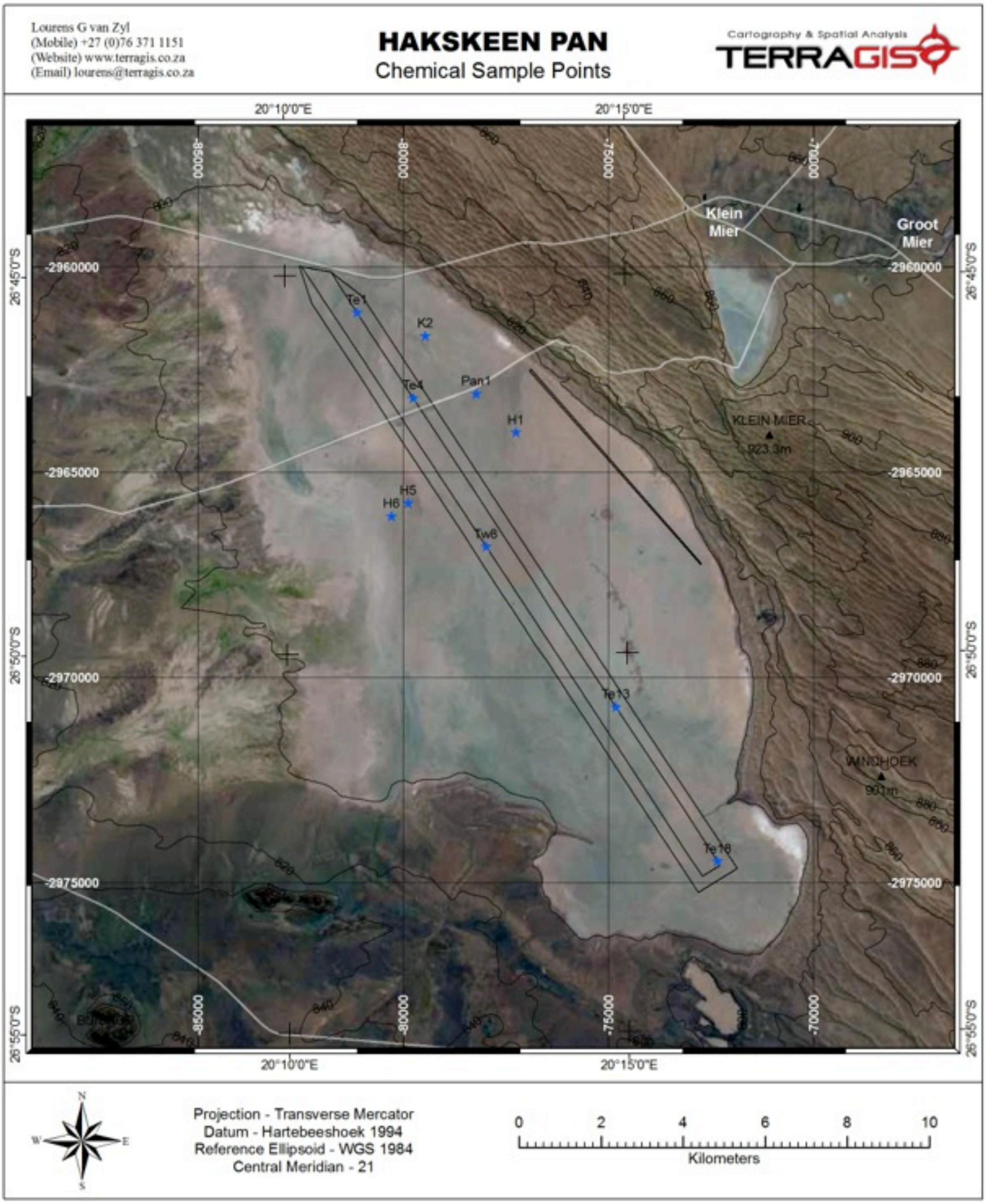

Figure 29 Sample collection points for chemical analysis

Comparison of Ca, Mg, K and Na (as well as anion) levels on an mg kg^{-1} basis is erroneous as they are of differing valence and molar mass. In order to facilitate comparison in the form of ratios the mg kg^{-1} values are recalculated taking into account the cation's (an anion's) valence and molecular mass and the result is an expression of cmol(+) kg^{-1} (or cmol(-) kg^{-1} in the case of anions). Here the concentrations are expressed on an equivalent basis and ratios of the cations can be calculated through the expression of their percentage of an S-value (the sum of the concentrations of Ca, Mg, K and Na). For the anions total values were not determined as the lack of carbonate results are considered to be a limitation. At the pH levels found in the soils the dominant carbonate species vary between HCO_3^- and CO_3^{-2} making a charge concentration comparison with cations problematic. Therefore, the deficit in negative (anion) charge in the summation of the anions is therefore ascribed to the presence of both the above species.

7.1.3.3 Results

The results of the chemical analysis are presented in Tables 3 to 6. The cation concentrations are provided in **Table 5** with the recalculated molar and SAR levels in **Table 7**. The anion concentrations are provided in **Table 6** with the recalculated molar and calculated HCO_3^-/CO_3^{-2} levels in **Table 8**.

The EC values for the soils (**Table 5**) are extremely high and indicative of significant concentrations of soluble salts. The pH values vary between 8 and 9 indicating that the soluble salts in the soils are predominantly alkaline cations with Na being the typical element that would yield the specific values. From the data is clear that Na is the dominant soluble cation in the soils of Hakskeenpan. The degree of dominance is very large indicating that the pan is the lowest point in the landscape and that all water is lost through evaporation. The high levels also indicate a considerable age for the pan as is the fact that the salts are relatively well distributed throughout. The dominance of Na is further emphasized by the contribution it makes in terms of charge equivalence (**Table 6**) – often in excess of 95 %. The lower (but still high) levels of Ca, Mg and K are consistent with evaporative environments.

Table 5 EC, pH and soluble cation results for the soils from Hakskeenpan

Lab No	Field No	Position	EC	pH	Ca^{+2}	Mg^{+2}	K^+	Na^+
			$mS.m^{-1}$		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
K140	K2 Borrel	Crust	290	8,3	204	36	179	23725
K141	K2 Sub	Subsoil	280	9,0	216	24	162	23664
K142	H1C	Crust	970	8,7	2059	133	661	89585
K143	H1	Subsoil	370	8,5	320	11	244	29121
K144	H5	Entire	960	8,7	2612	237	405	80994
K145	H6C	Crust	520	8,0	3532	308	364	38894
K146	H6 0-12	Subsoil	180	8,6	476	23	176	16365
K147	TE1 C	Crust	180	8,3	1182	65	224	14621
K148	TE1 0-15	Subsoil	190	9,0	251	38	261	18029
K149	TE4 C	Crust	710	8,6	1488	58	426	58822
K150	TE4 0-15	Subsoil	300	9,0	212	10	253	22330
K151	TE13 C	Crust	280	8,4	774	47	363	19263
K152	TE13 0-5	Subsoil	280	8,6	196	31	342	20601
K153	TE18C	Crust	350	8,3	766	49	436	25012
K154	TE18 0-5	Subsoil	310	8,9	273	10	358	23449
K155	TW8 C	Crust	390	8,5	1059	75	412	26533
K156	TW8 0-10	Subsoil	170	8,9	159	192	532	14520
K157	Pan 1	Enitre	180	8,4	266	240	890	14791

Table 6 Charge concentration and SAR of the cation results for the soils from Hakskeenpan

Lab No	Field No	Position	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	S-value	SAR
			cmol(c).kg^{-1}					
K140	K2 Borrel	Crust	1,0	0,3	0,5	103,2	104,9	127
K141	K2 Sub	Subsoil	1,1	0,2	0,4	102,9	104,6	129
K142	H1C	Crust	10,3	1,1	1,7	389,5	402,6	163
K143	H1	Subsoil	1,6	0,1	0,6	126,6	128,9	138
K144	H5	Entire	13,1	2,0	1,0	352,2	368,2	129
K145	H6C	Crust	17,7	2,5	0,9	169,1	190,2	53
K146	H6 0-12	Subsoil	2,4	0,2	0,5	71,2	74,2	63
K147	TE1 C	Crust	5,9	0,5	0,6	63,6	70,6	35
K148	TE1 0-15	Subsoil	1,3	0,3	0,7	78,4	80,6	89
K149	TE4 C	Crust	7,4	0,5	1,1	255,8	264,8	129
K150	TE4 0-15	Subsoil	1,1	0,1	0,7	97,1	98,9	129
K151	TE13 C	Crust	3,9	0,4	0,9	83,8	88,9	57
K152	TE13 0-5	Subsoil	1,0	0,3	0,9	89,6	91,7	114
K153	TE18C	Crust	3,8	0,4	1,1	108,8	114,1	75
K154	TE18 0-5	Subsoil	1,4	0,1	0,9	102,0	104,3	120
K155	TW8 C	Crust	5,3	0,6	1,1	115,4	122,3	67
K156	TW8 0-10	Subsoil	0,8	1,6	1,4	63,1	66,9	58
K157	Pan 1	Enitre	1,3	2,0	2,3	64,3	69,9	50

The soluble anions (**Table 5**) exhibit slightly larger variation than the cations in that Cl is dominant with SO_4 being present at significant concentrations as well. The NO_3 levels are also high for natural environments but it again indicates an evaporative environment. The high NO_3 levels are significant from a wetland description perspective and will be addressed later in the report.

Table 7 Soluble anion results for the soils from Hakskeenpan

Lab No	Field No	Position	SO_4^{-2}	NO_3^{-}	F^{-}	Cl
			mg.kg^{-1}			
K140	K2 Borrel	Crust	3365	138	48	21272
K141	K2 Sub	Subsoil	3237	123	36	20844
K142	H1C	Crust	9433	430	8	103805
K143	H1	Subsoil	3746	178	34	30664
K144	H5	Entire	1294	650	4	116024
K145	H6C	Crust	1407	443	3	47878
K146	H6 0-12	Subsoil	1027	266	50	17786
K147	TE1 C	Crust	2421	196	7	17455
K148	TE1 0-15	Subsoil	3535	111	20	16272
K149	TE4 C	Crust	6561	377	5	64286
K150	TE4 0-15	Subsoil	2875	110	30	22073
K151	TE13 C	Crust	2609	234	7	20253
K152	TE13 0-5	Subsoil	2542	237	21	20242
K153	TE18C	Crust	3434	258	7	28027
K154	TE18 0-5	Subsoil	4294	178	20	21453
K155	TW8 C	Crust	2955	327	3	32973
K156	TW8 0-10	Subsoil	2804	109	35	15240
K157	Pan 1	Enitre	1332	8	21	16435

The anion charge concentration (**Table 6**) values parallel the observations for the cations with Cl dominating. However, due to the variable speciation of HCO_3^-/CO_3^{-2} and accurate alignment with cation levels on a mass basis would not be possible. Therefore, the deficit in negative charge when the totalled cation values are compared to the totalled anion values is considered to be made up by variable concentrations of HCO_3^- and CO_3^{-2} – the former being more dominant around neutral pH values and the latter being more dominant at very alkaline pH values. The intermediate values determine din the soils point to a fluctuating but roughly equal concentration of the two species.

Table 8 Anion charge concentration and calculated carbonate results for the soils from Hakskeenpan

Lab No	Field No	Position	SO_4^{-2}	NO_3^-	F^-	Cl	HCO_3^-/ CO_3^{-2} (calculated)
			cmol(c).kg^{-1}				
K140	K2 Borrel	Crust	7,0	0,22	0,25	60,0	37,4
K141	K2 Sub	Subsoil	6,7	0,20	0,19	58,8	38,7
K142	H1C	Crust	19,7	0,69	0,04	292,8	89,4
K143	H1	Subsoil	7,8	0,29	0,18	86,5	34,2
K144	H5	Entire	2,7	1,05	0,02	327,3	37,1
K145	H6C	Crust	2,9	0,71	0,02	135,1	51,5
K146	H6 0-12	Subsoil	2,1	0,43	0,27	50,2	21,2
K147	TE1 C	Crust	5,0	0,32	0,03	49,2	16,0
K148	TE1 0-15	Subsoil	7,4	0,18	0,11	45,9	27,1
K149	TE4 C	Crust	13,7	0,61	0,03	181,3	69,1
K150	TE4 0-15	Subsoil	6,0	0,18	0,16	62,3	30,3
K151	TE13 C	Crust	5,4	0,38	0,03	57,1	26,0
K152	TE13 0-5	Subsoil	5,3	0,38	0,11	57,1	28,8
K153	TE18C	Crust	7,2	0,42	0,04	79,1	27,4
K154	TE18 0-5	Subsoil	9,0	0,29	0,11	60,5	34,5
K155	TW8 C	Crust	6,2	0,53	0,02	93,0	22,6
K156	TW8 0-10	Subsoil	5,8	0,18	0,19	43,0	17,7
K157	Pan 1	Enitre	2,8	0,01	0,11	46,4	20,6

7.1.4 Particle Size Analysis Data

7.1.4.1 Background

A particle size analysis is conducted for soils to determine aspects such as texture (expression of the ratio and percentage composition of sand, silt and clay sized particles) as well as specific size fractions that could impact on dust generation or compaction as well as consolidation potential. The characterization of the sand fraction (coarse to fine fractions) is important in engineering applications as it provides a direct indication of the compaction effort required for specific bulk densities. In conjunction with silt and organic carbon fractions the sand fraction analysis results are often used in erosion modelling. The determination of the clay fraction is important in soil chemical applications as the clay fraction is, due to specific surface and mineralogical characteristics, the chemically reactive fraction in the soil.

7.1.4.2 Methodology

Soil samples were collected at 48 points, mainly along the proposed track boundary on the pan. Two soil samples (one bulk soil sample and one crust sample) were taken at each point for the purpose of elucidating general (bulk) and crust characteristics of the pan soils. Of these samples 11 points (one bulk soil sample and one crust sample) were selected (**Figure 30**) for dedicated soil physical analysis.

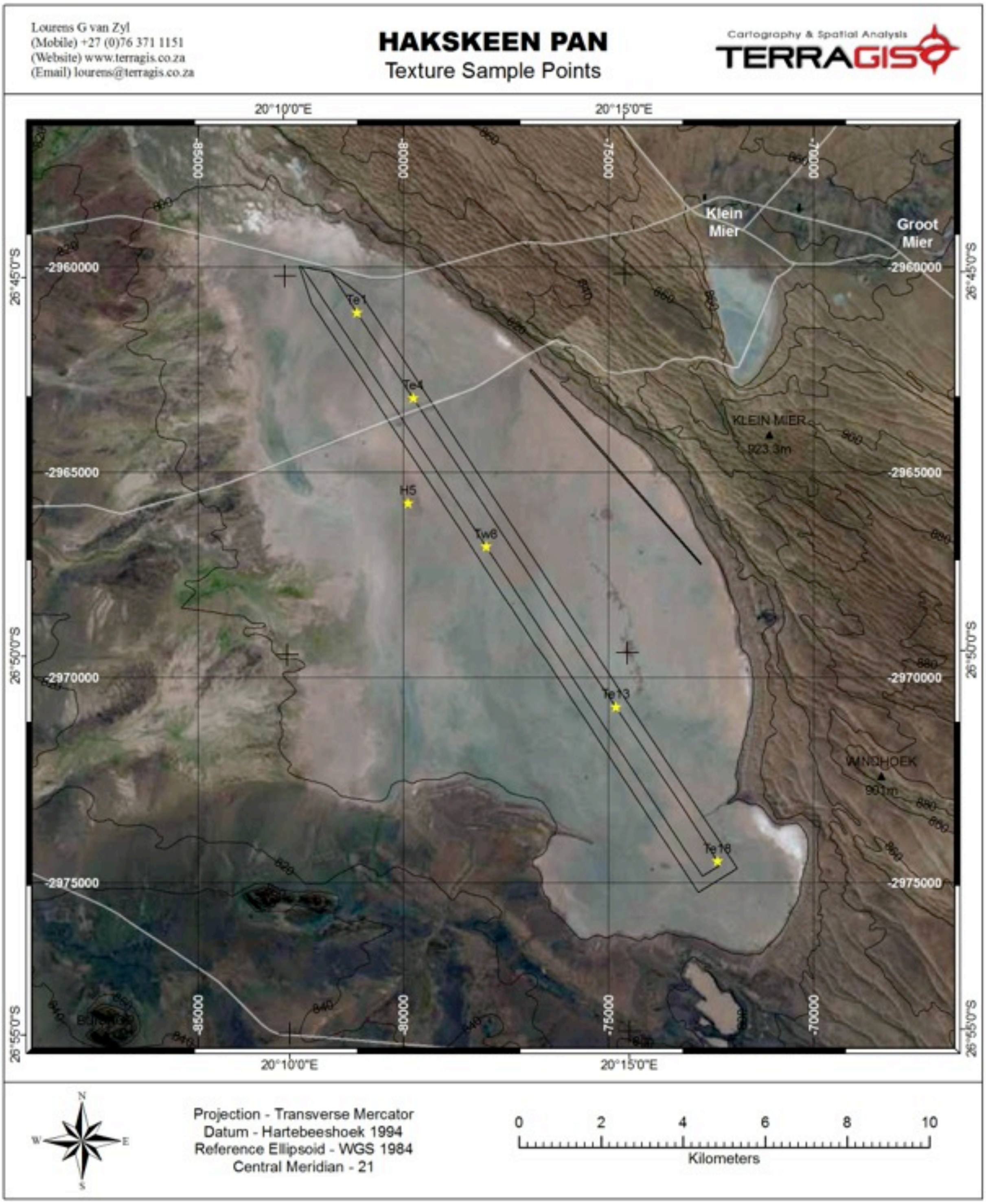

Figure 30 Sample points for soil texture analysis

The texture of the soil samples was determined through the hydrometer method as described by the The Non-Affiliated Soil Analysis Work Committee, 1990. Four sand fractions were determined through a sieve analysis, namely: very coarse sand (2-1 mm), coarse sand (1-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.1 mm) and very fine sand (0.1-0.05 mm). The silt and clay fraction was determined through a settling rate determination based on Stoke's Law with a hydrometer. All results are reported in percentage recovery from a sample of known mass.

The initial analysis of the samples yielded results that were considered to be inaccurate predominantly on the basis of the effect of high ionic concentration solutions on the flocculation of clay and silt particles as well as the mass loss due to solubilisation of salts. The subsequent determination include a pre-treatment step in which the samples were leached with a 0,2 N HCl to remove $CaCO_3$ cementing agents as well as most of the soluble salts. The resultant samples were dried and the "new" mass taken as the entire soil sample for texture determination.

7.1.4.3 Results

The texture results are provided in **Table 9**. The data indicates that the pan is dominated by materials of the fine / very fine sand fraction as well as silt and clay particles. The fine and very sand fractions are larger in the crust samples with a subsequent lower clay and silt content in the crust. This aspect points to the regular addition of fine sand fractions to the pan surface through aeolian processes. The subsoil samples exhibit marked increase in clay content when compared to the crust and this aspect, apart from a "dilution through sand" in the crust also points to the effect of dispersed clay particles washing into subsoil pores and cracks. This observation is in agreement with the penetrometer data that indicate drastic increases in density and hardness in the subsoil materials.

Table 9 Texture analysis and leaching loss of samples from Hakskeenpan

Lab No	Field No	Particle Size Fraction (%)							Weight loss (%) after 0.2N HCl leach *
Lab No	Field No	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	
Lab No	Field No	1-2 mm	0.5-1 mm	0.25-0.5 mm	0.1-0.25 mm	0.05-0.1 mm	2-50 µm	< 2 µm	
K144	H5	0,1	0,7	5,2	36,0	22,6	4,2	31,2	15,0
K147	TE1 C	0,1	0,3	2,1	19,7	18,4	21,6	37,8	6,4
K148	TE1 0-15	0,0	0,2	1,9	14,3	12,9	24,4	46,3	8,3
K149	TE4 C	0,1	0,3	2,0	18,5	14,9	20,0	44,2	14,0
K150	TE4 0-15	0,0	0,3	1,7	12,8	11,9	13,0	60,3	8,4
K151	TE13 C	0,0	0,3	2,4	31,7	20,7	8,8	36,0	6,7
K152	TE13 0-5	0,4	0,4	1,7	16,7	10,0	20,1	50,6	6,9
K153	TE18C	0,2	0,6	2,8	30,3	19,9	11,7	34,5	8,1
K154	TE18 0-5	0,0	0,3	2,1	20,8	11,9	12,8	52,1	8,0
K155	TW8 C	0,1	0,4	2,5	23,7	17,7	14,1	41,5	8,3
K156	TW8 0-10	0,1	0,2	1,2	11,6	8,2	17,9	60,8	7,3

7.1.5 Mineralogical Analysis

7.1.5.1 Background and Methodology

Soil samples were collected for four specific locations for mineralogical analysis (**Figure 31**). The mineralogy of a soil sample indicates the specific weathering and neoformation environment that the specific soil is subject to.

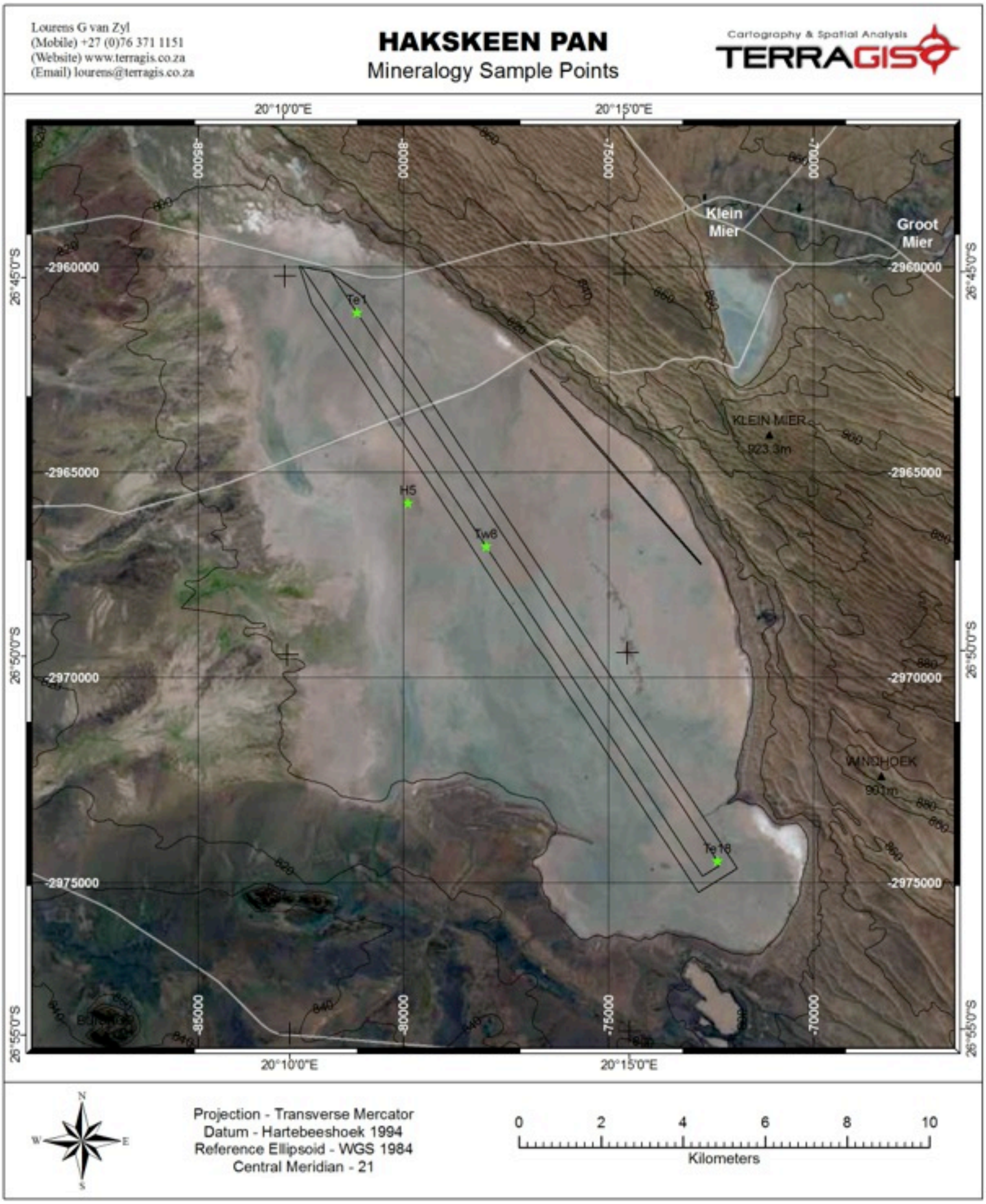

Figure 31 Soil mineralogical samples collected on the pan

Many soil minerals are inherited from parent rock or materials and are referred to as primary minerals. However, due to the specific weathering and chemical environments that make up the wide variation in soil many minerals are newly formed and synthesised in such environments. Most examples pertain to either highly weathered and altered primary minerals or to minerals that form in areas where evaporation of water leads to the supersaturation of the soil solution. These minerals are called secondary minerals. One example of such an environment is the playa surface of Hakskeenpan. The samples were subjected to clay fraction concentration and clay platelet orientation procedures and the mineralogy determined through X-ray diffraction (XRD).

7.1.5.2 Results

The results of the mineralogical analysis are presented in **Table 10**. The data confirms the presence of large concentrations of Na and Cl in the form of high percentages of halite. Most of the other minerals are not very soluble (and some are almost completely insoluble) and their constituents will therefore not have been detected with the chemical analysis of soil samples (section 7.1.3). However, the presence of significant quantities of $CaCO_3$ indicates the presence of large quantities of HCO_3^-/CO_3^{-2} anions, thus confirming the approach followed in section 7.1.3 to assume that the outstanding anions were such. The $CaCO_3$ is almost completely insoluble at the pH levels found in the pan soils and therefore it is considered to have made a very negligible contribution to the soluble Ca determined in the water extracts.

Table 10 Mineralogy analysis results for samples from Hakskeenpan

Sample No	Lab No	Mineral Identification (Rietveld Quantification %)						
		Quartz	Halite	Analcime	Muscovite	Albite	Calcite	Clinochlore
H5	K144	45,4	18,6	6,4	23,9	0,0	4,3	1,5
TE1 C	K147	42,8	1,6	7,8	39,7	0,0	4,6	3,5
TE1 0-15	K148	47,3	1,4	11,1	30,2	0,0	4,1	6,0
TE18C	K153	38,4	7,1	15,6	31,0	0,0	0,8	7,2
TE18 0-5	K154	19,5	2,5	16,1	52,5	1,2	0,9	7,4
TW8 C	K155	26,1	5,6	11,3	49,1	1,1	0,9	5,9
TW8 0-10	K156	27,5	1,0	15,8	43,8	0,0	1,0	10,9
Typical Formula		SiO_2	NaCl	$NaAlSi_2O_6.H_2O$	$KAl_2(AlSi_3O_{10})(F,OH)_2$	$NaAlSi_3O$	$CaCO_3$	$(Mg_5Al)(AlSi_3)O_{10}(OH)_8$

7.1.6 Gravel Fraction Analysis

7.1.6.1 Background and Methodology

Following on wheel tests that were conducted for Bloodhound with a specially constructed rig it was observed that pebbles and gravel fraction material embedded in the pan crust made small pock marks on the aluminium wheel. Due to the variability of the pan in terms of presence of rock and pebbles it was decided to conduct a dedicated investigation onto the presence of such fraction materials along the outer perimeter of the proposed Bloodhound track. The samples were collected at set intervals that conform to the original track points that were pegged for the track (**Figure 32**).

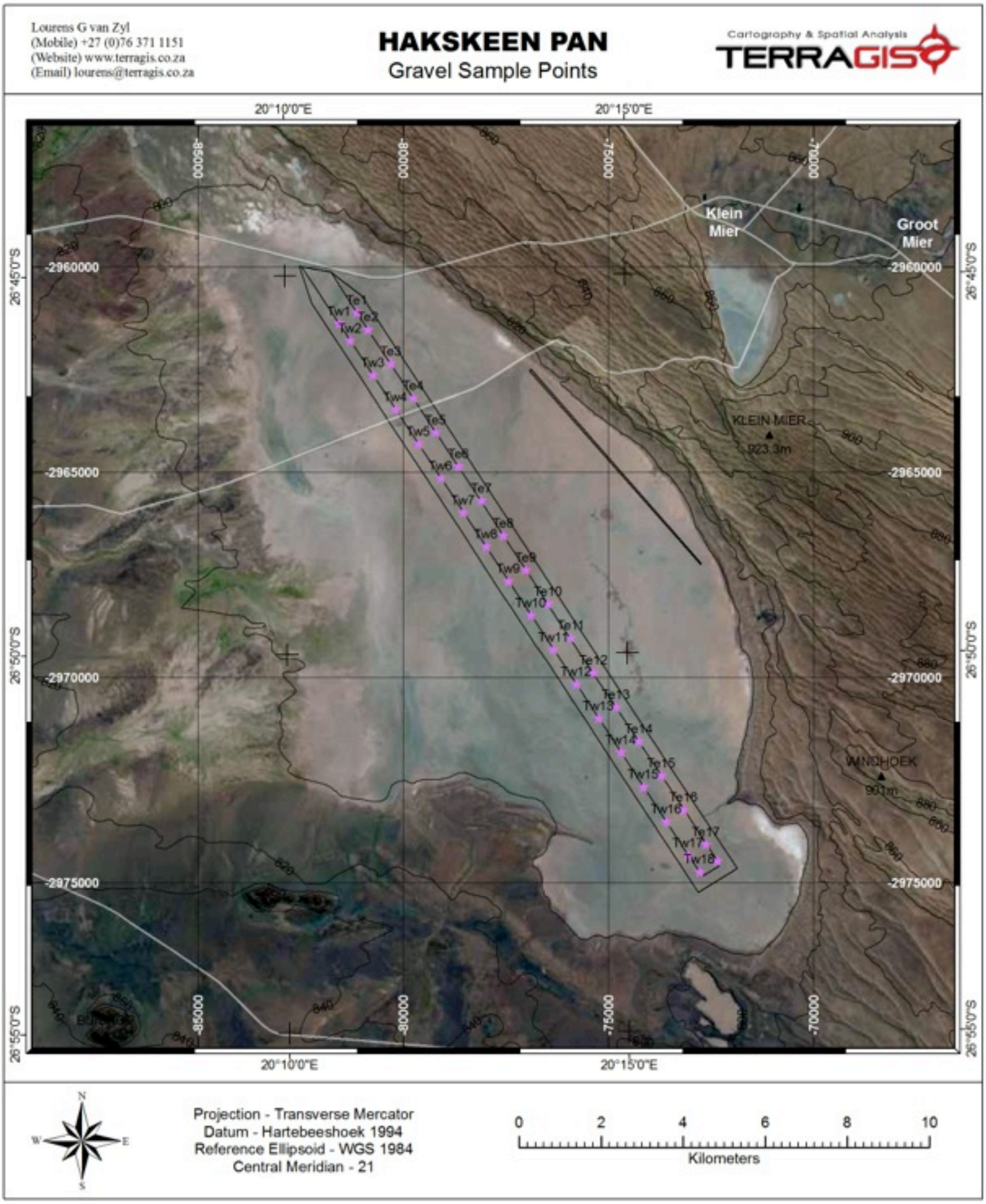

Figure 32 Gravel sample collection points on Hakskeenpan

A core sample was collected at each point with a 100 mm diameter soil auger bucket to a depth of 50 mm. The samples were sieved under running water through a 2 mm sieve with the washing of dispersive fine fraction material through the sieve. All the material that remained on the sieve was quantitatively assessed in terms of weight. However, on a mass basis the values for the gravel were several orders of magnitude smaller than the original soil mass. It was therefore decided to assess the gravel qualitatively ton a visual basis.

7.1.6.2 Results

The results of the gravel determination are presented in **Figures 33** to **34** with the figures referring to the western and eastern boundaries of the track respectively.

Figure 33 Gravel recovered from a soil core at intervals on the western boundary of the track

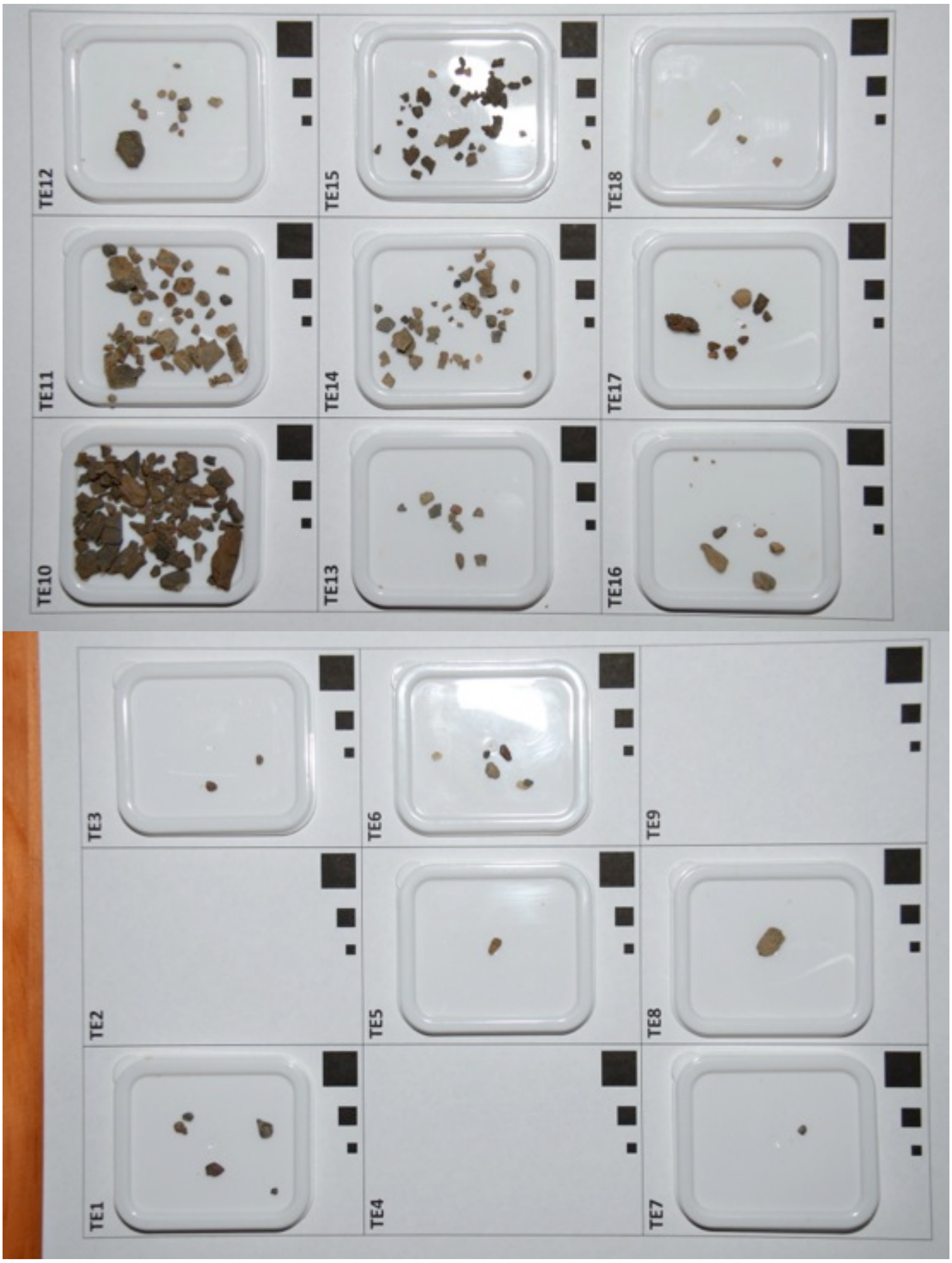

Figure 34 Gravel recovered from a soil core at intervals on the eastern boundary of the track

From the visual presentation of the gravel fraction it is evident that the TW1 to TW8 and TE1 to TE9 points fall into an area with a near absence of gravel. A significant increase in the gravel fraction is encountered at both points TW10 and TE10 with a slight tapering off in gravel content towards the southern most points.

The presence of the gravel poses a direct risk to any vehicular activity that is characterised by high speed and obliteration of the pan crust with the gravel particles essentially having the potential to act as "shrapnel". This aspect will not be discussed further in this section but will be elaborated upon during the risk assessment

7.1.7 Speedweek Track Investigation

7.1.7.1 Background

In preparation for the 2013 Speedweek event a private company (Dust-a-side) with dust suppression technology applied one of their products (detail subject to non-disclosure agreement) to a 7km long strip on the side of the pan (**Figure 35**). During the Speedweek event it was evident that the dust suppression product was only partially successful and that it degraded rapidly in the dusty and salty soil environment. The application of such materials was not repeated for the 2014 event.

Figure 35 Speedweek track on the eastern edge of the central part of Hakskeenpan

7.1.7.2 Methodology

The investigation into the nature and impact of the material applied to the pan was conducted in two phases namely: 1) intensive consultation with representatives from Dust-a-side regarding the composition and effect of the product and 2) a dedicated field investigation into the effects of the material and vehicle activities on the Speedweek track. It must be emphasized here that the nature of the product applied as well as its specific make-up is subject to commercial rights and as such the author had to enter into a non-disclosure agreement with Dust-a-side to obtain access to the necessary information. The specific information that will be communicated in this report is not subject to the agreement. Any material evidence that is subject to the non-disclosure agreement is packaged in such a way that the author provides informed and independent comment without divulging any critical information of commercial value.

7.1.7.3 Results

The material data regarding the product that was used on the track indicate that the material is for all intents and purposes inert in water environments. As such a key component is used, in combination with other materials, for the sealing of fish tanks and other clean water reservoirs. Confidential analysis data indicate the absence of any PAHs of concern.

During the field investigation in August 2014 it was found that very little of the material still persisted on the track (**Figure 36**). The material was present predominantly in what appeared to be flocculated and rolled clumps (**Figures 37**). The flocculated or clumpy appearance is consistent with carbon-based high viscosity materials in an environment with a very high ionic strength (such as the pan surface during events of sporadic wetting). It is therefore concluded here that the materials are ineffective in the specific environment for dust suppression, but due to the lack of any detrimental compounds, the material is also considered to be inert in terms of chemical impacts on the pan. This assessment is based on the verified data provided by Dust-a-side that indicates no detrimental compounds.

Figure 36 Speedweek track (2013) that was treated with a dust suppressant prior to the event

Figure 37 Remnants of the dust suppressant that was applied prior to the event for the Speedweek track (2013)

The vehicle impacts in terms of rutting appears to be more durable in that there was still a distinct depression along the track during the site visit. This aspect is considered to be temporary but the investigation points to a longer time requirement for "natural rehabilitation" through wetting, swelling and drying cycles of the crust material. This aspect will be addressed further in the sections to follow later in the report.

7.1.8 Bloodhound Track Preparation Investigation – Removal of Stone

7.1.8.1 Background

The track preparation for the Bloodhound SSC record attempt involved the removal of stones and pebbles by hand as well as limited excavation and removal of embedded, but protruding through the pan surface, rock and boulders. This process was started in 2009 and the final stages of preparation are said to be completed by the onset of the rainy season in 2014. According to Mr Nico Fourie (NCPG) the total volume of material removed by hand is 22968 m^3 and by plant through digging is 1200 m^3. According to anecdotal information the excavated holes were filled with a mixture of pan soil and gravel material. The in-filled material was not subjected to intensive compaction (under optimal moisture content) but rather was left to settle and consolidate naturally. After the filling of the pits the material was graded to provide a level surface.

7.1.8.2 Methodology

The Bloodhound SSC track was assessed during a number of visits spanning from 2009 to 2014. The assessment was only visual and was conducted along transects of driving only. This author therefore does not have any first hand information on the geographical distribution and extent of the excavated holes only along driving transects. Neither does this author have any information on the bearing capacity, shear strength, bulk density or effective consistence comparisons between natural pan soil and in-filled material. This aspect will be addressed further in risk assessments for the project in later documents.

7.1.8.3 Results

The extent, scale and possible implications of excavation and in-filling is provided by **Figures 38** to **42**.

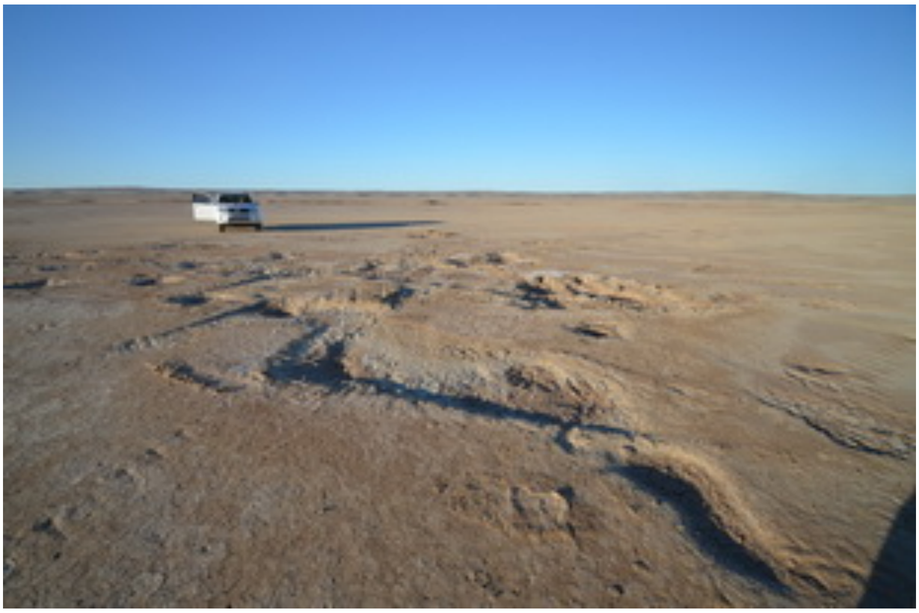

Figure 38 Excavated pits on Hakskeenpan

Figure 39 Excavation process on Hakskeenpan


Figure 40 In-filling and levelling process on Hakskeenpan


Figure 41 Completed in-filling and graded section on Hakskeenpan

Figure 42 Bearing capacity variation and consolidation under distributed loads (wide rubber tyres) on in-filled and graded sections on Hakskeenpan

From the sequence of images it is apparent that there are large trafficability challenges associated with the in-filled sections. The distribution of the excavated areas is as follows: 1) from the TE1/TW1 to the TE12/TW12 markers there has been no excavation; 2) from the TE12/TW12 to TE16/TW16 markers there has been sporadic excavation and in-filling; and 3) from the TE16/TW16 to beyond the TE18/TW18 markers there has been regular excavation and in-filling. The above is the full extent of information that is currently available on the distribution and intensity of excavation and in-filling activities. This aspect will be addressed in further detail in later reports dealing with risk assessments of the proposed activities on the pan. A dedicated proposal for a ground penetrating radar (GPR) pavement assessment as been made and will be elaborated upon in related reports to follow.

However, from a seepage of water and groundwater impact perspective the impacts are considered to be negligible as the high Na levels lead to dispersion of clays and subsequent sealing of cracks and voids. It is envisaged that the in-filled material will consolidate over time to yield a pan surface in the localised areas very similar to the original and surrounding pan surface.

7.1.9 Bloodhound Track Preparation Investigation – Removal of Old Causeway

7.1.9.1 Background

The original road from Mier to Philandersbron ran across Hakskeenpan over a causeway that was built from shale materials sourced from borrow pits on the pan (**Figure 43**). For a section of the causeway along the Bloodhound track the causeway has been removed, the material returned to the borrow pits and the area graded.

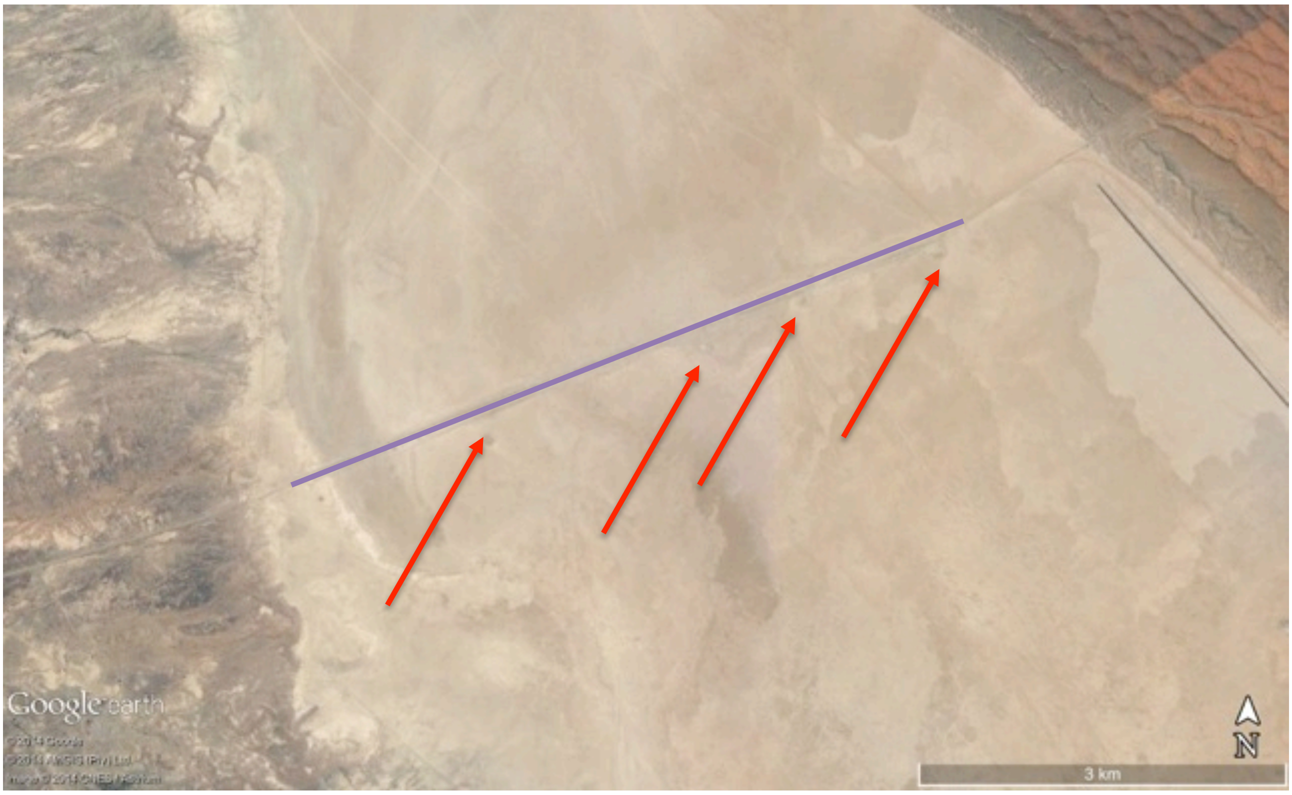

Figure 43 Position of the original causeway (purple line) and borrow pits (red arrows)

7.1.9.2 Methodology

The area along the causeway that was removed was investigated in the field and photographs were taken of relevant aspects.

7.1.9.3 Results

The removal of the old causeway has had no detrimental effects on the pan other than the original impacts of the causeway construction itself. However, the crust and soil characteristics in the old causeway footprint are significantly different to the background pan soil. As such the risk of the difference will be addressed in reports that will follow on this one.

7.2 Aerial Photograph Interpretation

From the aerial photograph interpretation the endorheic pan system of Hakskeenpan is clearly distinguishable (**Figure 44**). It is also apparent from the satellite images an extensive area to the west of Hakskeenpan acts as a catchment for the pan itself.

7.3 Terrain Unit Indicator

From the contour data a topographic wetness index (TWI) (**Figure 45**) was generated for the site. This aspect confirms the endorheic nature of the pan system.

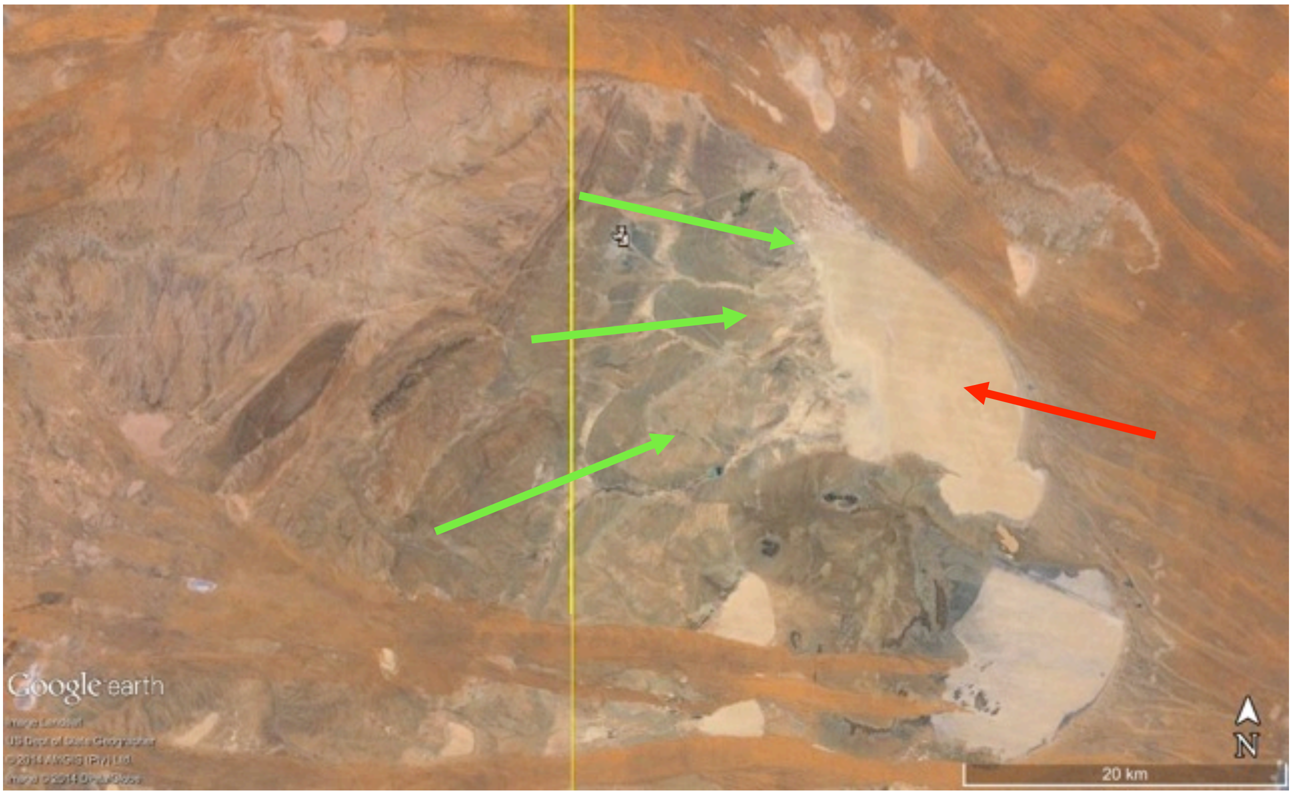

Figure 44 Hakskeenpan (red arrow) with catchment area (green arrows) extending into Namibia

7.4 Soil Form and Soil Wetness Indicators

From the detailed soil survey conducted for the site (as reported earlier) no hydromorphic soils were found. The only soils found in the pan and catchment are arid soil forms without redox morphology. All the soil features point to periodic influences of water but the expression of prolonged saturation in the form of redox indicators is lacking. In addition, the presence of relatively high levels of NO_3 on the pan indicates arid conditions in which there is not enough saturation (both in terms of intensity and duration) to reduce NO_3 compounds. This is a basic first step requirement for redox morphology to develop Therefore, there is no support for considering the pan a wetland area from a soil form or soil wetness indicator perspective.

7.5 Artificial Modifiers

The historical human impacts that altered and modified the pan system have been identified in previous sections of the report. These are limited to the old causeway, a relatively recent tar road in the northern section and low intensity grazing activities on the outer edges of the pan system. Recent impacts are limited to the excavation and in-filling of holes, removal of a section of the old causeway and dust suppressant addition to the pan surface over narrow 7 km long stretch.

Apart form the above human induced modifiers several natural modifiers can be identified in the form of erosion, sedimentation, salt migration and surface cracking. These, however are all natural and part of natural cycles and are therefore not considered in further detail.

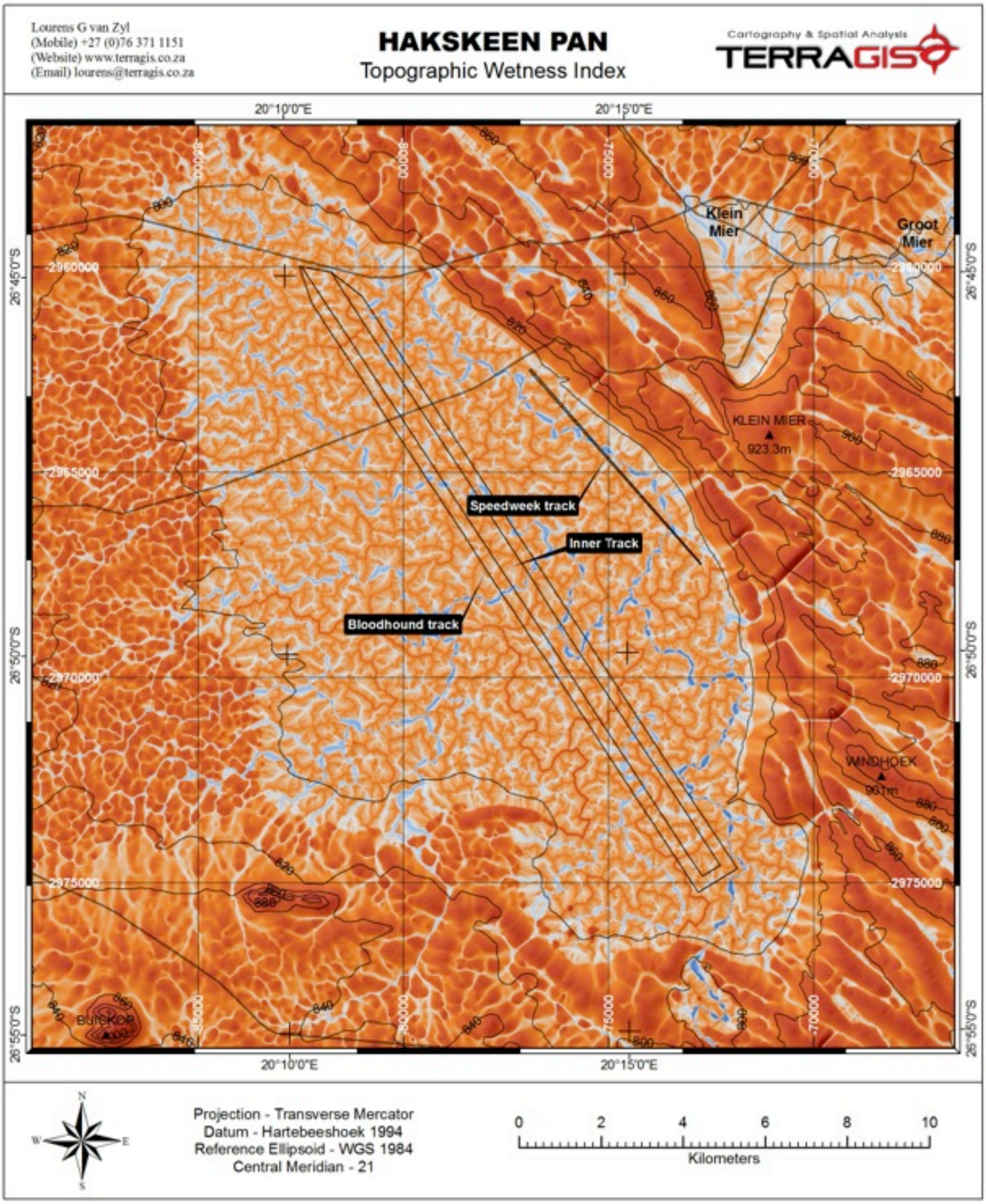

Figure 45 Topographic wetness index (TWI) of the Hakskeenpan area

8. CONCLUSIONS AND RECOMMENDATIONS

The soil, topographic and site visit data generated for the pan indicates the following:

1. The pan floor consists of dominantly slit and clay fraction minerals as well as a fraction of sand that is in all probability of wind-blown origin.
2. The chemistry of the pan soils indicate an absolute dominance of evaporative water losses. This is evident from the dominance of Na and Cl and the main soluble elements. The fact that Na is the dominant cation by many orders of magnitude leads to the conclusion that the pan soils are highly dispersive. This conclusion is confirmed through the morphological soil data obtained during the investigation.
3. The soil mineralogy data confirms the dominance of halite (NaCl) as secondary mineral (formed in situ due to weathering of parent materials) with quartz being the dominant primary mineral (inherited directly from parent materials).
4. The penetrometer data as well as the morphological data indicate the presence of a brittle crust varying from 1 to 2 cm thick on the surface with a much denser and harder subsoil. The morphological characteristics of both these horizons are consistent with the dominance of clay and silt fraction materials and Na.
5. The southern section of the pan is characterised by tillite outcrops. Most of these have been dug up and the rock material removed for the purpose of the Bloodhound SSC project. The resultant pits in the crust have been filled in with pan soil and rock material. Sodium dominated clays are not suited to mechanical compaction as the Na imparts a distinct swelling of clays upon wetting. The filled-in areas therefore have a very varying density and are not the same as the undisturbed pan soil in terms of load bearing capacity. This aspect requires a dedicated soil mechanics and load bearing investigation to determine the effects of the vehicle during runs across such areas.
6. The materials used for dust suppression on the Speedweek track are deemed inefficient as the materials started coagulating and degrading in the high salt and clay environment. The contents of the materials (subject to a non-disclosure agreement due to commercial rights) are deemed, in my professional opinion, to be innocuous regarding environmental impacts on the pan. The materials contain no readily soluble pollutants and the main ingredient is often used as a sealant for water reservoirs with or without aquatic species.
7. An old causeway is present roughly in the centre of the pan. This causeway has been removed for the purposes of the Bloodhound SSC project as well as due to the presence of a more recently constructed tar road through the northern portion of the pan. The removal of the causeway and road-bed materials is considered a positive impact on the pan as it re-establishes hydrological connectivity between the southern and northern sections. The risk associated with the removal of material is predominantly the poor state of roads outside of the pan under wet conditions if these materials are to be used for road construction. Due to the high Na content these materials are highly dispersive and will therefore erode rapidly and hamper vehicle traction during wet conditions.

The classification of the pan as a wetland is a function of the hydrology of the pan system and surrounding landscape as well as the fact that such systems often support aquatic species. At first glance it would not be evident that Haakskeenpan does support such species. However, the pan receives rainfall in summer and in some areas water may persist on the surface for periods exceeding one month. Under these conditions a range of organisms appear and these make up food resources for migrating birds. There is however a dearth of information regarding the ecological characteristics of the pan as mobility is extremely impaired during periods of inundation.

An interesting aspect of the chemistry of the soils is the fact that the N levels are very high. In order for an area to qualify as a wetland it must exhibit signs of chemical reduction in the soils. Without going into a protracted discussion the essence is that nitrates (as are dominant on the pan) would disappear before the development of morphological signs of Fe redox morphology. As this does not seem to be the case it begs the question as to whether the standard wetland definition as contained in the National Water Act can be applied to arid pan systems. In this regard a specific definition and description of such systems can be generated based on sound empirical investigation.

The following aspects are strongly recommended:

1. Detailed investigation into the biophysical properties of the soils of the pan and the surrounding landscape to shed light on hydrogeochemical functioning of the pan system and its ability to recover naturally from increased human activity.
2. Continuous monitoring of the impacts of vehicle activity on the pan in terms of physical alterations to the pan surface as well as recovery time of such impacts in such a dry environment.
3. Dedicated assessment of the invertebrate ecology of the pan during wet periods to elucidate the ecological functioning.
4. Impacts of earthworks and track preparation activities on the recovery of the pan as well as on vehicle performance.
5. Critical assessment of safety considerations of vehicles as the alteration of the pan surface remains untested regarding these influences of high speed vehicle performance.

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