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Soil and Water Science

SOIL, AGRICULTURAL POTENTIAL AND LAND CAPABILITY ASSESSMENT FOR THE DUEL COAL PROJECT, NEAR LOUIS TRICHARDT, LIMPOPO PROVINCE

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DECLARATION

I, Petrus Stephanus Rossouw, declare that I –

- act as an independent specialist consultant in the field of soil science;
- do not have and will not have any financial interest in the undertaking of the activity, other than remuneration for work performed in terms of the Environmental Impact Assessment Regulations, 2006;
- have and will not have any vested interest in the proposed activity proceeding;
- have no, and will not engage in, conflicting interests in the undertaking of the activity;
- undertake to disclose, to the competent authority, any material information that have or may have the potential to influence the decision of the competent authority or the objectivity of any report; and
- will provide the competent authority with access to all information at my disposal regarding the application, whether such information is favourable to the applicant or not.

PETRUS STEPHANUS ROSSOUW

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THE DUEL COAL PROJECT: SOIL, AGRICULTURAL POTENTIAL AND LAND CAPABILITY ASSESSMENT

1. TERMS OF REFERENCE

Jacana Environmentals cc contracted Rossouw and Associates – Soil and Water Science (Pty) Ltd to conduct a soil, agricultural potential, land use and land capability study, with emphasis on the impact of coal mining and related activities on the soil environment, for the so-called The Duel Coal Project.

2. INTRODUCTION

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2.1. Survey Area Location

The study area is situated on the Remaining Extent of the farm The Duel 186-MT, approximately 40 km from Louis Trichardt in the Limpopo Province. The size of the area is 885 ha. **Figure 1** is a locality map. **Figure 2** is satellite photo indicating the mining right application (MRA) area**.**

2.2. Agricultural Potential Background

The assessment of agricultural potential rests primarily on the identification of soils that are suited to crop production. In order to qualify as high potential soils they must have the following properties:

- Deep profile (more than 500 mm) for adequate root development,
- Deep profile and adequate clay content for the storing of sufficient water so that plants can weather short dry spells,
- Adequate structure (loose enough and not dense) that allows for good root development,
- Sufficient clay or organic matter to ensure retention and supply of plant nutrients,
- Limited quantities of rock in the matrix that would otherwise limit tilling options and water holding capacity,
- Adequate distribution of soils and size of high potential soil area to constitute a viable economic management unit, and
- Good enough internal and external (out of profile) drainage if irrigation practices are considered. Drainage is imperative for the removal (leaching) of salts that accumulate in profiles during irrigation and fertilization.

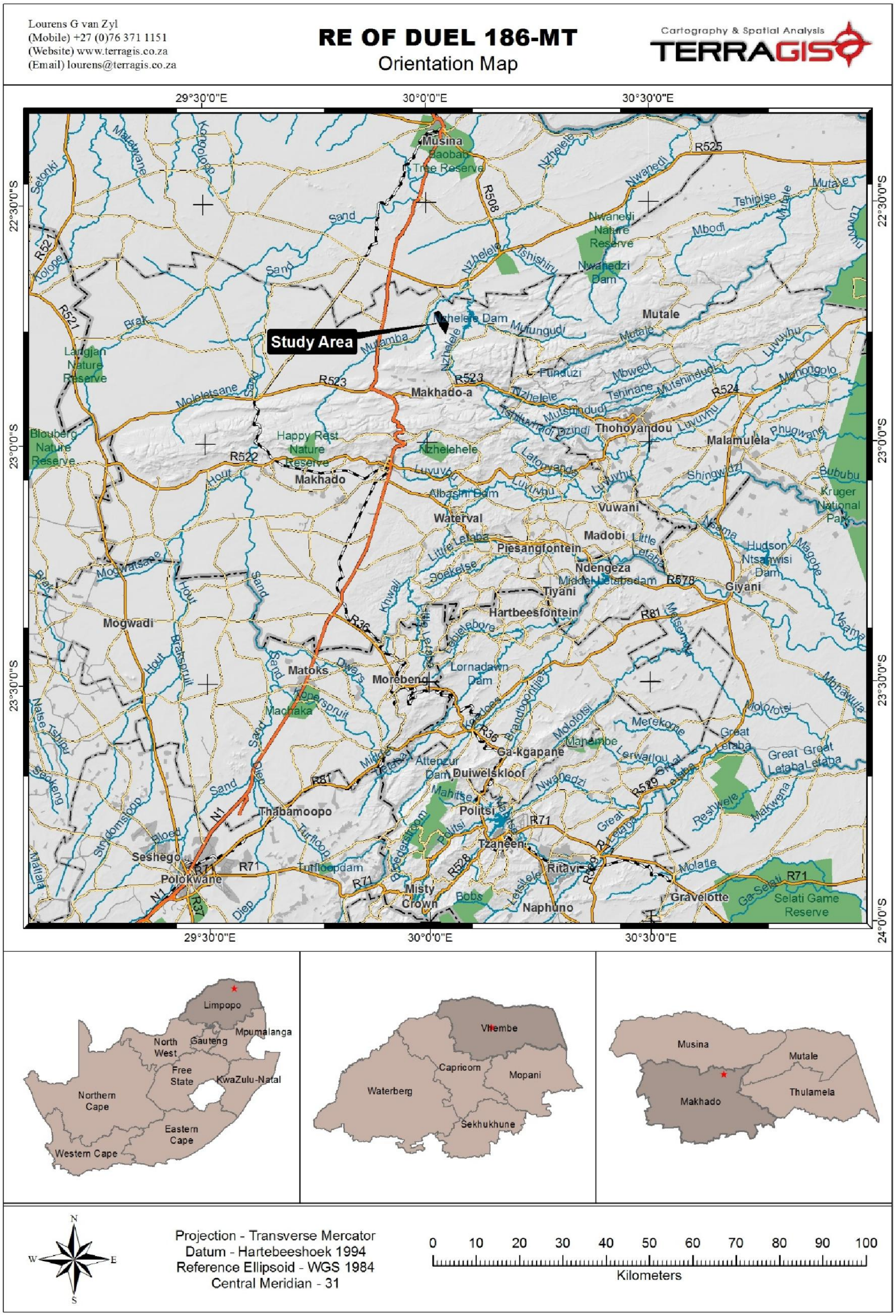

Figure 1 Locality map

Figure 2 Image indicating the mining right application area

In addition to pedological characteristics, climatic and soil chemical characteristics need to be assessed to determine the agriculture potential of a site. The latter entails determining the soil fertility levels of the soils, as well as an assessment of any factors that may inhibit plant growth. Saline and other forms of soil pollution, such as heavy metal contamination and acid/neutral/alkaline mine drainage, can adversely affect the production potential of the area.

It is especially important to determine soil salinity in areas of irrigation as poor irrigation scheduling often leads to a built up of salts in the soil. In these cases the sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are used to measure soil sodicity. Soil pollution through acid/neutral/alkaline mine drainage or other industrial activities was not assessed as the area has never been mined and industrial activity was no encountered.

The chemical characteristics of the soils of the area can be amended with soil ameliorants such as lime, organic matter and fertiliser. The more important factor governing the agricultural potential and land capability of the area is that of pedological characteristics as noted above.

Land capability classes were determined using the guidelines outlined in Section 7 of The Chamber of Mines Handbook of Guidelines for Environmental Protection (Volume 3, 1981). The Chamber of Mines pre-mining land capability system was utilised, given that this is the dominant capability class classification system utilized in the mining and industrial fields. The following land capability classes are identified:

- Wetland:
    - Land with organic soils; or
    - A horizon that is gleyed throughout more than 50 % of its volume and is significantly thick, occurring within 750mm of the surface.
- Arable Land:
    - Land, which does not qualify as a wetland;
    - The soil is readily permeable to the roots of common cultivated plants to a depth of 750mm;
    - The soil has a pH value of between 4,0 and 8.4;
    - The soil has a low salinity and SAR;
    - The soil has a permeability of at least 1,5-mm per hour in the upper 500-mm of soil;
    - The soil has less than 10 % (by volume) rocks or pedocrete fragments larger than 100-mm in diameter in the upper 750-mm;
    - Has a slope (in %) and erodibility factor (K) such that their product is <2.0; and
    - Occurs under a climatic regime, which facilitates crop yields that are at least equal to the current national average for these crops, or is currently being irrigated successfully.
- Grazing land:
    - Land, which does not qualify as wetland or arable land;
    - Has soil, or soil-like material, permeable to roots of native plants, that is more than 250-mm thick and contains less than 50 % by volume of rocks or pedocrete fragments larger than 100-mm; and

    - Supports, or is capable of supporting, a stand of native or introduced grass species, or other forage plants, utilizable by domesticated livestock or game animals on a commercial basis.
- Wilderness land:
    - Land, which does not qualify as wetland, arable land or grazing land.

3. METHODOLOGY

3.1. Soil Survey

The study area was traversed and observations regarding the landscape and occurrence of soils were made continuously. Specific soil characteristics were noted and logged. Augering was done to a maximum of 1500 mm. In many cases the occurrence of rocks hampered deep augering. The soils were classified according to the South African Soil Classification System (MacVicar*et al.,* 1994). Specific emphasis was placed on the identification of the following aspects as these aid in an assessment of the pedohydrology and agricultural potential of the area:

- Fe(II)/Fe(III) layered double hydroxides (green rusts) that is indicative of moderate conditions of reductions (Eh values of -0.5 to +0.5 V) and usually encountered in wetland soils;
- The accumulation of ferrihydrate, lepridocrosite, goethite and hematite in vesicular nodules (mottling) owing to the reduction of Fe(III) to Fe(II), under conditions of a fluctuating water table, which leads to the mobilisation of Fe;
- The occurrence of grey colours, especially where mottling is not present, as a further indication of Fe mobilisation and semi-permanent or permanent conditions of water saturation;
- The occurrence of bleached soil horizons that indicate lateral drainage of water;
- The occurrence of gleyed soil horizons that can be indicative of a permanent water table;
- The occurrence of uniform red and yellow colouration that is indicative of well drained areas;
- Signs of Mn mobilisation and/or precipitation as an indication of a fluctuating water table;
- The occurrence of smectite clays that lead to swelling and shrinking characteristics in soil and is conducive to saturated flow in the dry state but not in the wet state;
- Textural changes, and other aspects, in the soil profile that will influence saturated and unsaturated flow of water.
- Occurrence of layers that impede water flow.

Soils that display morphological indicators of temporary, seasonal or permanent wetness within 500 mm of the soil surface, together with those subject to prolonged and permanent saturation, make up the area that is described as hydromorphic or wetland soils (Department of Water Affairs and Forestry, 2005). This criteria overrides the criteria stipulated by the Land Capability classification system (section 3.1.) which stipulates that more than 50 % of the soil horizon must be gleyed.

3.2. Rainfall data

Rainfall data for the area was obtained from the Department of Agriculture (AGIS) and is indicated in **Figure 3**. The site falls within the 201 to 400 mm rainfall area.

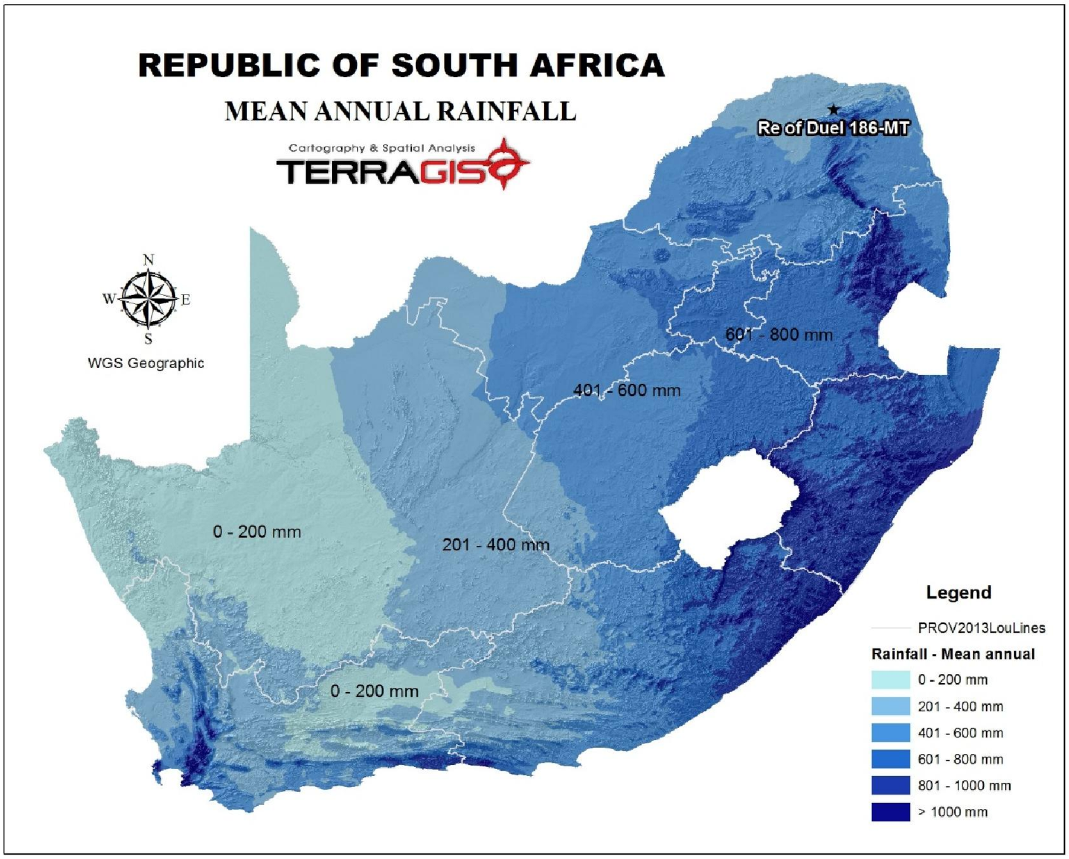

Figure 3 Rainfall map

3.2. Chemical and Physical Analyses of Soil Samples

Representative soil samples were collected and subjected to the following analyses:

- Soil pH is determined in the supernatant liquid of an aqueous suspension of soil after having allowed the sand fraction to settle out of suspension. The determination of the pH for the samples collected on the site was conducted in a KCl solution. pH(KCl) measured slightly lower that pH (H_2O) but is a more accurate measure of soil pH and therefore favoured by many soil science labs.
- Water soluble major cations and anions were determined in a saturated paste extract.
- Exchangable/weakly complexed major cation levels were determines through extraction with a NH_4-Acetate.
- Plant available P was determined using the Bray 1 method.
- Organic matter fraction was determined using the Walkley-Black method.

- Soil texture was determined through sedimentation with a hydrometer and with sieves.

It was decided not to determine NO_3, NO_2 or NH_4 content of the soils as these ions must be analysed for within 24 hours after sample collection for accurate results. The levels of N-compounds are expected to be low.

The following soil chemical aspects were calculated:

- Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP): Measures soil sodicity which is an indication of the hazard posed by irrigation in terms of clay dispersion and the subsequent inhibition of water infiltration.
  - Sodium adsorption ratio is calculated as follows:

    $$SAR = [Na+] / \{([Ca2+] + [Mg2+]) / 2\}^{1/2}$$

    where sodium, calcium, and magnesium are in milliequivalents/liter and calculations are based on data derived from a saturated paste extract.
  - The exchangeable sodium percentage is calculated as follows:

    $$ESP = \text{Exchangeable } \{(Na)/(Ca + Mg + K + Na)\} \times 100$$

  where calculations are based on the ammonium acetate extraction data set

The Wischmeier, Johnson and Cross (1971) nomograph uses the following parameters that is regarded as having a major effect on soil erodibility and stockpile sloping:

- The mass percentage of the fraction between 0.1 and 0.002 mm (very fine sand plus silt) of the topsoil.
- The mass percentage of the fraction between 0.1 and 2.0 mm diameter of the topsoil.
- Organic matter content of the topsoil. This “content” is obtained by multiplying the organic carbon content (in percentage – Walkley Black method) by a factor of 1.724.
- A numerical index of soil structure.
- A numerical index of the soil permeability of the soil profile. The least permeable horizon is regarded as horizon that governs permeability.

The erosion risk is based on the product of the slope (in percentage) and the K-value of erodibility (determined from the Wischmeier, Johnson and Cross (1971) nomograph). This product should not surpass a value of 2.0 in which case soil erosion becomes a major concern

3.3. Choice of Laboratory

The samples were analysed by the soil science laboratory at the University of Pretoria. This specific laboratory was used due to the fact that it is focussed on well-established soil analysis procedures and in this sense forms part of a laboratory proficiency scheme (AGRILASA). The laboratory is not SANAS accredited mainly due to the fact that none of the well-established soil analysis protocols and procedures for agricultural purposes have yet been assessed and included in the SANAS accreditation programme. It is hoped that this will happen in the near future.

3.4. 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) (Land Type Survey Staff, 1972 – 2006). 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 (MacVicar, C.N. et al. 1991).

3.5. Impact Tables

The following elucidates the logic behind the impact tables.

3.5.1. Nature of the Impact

The impact of the mining and other activities on the soil environment is classified as either positive or negative. A positive impact is regarded as a benefit to the soil environment while a negative impact is regarded as a detrimental impact.

3.5.2. Type of Impact

The impact on the soil environment is classified a direct, indirect or cumulative. The impact classification can be summarised as:

- *Direct Impact* is a reaction that is caused by the direct interaction of a planned action or activity on the receiving environment, e.g. the discharge of water into a water stream, the discharge of waste material onto land or the excavation of a pit for mining purposes. This type of impact is usually in close proximity to the action or activity.
- *Indirect Impact* is a reasonably foreseeable reaction that is indirectly caused as a result of a planned action or activity, the effects/ impacts are usually later in time and farther removed from the action or activity. Examples include rainwater leaching through a discard dump to pollute underground water, changes in patterns of land use, changes in population density or growth rate.
- *Cumulative Impact* is the impact on the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable future actions, regardless of undertakings by other industries, mines, developments or persons. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

3.5.3. Grouping of the Impact

Two groups of impacts can occur:

- Routine Impacts that occur as a result of expected and planned project activities; and

- Non-Routine Impacts that occur as a result of an unexpected and unplanned project activity. Usually occurs in emergency events or unforeseeable natural events such as flooding after an exceptionally heavy rainfall in a usually dry environment.

3.5.4. Certainty or Probability that the Impact will occur

Table 1 summarises the probability classes.

Table 1 Certainty classes

Certainty	Description	Rating
Unlikely	Less than 40% sure that the impact or benefit will occur.	1
Possible	Between 40% and 70% sure that the impact or benefit will occur.	2
Probable	Between 70% and 90% sure that the impact or benefit will occur.	3
Definite	Over 90% sure that the impact or benefit will occur.	4

3.5.5. Spatial Extent

The extent of the impact refers to the spatial scale of the impact or benefit of the proposed project and the area over which it extends. **Table 2** summarises the classes associated with the spatial extent of the impact.

Table 2 Spatial extent classes

Certainty	Description	Rating
Site specific	Effects felt within the site boundary area.	1
Local	Effects are felt within 5 km radius from the site boundary area.	2
Regional	Effects are felt within a 50 km radius from the site boundary area.	3
National	Effects are felt beyond a 50 km radius from the site boundary area within South Africa.	4

3.5.6. The Duration of the Impact

The duration of the impact refers to the time scale of the impact or benefit in terms of the period of time that the surrounding environment will be affected or altered by the proposed project as summarised in **Table 3**.

Table 3 Duration classes

Certainty	Description	Rating
Short term	Less than five years	1
Medium term	Between five and 20 years	2
Long term	Between 21 and 40 years	3
Permanent	Permanent	4

3.5.7. Reversibility of the Impact

Reversibility refers to the time it would take to reverse or undo the impact under discussion. These classes are summarised in **Table 4**.

Table 4 Duration classes

Certainty	Description	Rating
Short term	Less than five years	1
Medium term	Between five and 20 years	2
Long term	Between 21 and 40 years	3
Permanent	Permanent	4

3.5.8. Severity or Intensity of the Impact

The severity is the attempt to quantify the magnitude of the impact whether positive or negative, which is associated with the proposed project. The scale therefore accounts for the extent and magnitude but is subject to the value judgement as illustrated in **Table 5**.

Table 5 Severity classes

Status	Severity	Description	Rating
Negative	Slight	1. Minor deterioration, 2.Short to medium term duration, 3.Mitigation is easy, cost effective and quick.	1
	Moderate	1. Moderate deterioration, 2. Medium to long term duration, 3. Fairly easy to mitigate.	2
	Severe	1. Marked deterioration; 2. Long term duration, 3. Serious and severe impact, 4. Mitigation is very expensive, difficult or time consuming.	3
	Very severe	1. Substantial deterioration, 2. Irreversible or permanent, 3. Cannot be mitigated.	4
Positive	Slight	1. Minor improvement, 2. Short to medium term duration.	1
	Moderate	1. Moderate improvement, 2. Medium to long duration.	2
	Beneficial	1. Large Improvement, 2. Long term duration.	3
	Very beneficial	Permanent improvement.	4

3.5.9. The Significance of the Impact

The significance of a positive or negative impact describes and evaluates the importance of that impact in accordance with the scope of the project. Impacts can be described and evaluated in terms of their type, extent, complexity, intensity and duration. This evaluation criterion provides a basis for comparison and the application of judgement. The significance of an impact is calculated as follows (**Table 6** summarises the significant classes):

(Severity + Reversibility + Duration + Spatial) x Certainty = Significance

Table 6 Significant classes

Significant	Description		Rating
	Positive	Slightly beneficial impact, which constitutes a minor improvement; Short term duration; Enhancement measures to be implemented to increase the effect of the positive impact.	-
Low (1 – 2)	Negative	Marked deterioration; Short to medium term duration; Effects are not substantial. Society and/or specialists view the change as unimportant; Mitigation is easy, cheap or quick.	5-15
	Positive	Marked improvement; Short to medium term; Enhancement measures to be implemented to increase the effect of the positive impact.	
Moderate (2 – 3)	Negative	Constitutes as medium to long term effect; Effects are real but not substantial; Society and/or specialist do not view the impact as substantial and very important; Mitigation is fairly easily possible.	16 - 35
	Positive	Marked improvement; Medium to long term; Effects are real, but not substantial; and Enhancement measures to be implemented to increase the effect of the positive impact.	
High (3-4)	Negative	Long term effect; Society and specialist view the change as very serious; The reversibility of the impact is long term; Mitigation is very expensive, difficult and time consuming.	36-63
	Positive	Long term effect; Society and specialist view the change as very positive; Enhancement measures to be implemented to increase the effects of the positive impact.	
Very high (4)	Negative	Constitutes as a permanent change to the environment; Society and/or specialist view the change as very serious; The impact cannot be reversed; The impact cannot be mitigated.	64
	Positive	Constitutes as a permanent change to the environment; Society and specialist view the change as very positive; Impacts cannot be reversed.	

4. RESULTS AND DISCUSSION

4.1. Soil Survey

Figure 4 illustrates the dominant soil forms for the area. The different soil polygons indicated on the map show the soils that dominate the area, but other soil forms are encountered within these polygons.

The higher lying, mountainous areas comprise shallow soils that mostly occur as soil-rock complexes. **Figure 5, 6 and 7** illustrate the rockiness of these areas while **Figure 8 and 9** illustrate the typical augering depth of these soils. These areas comprise soils of the following soil forms:

- The Glenrosa soil form (Gs) comprises an orthic A-horizon overlying a lithocutanic B-horizon. The lithocutanic B-horizon is a pedologically young horizon where clay illuviation has occurred. It is often underlain by weathering rock. Soil depth ranges from 10 to 50 cm.
- The Mispah soil form (Ms) comprises an orthic A-horizon that overlies hard rock. These soils range in depth from 10 to 20 cm.

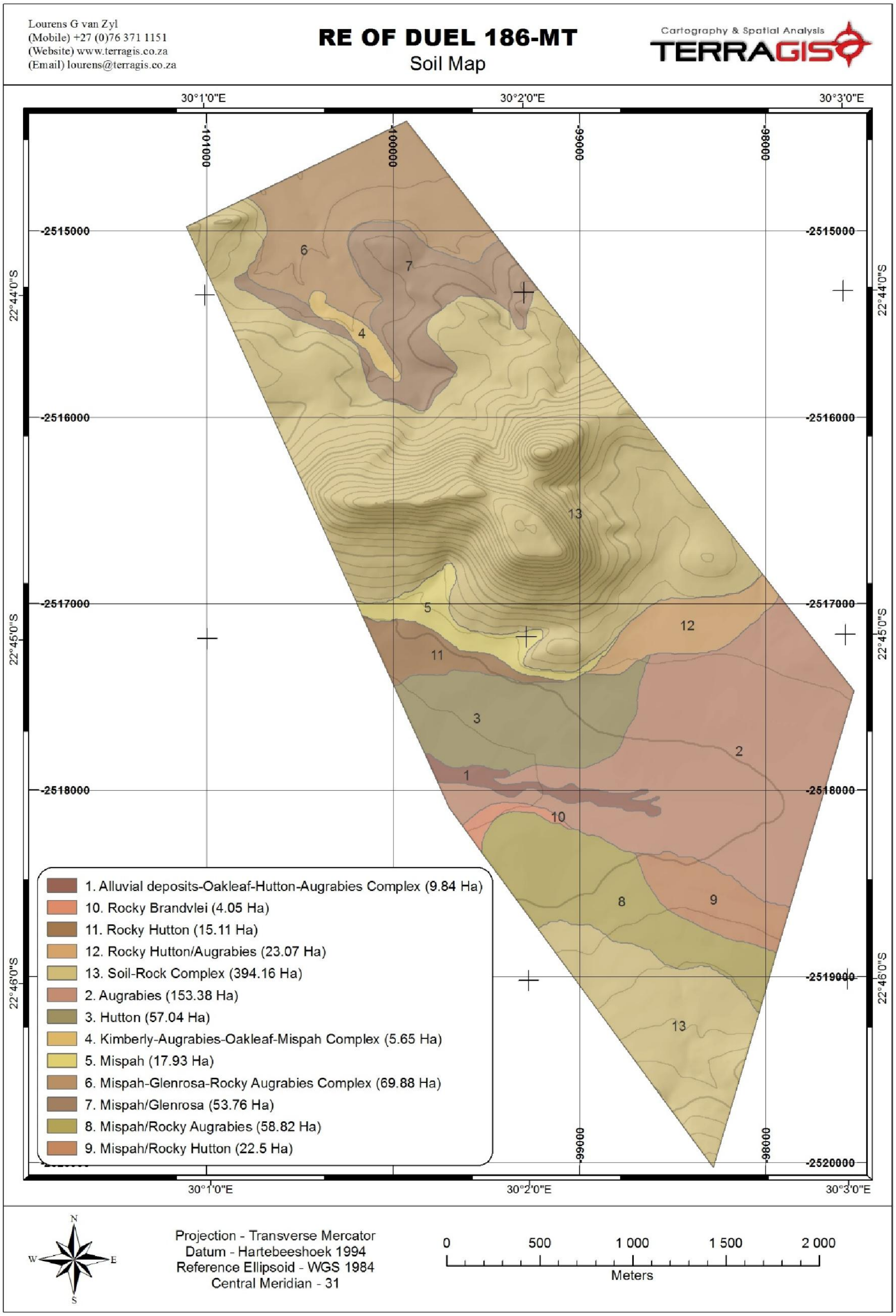

Figure 4 Soil map for the study area

Figure 5 Photo illustrating the rockiness of the area marked soil-rock complex on the soil distribution map – photo taken in the southern parts of the site (polygon 13)

Figure 6 Photo illustrating the rockiness of the area marked soil-rock complex on the soil distribution map – photo taken in the southern parts of the site (polygon 13)

Figure 7 Photo illustrating the rockiness of the area marked soil-rock complex on the soil distribution map – photo taken in the central/northern parts of the site (polygon 13)

Figure 8 Augering depth is shallow in the area described as soil-rock complexes (polygon 13) for the study area owing to the rockiness of the soils

Figure 9 Photo illustrating typical augering depth of the soils of the soil-rock complex areas (polygon 13)

Figure 10 Soil of the Mispah soil form which occur in the higer lying areas of the site (polygon 13)

The lower lying, undulating areas, as well as the areas adjacent the soil-rock complex system (polygon 13 on the soil distribution map) comprise the following soil forms:

<u>The Brandvlei soil form (Br)</u> comprises an orthic A-horizon which overlies a soft carbonate B-horizon. The soft carbonate B-horizon exhibits a morphology which is dominated by calcium and/or potassium–magnesium carbonates. These carbonates can be present as a powder in which case it dominates the colouration of the horizon, nodules, honeycombed structured material or blocks. In the case of the study area the carbonates are mainly present as a powder and/or honeycombed structured material. These soils are deeper than 150 cm. When reacted with 10 % HCl, the carbonate horizon bubbles. Mostly, these soils contain a high frequency of rocks and stones. **Figure 11** illustrates this soil form, while **Figure 12** shows the free calcium and/or potassium–magnesium carbonates encountered in the soft carbonate B-horizon. **Figure 13** illustrates the reaction of calcium and/or potassium–magnesium carbonates with a 10 % HCl solution. Near the mountainous and rocky regions, but still within the flat, relatively large rocks and stones are encountered in these soils.

- <u>The Augrabies soil form (Au)</u> comprises an orthic A-horizon which overlies a neocarbonate B-horizon and unconsolidated material. The neocarbonate B-horizon is dominated by calcium and/or potassium–magnesium carbonates to such an extent that it reacts (fizzes) with 10 % HCl. The carbonate mineral phases do not dominate the morphology (colouration) of the soil as is the case with the soft carbonate B-horizon. These soils are deeper than 150 cm**. Figure 14**exhibits the colouration of these soils while **Figure 15** illustrates the reaction with 10 % HCl. Near the mountainous and rocky regions, but still within the flat, relatively large rocks and stones are encountered in these soils. The soils towards the south of the site (polygon 2) show an abrupt transition between the A and B-horizons as illustrated by **Figure 16**.

- <u>The Hutton soil form (Hu)</u> comprises an orthic A-horizon overlying a red apedal B-horizon, underlain by unspecified material. The red apedal B-horizon has macroscopically weakly developed structure or is altogether without structure and reflects weathering under well drained, oxidised conditions. The clay fraction is dominated by non-swelling 1:1 clay minerals and the red colour of the soil is ascribed to iron oxide coatings on individual soil particles that are dominated by hematite (**Figure 17**). These soils are predominantly deeper than 150 cm.

  The soils of the Hutton soil form which are encountered close to the mountainous regions of the study area are very rocky and contain large stones. Augering into these soils are not possible, but profile pits showed that the soils are deeper than 100 cm.

The areas in the vicinity of drainage lines and drainage networks comprise, apart from some of the above mentioned, the following soils:

- <u>The Oakleaf soil form (Oa)</u> comprises an orthic A-horizon that overlies a neocutanic B-horizon and unspecified material. The neocutanic B-horizon is characterised by colour variation due to clay movement and accumulation and an apedal or weakly developed structure (**Figure 18**). Soils of this soil form range in depth from 50 to 120 cm. These soils are encountered in the vicinity of drainage lines that regularly floods the surrounding soils.

- <u>The Kimberley soil form (Ky)</u> comprises an orthic A-horizon which overlies a red apedal B-horizon and a soft carbonate B-horizon.

- <u>The Arcadia soil form (Ar)</u> comprises a vertic A-horizon that overlies unspecified material (**Figure 19**). The vertic A-horizon has strongly developed structure and exhibits clearly visible, regularly occurring slickensides in some part of the horizon or in the transition to an underlying layer (**Figure 20**). The horizon has a high clay content, is dominated by smectite clay minerals and possess the capacity to swell and shrink markedly in response to moisture changes. Swell-shrink potential is manifested typically by the formation of conspicuous vertical cracks in the dry state and the presence, at some depth, of slickensides (polished or grooved glide planes produced by internal movement).

Figure 11 An example of the Brandvlei soil form

Figure 12 Free calcium and/or potassium–magnesium carbonates encountered in the soft carbonate B-horizon

Figure 13 Fizzing of calcium and/or potassium–magnesium carbonates when reacted with a 10 % HCl solution

Figure 14 The red colouration and apedal nature of the Augrabies soil form

Figure 15 The neocutanic carbonate B-horizon, although not morphologically dominated by carbonates, fizzes when reacted with a 10 % HCl solution

Figure 16 Abrupt transition between the orthic A-horizon and neocutanic B-horizon in the soils of the Augrabies soil form which are situated in the southern section of the site

Figure 17 The red colouration of the red apedal B-horizon of the soils of the Hutton soil form is ascribed to hematite dominating the Fe oxide mineral phases

Figure 18 Colour variation in the Oakleaf soil form

Figure 19 An example of the Arcadia soil form which is encountered along ephemeral drainage lines in the central parts of the site (polygon

Figure 20 The blocky structure of the vertic A-horizon exhibiting pressure faces and slickensides

Table 1 summarises the hectares comprised by each soil form. None of the soils encountered on site showed hydromorphic characteristics within the top 50 cm of the soil profile with the exception of some of the soils of the Oakleaf and Augrabies soil forms which are encountered in polygon 4. The high pH and carbonate content of the soils dictate that the dominant Fe mineral phase, upon re-oxidation after having been reduced, is siderite as opposed to hematite, goethite and lepidocrosite as is the case in less alkaline soils. Siderite forms colourless mottles. A certain degree of carbonate leaching is therefore needed for hydromorphic features to occur in high alkaline environments. Drainage lines do occur on the site and soils such as the Oakleaf soil form are associated with the more prominent of these areas.

Table 7 A summary of the hectares which each soil form comprises

Soil form	Hectares
Soil-Rock Complex	394.164299
Kimberly-Augrabies-Oakleaf-Mispah Complex	5.651457
Mispah-Glenrosa-Rocky Augrabies Complex	69.879813
Mispah/Glenrosa	53.759564
Mispah/Rocky Hutton	22.50479
Mispah/Rocky Augrabies	58.82174
Rocky Brandvlei	4.047013
Augrabies	153.38204
Mispah	17.926366
Rocky Hutton	15.10727
Rocky Hutton/Augrabies	23.072324
Alluvial deposits-Oakleaf-Hutton-Augrabies Complex	9.835983
Hutton	57.040612
Total	**885.193271**

4.3. Chemical and Physical Properties of Representative Soil Samples

Table 8 and **Table 9** summarise the physical and chemical characteristics of the samples that were send for analyses. These samples represent the major soils forms found in the area.

4.3.1. Soil Texture

Soil texture is regarded as a permanent characteristic that influences the aeration of the soil, soil water relations, the capacity of the soil to retain nutrients (although the specific mineralogy of the soil plays an important part here), the compatibility of the substrate and the susceptibility to erosion.

The soils, apart from the soils of the Arcadia soil form, of the study area exhibit a high sand fraction which relates to soils that have a low water holding capacity and low unsaturated hydraulic conductivity. The saturated hydraulic conductivity are high and where crusting or

rockiness (coupled with a steep slope) do not occur, water infiltration and percolation is high. Nutrient retention is low.
The soils of the Oahleaf and Augrabies soil forms show higher levels of silt than the other soils and therefore a higher nutrient holding capacity and higher matric potential. These soils therefore hold water for longer periods of time, but also exhibit a lower infiltration and percolation rate.

The soils of the Arcadia soil form are high smectite clay content soils that swell and shrink in response to moisture changes. The matric potential of these soils are high and therefore conducive to the unsaturated flow of water, but not saturated flow of water. The water holding capacity is high as is the nutrient holding capacity.

Table 8 Texture analyses of the collected samples

Soil Form	Depth (cm)	Sand (%)	Silt (%)	Clay (%)
Arcadia (polygon 1)	0-50	31	18	51
Oakleaf (polygon 1)	0-50	62	28	9
Augrabies (polygon 2)	0-20	74	8	18
	20-100	72	10	18
	100-150	75	9	16
Hutton (polygon 3)	0-30	80	8	12
	30-80	72	6	22
	80-120	70	9	21
Kimberly (polygon 4)	0-10	63	15	22
	10-25	65	14	21
Augrabies (polygon 4)	0-50	61	16	24
Brandvlei (polygon 10)	0-50	78	7	15
Rocky Hutton (polygon 12)	0-50	78	8	14

4.3.2. Soil Fertility Status

The soils of the study area predominantly show alkaline or near neutral pH values. This is to be expected in an area where dolerite is the dominant parent material and free calcium and calcium-magnesium carbonates dominate many of the soil types. The neutral to slightly alkalike pH values result in soil where most macro nutrients are readily plant available.

The ammonium acetate extraction method (**Table 9**) is used to determine neutral salt dissolvable mineral phases and ions sorped onto the exchanged complex of the soils in such a way that they are extracted using a weak complexing agent. This extraction method is used to assess the plant availability of major cationic nutrients. Bray 1 is used to assess the plant available phosphate levels.

Ideal levels for maize production of Ca, Mg, K and PO_4 should be in the order of 300-400 mg/kg, 50-80 mg/kg, 100-120 mg/kg and 20 – 40 mg/kg, respectively. The soils of the area exhibit much higher levels of Ca, Mg and K than is required by maize. The phosphate levels are, however, low. This can be amended with soil ameliorants. The water extract is used to assess soil salinity levels which seem not to be an inhibiting factor.

Table 9 Chemical characteristics of the collected soil samples

				Ammonium Acetate Extract				
Soil form	**Sample Depth (cm)**	**pH (H_2O)**	**P(Bray 1)**	**K**	**Ca**	**Mg**	**Na**	**Org C**
			mg kg^{-1}	**mg kg^{-1}**	**mg kg^{-1}**	**mg kg^{-1}**	**mg kg^{-1}**	**%**
Arcadia (polygon 1)	0-50	8.2	13.2	46	551	885	8.2	0.19
Oakleaf (polygon 1)	0-50	7.5	3	106	1091	358	5.6	1.6
Augrabies (polygon 2)	0-20	8.6	2	188	11560	961	6.1	0.17
	20-100	8.4	5	389	17650	1120	2.3	0.08
	100-150	8.2	3	321	17800	1156	4.5	0.09
Hutton (polygon 3)	0-30	7.4	9	222	1493	779	6	0.83
	30-80	7,5	4	225	2671	653	2.3	0.69
	80-120	7.3	2	550	585	339	3.8	0.65
Kimberly (polygon 4)	0-10	7.8	6	453	19321	895	4.1	0,21
	10-25	8.6	7	489	19700	1056	2.8	0.36
Augrabies (polygon 4)	0-50	8.8	10	556	18252	786	6	0.96
Brandvlei (polygon 10)	0-50	8.7	11	569	16520	1253	2.9	0.8
Rocky Hutton (polygon 12)	0-50	7.5	10	500	2064	523	3.1	0.79

Table 9 Chemical and physical characteristics of collected soils samples (continue)

Soil form	Sample Depth (cm)	Water Extract (1:10)			
		Ca	Mg	K	Na
		mg/kg	mg/kg	mg/kg	mg/kg
Arcadia (polygon 1)	0-50	43	31.2	33.1	4.5
Oakleaf (polygon 1)	0-50	16.4	6.7	0.9	0.62
Augrabies (polygon 2)	0-20	44.3	5.3	1.7	0.61
	20-100	54.1	6.2	5.3	-
	100-150	63	6.2	4.8	-
Hutton (polygon 3)	0-30	5.9	8.7	3.8	0.8
	30-80	6.2	5.4	0.6	-
	80-120	8.9	10	4.0	-
Kimberly (polygon 4)	0-10	36	12.6	12.0	-1.65
	10-25	47.5	22.3	11.3	-
Augrabies (polygon 4)	0-50	43.1	22	16	1.7
Brandvlei (polygon 10)	0-50	56	19	12.9	0.2
Rocky Hutton (polygon 12)	0-50	7.8	19	8.4	0.9

4.4. Current Land Use

The area is currently used as a game farm.

4.5. Land Capability Classes

Figure 21 depicts the land capability of the area. **Table 10** correlates the land capability with certain soil types and lists the hectares each land capability class comprises. The higher lying, rocky areas comprise soils that fall into the wilderness or grazing land capability classes while medium potential arable land is encountered in the lower lying area. The latter comprise soils of the Augrabies and Hutton soil forms. These soils exhibit a loamy sand and sandy loam texture and is in most cases deeper than 150 cm.

The Augrabies and Hutton soils do not contain a high degree of stones or rocks within the top 100 cm, especially towards the central parts of the site. The area does fall into a relatively low rainfall region and this hampers dry-land production. These can, however, be irrigated if the irrigation scheduling is done in a way that does not lead to soil erosion or salinization of the soils. The soils are prone to crust formation and poorly scheduled irrigation may therefore lead to the erosion of the soils. Salinization will occur if the irrigation scheduling does not allow for a flushing of salts from the soils from time to time. This will, however, negatively impact lower lying watercourses and wetland systems.

Table 10 Land capability correlated with soil form

Soil Type	Land Capability	Area (Ha)	Percentage (%)
Soil-Rock Complex	Wilderness	394.16	44.5
Kimberly-Augrabies-Oakleaf-Mispah Complex	Riparian and Temporary to Seasonal Wetland	5.6514	0.6
Mispah-Glenrosa-Rocky Augrabies Complex	Grazing / Wilderness	69.87	7.8
Mispah/Glenrosa	Grazing	53.75	6.4
Mispah/Rocky Hutton	Grazing	22.50	2.5
Mispah/Rocky Augrabies	Grazing	58.82	6.6
Rocky Brandvlei	Grazing	4.04	0.4
Augrabies	Medium Potential Arable Land	153.38	17.2
Mispah	Grazing / Wilderness	17.92	2.4
Rocky Hutton	Grazing	15.10	1.6
Rocky Hutton/Augrabies	Grazing	23.07	2.5
Alluvial deposits-Oakleaf-Hutton-Augrabies Complex	Riparan and Temporary Wetland	9.8	1.1
Hutton	Medium Potential Arable Land	57.04	6.4
Total		**885.19**	

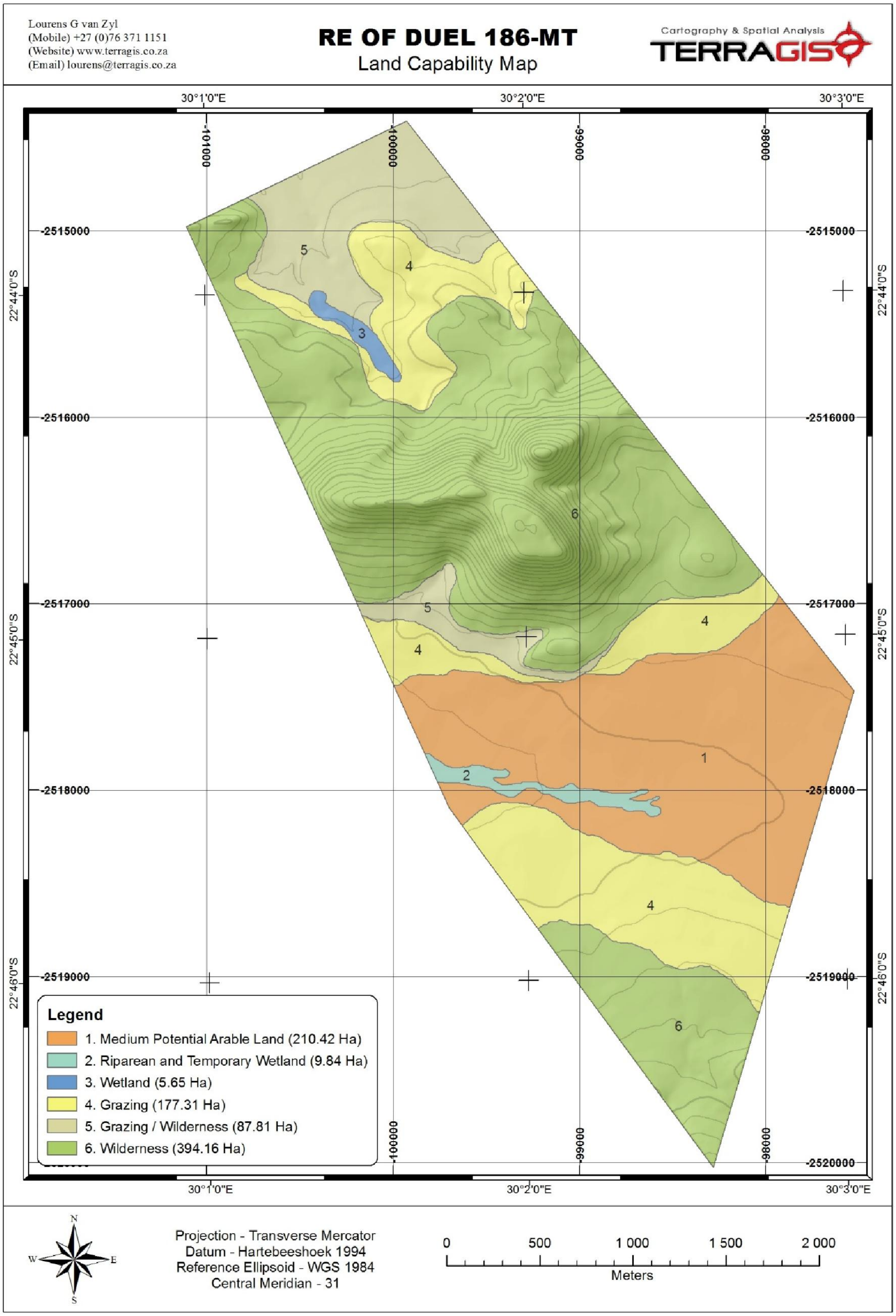

Figure 21 Land capability classes of the study area

4.6. Hydropedological Functioning of the Study area

Box 1 is an introduction to the flow of water in the landscape, while **Box 2** introduces the flow of water in a soil profile. Aspects discussed in the Boxes serve as background to the discussion on hydropedology of the area. **Table 11** summarises the hydropedological class for each soil form

Box 1: Water Movement in the Landscape

Water movement in a landscape is 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 A provides a simplified schematic representation of an idealised landscape. 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, i.e. 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 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. In a landscape there is a cumulative effect as water from higher lying areas flow to lower lying areas.

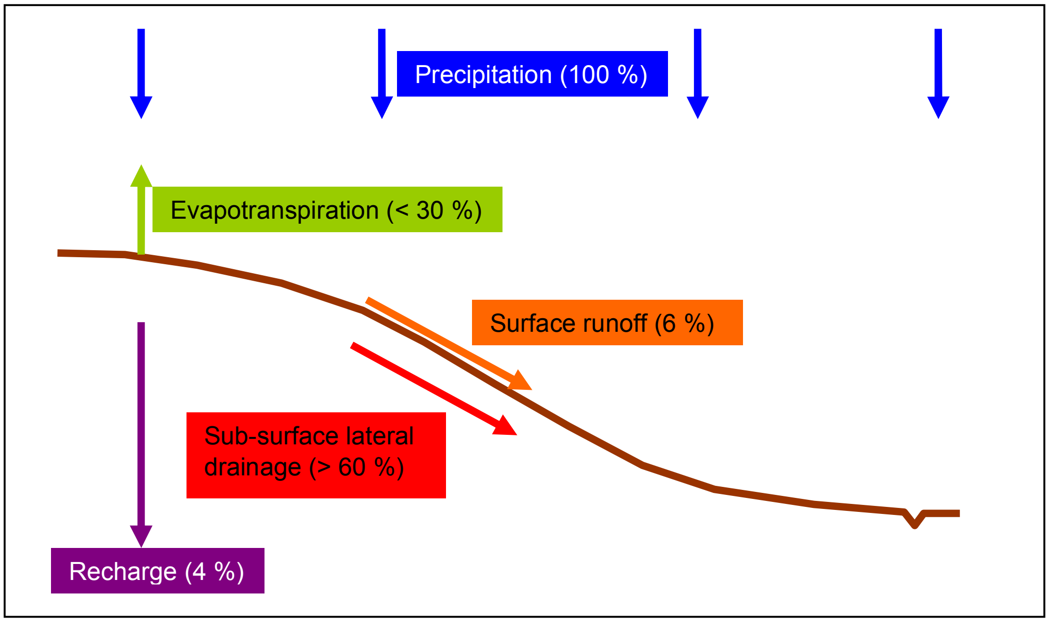

Figure A Idealised landscape with assumed quantities of water moving through the landscape expressed as a percentage of total precipitation (100 %).

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.

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. 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

Box 2: Water Movement in the Soil Profile

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

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

- Capillary rise refers to the process were 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:

Height = 0.15/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:

Gravitational potential = Gravity x 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 can aid in assessing the soil-water relations of an area. The South African soil classification system (MacVicar et al., 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).

Table 11 Soil form linked to hydropedological

Soil Type	Hydropedological class	Area (Ha)	Percentage (%)
Soil-Rock Complex	Discharge	394.16	44.5
Kimberly-Augrabies-Oakleaf-Mispah Complex	Responsive	75.2	9.5
Alluvial deposits-Oakleaf-Hutton-Augrabies Complex			
Mispah-Glenrosa-Rocky Augrabies Complex	Recharge		
Mispah/Glenrosa	Recharge	462.62	46
Mispah/Rocky Hutton			
Mispah/Rocky Augrabies			
Rocky Brandvlei			
Augrabies			
Mispah			
Rocky Hutton			
Rocky Hutton/Augrabies			
Hutton			
Total		**885.19**	

The soils of the Mispah and Glenrosa soil forms, especially those associated with the soil-rock complex (polygon 13), are mainly discharge soils. Meaning that these contribute minimally, if at all, to underground aquifers which might be located in the phreatic zone. These soils are mainly associated with the higher lying areas and rainwater infiltration into these soils minimal. Surface run-off is pronounce.

The rocky soils of polygons 5, 6, 7, 8, 9, 10, 11 and 12 (as indicated on the soil map) are situated in areas of less steep slope. Surface run-off of water falling directly onto these soils during a rainfall event is therefore less significant than is the case for the higher lying, steeper sloped areas. Infiltration could be high owing to the sandy nature of the soils and the frequency of rocks that leads to a higher saturated hydraulic conductivity. The water holding capacity of the soils is low. These soils can therefore act as recharge soils and contribute seepage to underground water bodies in the phreatic zone.

In many cases the soils of polygon 2, and to lesser extent polygon 3, are crusted as indicated by **Figure 22, 23**and **24**. When the soils are dry (in the order of a water potential level of – 1500 J/kg) water ponds on the soil surface and surface run-off is high as shown by **Figure 25** and **26**. As the crust becomes wet it disperses and water infiltration becomes rapid owing to the high saturated hydraulic conductivity of the sandy loam and loamy sand soils. In some areas, especially towards the south of polygon 2, an abrupt transition between the orthic A- and neocarbonate B-horizons is encountered. Water percolation occurs rapidly through the soils until the water reaches this layer (approximately 20 to 35 cm below the soil surface) at which point ponding and later water flow occurs. These soils are situated in an undulating environment and lateral water flow is slow, thus allowing vertical infiltration, over time, into the B-horizon. Ponding at this interface does not occur on a regular basis as no signs of wetness, i.e. mottling, gleying, grey colouration, are noted. These soils can contribute water to underground water bodies in the phreatic zone. Ephemeral watercourses are, however, are also fed by these soils, as well as the soils situated higher up the landscape as surface run-off rates are high.

Figure 22 Crusting seen in the carbonaceous soils that comprise polygon 2

Figure 23 An example of crusting of the soils that are encountered in polygon 2 on the soil map

Figure 24 The crusts found in the soils of polygon 2 are between 0.5 and 2 cm in thickness

Figure 25 Ponding on the crusted soils

Figure 26 Surface run-off owing to low infiltration capacity of crusted soils

Numerous ephemeral streams are encountered. These are indicated in **Figure 27**. These represent watercourses with a distinct channel that is continuous and contains regular or intermittent surface flows. These watercourses lack base flow and permanent wetland features as they only support surface flow for a short period of time after sufficient rainfall events. It can be argued that these drainage lines or watercourses should still be regarded as important landscape features based on international literature:

- The role and functions of headwater streams within catchments and their linkages with downstream aquatic systems are not thoroughly understood (Gomi et al., 2002). Recent research, however, ascribes increasing importance to these systems regarding catchment and water resource management (Berner et al., 2008).
- Headwater drainage lines are crucial systems for nutrient dynamics as a link between hillslopes and downstream watercourses (Gomi et al., 2002).

- They are directly linked to downstream aquatic systems and have a direct bearing on the health and functioning of larger aquatic systems, especially regarding water quality of downstream aquatic systems (Gomi et al., 2002; Dodds and Oaks 2008).
- Seasonal streams and wetlands are usually linked to the larger network through groundwater even when they have no visible overland connections.
- The large spatial extent of headwater channels in the total catchment area make these systems important sources of sediment, water, nutrients and organic matter for downstream systems (Gomi et al., 2002).

Figure 28 to **32** are photos of typical ephemeral watercourses encountered on site. Polygon 4 on the soil map indicates a temporary to seasonal wet system (**Figure 33** and **34**). This system is probably being kept wet by a weir that was built downstream and water may even be pumped into the wetland. Below the weir (**Figure 35**) the system is a typical ephemeral watercourse.

The area therefore does not comprise seep zones (interflow soils) or extensive permanent to seasonal wet zones. Surface run-off from the higher lying areas are high and the water discharging from the shallow rocky soils manifest as ephemeral water-courses and temporary to seasonally wet soils.

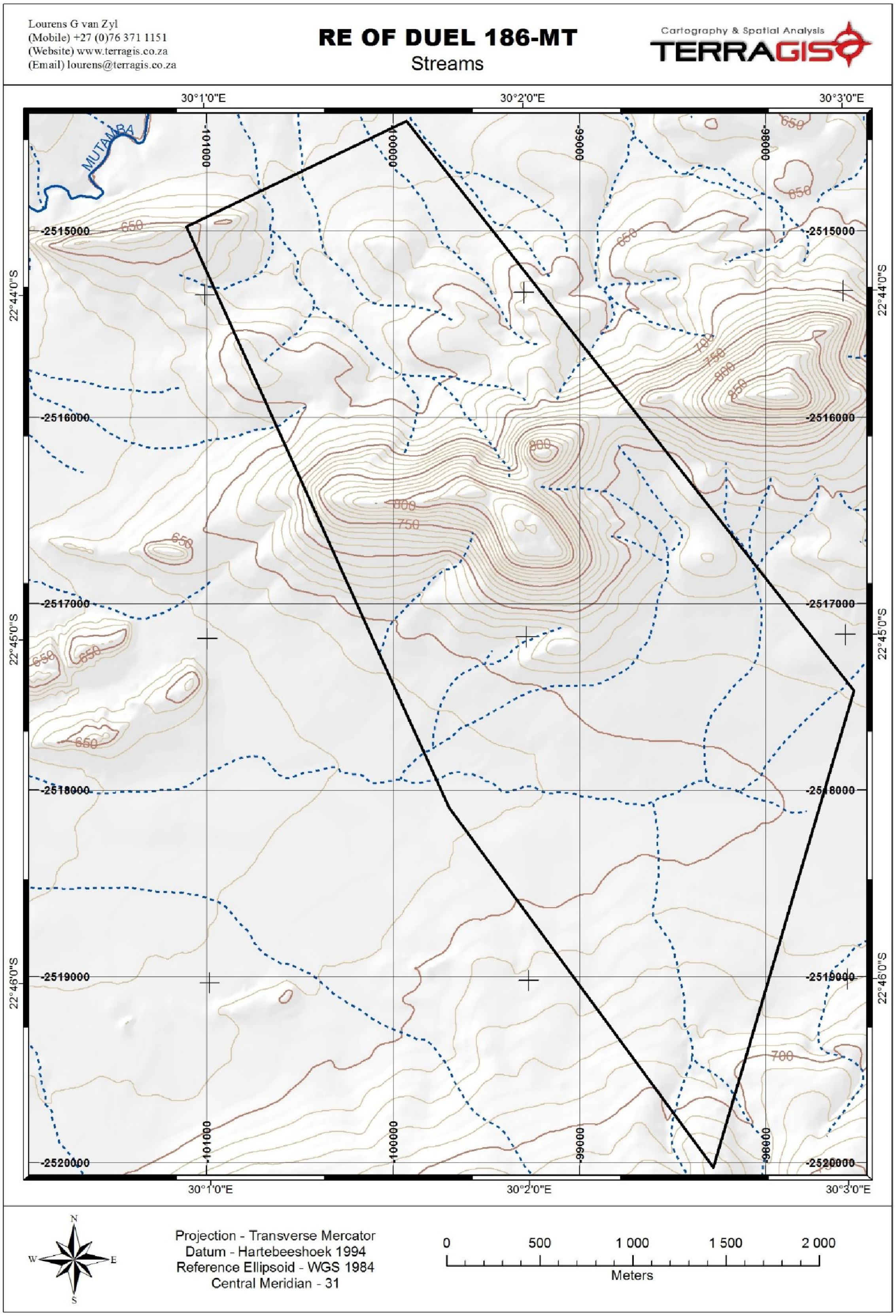

Figure 27 Ephemeral watercourses encountered on the site

Figure 28 Sandy ephemeral watercourse encountered on site – typical of the watercourses that transect polygons 1, 2 and 3 on the soil map

Figure 29 Sandy ephemeral watercourse encountered on site – typical of the watercourses that transect polygons 1, 2 and 3 on the soil map

Figure 30 Example of where a rocky ephemeral watercourse transitions to a sandy ephemeral system – typical of the watercourses that transect polygons 5, 11 and 12 on the soil map

Figure 31 Example of where a rocky ephemeral watercourse transitions to a sandy ephemeral system – typical of the watercourses that transect polygons 5, 11 and 12 on the soil map

Figure 32 Example of where a rocky ephemeral watercourse– typical of the watercourses that transect polygons 4,6, 7, 8, 9, 13 on the soil map

Figure 33 Wetness encountered in polygon 4 on the soil map

Figure 34 Wetness encountered in polygon 4 on the soil map

Figure 35 Photo of the watercourse traversing polygon 4 at a point below the weir that keeps the area upstream wet

4.7. Environmental Impact Assessment of the Proposed Mining Activities

4.7.1. Nature of the Impact

Figure 37 illustrates the position of the proposed opencast and underground mining areas including associated infrastructure, while **Figure 38** relates the area to be impacted to the soil forms encountered on the surveyed area. The proposed mining activities will negatively impact low to medium potential arable soils that comprise deep soils of the Augrabies and Hutton soil forms. A zone comprising riparian and temporary wet soils will be covered by a discard dump and the opencast pit cuts into these soils. Approximately 10 ha of the temporary wet soils of polygen 1 will be impacted by the opencast pit and discard dumps while approximately 200 hectares of low to medium potential arable land will be impacted by the opencast pits, discard dumps, waste dumps and associated infrastructure.

The envisaged opencast and underground mining activities will, however, mainly impact shallow, rocky soils of wilderness (approximately 210 ha) and grazing (approximately 140 ha) land capability. A number of head-water, ephemeral water courses will also be impacted. **Table 12** summarises the soils, the hectares to be impacted and their land capability class to be impacted.

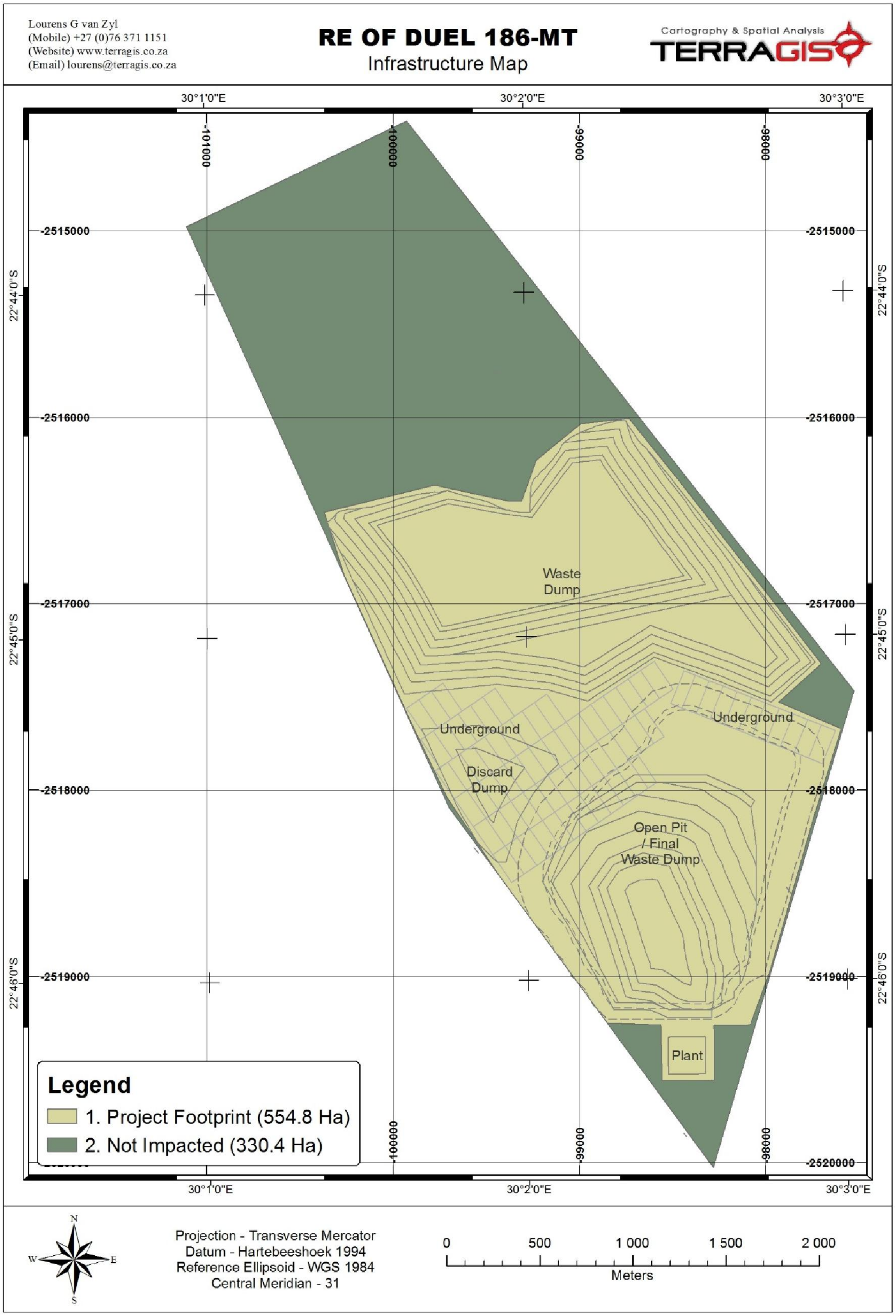

Figure 36 Map indicating the areas earmarked for mining and infrastructure

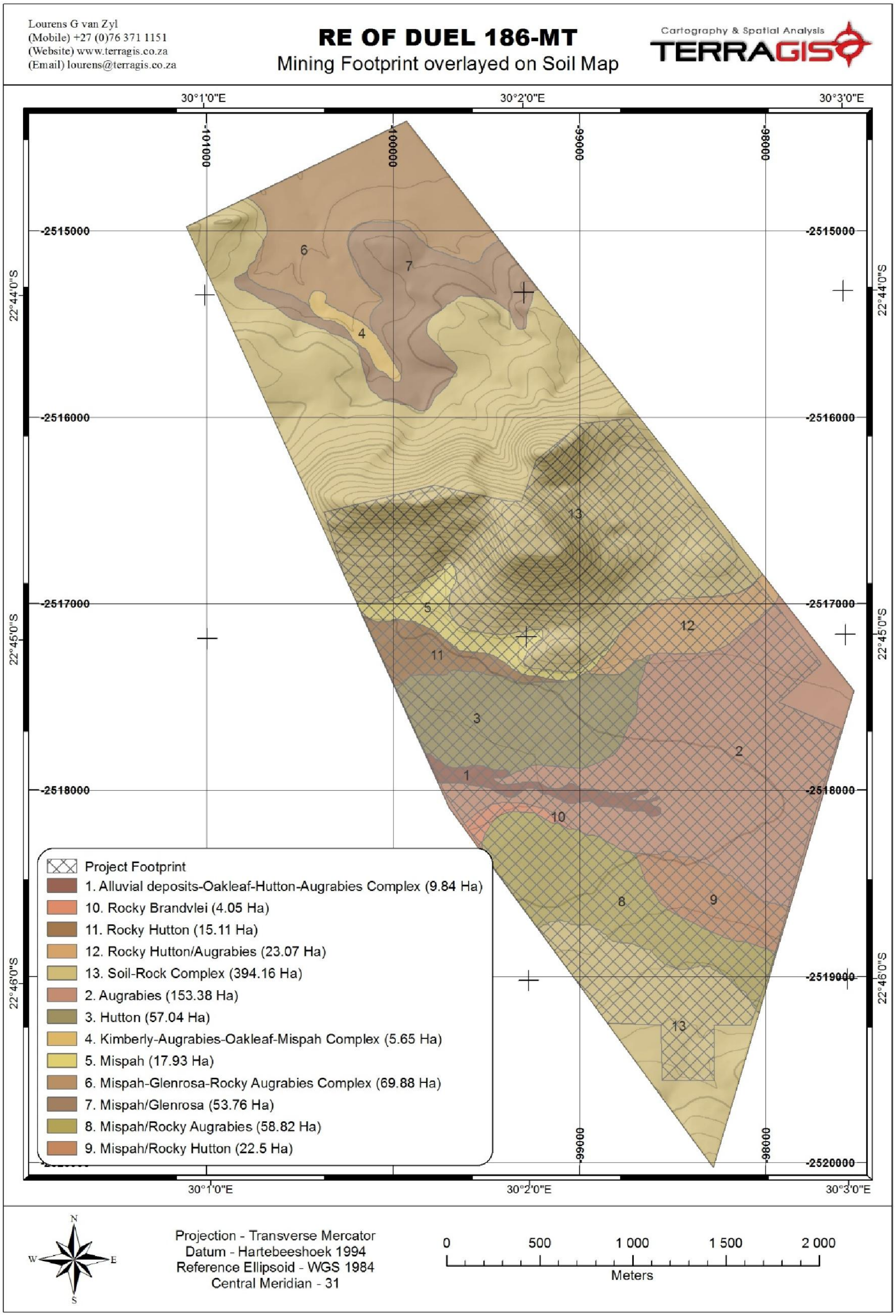

Figure 37 Map indicating the soil forms and areas that will be impacted by the envisaged mining activities

Table 12 Soil that will be impacted by the envisaged mining activities

Impact	**Soil Form**	**Land Capability**	**Area (Ha)**	**Percentage (%)**
Surrounding Impact Areas	Alluvial deposits-Oakleaf-Hutton-Augrabies Complex	Watercourse/temporary wetland	0.802116	0.144578
Discard Dump	Alluvial deposits-Oakleaf-Hutton-Augrabies Complex	Watercourse/temporary wetland	4.355166	0.784999
Open Pit / Final Waste Dump	Alluvial deposits-Oakleaf-Hutton-Augrabies Complex	Watercourse/temporary wetland	4.512806	0.813413
Surrounding Impact Areas	Augrabies	Low to medium ptential arable	15.4786	2.78995
Discard Dump	Augrabies	Low to medium ptential arable	6.169016	1.111938
Open Pit / Final Waste Dump	Augrabies	Low to medium ptential arable	101.6643	18.32455
Waste Dump	Augrabies	Low to medium ptential arable	18.49815	3.33421
Surrounding Impact Areas	Hutton	Low to medium ptential arable	34.23203	6.170173
Discard Dump	Hutton	Low to medium ptential arable	11.69732	2.10839
Open Pit / Final Waste Dump	Hutton	Low to medium ptential arable	2.085019	0.375815
Waste Dump	Hutton	Low to medium ptential arable	8.885919	1.601648
Surrounding Impact Areas	Mispah	Grazing	0.273584	0.049312
Waste Dump	Mispah	Grazing	17.63366	3.178389
Surrounding Impact Areas	Mispah/Rocky Augrabies	Grazing	4.6011	0.829328
Discard Dump	Mispah/Rocky Augrabies	Grazing	3.489431	0.628955
Open Pit / Final Waste Dump	Mispah/Rocky Augrabies	Grazing	50.30191	9.066697
Surrounding Impact Areas	Mispah/Rocky Hutton	Grazing	0.673941	0.121475
Open Pit / Final Waste Dump	Mispah/Rocky Hutton	Grazing	21.6182	3.896586
Surrounding Impact Areas	Rocky Brandvlei	Grazing	0.348765	0.062863
Discard Dump	Rocky Brandvlei	Grazing	2.69652	0.486036
Open Pit / Final Waste Dump	Rocky Brandvlei	Grazing	0.77895	0.140402
Surrounding Impact Areas	Rocky Hutton	Grazing	1.213578	0.218742
Waste Dump	Rocky Hutton	Grazing	13.80812	2.488852
Surrounding Impact Areas	Rocky Hutton/Augrabies	Grazing	0.350297	0.063139

Table 13 Soil that will be impacted by the envisaged mining activities (continue)

Impact	**Soil Form**	**Land Capability**	**Area (Ha)**	**Percentage (%)**
Waste Dump	Rocky Hutton/Augrabies	Grazing	22.03433	3.971591
Surrounding Impact Areas	Soil-Rock Complex	Wilderness	16.66466	3.003731
Open Pit / Final Waste Dump	Soil-Rock Complex	Wilderness	32.7952	5.91119
Plant	Soil-Rock Complex	Wilderness	4.000043	0.72099
Waste Dump	Soil-Rock Complex	Wilderness	153.1358	27.60205

4.7.1.1. Mining Related Infrastructure

Mining related impact and infrastructure include the preparation of areas for the discard dumps, coal and soil stockpiles, the construction of a processing plant, haul roads, pollution control dams, diversion channels, office buildings and other possible footprint structures.

The construction of these facilities will results in the loss of approximately 340 ha of land through compaction, excavation and covering of the soil surface by overburden, coal stockpiles, soil stockpiles and infrastructure. Heavy machinery traffic on the soil surface could lead to further compaction. The soils of the area mainly exhibit a sandy to sandy loam texture which is prone to compaction and crust formation. In fact, crust formation is a natural occurring process in this area with the carbonaceous soils being especially susceptible.

Pollution control dams that leak and discarded material that contain coaliferous material could impact negatively on the chemistry of the soils. Acid, neutral or alkaline mine drainage (from discarded material, spillage of material along haul roads and the underground and opencast mining) may be high in sulphates, heavy metals and other salts.

The nature of the impact of stockpiling of coal, waste dumps and discard dumps, the construction of plants, roads, pollution control dams and related infrastructure entails covering large areas of soil leading to a loss in agricultural land and therefore permanently alters land capability classes.

The area to be impacted by mining development comprise a total of 554.8 ha. Opencast mining and the final waste dump will impact 213.8 ha. Discard and waste dumps will impact 28.4 and 234 ha, respectively. The plant will impact 4 ha and mining related impact will comprise a further 74.6 ha. The area not to be directly impacted by mining comprises 330.4 ha.

4.7.1.2. Opencast Mining and Construction of Infrastructure

The opencast pit will be mined through the so-called truck and shovel method. This process of mining entails stripping, drilling, blasting, loading and hauling of overburden and coaliferous material to the waste dumped and ROM stockpile or processing plant area. It is envisaged that drilling and blasting will occur on 10 m and 15 m high benches with a maximum pit depth of 270 m.

The nature of the impact of opencast mining on the soil environment include the stripping and stockpiling of topsoil (consisting of A and B soil horizons) and the compaction of soils owing to heavy machinery traffic.

Stripping and stockpiling of topsoil will result in:

- Loss of the original spatial distribution of natural soil forms and horizon sequences which cannot be reconstructed similarly during rehabilitation.
- Loss of natural topography and drainage pattern.
- Loss of original soil depth and soil volume.

- Loss of original fertility and organic carbon content.
- Soil compaction from heavy machinery traffic during earthworks and rehabilitation will adversely affect effective soil depth, structure and density, thus influencing the pedohydrology and soil fertility of the area.
- Exposure of soils to weathering, compaction, erosion, and chemical alteration of nutrients, particularly nitrogen.
- Exposure of the soils to acidic, neutral or alkaline mine drainage that may be high in sulphates and heavy metals.

Subsistence, especially sag subsidence, could also occur where material settling occurs in the case of filled-in opencast pits. These areas can hold water if the post mining or post subsidence topography lends itself thereto. Water will seep into these areas if the subsidence intersects the water table or if surface runoff is high, which it likely will be owing to the hydropedological nature of the area. Very little can be done to combat subsidence in the mining environment.

4.7.1.2. Underground Mining and Subsidence

Underground longwall mining is planned for The Duel Project. Longwall underground mining essentially entails removing all the coal from a broad coal face while allowing the roof and overlying rock to collapse into the void left behind. The longwall mining shaft is envisaged to be accessed directly from the pit high wall in year nine of the mining operation. The longwall panels will be 190 meters wide and up to 1300 m long. The coal seam is between 130 m and 730 m below ground level.

Subsidence will most probably occur in the area. This is the process through which the earth's surface lowers owing to the collapse of bedrock and unconsolidated materials (sand, gravel, salt, and clay) into underground mined areas. Subsidence can occur rapidly or gradually. **Figure 36** is an illustration of a typical longwall face and subsidence owing to goafing.

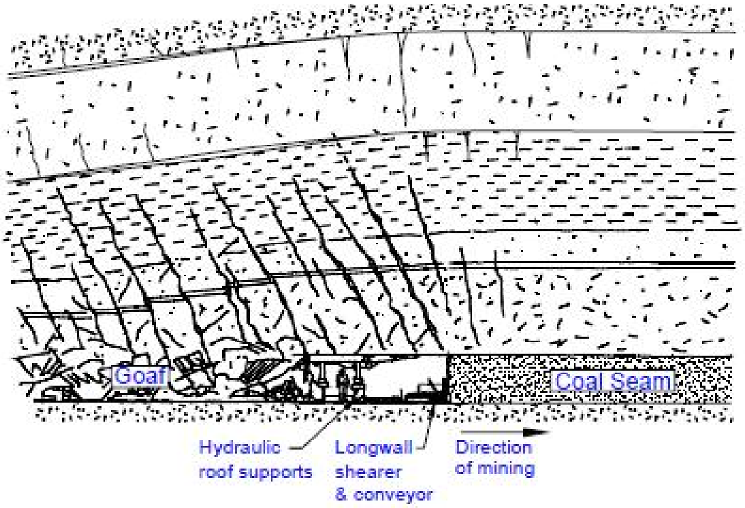

Figure 38 Illustration of typical longwall face (from Mine Subsidence Engineering Consultants, 2007)

The angle at which the subsidence spreads out toward the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw is typically between 10 and 35 degrees from vertical and depends on the strength and depth of the strata above the mined out coal seam. Subsidence is typically less than the thickness of the coal seam that is removed during mining due to the voids that are left in the collapsed material. The porosity of the strata above the mined coal seam therefore increases during subsidence. The effect on the soils (ground surface) is influenced by the strength of the underlying rock strata and its capacity to bridge the voids left by longwall mining. When a panel has a width that is small relative to the overlying material, minimal subsidence will occur. As the panel width increases, the overlying rock is less able to span the goaf and support the roof, thus resulting in pronounce subsidence. As the subsidence approaches a point on the surface, the soil and underlying material is displaced in a horizontally and is subjected to tensile strains which built from zero to maximum as illustrated by **Figure 37**. The position of maximum hogging curvature is the position of maximum strain. When vertical subsidence is approximately half the maximum subsidence, the ground reached its maximum horizontal displacement and the tensile strain equals zero again.

As the longwall face moves further away from the maximum point of subsidence on the surface, horizontal displacement reduces and the surface is subjected to compressive strains. Between the tensile and compressive zones is the point of inflection (maximum horizontal displacement and tilt). As the longitudinal wave passes, the traverse subsidence profile develops and displacement is completed as maximum subsidence is reached.

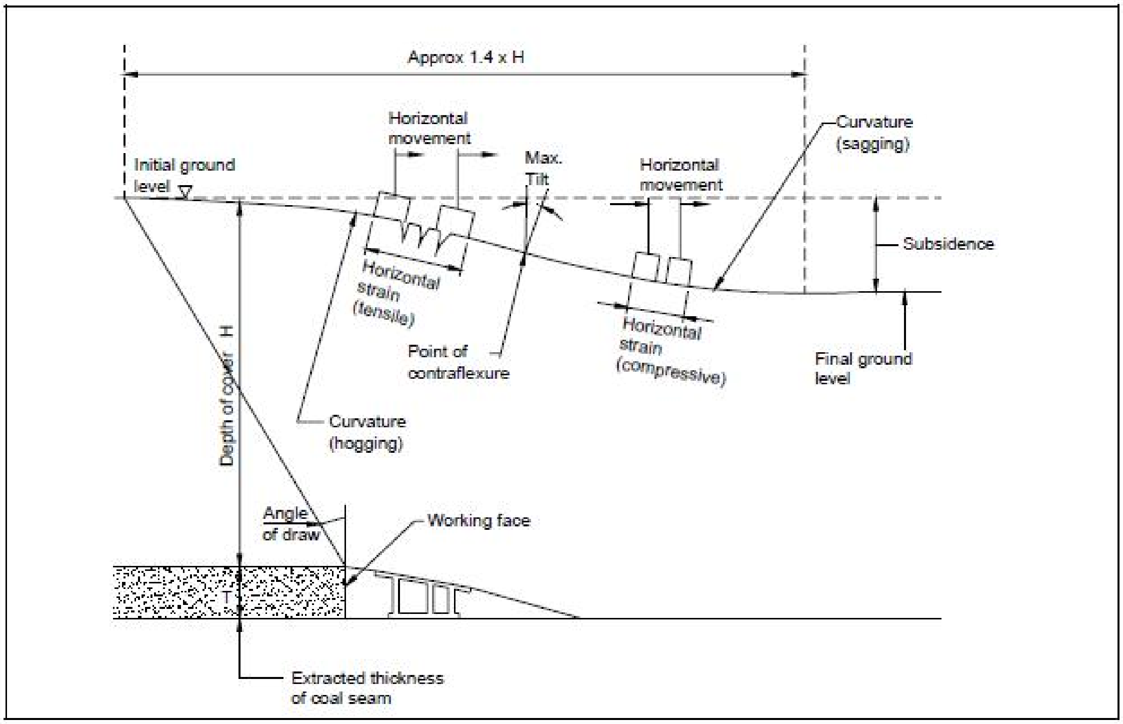

Figure 39 Development of a subsidence through (exaggerated vertical axis) (from Mine Subsidence Engineering Consultants, 2007)

The soils above the underground mining area will therefore be subjected to movement in three dimensions with tilt, strain and curvature in both the longitudinal and traverse directions. The soils are therefore “stretched” and “compressed” during subsidence resulting in certain section of the landscape becoming more porous while other horizon within the soil profile becoming compacted. Mixing of soil horizons should not occur. The degree of transformation is subjected to the position of the soil in relation to the subsidence through with maximum soil disturbance occurring at the point of maximum subsidence.

The hydropedological functioning of the area is therefore negatively impacted with discharge soils potentially becoming recharge soils and recharge soils potentially becoming interflow soils. The soil water holding capacity, saturated and unsaturated hydraulic conductivity and overall soil-water regime may be permanently altered. The agricultural potential of the soils of the area is subject to their hydropedological functioning. Where this changes significantly, the land capability of the soils will change. The exact changes that will occur cannot be predicted and must be assessed as part of a post-mining monitoring and rehabilitation program.

In addition to the potential changes to the hydropedological and land capability of the soils, subsidence may result in different surface flow paths forming which could lead to water accumulating at the point of maximum subsidence, thus forming a pond or artificial wetland. The latter will form in areas where soil compaction has occurred or where non-permeable subsoil layers are present. The land capability is therefore altered. Alternatively, the porosity of the soils and subsoil layers may have increased, thus leading to water percolating through the soils at a higher than normal rate and leaving the soil profile (zone of roor growth) before plants have had a change to take up adequate levels of water.

4.7.2. Possible Mitigation Measures

4.7.2.1. General Measures

The success of soil rehabilitation will determine the degree of land capability restoration that is possible. The choice of vegetation, management of plant systems and management of soil fertility is critical for the long-term success and economy of rehabilitation. Monitoring of certain soil, vegetation and climate parameters during rehabilitation is essential.

General mitigation practices and principles that could apply to any or all phases of a coal mine project include:

- Save topsoil removed at the start of the project and use it to reclaim disturbed areas upon completion of mining activities.
- Reclaim or apply protective covering on disturbed soils as quickly as possible.
- Apply erosion controls relative to possible soil erosion from vehicular traffic and during mining activities (e.g., jute netting, silt fences, and check dams).
- Avoid creating excessive slopes during stockpiling of soil and discard material.
- Dispose of excess excavation materials in approved areas to control erosion and minimize leaching of hazardous materials.
- Clean and maintain catch basins, drainage ditches, and culverts regularly.
- Re-establish the original grade and drainage pattern to the extent practicable

- Stabilize all areas of disturbed soil using weed-free native shrubs, grasses, and forbs.
- Backfill or re-contour strip-mined or contour-mined areas, any foundations, and trenches, preferably with excess excavation material generated during mining.

4.7.2.2. Soil Utilisation Plan

4.7.2.2.1. Topsoil Handling and Stockpiling

Topsoil handling is critical to the whole rehabilitation effort and guidelines should be followed earnestly. Detail instructions for soil stripping and stockpile placement should be formulated within the context of the mine plan (individual strips) and distinguishing differences in soil types should be pointed out for accurate identification. **Table 13** presents stripping depths and approximate volumes of soil stockpiles for the opencast areas. Stripping and stockpiling is mainly associated with opencast mining.

Separate stockpiling of the different soil forms that comprise the Mispah-Genrosa complex, the Mispah/rocky Augrabies complex, the Mispah/rocky Hutton complex and alluvial soil complex of polygon 1 is not practical. The A-horizons of these soils can therefore be stockpiled together. For the purposes of this document, this stockpile is referred to as Stockpile A1 in **Table 13**. The B-horizons of these soils should be stored as Stockpile B1.

The A-horizons of the deeper soils must be stockpiled separately from stockpile A1. The A-horizons of the Augrabies and Hutton soil forms can be stored together as Stockpile A2. The A-horizon of the Augrabies soil form does not differ much in terms of chemical and physical characteristics from that of the soils of the Augrabies soil form. The subsoil horizons of these soil forms must be stockpiled separately as the B-horizon of the Hutton soil form differ substantially from that of the soils of the Augrabies soil form. These stockpiles are referred to as Stockpile B2 and B3 in **Table 13**. Mixing of these materials will lead to large scale erosion of the stockpiled material and the post rehabilitation landscape, as well as a decrease in soil fertility levels.

It is impractical to separate the rocky Hutton, rocky Augrabies and rocky Brandvlei soil forms as these occur as complexes. These soils can be stripped to bedrock and stockpiled as Stockpile A3. The soils of the soil-rock complex can be stockpiled as Stockpile A4.

During stockpiling the organic matter in the soil decompose, microbial activity decreases and plant seeds and microbial survival structures lose viability with time. It is therefore recommended that stockpiles are utilised as soon as possible and that erosion of stockpile material be managed (slope and orientation of stock-pile, movement of surface water etc).

Management and promotion of soil fertility with fertilizer and amendments is an important aspect of rehabilitation and specifically revegetation. Plant nutrient deficiencies and mineral disorders in soil must be detected and rectified. Movement and mixing of soil may result in contamination by coaliferous spoil and coal waste, making soil nutrient and acidity levels unpredictable. Soil analysis provides the best guide and a sound monitoring programme is regarded as mandatory for proper rehabilitation. Management of soil organic matter through organic amendments and the use of mulches should receive attention with the aim of improving functional microbial diversity, nutrient cycling and revegetation.

The aforementioned approach would be similar to the guidelines contained in “Guidelines for the rehabilitation of mined land as drawn up by Tanner (2007) for the Chamber of Mines of South Africa / Coaltech 2020. This document contains detail regarding the rehabilitation procedures and approaches during opencast mining operations. Due to the volume of information contained in the aforementioned document it will not be repeated here.

4.7.2.2.2. Stockpile Slopes and Erosion

Table 14 summarises the maximum allowable slope for the soils that are to be stockpiled, as well as the erodibility factor as defined by Wischmeier, Johnson and Cross (1971). Soil stockpiles (as detailed in **Table 13**) A1, A2 and A3 should not be stockpiled at slopes higher than 8 % for stockpile A1 and 12 % for stockpiles A2 and A3. All of the B-horizon stockpiles (B-numbers in **Table 13**) should be stockpiled at slopes of less than 12 %. Stockpiling at higher slopes will result in erosion and loss of valuable soil that must be used during the rehabilitation phase.

4.7.2.3. Mitigation Measures in Areas that have undergone Subsidence

Surface ponds or artificial wetlands often form in areas where subsidence have occurred. The following can be done to mitigate the effect of subsidence on land capability and land use:

- Re-contour the surface or install waterways to carry away water collected in depressions;
- Cut and fill operations can be conducted to help restore surface drainage;
- Subsurface drains can be installed to aid drainage; or
- A combination of the above.

Tension ground cracks often form in areas that have undergone subsidence. These cracks can vary from a few millimetres to approximately 25 cm in width. To mitigate these, the following can be done:

- In cultivated fields, ploughing can be used to close up the cracks. This is not an option for the area under investigation as no cultivated land will be impacted.
- Wide cracks can be filled with soil material and mulched to combat erosion.

Repair to the impacted land can only be done once subsidence has ceased and the soil surface has become stable. Otherwise any mitigation measures will have to be repeated later on. In addition, cracks often close up as the soils settle.

4.8 Impact Rating

The predicted negative impact rating (before and after mitigation) of the proposed activities on land use, land capability and hydropedolgy is summarised in **Table 15, 16** and **17**.

Table 14 Stripping depths and volumes for opencast area

Soil form	Area to be impacted (Ha)	A-horizon stripping depth (m)	Stockpile number	Stockpile volume (m^3)	B-horizon stripping depth (m)	Stockpile number	Stockpile Volume (m^3)
Alluvial deposits/Oakleaf/Hutton/Augrabies Complex	4.5	0.3	A1	13 500	1.5	B1	67 500
Augrabies	101.6	0.3	A2	310 800	1.5	B2	1524 000
Hutton	2.0	0.3			1.5	B3	30 000
Mispah/Rocky Augrabies	50.3	0.5	A3	361 600	-	-	
Mispah/Rocky Hutton	21.6	0.5			-	-	
Rocky Brandvlei	0.7	0.3			-	-	
Soil Rock Complex	32.7	0.5	A4	163 500	-	-	
Total area to be impacted by opencast mining	**213.75 ha**						
Total volume of stockpiled soil	**2 488 900 m^3**						
Total area covered by stockpiled soil (3 m high stockpiles are assumed) in m^2	**829 634 m^2**						
Total area covered by stockpiled soil (3 m high stockpiles are assumed) in ha	**83 ha**						

Table 15 Maximum allowable slopes for stockpiled soils

Soil	Soil sample depth (cm)	Percentage silt	Percentage sand	Organic matter content	Structure index	Permeability index	Approximate Erodibility-factor (K)	Maximum allowable slope (%)	Soil stockpile number
Arcadia (polygon 1)	0-50	18	31	0.19	4	6	0.24	8	A1
Oakleaf (polygon 1)	0-50	28	62	1.6	1	3	0.1	20	A1
Augrabies (polygon 2)	0-20	8	74	0.17	1	1	0.1	20	A2
	20-100	10	72	0.08	1	2	0.1	20	B2
	100-150	9	75	0.09	1	2	0.1	20	B2
Hutton (polygon 3)	0-30	8	80	0.83	1	1	0.1	20	A2
	30-80	6	72	0.69	1	1	0.1	20	B3
	80-120	9	70	0.65	1	1	0.1	20	B3
Kimberly (polygon 4)	0-10	15	63	0,21	1	1	0.1	20	N/A
	10-25	14	65	0.36	1	2	0.1	20	N/A
Augrabies (polygon 4)	0-50	16	61	0.96	1	1	0.1	20	N/A
Brandvlei (polygon 10)	0-50	7	78	0.8	1	1	0.1	20	A3
Rocky Hutton (polygon 12)	0-50	8	78	0.79	1	1	0.1	20	A3

Note: It is advisable to never stockpile at slopes steeper than 12 percent even if the erodibility nomograph of Wischmeier, Johnson and Cross (1971) predicts that the stockpiles will be stable at steeper slopes.

Table 16 Predicted negative impact assessment of mining related activities on current land use

Description		**Type**	**Certainty**	**Extent**	**Duration**	**Reversibility**	**Severity**	**Significance**	**Significance class**
Prior to mitigation measures	Opencast mining	Direct	4	1	4	4	2	44	High
	Underground mining (if subsidence does not occur)	Indirect	1	1	4	4	3	12	Low
	Underground mining (if subsidence occurs)	Direct	4	1	4	3	2	40	High
	Infrastructure	Direct	4	1	4	3	2	40	High
With mitigation measures in place	Opencast mining	Direct	3	1	4	4	2	33	Moderate
	Underground mining (if subsidence does not occur)	Indirect	1	1	4	4	3	12	Low
	Underground mining (if subsidence occurs)	Direct	3	1	4	3	2	30	Moderate
	Infrastructure	Direct	3	1	4	3	2	30	Moderate

Table 17 Predicted negative impact assessment of mining related activities on land capability and agricultural potential

Description		**Type**	**Certainty**	**Extent**	**Duration**	**Reversibility**	**Severity**	**Significance**	**Significance class**
Prior to mitigation measures	Opencast mining	Direct	4	1	4	4	3	48	High
	Underground mining (if subsidence does not occur)	Indirect	1	1	4	4	3	12	Low
	Underground mining (if subsidence occurs)	Direct	4	1	4	3	3	44	High
	Infrastructure	Direct	4	1	4	4	3	48	High
With mitigation measures in place	Opencast mining	Direct	3	1	4	4	3	36	High
	Underground mining (if subsidence does not occur)	Indirect	1	1	4	4	3	12	Low
	Underground mining (if subsidence occurs)	Direct	3	1	4	3	2	30	Moderate
	Infrastructure	Direct	3	1	4	4	3	36	High

Table 18 Predicted negative impact assessment of mining related activities on the hydropedological functioning of the area

Description		**Type**	**Certainty**	**Extent**	**Duration**	**Reversibility**	**Severity**	**Significance**	**Significance class**
Prior to mitigation measures	Opencast mining	Direct	4	4	4	4	4	64	Very high
	Underground mining (if subsidence does not occur)	Indirect	2	4	4	4	4	32	Moderate
	Underground mining (if subsidence occurs)	Direct	4	4	4	4	4	64	Very high
	Infrastructure	Direct	4	3	4	4	3	56	High
With mitigation and rehabilitation measures in place	Opencast mining	Direct	4	4	4	3	3	56	Very high
	Underground mining (if subsidence does not occur)	Indirect	2	4	4	4	4	32	Moderate
	Underground mining (if subsidence occurs)	Direct	3	4	4	3	2	39	High
	Infrastructure	Direct	3	3	4	3	3	39	High

4.7.4. Post Mining Land Capability

It is doubtful that the area affected by opencast mining will ever function in the same manner as is presently the case from a hydropedological perspective. If traditional approaches are followed, one can assume that the rehabilitated land in the opencast pit area will exhibit a much higher infiltration and percolation rate than is presently the case for the high-lying soils. Rehabilitated land tend to be rather permeable and large volumes of water that currently manifests as surface runoff will end up in the opencast pits – even after infilling. In addition, large sections of the deeper Hutton and Augrabies soils, as well as section of the alluvial deposits will be disturbed and their hydropedological and chemical nature will be changed. Hard-setting and crusting are significant concerns and the post-mining landscape could exhibit a much different soil environment than is now the case. The arable and temporary wetland areas to be impacted by opencast mining will probably only be restored to grazing land during rehabilitation while the grazing land will probably only be restored to wilderness land.

In the area where subsidence owing to underground mining could occur, the hydropedological characteristics could be negatively impacted, resulting in areas of water ponding or higher levels of internal drainage. Surface cracking and erosion is a further concern. With the correct mitigation measures these areas can retain their land capability class in the post-mining landscape.

5. CONCLUSION

The following can be concluded:

1. The northern and southern sections of the study area mainly comprise shallow or rocky soils that fall into the wilderness and grazing land capability classes.
2. The mid-section of the site, which is relatively flat, mainly comprise deep soils of the Augrabies, Hutton and Brandvlei soil forms. These are potentially low to medium potential arable land if irrigation water is available.
3. Alluvial soils which indicate a riparian and temporary wet area is located in the mid-section of the site. Numerous ephemeral streams are encountered. These represent watercourses with a distinct channel that is continuous and contains regular or intermittent surface flows. These watercourses lack base flow and wetland features as they only support surface flow for a short period of time after sufficient rainfall events.
4. The proposed mining activities will impact low to medium potential arable soils that comprise deep soils of the Augrabies and Hutton soil forms. A zone comprising riparian and temporary wet soils will be covered by a discard dump and excavated during mining to form an open cast pit. Underground mining will probably result in subsidence. The majority of the soils to be impacted by mining ad related activities are shallow or rocky and fall into the grazing or wilderness land capability class.
5. The farm has been developed as a game farm.
6. Mitigation and rehabilitation measures will result, in areas where opencast mining have occurred, in soils falling into the arable and wetland land land capability classes to be restored to grazing and wilderness land.

7. Where subsidence have occurred because of underground mining, mitigation and rehabilitation measures could restore the land to its current land capability class, although the hydropedological functioning will be altered.

6. REFERENCES

BARKLEY, D. 1999. Implementation of Subsidence Control Regulatory Measures. Annual National Conference of American Surface Mining and Reclamation, Scotsdale, Arizona.

BRADY, N.C. and WEIL, R.P. 1999. The Nature and Properties of Soils. Twelfth edition., Upper Saddle River, New Jersey: Prentice Hall.

TANNER, P. 2007. Chamber of Mines of South Africa.Handbook of Guidelines for Environmental Protection, Volume 3/1981. The Rehabilitation of Land Disturbed by Surface Coal Mining in South Africa.

HILLEL, D. 1982. Introduction to soil physics. Academic Press, INC. Harcourt Brace Javonovich, Publishers.

Land Type Survey Staff. 1972 – 2006. Land Types of South Africa: Digital map (1:250 000 scale) and soil inventory databases. ARC-Institute for Soil, Climate and Water, Pretoria.

MacVicar, C.N. et al. 1977. Soil Classification. A binomial system for South Africa. Sci. Bull. 390. Dep. Agric. Tech. Serv., Repub. S. Afr., Pretoria.

MacVicar, C.N. et al. 1991. Soil Classification. A taxonomic system for South Africa. *Mem. Agric. Nat. Resour. S.Afr.* No.15. Pretoria.

MINE SUBSIDENCE AND ENGINEERING CONSULTANTS. 2007. Introduction to longwall mining and subsidence.http://www.minesubsidence.com/index_files/files/Intro_Longwall_Mining_and_Subs.pdf

WISCHMEIER, W.H., JOHNSON, C.B., AND CROSS, V. 1971. A soil erodibility nomograph for farmland and construction sites. Journal of soil and water conservation. 25(5): 189-193