# TROPICAN GOLD PROJECT

## AngloGold Ashanti Australia Limited, on behalf of the

## Tropicana Joint Venture

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Characterisation of soils and regolith material from RC drilling

September 2008

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# AngloGold Ashanti Australia Limited, on behalf of the Tropicana JV Gold Project

**Characterisation of soils and regolith material from RC drilling**

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**Document Control for Job Number: ATC-SS-0807**

| Document Status | Author | Reviewer | Signature | Date of Issue |
|---|---|---|---|---|
| Draft Report | B. Gordon | M. Braimbridge | | 21 Dec 07 |
| | C. Weston | D. Jasper | | |
| | | B. Bastow | | |
| Final Report | B. Gordon | M. Braimbridge | | 24 Sept 08 |
| | | | | |

# Executive Summary

Outback Ecology Services (OES) was commissioned by AngloGold Ashanti Australia Limited on behalf of the Tropicana JV to undertake a baseline characterisation of soils and regolith materials from RC drilling samples at the proposed Tropicana Gold Project, located 330 km northeast of Kalgoorlie. This information is required to develop a greater understanding of the soil and regolith materials, to provide information on potentially problematic materials, and to assist with the development of recommendations for managing soils / regolith materials for optimum rehabilitation outcomes.

Samples from a variety of geological descriptions were characterised according to their position within the regolith profile (the weathered zone above fresh rock), in either the ‘upper profile’ between 0 and 2 m and the ‘lower profile’ between 3 and 7 m for the samples provided. A significant degree of variation was apparent in regolith morphology, physical and chemical characteristics, both within and between the drill sites sampled.

*Soil physical characteristics*

Many of the materials sampled exhibited dispersive properties, or the tendency to disperse following severe disturbance. This was reflected in the high values of exchangeable sodium (ESP) measured for many samples. Measurements of soil strength upon drying indicated that while the majority of the materials did not hardset, approximately 10 % of the materials measured had modulus of rupture (MOR) values considered to be high. The majority of materials with high MOR results were sampled from the lower regolith profile, however there was little consistency between hard-setting characteristics and the type of regolith material. The dominant soil colours of red and yellowish-red was identified for the majority of samples of ‘Quaternary sand’ geological description, however no clear relationship between colour rating and sampling depth through the regolith profile was identified.

*Soil chemical characteristics*

The soils and regolith materials sampled exhibited a wide range of pH values (pH ($CaCl_2$) 4.5 to 8.5) with little consistency between soil pH and regolith type. In general, there was a slight increase in soil pH with depth at most sites. The majority of materials were classed as non-saline, with electrical conductivity typically increasing with depth in most profiles.

Soil nutrient analyses indicated generally low levels of plant-available nutrients (N, P, K and S) typical for arid land soils. There was no apparent correlation between nutrient concentration and the soil or regolith type.

Cation exchange capacity (CEC) generally increased with depth, though the Exchangeable Sodium Percentage generally decreased with depth through the regolith profiles. The majority of samples returned ESP values classed as sodic, with a number of samples throughout the different regolith types classed as extremely sodic.

Analysis of total metal concentrations indicated no detectable results for As and Cd, with only Cr, Cu, Pb and Ni regularly measured above detectable levels and two individual results for Zn and Hg. No apparent correlation between sample depth or soil / regolith type with heavy metal concentrations was found. Comparison with average crustal abundances found that a few individual results for Cr and Pb were above average crustal abundances in materials of 'Quaternary sand over laterite' and 'Sandstone or ferricrete' regolith type. All heavy metal concentrations were below the DoE EILs with the exception of average Cr results for 'Quaternary sand over laterite' and 'Sandstone or ferricrete' materials.

*Conclusions and Recommendations*

From a geological perspective, broad comparisons between soil and regolith types within the study area are difficult, due to the wide range of materials sampled and analysed, and the wide range of results obtained for many of the measured parameters. Little correlation has been identified between the measured physical and chemical properties and sample depth or soil / regolith type. Quaternary sand materials appear to be the most physically and chemically appropriate for rehabilitation use, though these materials made up the majority of samples analysed in this study. Further characterisation of topsoils according to landform type, or position within the landscape, and vegetation community / soil associations, as well as regolith materials deeper than 7 m, could provide a greater insight into the locations of different soils and regolith materials (particularly surface soils) with consistent characteristics considered appropriate for rehabilitation use.

The study has identified a number of sodic / potentially dispersive and hardsetting materials that may be problematic, particularly if left exposed at the surface following mining and rehabilitation operations. The most dispersive, structurally unstable materials were identified from samples mostly from lower profile depths in the 'Quaternary sand', 'Quaternary sand over laterite', 'Quaternary sand over saprolite' and 'Arenite' regolith types. Samples with MOR values above 60 kPa, and potentially problematic hard-setting behaviour, were from sites of 'Quaternary sand', 'Quaternary sand over laterite' or 'saprolitic clay and laterite' geological descriptions, also from deeper in the regolith profile. Further testing of these materials as they are encountered during operations may be pertinent, with careful consideration made to their handling and placement within reconstructed landforms.

# TABLE OF CONTENTS



**List of Figures**

**List of Tables**

**Appendices**

# 1.0 INTRODUCTION

The Tropicana JV is currently evaluating the Tropicana/Havana gold deposit with the intent of seeking approval to establish a gold mine and access road. The Tropicana Gold Project is located 330 km east-north-east of Kalgoorlie on the edge of the Great Victoria Desert. The Tropicana JV is managed by AngloGold Ashanti Australia (70 %) on behalf of their JV partner Independence Group (30 %).

Outback Ecology Services (OES) was commissioned by AngloGold Ashanti Australia Limited to assess soil and regolith characteristics through targeted sampling of RC drill samples from the Tropicana site, during October 2007. This information is required to develop a general understanding of soils / regolith and their properties in the project area, to provide baseline information identifying potentially problematic materials, and to provide information to assist with the development of recommendations for managing soils and regolith materials for optimum rehabilitation outcomes.

The characterisation of the sampled materials included analysis of the following soil properties:

- soil colour,
- soil chemical analysis (pH, electrical conductivity, plant-available nutrients, soil organic matter, total nitrogen, cation exchange capacity, exchangeable cations),
- total metals (selected samples), and
- potential for clay dispersion (Emerson Aggregate Test) and hard-setting (Modulus of Rupture).

Other soil physical properties such as soil texture and soil structure were not able to be measured due to the impact of the RC drilling on the sampled material.

# 2.0 MATERIALS AND METHODS

## 2.1 Sampling regime

RC drilling samples, to a maximum depth of 9 m, were selected from 45 locations from within the study area (Figure 1) and sent to OES for analyses of chemical and physical parameters. Sites were chosen to acquire samples from a range of geologies throughout the tenements, for which information was supplied by the Tropicana JV (Table 1). Samples from each location were then selected to include a range of regolith depths between 0 and 7 m from the drill samples provided, with 'upper profile' samples representative of the 0 – 2 m depth range and 'lower profile' samples representative of the 3 – 7 m depth range.

## 2.2 Test work and procedures

CSBP Soil and Plant Laboratories conducted analyses on the soil and regolith samples for ammonium and nitrate (Scarle 1984), extractable phosphorus and potassium (Colwell 1965; Rayment and Higginson 1992), extractable sulphur (Blair *et al*. 1991), and organic carbon (Walkley and Black 1934). Analysis of total nitrogen was conducted by combustion at 950°C in oxygen using a Leco FP-428 Nitrogen Analyser. Measurements of electrical conductivity (1:5 $H_2O$), soil pH (1:5 $H_2O$ and 1:5 $CaCl_2$), were conducted using the methods described in Rayment and Higginson (1992). Analysis of the total metal concentrations of samples from each site was conducted by ALS Environmental on an acid digest using ICP-AES.

A measure of soil slaking and dispersive properties (Emerson Aggregate Test) was conducted by OES staff as described in McKenzie *et al.* (2002). Soil strength and the resulting tendency of each material to hardset were assessed using a modified Modulus of Rupture test (Aylmore and Sills 1982; Harper and Gilkes 1994). Soil colour was determined using a Munsell® soil colour chart.

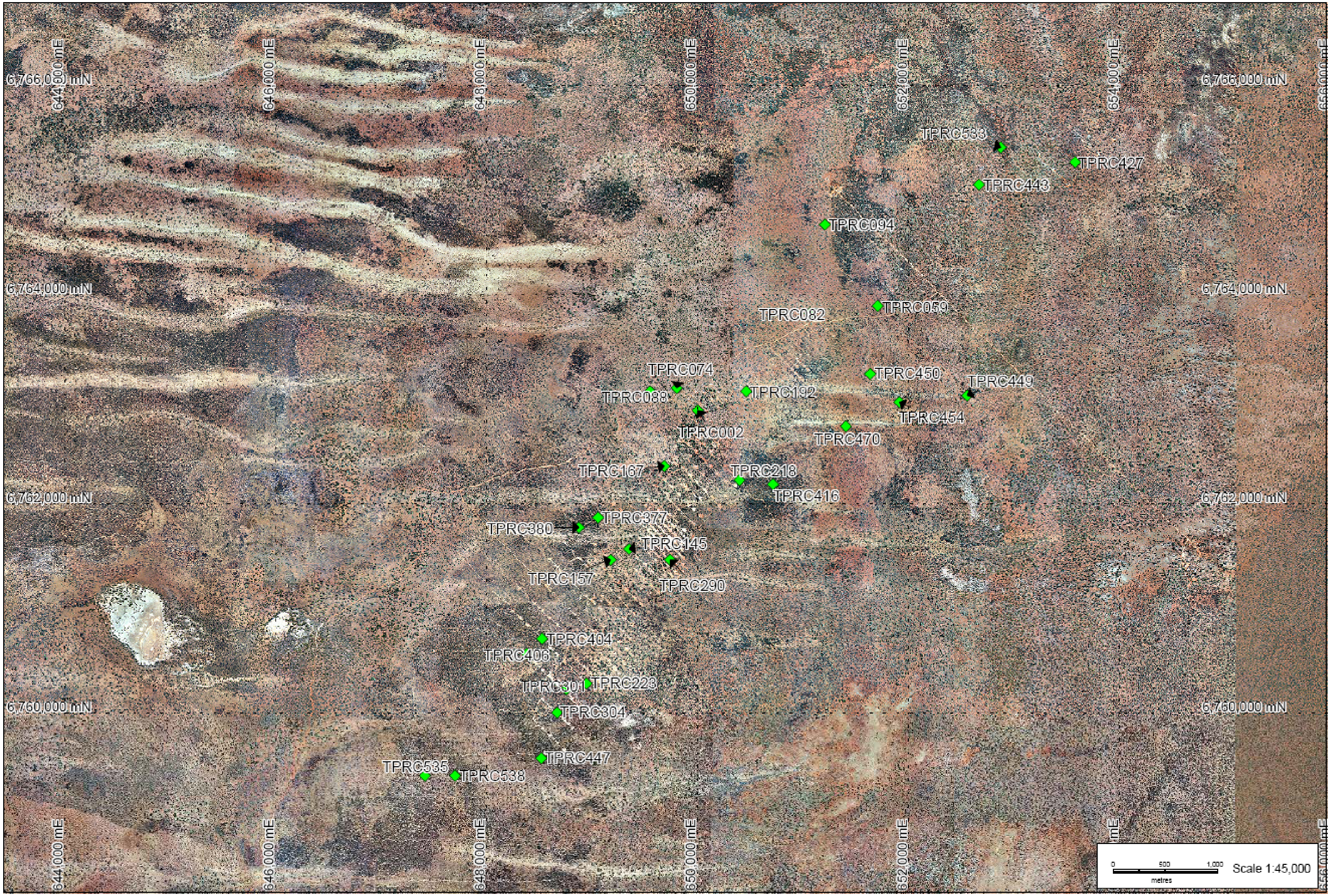


**Figure 1 Location of drill sampling sites for Stage 1.**

**Table 1 Summary table of Tropicana Stage 1 sampling sites and locations.**

| Drill hole # | Coordinates (Projection: UTM Zone 51J, Datum: GDA 94) | | Depth intervals sampled (m) | Geology |
|---|---|---|---|---|
| | Easting (mE) | Northing (mN) | | |
| TPRC002 | 0650003 | 6762890 | 0, 1, 2, 3 | Quaternary sand over lateritic duricrust |
| TPRC059 | 0651705 | 6763888 | 0, 1, 2, 3 | Quaternary sand |
| TPRC074 | 0649798 | 6763104 | 0, 1, 4 | Quaternary sand over ferricrete |
| TPRC082 | 0651067 | 6763816 | 0, 1, 4, 6 | Quaternary sand |
| TPRC088 | 0649545 | 6763075 | 0, 1, 4 | Quaternary sand over calcrete |
| TPRC094 | 0651206 | 6764669 | 0, 1, 2 | - |
| TPRC145 | 0649353 | 6761565 | 0, 1, 2, 3 | Tertiary sand over arenite |
| TPRC157 | 0649174 | 6761463 | 0, 2, 3 | Quaternary sand over saprolitic clay |
| TPRC167 | 0649686 | 6762356 | 0, 1, 3 | Quaternary sand |
| TPRC192 | 0650464 | 6763073 | 1, 2 | Quaternary sand over calcrete |
| TPRC218 | 0650395 | 6762225 | 0, 1, 3 | Quaternary sand |
| TPRC223 | 0648944 | 6760279 | 0, 1, 2 | Quaternary sand |
| TPRC290 | 0649741 | 6761462 | 0, 1, 2, 3 | Quaternary sand over possible sandstone |
| TPRC301 | 0648753 | 6760226 | 0, 1, 4 | Arenite over conglomerate |
| TPRC304 | 0648664 | 6759999 | 1, 3 | Arenite |
| TPRC377 | 0649052 | 6761869 | 0, 1, 2, 3 | Quaternary sand over calcrete |
| TPRC380 | 0648873 | 6761772 | 0, 1, 3, 4 | Lateritic duricrust |
| TPRC404 | 0648521 | 6760705 | 0, 1, 2, 3 | Sandstone or ferricrete |
| TPRC406 | 0648380 | 6760563 | 0, 1, 4 | Calcrete |
| TPRC416 | 0650712 | 6762184 | 0, 1, 3, 4 | Quaternary sand over laterite |
| TPRC427 | 0653576 | 6765266 | 0, 1, 2, 3 | Quaternary sand |
| TPRC443 | 0652663 | 6765051 | 0, 1 | - |
| TPRC447 | 0648513 | 6759570 | 0, 1, 2, 4 | Quaternary sand |
| TPRC449 | 0652553 | 6763030 | 0, 1, 2, 5 | Quaternary sand |
| TPRC450 | 0651634 | 6763240 | 0, 1, 2 | Laterite |
| TPRC454 | 0651916 | 6762967 | 0, 1, 2 | Calcrete over silcrete |
| TPRC470 | 0651404 | 6762740 | 0, 1, 2, 3 | Quaternary sand over possible laterite |
| TPRC533 | 0652870 | 6765405 | 1, 2, 3 | Quaternary sand over possible laterite |
| TPRC535 | 0647412 | 6759400 | 0, 1, 3 | Quaternary sand over tertiary sand |
| TPRC538 | 0647698 | 6759397 | 0, 1, 4 | Quaternary sand over possible laterite |

# 3.0 RESULTS AND DISCUSSION

## 3.1 Soil physical properties

### 3.1.1 Soil / regolith profile morphology

Information provided about the geological description associated with the drill sites and samples was used to group the sites for ease of comparison. Geological and associated material descriptions were provided for most sites and sampled depth intervals, however no descriptions were available for the uppermost 'surface' materials (0 m depth samples) (Appendix E). Two sites with unknown geologies (TPRC094 and TPRC443) were included in this study given their location towards the northern boundary of the proposed operational area, away from the majority of other sites. Where this information has been provided, it is clear that the regolith morphology is highly variable, both between sites of differing geology, and between depths at each site.

The major trends in regolith geology / lithology were as follows:

- Dominant regolith profile lithologies included quaternary sands, quaternary sands underlain by calcrete or (suspected) laterite, and combinations of arenite topsoils or subsoils. Soil profiles at sites with arenite materials consisted either entirely of arenite, arenite over conglomerate rock or sand over arenite.
- Other regolith lithologies included;
  - quaternary sand over ferricrete
  - quaternary sand over (suspected) saprolitic clay
  - quaternary sand over sandstone
  - quaternary sand over tertiary sand
  - calcrete,
  - calcrete over silcrete
  - laterite / lateritic duricrust
  - (suspected) sandstone or ferricrete.
- Quaternary sands extended mostly to between 2 and 3 m depth, with some sites including sand descriptions to 7 m depth.
- Quaternary sands mostly consisted of fine grained sand, often with some gravel, rock chips or 'powdery' material at depth. The description for TPRC447 included sand and gravel with a clay matrix at 4 m.
- For sites with quaternary sands over a contrasting subsoil material (either calcrete, laterite, ferricrete, sandstone, saprolitic clay or tertiary sands) or tertiary sand over arenite, depth of the overlying sand to the contrasting material was consistently described to be between 2 and 4 m.
- Laterite / lateritic duricrust materials were described as light to dark brown sands or gravels, with some light clay.

- Calcrete and arenite materials were easily identified from the coarse, red quaternary sands. Calcrete and arenite was described as fine or powdery, white/pale grey to light brown in colour often with gravel chips

For ease of comparison between the geological descriptions above, the range of depth intervals sampled through the regolith profiles have been summarised as upper or lower profile depths, with the 'upper' profile generally consisting of soils and regolith between 0 and 2 m, and the 'lower' profile comprising materials sampled from 3 to 7 m.

### 3.1.2 Structural stability

Soil structure describes the arrangement of solid particles and void space in a soil. It is an important factor influencing the ability of soil to support plant growth, store and transmit water and resist erosional processes. A well-structured soil has fractures and pores which allow water, air and roots to enter the soil easily. When a soil material is disturbed, the breakdown of aggregates into primary particles can lead to structural decline (Needham *et al.* 1998). This can result in hard-setting and crusting at the soil surface and a 'massive' soil structure at depth, potentially reducing the ability of seeds to germinate, roots to penetrate the soil matrix and water to infiltrate to the root zone.

The structural stability of a soil and its susceptibility to structural decline is complex and depends on the net effect of a number of properties, including the amount and type of clay present, organic matter content, soil chemistry and the nature of disturbance. Two soil properties which can lead to loss of structure are slaking and dispersion. Slaking is a process by which aggregated particles in a structured soil will collapse during wetting, breaking down to leave primary particles and micro-aggregates, because they have insufficient strength to resist the stresses caused by rapid-water intake (Needham *et al*. 1998).

In dispersive soils, clay particles swell in the presence of water, and individual clay layers disperse into the soil solution. This reaction is principally due to a dominance of sodium ions adsorbed to the clay surfaces. Soil aggregates that slake and disperse indicate an unstable soil structure, which is not favourable for infiltration by water (potentially leading to run-off and erosion), or for root exploration (Needham *et al*., 1998), and can be easily degraded. These soils should be seen as potentially problematic when used for the construction of landforms or reconstruction of soil profiles for rehabilitation, particularly if left exposed at the surface.

The Emerson Aggregate Test identifies the potential slaking and dispersive properties of soil aggregates. The dispersion test identifies the properties of the soil materials under a worst case scenario, where severe stress is applied to the soil material and slaking and dispersion are observed over a 24 hour period. Generally, samples allocated into Emerson classes 1 and 2 are those most likely to exhibit dispersive properties and therefore be the most problematic.

Emerson Test results from the Tropicana drill samples indicate a wide range of slaking and dispersive behaviours both between sites of different geology and between samples at different regolith profile depths (Table 2). While no samples were allocated the highest Emerson Test Class 1, the most dispersive, structurally unstable (Class 2) results were for samples mostly from lower profile depths from the ‘Quaternary sand’, ‘Quaternary sand over laterite’, ‘Quaternary sand over saprolite’ and ‘Arenite’ regolith geological descriptions. Some samples, particularly those from surface materials (0 and 1 m depth intervals), exhibited an increase in dispersion over the 24 hour testing period, from non-slaking and non-dispersive to slaking and completely dispersive upon remoulding (Appendix C). An increase in dispersive behaviour during the testing timeframe indicates potential susceptibility to soil structure decline under waterlogged conditions.

The majority of individual samples allocated Emerson Test Class 2 in the ‘Quaternary sand’, ‘Quaternary sand over saprolitic clay’ and ‘Arenite’ regolith types were associated with high ESP results (greater than 15 % ESP) (see Section 3.2.5), indicating the influence of sodicity on increased dispersion and structural instability. However, a few individual samples from the ‘Quaternary sand’, ‘Quaternary sand over calcrete’, ‘Quaternary sand over sandstone’, ‘Arenite’ and ‘Unknown geology’ regolith types with lower Emerson Test classes (3b, 4-6) were also classified as moderately to very saline. High soil EC can have a flocculating effect on soil particles despite high sodicity, with clay dispersion potentially increasing as salt is leached from the material.

### 3.1.3 Soil strength

A modified Modulus of Rupture (MOR) test was conducted on all samples collected. This test is a measure of soil strength and identifies the tendency of a soil to hard-set as a direct result of soil slaking and dispersion. A modulus of rupture of over 60 kPa has been described as the critical value for distinguishing potentially problematic soils in agricultural scenarios (Cochrane and Aylmore 1997). Restricted root penetration into the soil matrix is a likely consequence of a high modulus of rupture. In reconstructed soil profiles, materials normally deep within the profile that may have a high MOR can often be re-deposited closer to the surface, leading to germination / emergence and root penetration problems.

The majority of samples from the Tropicana sites exhibited MOR values below 60 kPa (Figure 2) and can be considered non-problematic from a potentially hard-setting perspective. Samples with MOR values above 60 kPa, and potentially problematic hard-setting behaviour, were from sites of ‘Quaternary sand’, ‘Quaternary sand over laterite or saprolitic clay and laterite’ geological descriptions. The highest MOR value of 458.8 kPa was measured for one sample from 1 m depth at Site TPRC443 (unknown geology, not graphed, Table 3). The next highest value of 162.1 kPa was measured for one laterite/lateritic duricrust sample. Higher MOR values were measured predominantly on samples from deeper in the regolith profile (below 2 m depth) than on samples from the surface or upper profile.

**Table 2 Summary of slaking/dispersion properties (Emerson Test) results, indicating structural stability after the 24 hour testing period. Emerson Test classes are included in Appendix B.**

| Geological description | Number of sites | Regolith profile depth | Emerson class range (24 hour) | Description |
|---|---|---|---|---|
| Quaternary sand | 8 | Upper | 2 to 7/8 | Slaked with some dispersion (2), remoulded soil minor dispersion (3b), to no slaking or dispersion (7/8) |
| | | Lower | 2 to 4-6 | Slaked with some severe dispersion (2), mostly no dispersion (4-6) |
| Quaternary sand over laterite | 5 | Upper | 3b to 7/8 | Surface materials mostly slaked with remoulded soil partly dispersive (3b). |
| | | Lower | 2 to 4-6 | One soil slaked and severely dispersed (2), most soils slaked with minor or no remoulded dispersion (3b, 4-6) |
| Quaternary sand over ferricrete | 1 | Upper | 3b | Slaked, remoulded soil partly dispersive |
| | | Lower | 4-6 | Slaked, no dispersion |
| Quaternary sand over calcrete | 3 | Upper | 3b | Slaked, remoulded soil partly dispersive |
| | | Lower | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| Quaternary sand over saprolitic clay | 1 | Upper | 3b | Slaked, remoulded soil partly dispersive |
| | | Lower | 2 to 4-6 | Slaked with partial dispersion (2), mostly no dispersion (4-6) |
| Quaternary sand over sandstone | 1 | Upper | 3a to 7/8 | Most soils slaked with no dispersion (4-6), one soil partly dispersive (2) |
| | | Lower | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| Quaternary sand over tertiary sand | 1 | Upper | 3b | Slaked, remoulded soil partly dispersive |
| | | Lower | 2 to 4-6 | Most soils slaked with no dispersion (4-6), one soil partly dispersive (2) |
| Arenite / sand over arenite / arenite over conglomerate | 3 | Upper | 2 to 4-6 | Slaked with some severe dispersion (2), mostly no dispersion (4-6) |
| | | Lower | 2 to 4-6 | One sample slaked with partial dispersion (2), mostly no dispersion (4-6) |
| Calcrete / calcrete over silcrete | 2 | Upper | 3b | Slaked, remoulded soil partly dispersive |
| | | Lower | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| Laterite / lateritic duricrust | 2 | Upper | 3b to 7/8 | Most slaked with remoulded soils partly dispersive (3b), one soil did not slake or disperse (7/8) |
| | | Lower | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| Sandstone or ferricrete | 1 | Upper | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| | | Lower | 3b to 4-6 | Slaked, some remoulded soils partly dispersive (3b), some not dispersive (4-6) |
| Unknown geology | 2 | Upper | 3a to 3b | Slaked, one remoulded soil completely dispersive (3a), most remoulded soils partially dispersive (3b) |
| | | Lower | 3b | Slaked, remoulded soil partly dispersive |

As the MOR test is conducted on reconstructed soil blocks composed of the < 2 mm soil fraction (as derived from pulverised RC drill samples), it does not take into account the effect of soil texture, gravel content or soil structure on soil strength, nor any degree of compaction that may be present in the field. It does, however, provide insight into the relative potential for layers to hard-set and compact with repeated wetting and drying cycles, and the ability of roots to fracture the soil and penetrate crack faces.

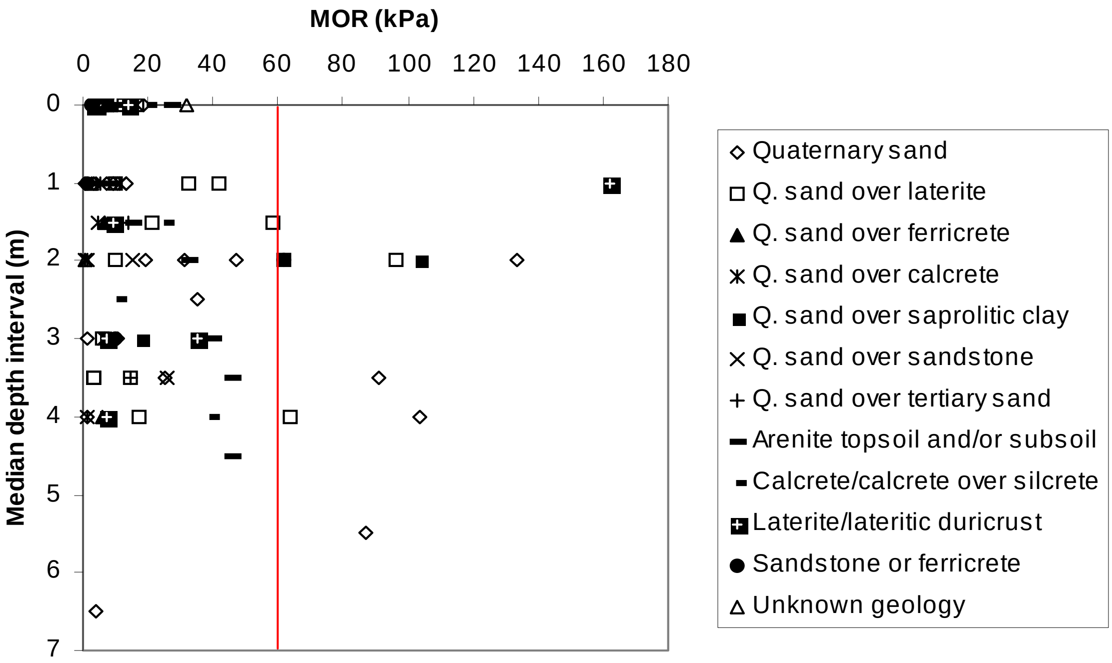


**Figure 2 Modulus of Rupture (kPa) with corresponding depth for all samples from 30 sites grouped according to geological description. Red line indicates potential restrictions to plant and root development (Cochrane and Aylmore 1997). Sample from TPRC443 (1 m) with MOR of 458 kPa (outlier) not graphed.**

### 3.1.4 Soil colour

Soil colour is the most distinctive soil property and is frequently used by soil scientists for the identification and classification of soil. As a function of parent material, soil colour may also be used as an indicator of physical and chemical properties such as texture, mineralogy and iron content (Schwertmann 1993), as well as biological properties and soil processes. Soil colour is described using three colour dimensions known as hue, value and chroma, which are coded to describe each individual grade of colour (Munsell® Soil Colour Charts 2000). Hue indicates the relation of a colour to red, yellow, green, blue and purple, value indicates lightness and chroma indicates colour strength.

There was a substantial range of soil colours exhibited in the Tropicana drill samples, ranging from dark red, pink, brown and yellow to light gray (Appendix C), based on the Munsell® soil colour system.

**Table 3 Summary of ranges for Modulus of Rupture (MOR), soil pH, electrical conductivity (EC) and percentage organic carbon (OC), grouped according to geological description and sampling depth within the regolith profile. 'Upper' regolith profile depth refers to samples taken between 0 and 2 m, 'lower' refers to samples between 3 and 7 m depth. Dashes indicate either only one sample present, or the same result, resulting in no range.**

| Geological description | Number of sites | Regolith profile depth | MOR (kPa) | | | pH ($CaCl_2$) | | | EC (dS/m) | | | OC (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. |
| Quaternary sand | 8 | Upper | 1 | 133.2 | 17.5 | 4.9 | 8.4 | 6.3 | 0.01 | 0.81 | 0.13 | 0.06 | 0.59 | 0.22 |
| | | Lower | 1.3 | 103.6 | 40.6 | 6.3 | 8.5 | 7.3 | 0.02 | 0.94 | 0.33 | 0.05 | 0.26 | 0.14 |
| Quaternary sand over laterite | 5 | Upper | 4.2 | 96.2 | 31.1 | 4.5 | 7.2 | 6.1 | 0.01 | 0.10 | 0.05 | 0.05 | 0.54 | 0.22 |
| | | Lower | 3.6 | 63.7 | 18.1 | 6.0 | 7.9 | 7.3 | 0.06 | 0.73 | 0.20 | 0.05 | 0.26 | 0.10 |
| Quaternary sand over ferricrete | 1 | Upper | 6.8 | 8.5 | 7.2 | 6.2 | 7.7 | 6.9 | 0.02 | 0.11 | 0.06 | 0.13 | 0.22 | 0.17 |
| | | Lower | 5.9 | - | - | 6.4 | - | - | 0.06 | - | - | 0.16 | - | - |
| Quaternary sand over calcrete | 3 | Upper | 0.4 | 11.4 | 4.9 | 5.0 | 7.7 | 6.6 | 0.02 | 0.46 | 0.16 | 0.14 | 1.00 | 0.31 |
| | | Lower | 1.3 | 6.4 | 3.8 | 7.7 | 7.9 | 7.8 | 0.13 | 1.30 | 0.72 | 0.16 | 0.37 | 0.26 |
| Quaternary sand over saprolitic clay | 1 | Upper | 3.1 | 103.9 | 53.5 | 4.7 | 6.9 | 5.8 | 0.08 | 0.15 | 0.12 | 0.19 | 0.40 | 0.29 |
| | | Lower | 18.2 | - | - | 6.9 | - | - | 0.13 | - | - | 0.08 | - | - |
| Quaternary sand over sandstone | 1 | Upper | 7.5 | 15.3 | 11.4 | 5.4 | 6.2 | 5.8 | 0.01 | 0.01 | 0.02 | 0.16 | 0.23 | 0.20 |
| | | Lower | 26.0 | - | - | 7.8 | - | - | 0.70 | - | - | 0.14 | - | - |
| Quaternary sand over tertiary sand | 1 | Upper | 8.8 | 14.2 | 11.5 | 4.5 | 4.7 | 4.6 | 0.01 | 0.02 | 0.02 | 0.12 | 0.32 | 0.22 |
| | | Lower | 14.4 | - | - | 6.9 | - | - | 0.1 | - | - | 0.11 | - | - |
| Arenite / sand over arenite / arenite over conglomerate | 3 | Upper | 4.7 | 32.4 | 16.5 | 6.3 | 8.4 | 7.5 | 0.10 | 1.20 | 0.40 | 0.09 | 0.37 | 0.22 |
| | | Lower | 39.9 | 46.0 | 43.8 | 6.9 | 7.9 | 7.3 | 0.29 | 0.59 | 0.46 | 0.05 | 0.15 | 0.08 |
| Calcrete / calcrete over silcrete | 2 | Upper | 3.4 | 25.3 | 14.2 | 6.3 | 7.9 | 7.4 | 0.03 | 0.20 | 0.12 | 0.07 | 0.19 | 0.14 |
| | | Lower | 10.4 | 39.5 | 24.9 | 8.0 | 8.0 | 8.0 | 0.14 | 0.15 | 0.15 | 0.05 | 0.07 | 0.06 |
| Laterite / lateritic duricrust | 2 | Upper | 3.7 | 162.1 | 47.3 | 4.7 | 7.6 | 6.1 | 0.03 | 0.16 | 0.09 | 0.16 | 0.37 | 0.25 |
| | | Lower | 7.2 | 35.4 | 24.5 | 6.4 | 7.7 | 6.9 | 0.04 | 0.22 | 0.11 | 0.05 | 0.10 | 0.07 |
| Sandstone or ferricrete | 1 | Upper | 1.0 | 61.6 | 21.8 | 4.5 | 6.6 | 5.7 | 0.02 | 0.11 | 0.07 | 0.05 | 0.28 | 0.13 |
| | | Lower | 9.7 | - | - | 7.6 | - | - | 0.14 | - | - | 0.05 | - | - |
| Unknown geology | 2 | Upper | 2.4 | 458.8 | 124.8 | 6.9 | 7.8 | 7.4 | 0.07 | 0.99 | 0.34 | 0.06 | 0.19 | 0.23 |
| | | Lower | 0.9 | - | - | 7.9 | - | - | 0.24 | - | - | 0.14 | - | - |

Overall, no clear relationship between colour rating and sampling depth through the regolith profile was identified. However, some general colour trends were found as follows;

- Samples from quaternary sand sites (including sites with quaternary sand over a contrasting material) were dominated by red and yellowish red colours, particularly in the upper regolith profile (Appendix C).
- Colours in the lower profile at quaternary sand sites also included pink, reddish yellow, strong brown and reddish brown, with some red colours.
- Pale colours such as pink and light reddish brown colours were generally associated with lower profiles from arenite and calcrete sites, and sites with sand over calcrete or saprolitic clay.
- Soil colours from laterite and sandstone / ferricrete sites were dominated by reddish yellow and reddish brown colours in the lower profile and yellowish reds in the upper profile.

## 3.2 Soil chemical properties

### 3.2.1 Soil pH

The soil pH gives a measure of the soil acidity or alkalinity. The ideal pH range for plant growth of most agricultural species is considered to be between 5.0 and 7.5 (Moore, 1998). Outside of this range, the plant-availability of some nutrients is affected, while various metal toxicities (e.g. Al and Mn) can become limiting to plant growth at low pH. For native species, which are known to be tolerant of wider ranges in soil pH, preferred pH ranges are best inferred from the soil in which they are observed to occur. Soil pH measured in 0.01 M calcium chloride ($CaCl_2$) is considered a more accurate measurement of hydrogen ion concentration ($[H^+]$), closer to that of the natural soil solution which is taken up by plants (Hunt and Gilkes 1992). As a result, soil pH measured in $CaCl_2$ is lower than pH measured in water, however both measurements are taken for a complete assessment.

A broad range of soil pH results were found for all sites, reflecting the variation and complexity of the soils and regolith materials sampled. Soil pH generally increased slightly with sampling depth through the regolith profile (Figure 3). Most results fell between pH 6 and 8, which can be rated as slightly acidic to neutral to slightly alkaline for pH measured in 1:5 soil:water (Hazelton and Murphy 2007). Samples between pH 4 and 6 are classed as strongly to moderately acid, and samples above pH 8 are classed as moderately to strongly alkaline. Soil pH ranges between sites of different geology are included in Table 3.

Results for pH ($CaCl_2$) were typically lower (less alkaline) than the pH ($H_2O$) results. From a plant growth perspective, the pH ($CaCl_2$) results indicate favourable growth conditions that range from slightly acidic to slightly alkaline, and are likely to be suitable for plant re-establishment if local species are used in rehabilitation.

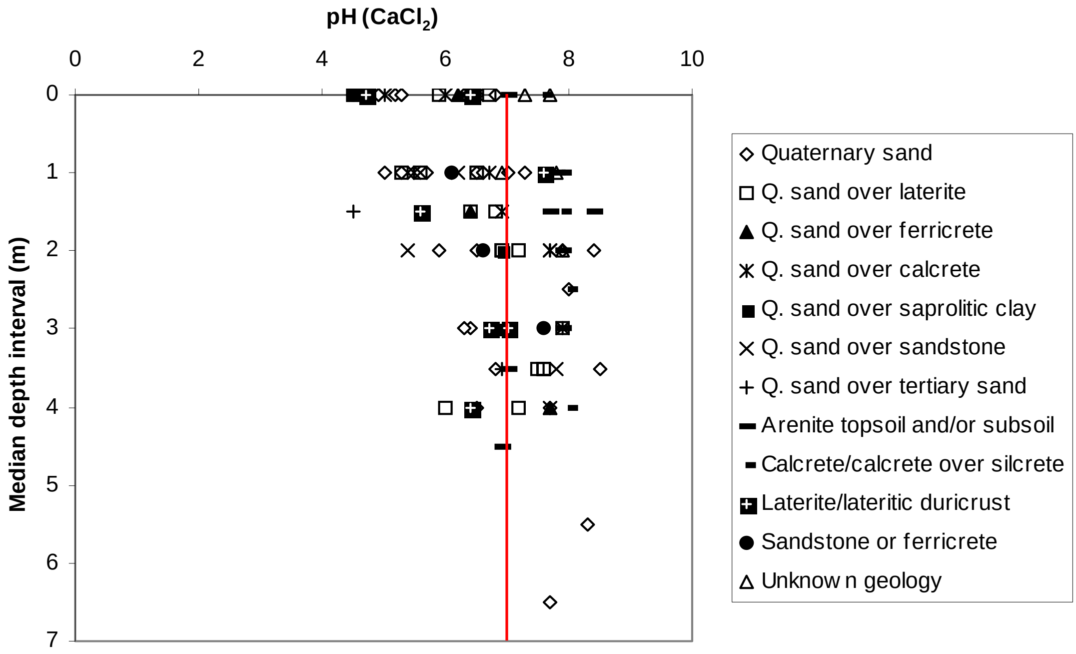


**Figure 3** **Soil pH ($CaCl_2$) with corresponding depth for all samples from 30 sites grouped according to geological description. Red line indicates neutral pH 7.0.**

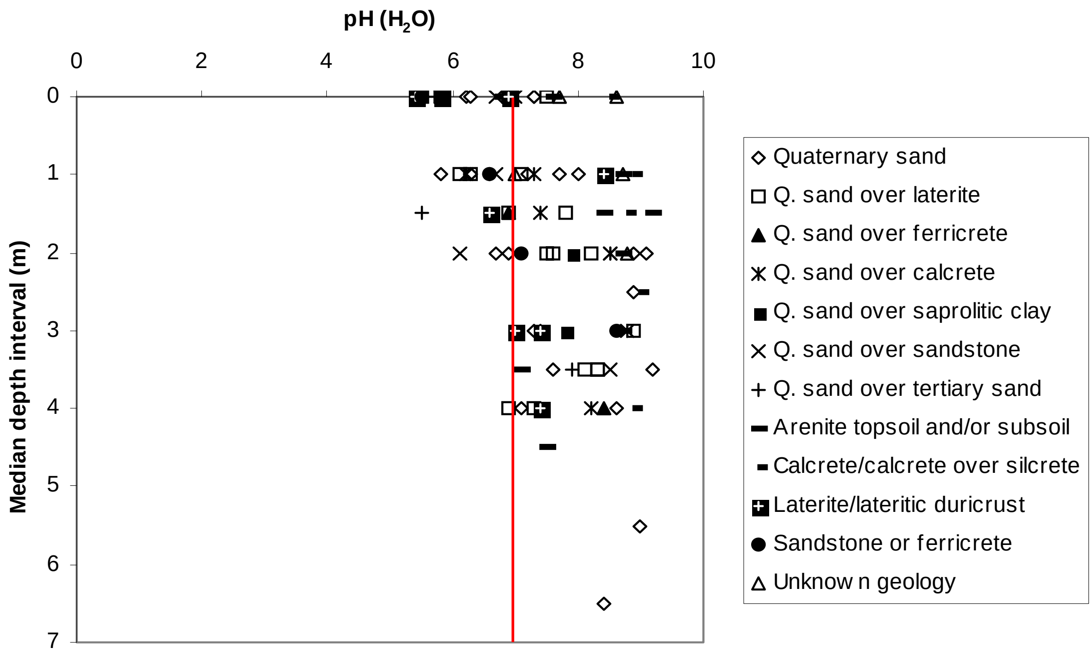


**Figure 4** **Soil pH ($H_2O$) with corresponding depth for all samples from 30 sites grouped according to geological description. Red line indicates neutral pH 7.0.**

### 3.2.2 Electrical conductivity

Electrical conductivity (EC) is a measure of the soluble salts in soils or water. Soil salinity results from natural processes of landscape evolution, hydrological processes and rainfall (Hunt and Gilkes, 1992), and is categorised according to soil texture.

EC generally increased with depth for the majority of samples (Figure 5). While texture was not assessed for the Tropicana drill samples, the dominance of sandy textures in the majority of material descriptions lends to classification of most samples as non-saline to moderately saline (Appendix D). Few samples had EC recordings of over 0.5 dS/m (moderate to very saline classification).

Typical EC values for arid zone soils may range between 0.05 to 1 dS/m (non-saline to slightly saline to moderately saline), but are strongly dependant on soil texture and other factors such as landscape position, regolith depth, and proximity to salt lakes and paleochannels. Only two samples (TPRC088 at 4 m and TPRC301 at 0 m) recorded EC values over 1.0 dS/m (extremely saline classification). The outliers above 0.5 dS/m are mostly individual samples from the 'Quaternary sand over calcrete', 'Arenite', 'Unknown geology' and 'Quaternary sand over sandstone' regolith types from lower profile depths. However, four of these outliers are of the 'Quaternary sand' regolith type.

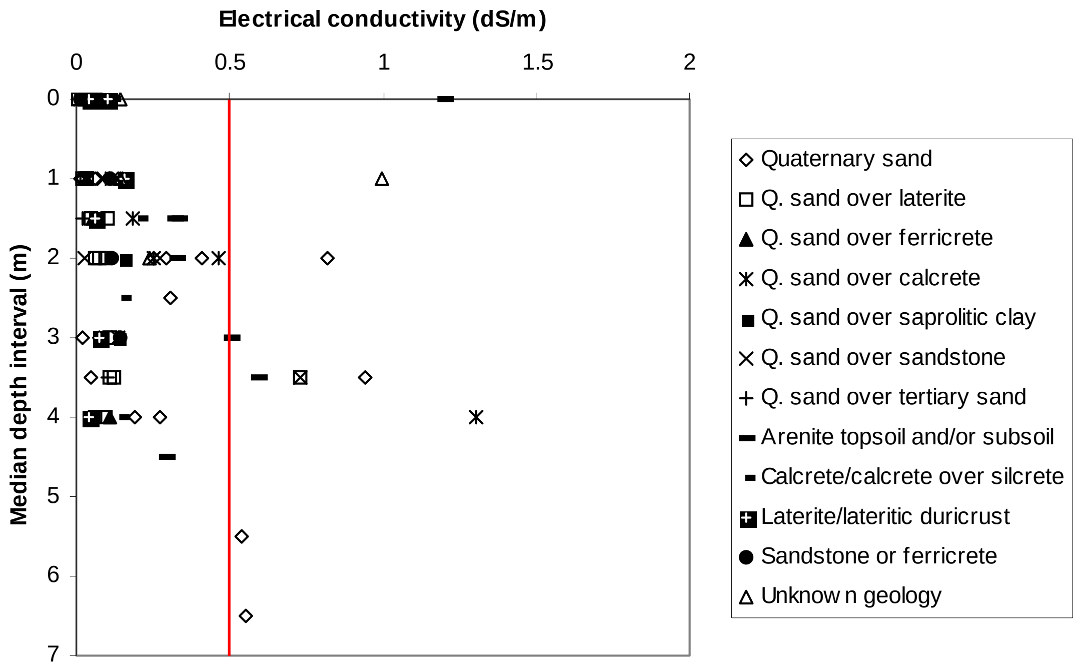


**Figure 5 Electrical conductivity (EC 1:5 $H_2O$) with corresponding depth for all samples from 30 sites grouped according to geological description. Values above 0.5 dS/m are considered to be moderate to very saline indicated by the red line.**

### 3.2.3 Soil organic matter

The organic matter content of a soil is an important factor influencing many physical, chemical and biological soil characteristics. It is directly derived from plants and animals and its functions in soil include supporting the micro and macro-organisms in the soil, increasing the water retention capacity of the soil, buffering pH and improving soil structure.

The amount of organic carbon within the majority of the soils sampled was low, as is the case in many natural Western Australian soils (Figure 5). The highest levels of organic carbon were found in surface samples from quaternary sand, quaternary sand over calcrete and quaternary sand over laterite sites. Overall, the organic carbon content of all samples can be classified as low to extremely low (<1.0 % OC) (Hazelton and Murphy 2007). As would be expected the level of soil organic carbon typically decreased slightly with depth.

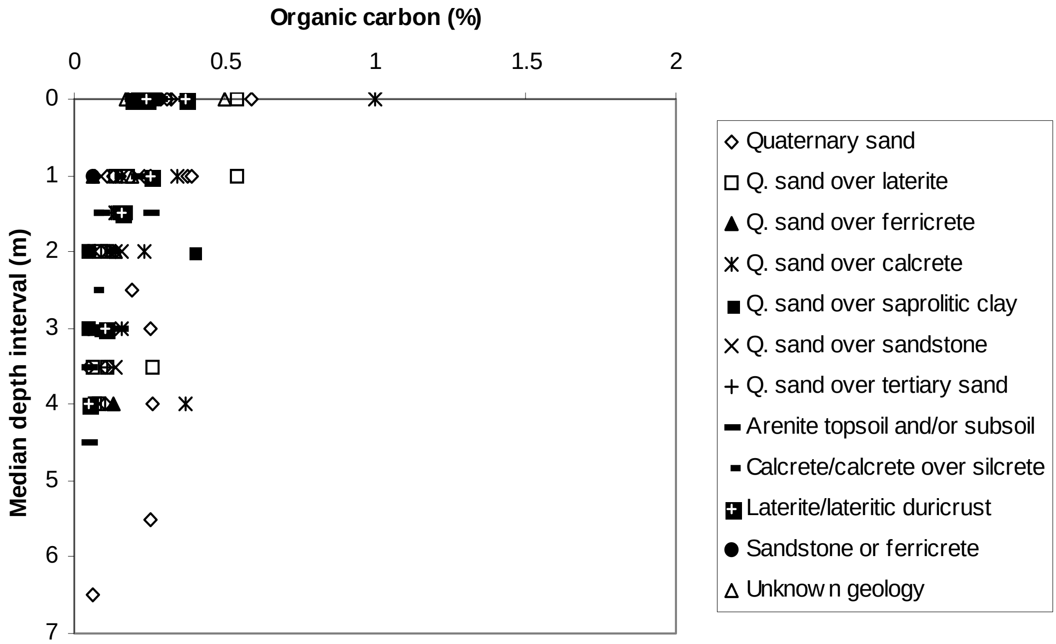


**Figure 6 Soil organic carbon (%) with corresponding depth for all samples from 30 sites grouped according to geological description.**

### 3.2.4 Soil nutrients

The most important macro-nutrients for plant growth are nitrogen (N), phosphorus (P), potassium (K), and sulphur (S). These nutrients are largely derived from the soil and organic matter. While the definition of adequate levels of these nutrients are well known for agricultural species, relatively little information is available for the nutrient requirements of native species.

The amount of plant available nutrients held within the Tropicana soil and regolith materials sampled were variable between material types and sampling depth (Table 4, Figures 7 to 11). Total nitrogen

**Table 4 Summary of average and range of soil nutrient analysis results, grouped according to geological description and sampling depth within the regolith profile. 'Upper' regolith profile depth refers to samples taken between 0 and 2 m, 'lower' refers to samples between 3 and 7 m. Dashes indicate either only one sample present or the same result, resulting in no range.**

| Geological description | Number of sites | Regolith profile depth | Total N (%) | | | Extractable nutrients (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Nitrate ($NO_3^-$) | | | P | | | K | | | S | | |
| | | | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. |
| Quaternary sand | 8 | Upper | 0.01 | 0.05 | 0.02 | 1 | 15 | 2.9 | 2 | 8 | 2.5 | 45 | 1348 | 188 | 1.0 | 193 | 21.4 |
| | | Lower | 0.01 | 0.02 | 0.01 | 1 | 12 | 2.7 | 2 | 6 | 2.5 | 62 | 801 | 490 | 3.1 | 155 | 21.5 |
| Quaternary sand over laterite | 5 | Upper | 0.01 | 0.05 | 0.02 | 1 | 5 | 2.0 | 2 | 7 | 2.6 | 46 | 350 | 165 | 2.3 | 19.8 | 6.8 |
| | | Lower | 0.01 | 0.01 | 0.01 | 1 | 5 | 1.8 | 2 | 2 | 2.0 | 189 | 650 | 425 | 6.8 | 100 | 25.7 |
| Quaternary sand over ferricrete | 1 | Upper | 0.01 | 0.02 | 0.01 | 1 | 5 | 3.0 | 2 | 2 | 2.0 | 89 | 309 | 199 | 2.4 | 6.3 | 4.3 |
| | | Lower | 0.01 | - | - | 2 | - | - | 2 | - | - | 84 | - | - | 7.7 | - | - |
| Quaternary sand over calcrete | 3 | Upper | 0.01 | 0.1 | 0.03 | 1 | 4 | 1.8 | 2 | 3 | 2.1 | 40 | 1067 | 232 | 4.0 | 75 | 21.1 |
| | | Lower | 0.02 | 0.03 | 0.02 | 1 | 1 | 1 | 2 | 2 | 2.0 | 281 | 1702 | 991 | 13.9 | 114 | 63.9 |
| Quaternary sand over saprolitic clay | 1 | Upper | 0.02 | 0.04 | 0.03 | 1 | 1 | 1 | 2 | 3 | 2.5 | 42 | 154 | 98 | 2.1 | 19.3 | 10.7 |
| | | Lower | 0.06 | - | - | 1 | - | - | 2 | - | - | 371 | - | - | 15.1 | - | - |
| Quaternary sand over sandstone | 1 | Upper | 0.02 | 0.02 | 0.02 | 1 | 1 | 1 | 2 | 2 | 2.0 | 70 | 103 | 83 | 2.2 | 3.6 | 2.9 |
| | | Lower | 0.01 | - | - | 2 | - | - | 2 | - | - | 1094 | - | - | 97.6 | - | - |
| Quaternary sand over tertiary sand | 1 | Upper | 0.01 | 0.03 | 0.02 | 1 | 1 | 1 | 2 | 3 | 2.5 | 63 | 76 | 69.5 | 13.3 | 17.7 | 15.5 |
| | | Lower | 0.01 | - | - | 2 | - | - | 2 | - | - | 165 | - | - | 19.7 | - | - |
| Arenite / sand over arenite / arenite over conglomerate | 3 | Upper | 0.01 | 0.03 | 0.02 | 1 | 24 | 7.1 | 2 | 2 | 2.0 | 75 | 880 | 344 | 2.7 | 86 | 33.0 |
| | | Lower | 0.01 | 0.01 | 0.01 | 1 | 11 | 4.3 | 2 | 2 | 2.0 | 300 | 547 | 431 | 47.6 | 124 | 77.8 |
| Calcrete / calcrete over silcrete | 2 | Upper | 0.01 | 0.02 | 0.01 | 1 | 6 | 2.2 | 2 | 3 | 2.2 | 32 | 647 | 325 | 3.5 | 24.3 | 11.5 |
| | | Lower | 0.01 | 0.01 | 0.01 | 2 | 2 | 2.0 | 2 | 2 | 2.0 | 529 | 939 | 734 | 11.2 | 20.6 | 15.9 |
| Laterite / lateritic duricrust | 2 | Upper | 0.02 | 0.03 | 0.02 | 1 | 5 | 2.5 | 2 | 2 | 2.0 | 70 | 261 | 145 | 4.3 | 22.1 | 10.2 |
| | | Lower | 0.01 | 0.01 | 0.01 | 1 | 4 | 2.0 | 2 | 2 | 2.0 | 277 | 551 | 384 | 9.5 | 16.5 | 12.7 |
| Sandstone or ferricrete | 1 | Upper | 0.01 | 0.03 | 0.02 | 1 | 2 | 1.3 | 2 | 2 | 2.0 | 66 | 201 | 126 | 6.6 | 14.1 | 11.2 |
| | | Lower | 0.01 | - | - | 1 | - | - | 2 | - | - | 455 | - | - | 14.9 | - | - |
| Unknown geology | 2 | Upper | 0.01 | 0.05 | 0.02 | 2 | 23 | 7.5 | 2 | 6 | 3.0 | 95 | 774 | 369 | 3.0 | 238 | 65.0 |
| | | Lower | 0.01 | - | - | 32 | - | - | 2 | - | - | 864 | - | - | 21.6 | - | - |

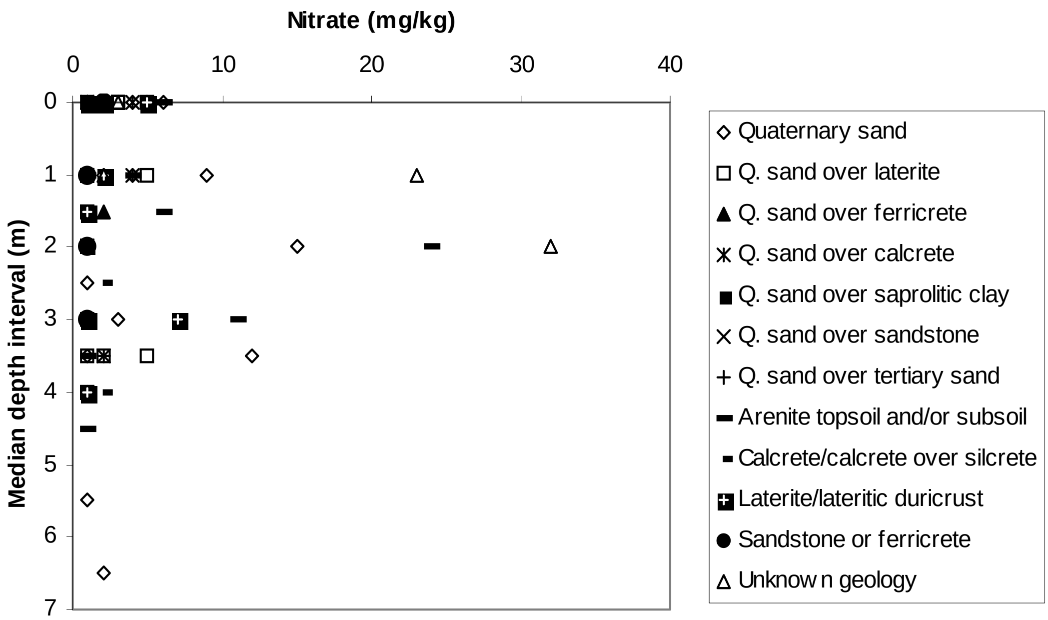


**Figure 7 Extractable nitrate (N) (mg/kg) with corresponding depth for all samples from 30 sites grouped according to geological description.**

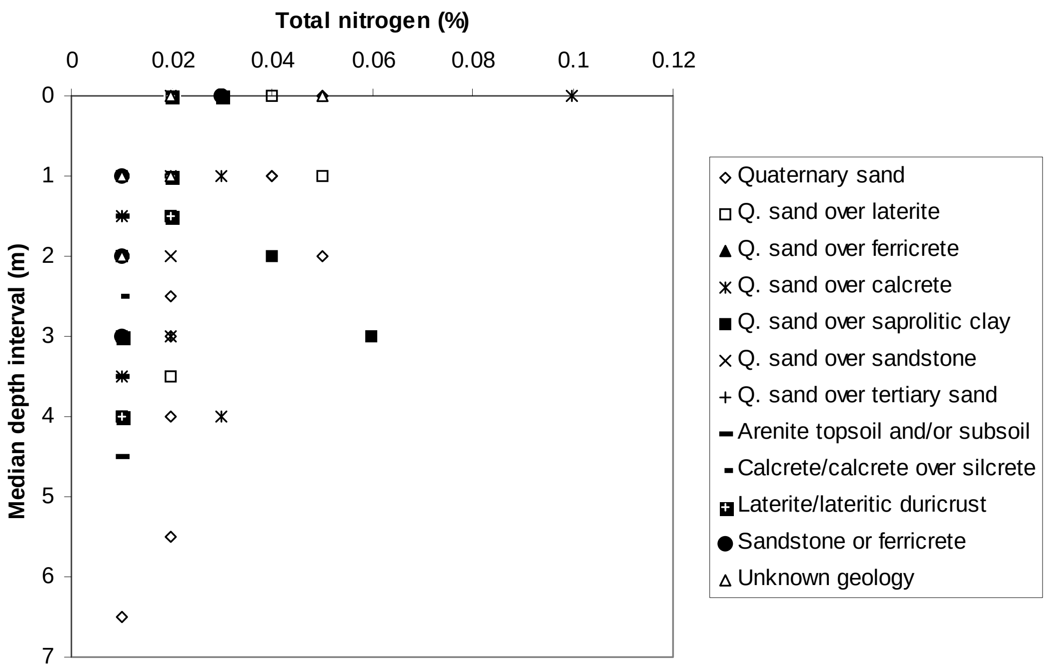


**Figure 8 Total nitrogen (N) (%) with corresponding depth for all samples from 30 sites grouped according to geological description.**

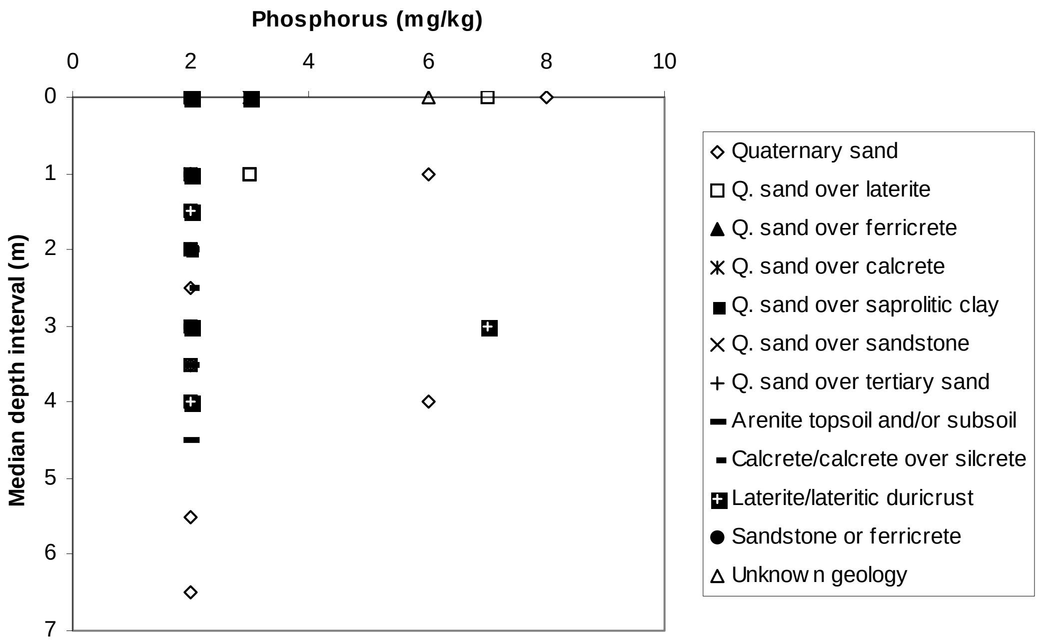


**Figure 9** **Extractable phosphorus (P) (mg/kg) with corresponding depth for all samples from 30 sites grouped according to geological description.**

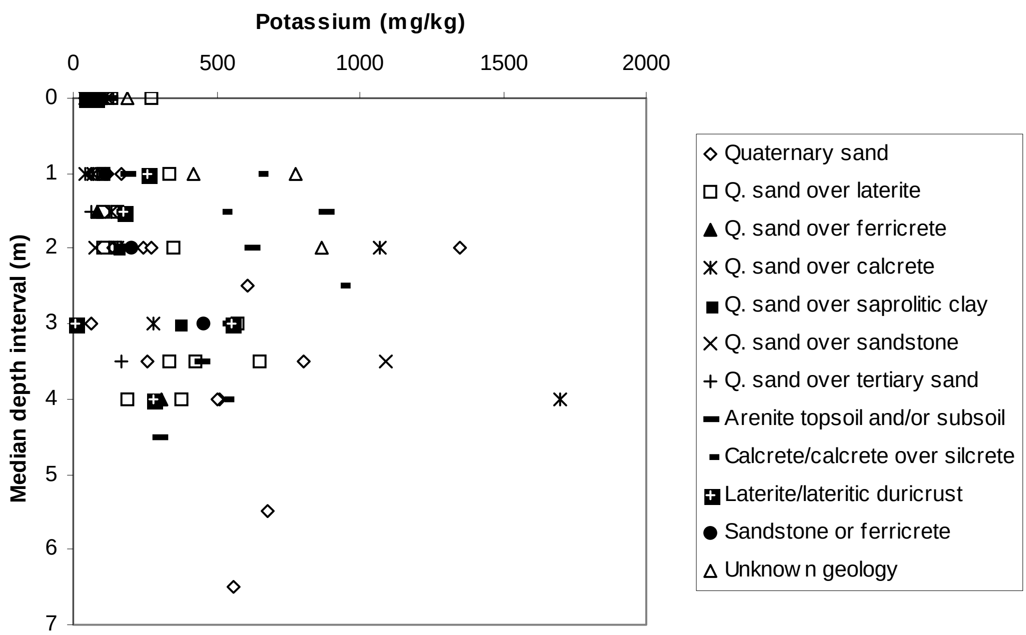


**Figure 10** **Extractable potassium (K) (mg/kg) with corresponding depth for all samples from 30 sites grouped according to geological description.**

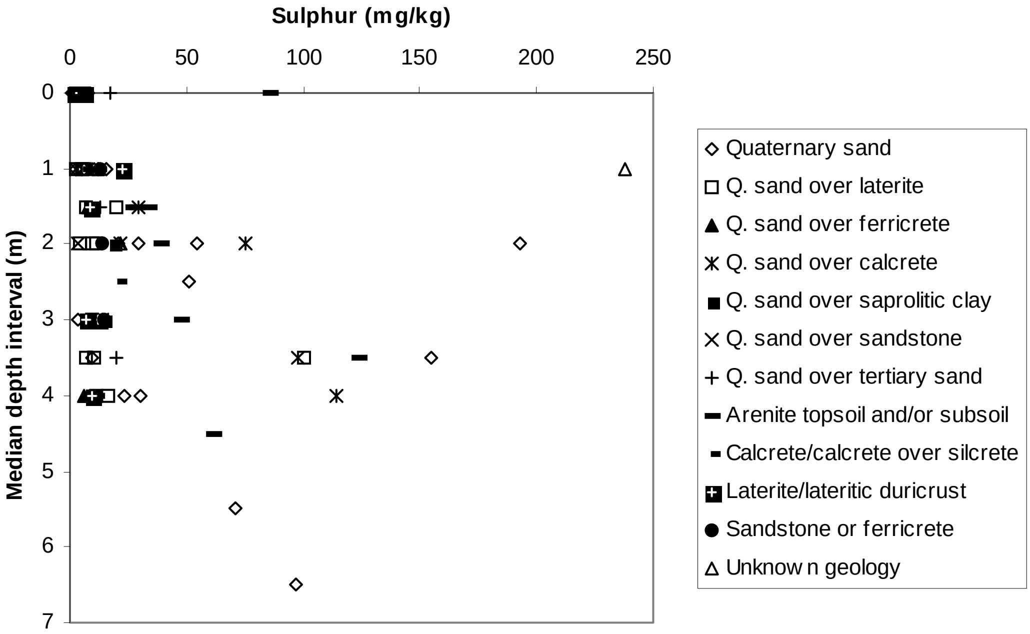


**Figure 11 Extractable sulphur (S) (mg/kg) with corresponding depth for all samples from 30 sites grouped according to geological description.**

and phosphorus concentrations decreased with depth for most sites, while nitrate generally decreased with depth with the exception of some samples from 'Quaternary sand' and 'Unknown geology' regolith types. Potassium and sulphur concentrations increased with depth with the highest sulphur concentrations found for some 'Quaternary sand' and 'Unknown geology' materials.

Nutrient contents for typical arid zone soils are highly variable and often strongly dependant on depth within the regolith profile and the mineralogy of the soil fabric. Approximate values that may be considered typical for arid zone soils include total N values less than 0.1 %, nitrate and phosphorus values between 5 – 10 mg/kg, potassium values between 150 – 200 mg/kg (close to the critical thresholds for plant growth (Hazelton and Murphy 2007)), and approximately <100 mg/kg sulphur. Nutrient contents for the Tropicana soil and regolith materials were generally low on average for total N and all extractable nutrients, with the exception of extractable potassium for the ' Quaternary sand over calcrete', 'Arenite' and 'Calcrete / calcrete over silcrete' regolith types. Extractable potassium also consistently increased with depth for each of the regolith types.

### 3.2.5 Cation Exchange Capacity (CEC) and Exchangeable Sodium percentage (ESP)

The cation exchange capacity (CEC) of a soil is an indication of its capacity to hold cation nutrients, and is essentially determined by the type and amount of clay, and / or humus (organic matter), that is present. These two colloidal substances are essentially the cation reservoir of the soil. Sandy soils with very little organic matter have a low CEC, but heavy clay soils with high levels of organic matter, typically have a much greater capacity to hold cations. Clay mineralogy also influences the levels of cations able to be held on clay exchange sites. CEC affects the buffering capacity of the soil, or the ability to resist changes in soil pH, as well as levels of total and plant-available nutrient, the exchangeable sodium percentage (ESP), and in turn, soil stability (Hazelton and Murphy 2007).

The levels of exchangeable cations and the CEC for the Tropicana soil and regolith samples were highly variable (ranging from 1.0 to 23.8 meq / 100g), reflecting the wide range of materials sampled (Table 5, Figure 12). There was a general trend of increasing CEC with depth, most likely reflecting an increase in clay content with depth.

The exchangeable sodium percentage (ESP) is a measure of the percentage of sodium ions held on the exchange sites of the colloidal surfaces. Soils with an ESP of 6 to 15 are classed as sodic, and highly sodic if their ESP is more than 15 (Moore 1998). Sodic and highly sodic soils are generally prone to soil dispersion and soil structural decline.

The ESP of the Tropicana soils and regolith materials ranged from 0.9 to 49.4 % (Table 5, Figure 13). The majority of samples returned ESP values classed as sodic (ESP > 6), with 28 samples classed as extremely sodic (ESP >15) from all material types *excluding* the 'Quaternary sand over ferricrete / calcrete / tertiary sand' geological descriptions. Overall, ESP generally decreased with depth through the regolith profiles. The high levels of sodicity measured were reflected in the Emerson Aggregate Test results, with many of the sodic samples classed as dispersive. There was also a very weak relationship identified between ESP and hardsetting / soil strength (MOR) (Figure 14), though other relationship was found between ESP and other properties such as soil colour.

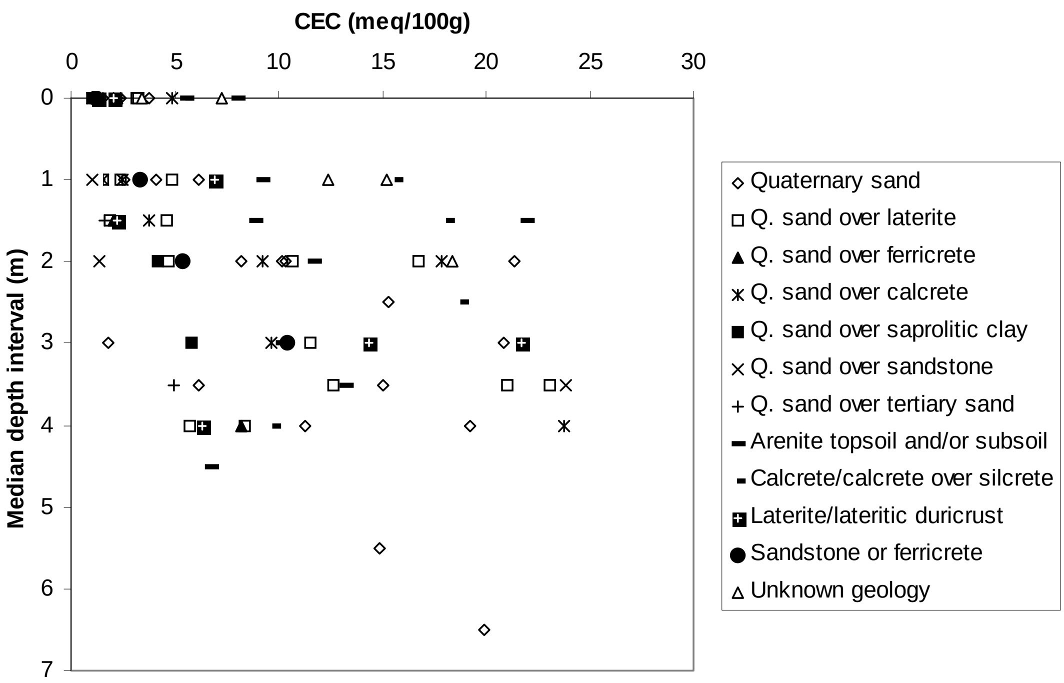


**Figure 12 Cation Exchange Capacity (CEC) (meq/100g) with corresponding depth for all samples from 30 sites grouped according to geological description.**

**Table 5 Ranges for exchangeable cations; calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($NA^{+}$), potassium ($K^{+}$) and aluminium ($Al^{3+}$); Effective Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP) grouped according to geological description and sampling depth within the regolith profile. 'Upper' regolith profile depth refers to samples taken between 0 and 2 m, 'lower' refers to samples between 3 and 7 m. Dashes indicate either only one sample present, the same result, or a result of 0, resulting in no range.**

| Geological description | Number of sites | Regolith profile depth | Exchangeable cations (meq/100g) | | | | | | | | | | | | CEC (meq/100g) | | | ESP (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Ca^{2+}$ | | | $Mg^{2+}$ | | | $Na^{+}$ | | | $K^{+}$ | | | | | | | | |
| | | | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. |
| Quaternary sand | 8 | Upper | 0.54 | 4.63 | 2.27 | 0.11 | 5.25 | 1.20 | 0.03 | 9.8 | 0.90 | 0.14 | 3.3 | 0.43 | 1.13 | 21.33 | 4.89 | 0.97 | 45.94 | 9.84 |
| | | Lower | 1.39 | 9.88 | 5.49 | 0.2 | 7.41 | 3.95 | 0.04 | 4.84 | 3.05 | 0.16 | 1.82 | 1.13 | 1.79 | 20.89 | 13.64 | 2.23 | 47.87 | 20.25 |
| Quaternary sand over laterite | 5 | Upper | 0.36 | 10.05 | 2.91 | 0.09 | 5.33 | 1.11 | 0.03 | 0.54 | 0.18 | 0.11 | 0.82 | 0.38 | 1.17 | 16.74 | 4.69 | 0.93 | 12.97 | 4.46 |
| | | Lower | 2.61 | 13.56 | 7.54 | 1.15 | 7.36 | 3.81 | 0.71 | 3.1 | 1.38 | 0.45 | 1.47 | 0.98 | 5.70 | 23.10 | 13.73 | 3.07 | 24.54 | 11.83 |
| Quaternary sand over ferricrete | 1 | Upper | 1.49 | 5.02 | 3.25 | 0.44 | 0.5 | 1.22 | 0.06 | 0.15 | 0.24 | 0.19 | 0.79 | 0.49 | 2.07 | 2.24 | 5.20 | 2.68 | 7.25 | 3.90 |
| | | Lower | 1.29 | - | - | 1.94 | - | - | 0.42 | - | - | 0.79 | - | - | 8.17 | - | - | 5.14 | - | - |
| Quaternary sand over calcrete | 3 | Upper | 0.32 | 7.57 | 3.28 | 0.06 | 5.25 | 1.28 | 0.03 | 2.43 | 0.63 | 0.08 | 2.58 | 0.54 | 1.01 | 17.83 | 5.82 | 1.19 | 17.63 | 8.27 |
| | | Lower | 6.13 | 7.63 | 6.88 | 1.78 | 3.43 | 2.60 | 1.15 | 8.77 | 4.96 | 0.63 | 3.96 | 2.29 | 9.69 | 23.79 | 16.74 | 11.87 | 36.86 | 24.36 |
| Quaternary sand over saprolitic clay | 1 | Upper | 0.48 | 2.34 | 1.41 | 0.13 | 0.92 | 0.52 | 0.04 | 0.67 | 0.35 | 0.07 | 0.27 | 0.17 | 1.00 | 4.2 | 2.60 | 4.00 | 15.95 | 9.97 |
| | | Lower | 1.67 | - | - | 1.43 | - | - | 2.04 | - | - | 0.68 | - | - | 5.82 | - | - | 35.05 | - | - |
| Quaternary sand over sandstone | 1 | Upper | 0.54 | 1.05 | 0.75 | 0.31 | 0.41 | 0.33 | 0.06 | 0.1 | 0.07 | 0.16 | 0.26 | 0.20 | 1.02 | 1.78 | 1.40 | 3.37 | 7.09 | 5.44 |
| | | Lower | 3.08 | - | - | 9.12 | - | - | 8.84 | - | - | 2.77 | - | - | 23.81 | - | - | 37.13 | - | - |
| Quaternary sand over tertiary sand | 1 | Upper | 0.56 | 1.22 | 0.89 | 0.16 | 0.44 | 0.30 | 0.08 | 0.22 | 0.15 | 0.14 | 0.19 | 0.16 | 1.60 | 2.41 | 2.00 | 5.00 | 9.13 | 7.06 |
| | | Lower | 3.01 | - | - | 0.94 | - | - | 0.61 | - | - | 0.41 | - | - | 4.97 | - | - | 12.27 | - | - |
| Arenite / sand over arenite / arenite over conglomerate | 3 | Upper | 3.13 | 7.25 | 5.52 | 0.75 | 8.06 | 2.66 | 0.08 | 4.65 | 1.88 | 0.18 | 1.56 | 0.81 | 5.54 | 21.96 | 10.87 | 1.44 | 31.0 | 15.57 |
| | | Lower | 1.75 | 3.68 | 2.54 | 1.21 | 5.91 | 3.01 | 3.01 | 4.19 | 3.47 | 0.76 | 1.39 | 1.02 | 6.73 | 13.23 | 10.05 | 31.47 | 44.73 | 35.95 |
| Calcrete / calcrete over silcrete | 2 | Upper | 0.8 | 9.54 | 5.75 | 0.12 | 6.69 | 2.86 | 0.08 | 2.32 | 0.82 | 0.07 | 1.21 | 0.64 | 1.07 | 15.67 | 10.09 | 1.62 | 12.82 | 6.78 |
| | | Lower | 4.71 | 7.45 | 6.08 | 1.94 | 7.03 | 4.48 | 1.99 | 2.06 | 2.02 | 1.12 | 2.28 | 1.70 | 9.76 | 18.82 | 14.29 | 10.95 | 20.39 | 15.66 |
| Laterite / lateritic duricrust | 2 | Upper | 0.61 | 5.02 | 2.09 | 0.12 | 1.31 | 0.56 | 0.05 | 0.38 | 0.21 | 0.15 | 0.24 | 0.19 | 1.25 | 6.95 | 3.13 | 3.35 | 16.0 | 7.20 |
| | | Lower | 2.96 | 5.51 | 7.32 | 1.95 | 5.92 | 4.50 | 0.74 | 1.79 | 1.33 | 0.7 | 1.38 | 0.95 | 6.35 | 21.68 | 14.11 | 6.83 | 12.5 | 10.32 |
| Sandstone or ferricrete | 1 | Upper | 0.36 | 2.14 | 1.34 | 0.11 | 1.76 | 0.93 | 0.08 | 0.99 | 0.56 | 0.17 | 0.48 | 0.29 | 1.18 | 5.37 | 3.28 | 6.78 | 18.79 | 14.66 |
| | | Lower | 5.25 | - | - | 2.34 | - | - | 1.71 | - | - | 1.13 | - | - | 10.43 | - | - | 16.40 | - | - |
| Unknown geology | 2 | Upper | 1.98 | 10.87 | 5.34 | 0.36 | 3.7 | 1.77 | 0.11 | 6.12 | 1.91 | 0.21 | 0.94 | 0.54 | 3.45 | 15.21 | 9.58 | 2.20 | 49.39 | 15.76 |
| | | Lower | 8.41 | - | - | 5.51 | - | - | 2.42 | - | - | 2.01 | - | - | 18.35 | - | - | 13.19 | - | - |

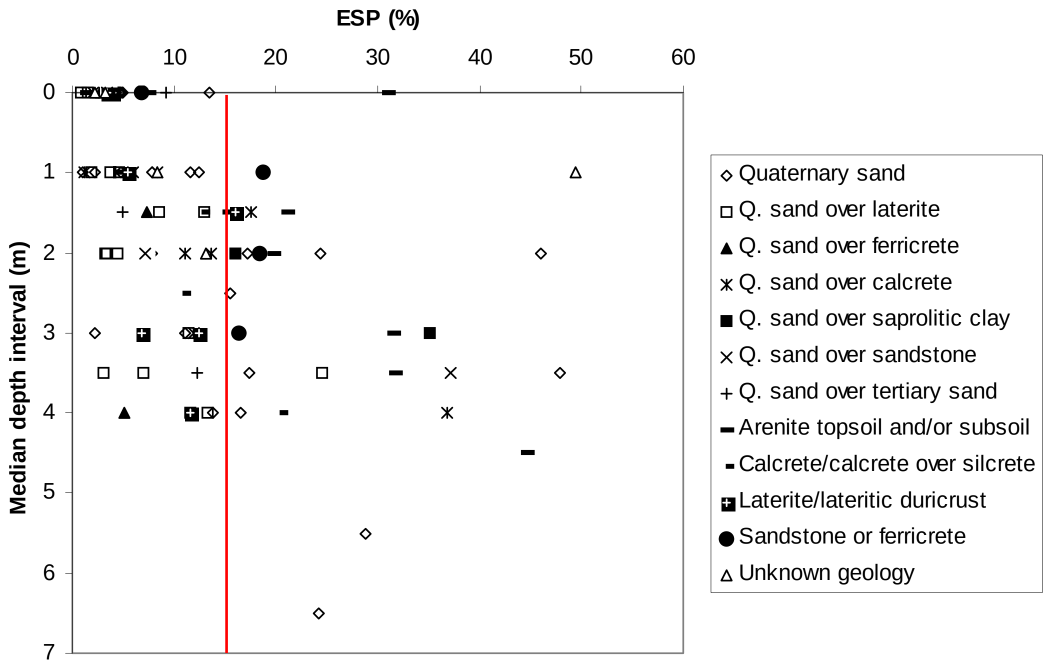


**Figure 13 Exchangeable Sodium Percentage (ESP) (%) with corresponding depth for all samples from 30 sites grouped according to geological description. Values above 15 % ESP are considered highly sodic, indicated by the red line (Moore 1998).**

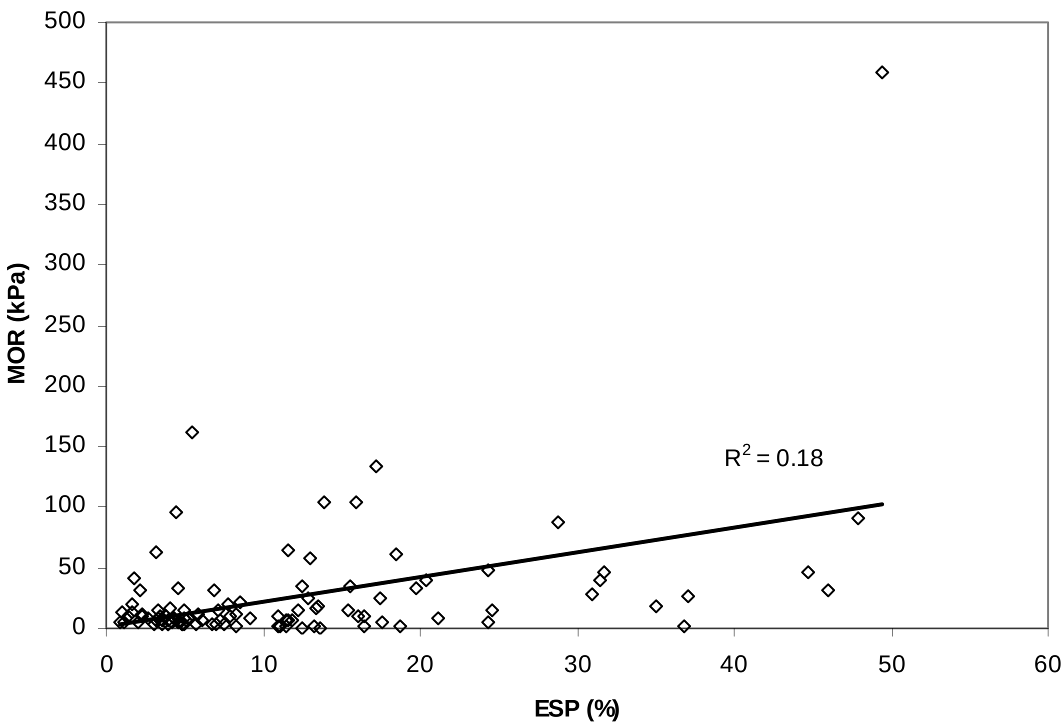


**Figure 14 Comparison of exchangeable sodium percentage (ESP) and modulus of rupture (MOR).**

### 3.2.6 Heavy metals

Measurement of total metal concentrations of selected samples indicated that only very low levels of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and mercury (Hg) were generally present (Table 6). Many materials sampled were below the detectable limit (Limit of Reporting, LOR) for As, Cd, Pb, Zn and Hg, with only Cr, Cu and Ni regularly measured at a detectable level. Comparison with average crustal abundances found that some individual results for Cr and Pb were above the 100 mg/kg and 12.5 mg/kg average crustal abundances for these elements in both the ‘Quaternary sand over laterite’ and ‘Sandstone or ferricrete’ regolith types (Australian Institute of Metallurgy and Mining (AIMM) 2001). All other results for Cu, Ni and Zn were below average crustal abundances, although the one Hg result in the ‘arenite’ regolith type was above 0.08 mg/kg average crustal abundance for Hg.

The Department of Environment (DoE) (2003) Ecological Investigation Levels (EILs) relate to element bioavailability, representing threshold levels related to, for example, the potential uptake of contaminants which may impact upon plant growth. The EILs can be used to gauge the potential for environmental impact in relation to heavy metal concentrations (DoE 2003). Comparison with the DoE EILs found that all heavy metal concentrations for the Tropicana regolith materials here assessed were below EILs for Cu (60 mg/kg), Pb (300 mg/kg), Ni (60 mg/kg), Zn (200 mg/kg), and Hg (1 mg/kg), with the exception of the average Cr results for ‘Quaternary sand over laterite’ and ‘Sandstone or ferricrete’, which were above the Cr EIL of 50 mg/kg.

There was no apparent correlation between sample depth or soil / regolith type, and as such results are only presented according to geological description without upper or lower profile depths. No samples from the ‘quaternary sand over saprolitic clay / sandstone / tertiary sand’ geologies, or ‘unknown geology’, were analysed for heavy metal concentrations.

**Table 6** Range and average of total metal concentrations for selected samples. LOR = Limit of analysis reporting.

| Geological Description | # sites | Arsenic (mg/kg) | | | Cadmium (mg/kg) | | | Chromium (mg/kg) | | | Copper (mg/kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LOR 5 mg/kg | | | LOR 1 mg/kg | | | LOR 2 mg/kg | | | LOR 5 mg/kg | | |
| | | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. |
| Quaternary sand | 2 | - | - | - | - | - | - | 24 | 55 | 43.8 | 6 | 7 | 6.5 |
| Quaternary sand over laterite | 4 | - | - | - | - | - | - | 17 | 103[1,2] | 56.7[2] | 7 | 23 | 12.3 |
| Quaternary sand over ferricrete | 1 | - | - | - | - | - | - | 43 | 44 | 43.5 | - | - | - |
| Quaternary sand over calcrete | 1 | - | - | - | - | - | - | 17 | 36 | 26.5 | 12 | - | - |
| Arenite / sand over arenite / arenite over conglomerate | 2 | - | - | - | - | - | - | 15 | 36 | 21.3 | 5 | - | - |
| Calcrete / calcrete over silcrete | 1 | - | - | - | - | - | - | 10 | 43 | 21.7 | 5 | 12 | 8.5 |
| Laterite / lateritic duricrust | 2 | - | - | - | - | - | - | 28 | 53[2] | 43.5 | 9 | - | - |
| Sandstone or ferricrete | 1 | - | - | - | - | - | - | 44 | 114[1,2] | 79[2] | 6 | 8 | 7 |

| Geological Description | # sites | Lead (mg/kg) | | | Nickel (mg/kg) | | | Zinc (mg/kg) | | | Mercury (mg/kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LOR 5 mg/kg | | | LOR 2 mg/kg | | | LOR 5 mg/kg | | | LOR 0.1 mg/kg | | |
| | | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. | Min | Max | Avg. |
| Quaternary sand | 2 | 5 | 9 | 6.7 | 2 | 16 | 6.3 | 6 | - | - | - | - | - |
| Quaternary sand over laterite | 4 | 6 | 25[1] | 13.4[1] | 2 | 20 | 6 | - | - | - | - | - | - |
| Quaternary sand over ferricrete | 1 | - | - | - | 3 | - | - | - | - | - | - | - | - |
| Quaternary sand over calcrete | 1 | - | - | - | 2 | 8 | 5 | - | - | - | - | - | - |
| Arenite / sand over arenite / arenite over conglomerate | 2 | - | - | - | 3 | 6 | 4.7 | - | - | - | 0.2[1] | - | - |
| Calcrete / calcrete over silcrete | 1 | - | - | - | 2 | 5 | 3.3 | - | - | - | - | - | - |
| Laterite / lateritic duricrust | 2 | 6 | - | - | 2 | 22 | 9.5 | - | - | - | - | - | - |
| Sandstone or ferricrete | 1 | 6 | 17[1] | 11.5 | 4 | 9 | 6.5 | - | - | - | - | - | - |

1. Concentration is above average crustal abundance (AIMM 2001). 2. Concentration is above the DoE EIL of 50 mg/kg for chromium.

# 4.0 CONCLUSIONS and RECOMMENDATIONS

The physical and chemical properties of the Tropicana soil and regolith materials were generally difficult to compare due to the variety of geological descriptions and often highly variable results. From a rehabilitation perspective, the separate identification and collection of appropriate topsoil and regolith materials from within the proposed Tropicana disturbance areas will be an important component to the construction of stable landforms and successful rehabilitation of target vegetation communities. Differences in soil properties and profile characteristics between the various materials complicate the requirements for material handling and there will inevitably be a degree of mixing of materials with differing properties. The baseline information presented in this report was analysed using available material information with the aim of identifying potentially problematic materials, and to provide information to assist with the development of recommendations for managing soils and regolith materials from within the proposed Tropicana project area for optimum rehabilitation outcomes.

## 4.1 Soil physical properties

Assessment of physical properties such as structural stability and soil strength were limited in this study due to the physically altered nature of the RC drill samples. The most dispersive, structurally unstable (Emerson Class 2) results were mostly from lower profile depths from the ‘Quaternary sand / over laterite / over saprolite’ and ‘Arenite’ regolith geological descriptions. However, Emerson classes for a number of samples of various regolith types were influenced by sodicity and salinity, with many of the sodic and highly sodic samples classed as dispersive. The masking effect of high salinity on dispersive properties was noted for some samples with high sodicity and moderate to high salinity which were not found to be dispersive.

The majority of samples from the Tropicana sites exhibited MOR values below the 60 kPa considered to be problematic from a hard-setting perspective. Samples with MOR values above 60 kPa were from sites of ‘Quaternary sand / over laterite / over saprolitic clay’ geological descriptions. Higher MOR values were mostly reported for samples from deeper in the regolith profile (i.e. below 2 m depth).

Assessment of soil colour found a substantial range of soil colours in the Tropicana drill samples, ranging from dark red, pink, brown and yellow to light gray, though no clear relationship between colour rating and sampling depth through the regolith profile was identified. Overall, the majority of samples were from the ‘Quaternary sand’ sites (including sites with quaternary sand over a contrasting material) which were dominated by red and yellowish red colours, particularly in the upper regolith profile.

## 4.2 Soil chemical properties

Soil pH results were variable between the different Tropicana regolith materials, but generally increased slightly with sampling depth through the regolith profile, with the majority of results falling between pH 6 and 8 (slightly acidic to neutral to slightly alkaline (pH 1:5 soil:water)). Results for pH ($CaCl_2$) were typically lower (less alkaline) than the pH ($H_2O$) results, indicating a predominantly neutral pH range favourable for plant growth. Soil EC also increased with depth for the majority of samples, although most samples were classified as non-saline to moderately saline, with only a few samples recording EC results over 0.5 dS/m (moderate to very saline).

Assessment of CEC and ESP results found a general trend of increasing CEC with depth, most likely reflecting an increase in clay content with depth. The majority of samples returned ESP values classed as sodic (ESP > 6), with 28 individual samples from most of the different regolith types (*excluding* the 'Quaternary sand over ferricrete / calcrete / tertiary sand' geological descriptions) classed as extremely sodic (ESP >15). Unlike CEC, ESP generally decreased with depth through the regolith profiles.

Average nutrient contents for the Tropicana soil and regolith materials were generally low for total N and all extractable nutrients, as is commonly found for arid zone soils, with the exception of extractable potassium for the ' Quaternary sand over calcrete', 'Arenite' and 'Calcrete / calcrete over silcrete' regolith types, which also consistently increased with depth through the regolith profiles.

Analysis of heavy metal concentrations reported no detectable results for As, and Cd, with only Cr, Cu, Pb and Ni regularly measured above the limit of reporting and two individual sample results for Zn and Hg. Comparison with average crustal abundances found that some individual results for Cr and Pb were above average crustal abundances for these elements in both the 'Quaternary sand over laterite' and 'Sandstone or ferricrete' regolith types. Comparison with the DoE EILs found all heavy metal concentrations for the Tropicana drill samples were below EILs with the exception of the average Cr results for 'Quaternary sand over laterite' and 'Sandstone or ferricrete'.

### 4.3 Materials for rehabilitation

Quaternary sands comprised the majority of the samples assessed in this study. Aside from a few individual hard-setting, dispersive and moderately saline individual sample results from lower in the regolith profile, the 0 – 2 m depth range from sites with 'Quaternary sand' geological descriptions appears to be a physically and chemically appropriate material for use as a rehabilitation medium. Regolith materials of laterite, calrete, saprolite, ferricrete or sandstone beneath Quaternary sand in the upper profile had highly variable results and further characterisation of these materials may be required to determine their potential for rehabilitation use.

Regolith materials with the 'Arenite / sand over arenite / arenite over conglomerate' geological description are likely to be the least appropriate with high average ESP, moderately salinity, moderate to strong alkalinity and some structural instability, although comparatively few samples of this descriptions were assessed compared to the Quaternary sands. All materials identified as highly structurally instable, and with high ESP and/or high salinity are likely to require conservative management practises for material handling and their use in site rehabilitation strategies.

### 4.4 Recommendations for further work

Further physical and chemical characterisation of regolith (weathered zone) materials, particularly at depths below 7 m to approximately 40 m, is recommended to gain a greater understanding of these materials if they are to be become waste materials during the mining process. Analysis of the bioavailability of potential heavy metal contaminants is also suggested. Targeted assessment of soil profile characteristics in the upper 0 – 2 m of the regolith profile is strongly recommended for potential correlation with different vegetation units and identification of soil profile requirements for rehabilitation prescriptions.

This study has identified a number of potentially dispersive / sodic and hard setting materials that may prove problematic, particularly if left exposed at the surface following mining and rehabilitation operations. Further testing of these materials as they are encountered during operations may be pertinent, with careful consideration made to their handling and placement within reconstructed and rehabilitated landforms.

For greater accuracy in assessing physical properties such as structural stability and water holding capacity, further testing of bulk materials (or drill core samples) is recommended to determine the coarse material particle size and abundance expected to be produced during mining. More information about how materials from different areas within the Tropicana project are likely to behave in their final form when placed in waste dumps or used as surface materials, will aid in determining appropriate and successful rehabilitation strategies.

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# Appendix A

## Glossary of terms

**Glossary of terms**

| | |
|---|---|
| ***Aggregate (or ped)*** | A cluster of primary particles separated from adjoining peds by natural planes of weakness, voids (cracks) or cutans. |
| ***Bulk density*** | Mass per unit volume of undisturbed soil, dried to a constant weight at 105°C. |
| ***Clay*** | The fraction of mineral soil finer than 0.002mm (2µm). |
| ***Coarse fragments*** | Particles greater than 2mm in size. |
| ***Consistence*** | The strength of cohesion and adhesion in soil. |
| ***Dispersion*** | The process whereby the structure or aggregation of the soil is destroyed, breaking down into primary particles. |
| ***Electrical conductivity*** | How well a soil conducts an electrical charge, related closely to the salinity of a soil. |
| ***Massive soil structure*** | Coherent soil, no soil structure, separates into fragments when displaced. Large force often required to break soil matrix. |
| ***Modulus of Rupture (MOR)*** | This test is a measure of soil strength and identifies the tendency of a soil to hard-set as a direct result of soil slaking and dispersion. |
| ***Organic Carbon*** | Carbon residue retained by the soil in humus form. Can influence many physical, chemical and biological soil properties. Synonymous with organic matter (OM). |
| ***Plant available water*** | The ability of a soil to hold that part of the water that can be absorbed by plant roots. Available water is the difference between field capacity and permanent wilting point. |
| ***Regolith*** | The unconsolidated rock and weathered material above bedrock, including weathered sediments, saprolites, organic accumulations, soil, colluvium, alluvium and aeolian deposits. |

| | |
|---|---|
| ***Single grain structure*** | Loose, incoherent mass of individual particles. Soil separates into individual particles when displaced. |
| ***Slaking*** | The partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces. |
| ***Soil horizon*** | Relatively uniform materials that extend laterally, continuously or discontinuously throughout the profile, running approximately parallel to the surface of the ground and differs from the related horizons in chemical, physical or biological properties. |
| ***Soil pH*** | The negative logarithm of the hydrogen ion concentration of a soil solution. The degree of acidity or alkalinity of a soil expressed in terms of the pH scale, from 2 to 10. |
| ***Soil structure*** | The distinctness, size, shape and arrangement of soil aggregates (or peds) and voids within a soil profile. Can be classed as *'apedal'*, having no observable peds, or *'pedal'*, having observable peds. |
| ***Soil strength*** | The resistance of a soil to breaking or deformation. '*Hardsetting'* refers to a high soil strength upon drying. |
| ***Soil texture*** | The size distribution of individual particles of a soil. |
| ***Subsoil*** | The layer of soil below the topsoil or A horizons, often of finer texture (i.e. more clayey), denser and stronger in colour. Generally considered to be the 'B-horizon' above partially weathered or un-weathered material. |
| ***Topsoil*** | Soil consisting of various mixtures of sand, silt, clay and organic matter; considered to be the nutrient-rich top layer of soil – The 'A-horizon'. |

# Appendix B

## Summary of methods of soil analyses used by Outback Ecology

## 1. Soil texturing

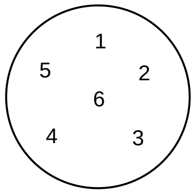
Soils were worked by hand, and the texture, shearing capacity, particle size and ribbon length were observed according to methods described in McDonald *et al.* (1998) as follows.

| Texture Grade | Behaviour of Moist Bolus | Approximate clay content | Code |
|---|---|---|---|
| **Sand** | Nil to very slight coherence; cannot be moulded; single sand grains adhere to fingers | <5% | **S** |
| **Loamy sand** | Slight coherence; can be sheared between thumb and forefinger to give minimal ribbon of about 5mm | 5% | **LS** |
| **Clayey sand** | Slight coherence; sticky when wet; many sand grains stick to fingers; discolours fingers with stain; forms minimal ribbon of 5-15mm | 5-10% | **CS** |
| **Sandy loam** | Bolus coherent but very sandy to touch; dominant sand grains of medium size and readily visible ; ribbon of 15-25mm | 10-20% | **SL** |
| **Loam** | Bolus coherent and rather spongy; no obvious sandiness or silkiness; forms ribbon of about 25mm | 25% | **L** |
| **Sandy clay loam** | Strongly coherent bolus; sandy to touch; ribbon of 25-40mm | 20-30% | **SCL** |
| **Clay loam** | Coherent plastic bolus, smooth to touch, ribbon of 25mm to 40mm | 30-35% | **CL** |
| **Clay loam, sandy** | Coherent plastic bolus, sand grains visible in finer matrix, ribbon of 40-50mm; sandy to touch | 30-35% | **CLS** |
| **Light clay** | Plastic bolus, smooth to touch; slight resistance to shearing; ribbon of 50-75mm | 35-40% | **LC** |
| **Light medium clay** | Ribbon of about 75mm, slight to moderate resistance to ribboning shear | 40-45% | **LMC** |
| **Medium clay** | Smooth plastic bolus, handles like plasticine and can be moulded into rods without fracture; moderate resistance to ribboning shear, ribbon of 75mm or longer | 45-55% | **MC** |
| **Medium heavy clay** | Ribbon of 75mm or longer, handles like plasticine, moderate to firm resistance to ribboning shear | >50% | **MHC** |
| **Heavy Clay** | Handles like stiff plasticine; firm resistance to ribboning shear, ribbon of 75mm or longer | >50% | **HC** |

## 2. Emerson Dispersion Test

Emerson dispersion tests were carried out on all samples according to the following procedure:

1. A petri dish was labelled 1 to 6.  eg.




2. The petri dish was filled with DI water.
3. A 3-5mm soil aggregate is taken from each sample and gently placed into the labelled petri dish (3 per dish).
4. Additional aggregates, remoulded by hand, are placed into the labelled petri dish (3 per dish).
5. Observations are made of the dispersivity or slaking nature of the sample according to the following table:

*Emerson Aggregate test classes (Moore 1998)*

| Class | Description |
|---|---|
| **Class 1** | Dry aggregate slakes and completely disperses |
| **Class 2** | Dry aggregate slakes and partly disperses |
| **Class 3a** | Dry aggregate slakes but does not disperse; remoulded soil disperses completely |
| **Class 3b** | Dry aggregate slakes but does not disperse; remoulded soil partly disperses |
| **Class 4** | Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are present |
| **Class 5** | Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are absent; 1:5 suspension remains dispersed |
| **Class 6** | Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are absent; 1:5 suspension remains flocculated |
| **Class 7** | Dry aggregate does not slake; aggregate swells |
| **Class 8** | Dry aggregate does not slake; aggregate does not swell |

The samples were left in the dish for a 24 hour period, after which the samples were observed again and rated according to the above Table.

# Appendix C

## Outback Ecology soil analysis results

**Summary of Outback Ecology results for soil colour using the Munsell soil colour system, slaking / dispersion (Emerson Test), and soil strength (Modulus of Rupture). Shaded cells indicate that no aggregates were found for the Emerson Test, and only remoulded soil was assessed.**

| Site ID | Sample ID | Depth (m) | Colour | | Emerson class (24 hour) | MOR |
|---|---|---|---|---|---|---|
| | | | Munsell code | Colour description | | |
| TPRC002 | SPR002000 | 0m | 2.5YR 4.5/6 | red | 3b | 4.2 |
| | SPR002001 | 1m | 10R 4/7 | red | 3b | 10.1 |
| | SPR002002 | 2m | 10R 4/8 | red | 3b | 10.0 |
| | SPR002003 | 3&4m | 2.5YR 5/8 | red | 2 | 14.7 |
| TPRC059 | SPR059000 | 0m | 2.5YR 4.5/8 | red | 2 | 4.3 |
| | SPR059001 | 1m | 2.5YR 4/8 | red | 3b | 1.0 |
| | SPR059002 | 2m | 2.5YR 4/8 | red | 2 | 133.2 |
| | SPR059003 | 3m | 7.5YR 6/6 | reddish yellow | 2 | 1.5 |
| TPRC074 | SPR074000 | 0m | 2.5YR 4/8 | red | 3b | 8.5 |
| | SPR074001 | 1&2 | 2.5YR 4/8 | red | 3b | 6.8 |
| | SPR074003 | 4 | 2.5YR 4/8 | red | 4-6 | 5.9 |
| TPRC082 | SPR082000 | 0m | 2.5YR 4/8 | red | 3b | 18.6 |
| | SPR082001 | 1m | 2.5YR 4/8 | red | 3b | 0.8 |
| | SPR082003 | 4m | 2.5YR 5/7 | red | 2 | 1.3 |
| | SPR082005 | 6&7m | 2.5YR 4/8 | red | 3b | 4.3 |
| TPRC088 | SPR088000 | 0m | 2.5YR 4/6 | red | 3b | 4.2 |
| | SPR088001 | 1&2m | 10R 4/7 | red | 3b | 4.4 |
| | SPR088003 | 4m | 2.5YR 5/7 | red | 3b | 1.3 |
| TPRC094 | SPR094000 | 0m | 2.5YR 4/8 | red | 3a | 6.2 |
| | SPR094001 | 1m | 5YR 6/6 | reddish yellow | 3b | 2.4 |
| | SPR094002 | 2m | 5YR 5/6 | yellowish red | 3b | 0.9 |
| TPRC145 | SPR145000 | 0m | 2.5YR 4/8 | red | 2 | 10.7 |
| | SPR145001 | 1m | 5YR 7/6 | reddish yellow | 3b | 4.7 |
| | SPR145002 | 2m | 5YR 7/4 | pink | 4-6 | 32.4 |
| | SPR145003 | 3m | 7.5YR 8/3 | pink | 4-6 | 39.9 |

| Site ID | Sample ID | Depth (m) | Colour | | Emerson class (24 hour) | MOR |
|---|---|---|---|---|---|---|
| | | | Munsell code | Colour description | | |
| TPRC157 | SPR157000 | 0m | 2.5YR 5/7 | red | 3b | 3.1 |
| | SPR157002 | 2m | 2.5YR 5/6 | red | 2 | 103.9 |
| | SPR157003 | 3m | 5YR 8/4 | pink | 3b | 18.2 |
| TPRC167 | SPR167000 | 0m | 2.5YR 4.5/8 | red | 3b | 3.7 |
| | SPR167001 | 1m | 2.5YR 4.5/8 | red | 3b | 10.3 |
| | SPR167003 | 3m | 2.5YR 4/8 | red | 3b | 10.8 |
| TPRC192 | SPR192001 | 1m | 2.5YR 4/8 | red | 3b | 5.5 |
| | SPR192002 | 2m | 2.5YR 6/5 | light reddish brown / light red | 3b | 0.4 |
| TPRC218 | SPR218000 | 0m | 5YR 5/7 | yellowish red | 3b | 5.3 |
| | SPR218001 | 1m | 5YR 5/6 | yellowish red | 3b | 7.4 |
| | SPR218003 | 3&4m | 2.5YR 5.5/6 | light red / red | 3b | 24.9 |
| TPRC223 | SPR223000 | 0m | 2.5YR 4/8 | red | 3a | 7.5 |
| | SPR223001 | 1m | 10R 4/7 | red | 3b | 13.4 |
| | SPR223002 | 2m | 2.5YR 5/8 | red | 4-6 | 47.4 |
| TPRC290 | SPR290000 | 0m | 2.5YR 4.5/8 | red | 3a | 7.5 |
| | SPR290001 | 1m | 2.5YR 4.5/8 | red | 3b | 11.5 |
| | SPR290002 | 2m | 2.5YR 4.5/8 | red | 3b | 15.3 |
| | SPR290003 | 3&4m | 5YR 6/6 | reddish yellow | 4-6 | 26.0 |
| TPRC301 | SPR301000 | 0m | 5YR 5/6 | yellowish red | 2 | 27.3 |
| | SPR301001 | 1&2m | 2.5YR 6/6 | light red | 4-6 | 15.4 |
| | SPR301003 | 4 & 5m | 2.5YR 7/4 | light reddish brown | 4-6 | 45.6 |
| TPRC304 | SPR304001 | 1&2m | 7.5YR 7/5 | pink / reddish yellow | 3b | 8.5 |
| | SPR304002 | 3&4m | 7.5YR 7/4 | pink | 2 | 46.0 |
| TPRC377 | SPR377000 | 0m | 2.5YR 4.5/8 | red | 3b | 7.1 |
| | SPR377001 | 1m | 2.5YR 4/8 | red | 3b | 11.4 |
| | SPR377002 | 2m | 2.5YR 4/8 | red | 4-6 | 1.6 |
| | SPR377003 | 3m | 2.5YR 6/5 | light reddish brown / light red | 4-6 | 6.4 |
| TPRC380 | SPR380000 | 0m | 5YR 5/7 | yellowish red | 3b | 3.7 |

| Site ID | Sample ID | Depth (m) | Colour | | Emerson class (24 hour) | MOR |
|---|---|---|---|---|---|---|
| | | | Munsell code | Colour description | | |
| | | | | | | |
| | SPR380001 | 1&2m | 5YR 4.5/6 | yellowish red | 3b | 9.3 |
| | SPR380002 | 3m | 5YR 6/5 | light reddish brown / reddish yellow | 3b | 35.4 |
| | SPR380003 | 4m | 5YR 7/4 | pink | 4-6 | 7.2 |
| TPRC404 | SPR404000 | 0m | 5YR 5/6 | yellowish red | 3b | 2.8 |
| | SPR404001 | 1m | 2.5YR 2.5/4 | dark reddish brown | 4-6 | 1.0 |
| | SPR404002 | 2m | 5YR 5/4 | reddish brown | 3b | 61.6 |
| | SPR404003 | 3m | 7.5YR 6/5 | light brown / reddish yellow | 3b | 9.7 |
| TPRC406 | SPR406000 | 0m | 2.5YR 4.5/8 | red | 3b | 3.4 |
| | SPR406001 | 1&2m | 5YR 6.5/4 | pink / light reddish brown | 4-6 | 25.3 |
| | SPR406003 | 4m | 10YR 8/3.5 | very pale brown | 4-6 | 39.5 |
| TPRC416 | SPR416000 | 0m | 5YR 5/8 | yellowish red | 7/8 | 16.9 |
| | SPR416001 | 1&2m | 2.5YR 3/6 | dark red | 4-6 | 21.4 |
| | SPR416002 | 3m | 2.5YR 5/6 | red | 3b | 6.2 |
| | SPR416003 | 4m | 5YR 7/4 | pink | 3b | 17.0 |
| TPRC427 | SPR427000 | 0m | 2.5YR 4/7 | red | 3a | 6.4 |
| | SPR427001 | 1m | 2.5YR 4/6 | red | 3b | 3.7 |
| | SPR427002 | 2m | 2.5YR 6/6 | light red | 4-6 | 31.4 |
| | SPR427003 | 3&4m | 7.5YR 7/5 | pink / reddish yellow | 4-6 | 91.0 |
| TPRC443 | SPR443000 | 0m | 5YR 4/6 | yellowish red | 3b | 31.7 |
| | SPR443001 | 1m | 5Y 7/2 | light gray | 4-6 | 458.8 |
| TPRC447 | SPR447000 | 0m | 5YR 5/8 | yellowish red | 3a | 3.2 |
| | SPR447001 | 1m | 2.5YR 4.5/8 | red | 3b | 3.5 |
| | SPR447002 | 2m | 10R 4/6 | red | 4-6 | 19.5 |
| | SPR447004 | 4m | 7.5YR 5/6 | strong brown | 4-6 | 103.6 |
| TPRC449 | SPR449000 | 0m | 5YR 4.5/6 | yellowish red | 3b | 3.4 |
| | SPR449001 | 1m | 2.5YR 4.5/6 | red | 3b | 9.2 |
| | SPR449002 | 2&3m | 2.5YR 6/4 | light reddish brown | 2 | 35.0 |
| | SPR449004 | 5&6m | 2.5YR 7/4 | light reddish brown | 2 | 87.2 |

| Site ID | Sample ID | Depth (m) | Colour | | Emerson class (24 hour) | MOR |
|---|---|---|---|---|---|---|
| | | | Munsell code | Colour description | | |
| TPRC450 | SPR450000 | 0m | 2.5YR 4/8 | red | 3b | 14.1 |
| | SPR450001 | 1m | 2.5YR 5/6 | red | 4-6 | 162.1 |
| | SPR450002 | 2,3 & 4m | 5YR 6/6 | reddish yellow | 4-6 | 31.1 |
| TPRC454 | SPR454000 | 0m | 2.5YR 4/8 | red | 3b | 19.8 |
| | SPR454001 | 1m | 7.5YR 8/4 | pink | 3b | 8.4 |
| | SPR454002 | 2&3m | 7.5YR 7/4 | pink | 3b | 10.4 |
| TPRC470 | SPR470000 | 0m | 2.5YR 4/6 | red | 3b | 12.5 |
| | SPR470001 | 1m | 2.5YR 4/6 | red | 3b | 32.6 |
| | SPR470002 | 2m | 2.5YR 4/8 | red | 4-6 | 96.2 |
| | SPR470003 | 3&4m | 7.5YR 6/6 | reddish yellow | 3b | 3.6 |
| TPRC533 | SPR533001 | 1m | 2.5YR 4/8 | red | 3b | 41.8 |
| | SPR533002 | 2m | 5YR 4.5/6 | yellowish red | 4-6 | 62.0 |
| | SPR533003 | 3&4m | 5YR 5.5/6 | reddish yellow / yellowish red | 3b | 3.6 |
| TPRC535 | SPR535000 | 0m | 5YR 4.5/6 | yellowish red | 3b | 8.8 |
| | SPR535001 | 1&2m | 2.5YR 4/8 | red | 3b | 14.2 |
| | SPR535002 | 3&4m | 7.5YR 8/3 | pink | 4-6 | 14.4 |
| TPRC538 | SPR538000 | 0m | 5YR 5/6 | yellowish red | 3b | 7.4 |
| | SPR538001 | 1&2m | 5YR 4.5/6 | yellowish red | 4-6 | 58.1 |
| | SPR538003 | 4m | 5YR 4/6 | yellowish red | 4-6 | 63.7 |

## Appendix D

## Soil electrical conductivity (EC) classes

**Soil Electrical Conductivity classes** (based on standard USDA and CSIRO categories)

| EC (1:5) (dS/m) | | | | | | |
|---|---|---|---|---|---|---|
| **Salinity Class** | **Sand** | **Sandy loam** | **Loam** | **Clay loam** | **Light / Med Clay** | **Heavy Clay** |
| Non-saline | <0.13 | <0.17 | <0.20 | <0.22 | <0.25 | <0.33 |
| Slightly Saline | 0.13-0.26 | 0.17-0.33 | 0.20-0.40 | 0.22-0.44 | 0.25-0.50 | 0.33-0.67 |
| Moderately Saline | 0.26-0.52 | 0.33-0.67 | 0.40-0.80 | 0.44-0.89 | 0.50-1.00 | 0.67-1.33 |
| Very Saline | 0.52-1.06 | 0.67-1.33 | 0.80-1.60 | 0.89-1.78 | 1.00-2.00 | 1.33-2.67 |
| Extremely Saline | >1.06 | >1.33 | >1.60 | >1.78 | >2.00 | >2.67 |

# Appendix E

## Drill site geology and material descriptions

**Drill site geology and material descriptions (provided by Anglogold Ashanti Limited - Tropicana)**

| Hole ID | Sample No | Depth (m) | Geology | Description |
|---|---|---|---|---|
| TPRC002 | SPR002000 | 0 | | |
| | SPR002001 | 1 | Quaternary sand | |
| | SPR002002 | 2 | Quaternary sand | |
| | SPR002003 | 3-4 | Lateritic duricrust/quaternary sand | Lateritic sand with calcrete gravel |
| TPRC059 | SPR059000 | 0 | | |
| | SPR059001 | 1 | Quaternary sand | |
| | SPR059002 | 2 | Quaternary sand | |
| | SPR059003 | 3 | | |
| TPRC074 | SPR074000 | 0 | | |
| | SPR074001 | 1-2 | Quaternary sand | Fine grained dark red in colour |
| | SPR074003 | 4 | Ferricrete | Lateritic sand with calcrete present |
| TPRC082 | SPR082000 | 0 | | |
| | SPR082001 | 1 | Quaternary sand | Fine grained sand |
| | SPR082003 | 4 | Quaternary sand | Fine grained sand and gravel |
| | SPR082005 | 6-7 | Quaternary sand | Fine grained sand and gravel |
| TPRC088 | SPR088000 | 0 | | |
| | SPR088001 | 1-2 | Quaternary sand | |
| | SPR088003 | 4 | Calcrete | Very fine sand with calcrete. Light brown/white in colour |
| TPRC094 | SPR094000 | 0 | | |
| | SPR094001 | 1 | | |
| | SPR094002 | 2 | | |
| TPRC145 | SPR145000 | 0 | | |
| | SPR145001 | 1 | Tertiary sand | Pale white/brown sand and gravel |
| | SPR145002 | 2 | Arenite | Pale white/brown sand and gravel |
| | SPR145003 | 3 | Arenite | Pale white medium/coarse sand and gravel |
| TPRC157 | SPR157000 | 0 | | |
| | SPR157002 | 2 | Quaternary sand | Very fine grained red/brown sand |
| | SPR157003 | 3 | Saprolitic clay (?) | Light white powder with a slight brown tinge, very fine. |
| TPRC167 | SPR167000 | 0 | | |
| | SPR167001 | 1 | Quaternary sand | Fine grained |

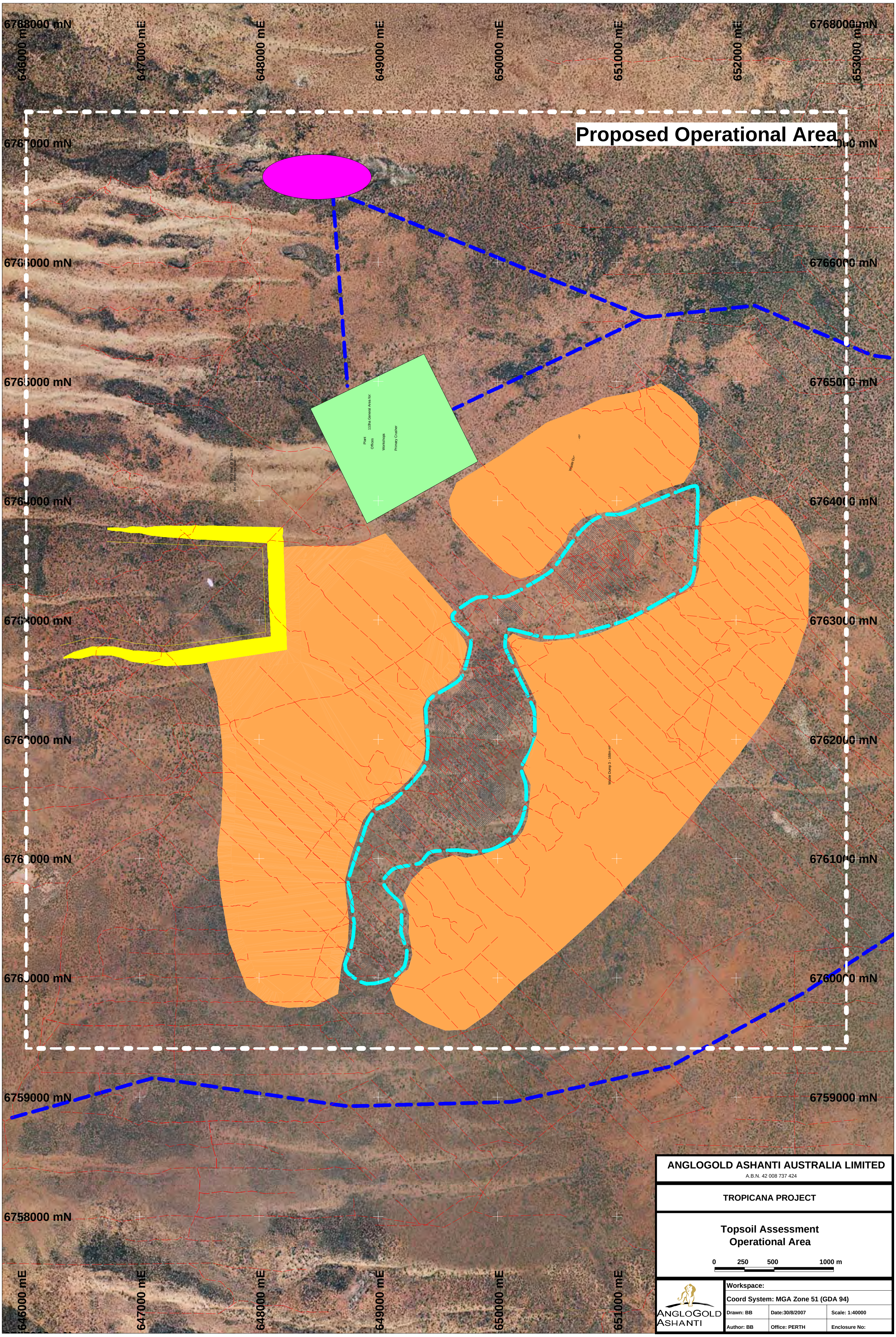
| Hole ID | Sample No | Depth (m) | Geology | Description |
|---|---|---|---|---|
| | SPR167003 | 3 | Quaternary sand | Fine grained |
| TPRC192 | SPR192001 | 1 | Quaternary sand | Sand, very fine grained |
| | SPR192002 | 2 | Calcrete | Calcrete gravel with some sand |
| TPRC218 | SPR218000 | 0 | | |
| | SPR218001 | 1 | Quaternary sand | Fine grained sand with coarse gravel |
| | SPR218003 | 3-4 | | Very fine sand and gravel, pale red/white in colour |
| TPRC223 | SPR223000 | 0 | | |
| | SPR223001 | 1 | Quaternary sand | Fine grained red/brown sand |
| | SPR223002 | 2 | Quaternary sand | Fine grained red/brown sand |
| TPRC290 | SPR290000 | 0 | | |
| | SPR290001 | 1 | Quaternary sand | Fine grained sand |
| | SPR290002 | 2 | Quaternary sand | Fine grained sand |
| | SPR290003 | 3-4 | Possibly sandstone | Fine grained powder light brown in colour |
| TPRC301 | SPR301000 | 0 | | |
| | SPR301001 | 1-2 | Arenite | Very fine powder with small gravel/rock chips. Light red/purple in colour |
| | SPR301003 | 4-5 | Conglomerate | Very fine powder with small gravel/rock chips. Slightly lighter red/purple colour. |
| TPRC304 | SPR304001 | 1-2 | Arenite | Very fine powder with medium coarse gravel, pale white/brown in colour |
| | SPR304002 | 3-4 | Arenite | Very fine powder with medium coarse gravel, pale white/brown in colour |
| TPRC377 | SPR377000 | 0 | | |
| | SPR377001 | 1 | Quaternary sand | Fine sand light brown in colour |
| | SPR377002 | 2 | Quaternary sand | Fine sand light brown in colour |
| | SPR377003 | 3 | Logged as calcrete | Fine grained sand with small gravel chips, light brown/red in colour. Possible laterite |
| TPRC380 | SPR380000 | 0 | | |
| | SPR380001 | 1-2 | Lateritic duricrust | Wet sample. Dark brown sand and round gravel |
| | SPR380002 | 3 | Lateritic gravel | Wet sample, finer grained sand and gravel. Dark brown/purple colour |
| | SPR380003 | 4 | Laterite | Very fine powder with occasional gravel. White/brown in colour |
| TPRC404 | SPR404000 | 0 | | |
| | SPR404001 | 1 | Sandstone or ferricrete | Very dark brown sand and gravel, logged as sandstone possibly ferricrete? |
| | SPR404002 | 2 | | Very fine sand with small rock chips/gravel and dark brown in colour |

| Hole ID | Sample No | Depth (m) | Geology | Description |
|---|---|---|---|---|
| | SPR404003 | 3 | | Very fine sand with rock chips/gravel. Light brown in colour. Possible sandstone/calcrete |
| TPRC406 | SPR406000 | 0 | | |
| | SPR406001 | 1-2 | Calcrete | Sand and gravel. Light brown/grey in colour. Coarse gravel |
| | SPR406003 | 4 | | White in colour, very fine powder with medium coarse gravel |
| TPRC416 | SPR416000 | 0 | | |
| | SPR416001 | 1-2 | Quaternary sand | Sand and gravel, coarse grained |
| | SPR416002 | 3 | Possible laterite (logged as tertiary sands) | Fine sand and gravel, with occasional rock chips, Light brown in colour |
| | SPR416003 | 4 | Possible laterite (logged as tertiary sands) | Fine powder with small rock chips, Light brown in colour |
| TPRC427 | SPR427000 | 0 | | |
| | SPR427001 | 1 | Quaternary sand | Dark brown sand with organic material present |
| | SPR427002 | 2 | | Very fine light red/brown powder with small rock chips present |
| | SPR427003 | 3-4 | | Very fine light orange/brown powder with small rock chips present |
| TPRC443 | SPR443000 | 0 | | |
| | SPR443001 | 1 | | |
| TPRC447 | SPR447000 | 0 | | |
| | SPR447001 | 1 | Quaternary sand | Fine grained sand |
| | SPR447002 | 2 | Quaternary sand | Fine grained sand |
| | SPR447004 | 4 | | Sand and gravel with a clay matrix |
| TPRC449 | SPR449000 | 0 | | |
| | SPR449001 | 1 | Quaternary sand | Fine grained |
| | SPR449002 | 2-3 | | Very fine sand, medium gravel. Light brown/white in colour |
| | SPR449004 | 5-6 | | Very fine brown/white powder |
| TPRC450 | SPR450000 | 0 | | |
| | SPR450001 | 1 | Laterite | Dark brown fine powder with small rock/gravel chips |
| | SPR450002 | 2-4 | Laterite | Very fine powder with small rock chips, pale brown/red colour |
| TPRC454 | SPR454000 | 0 | | |
| | SPR454001 | 1 | Calcrete | Fine grained white sand with some gravel |
| | SPR454002 | 2-3 | Silcrete | Very fine, slightly darker white powder with occasional gravel |
| TPRC470 | SPR470000 | 0 | | |

| Hole ID | Sample No | Depth (m) | Geology | Description |
|---|---|---|---|---|
| | SPR470001 | 1 | Quaternary sand | Fine grained light brown sand |
| | SPR470002 | 2 | Possible laterite | Fine grained with rock chips. Red/purple in colour |
| | SPR470003 | 3-4 | Possible laterite | Light brown/purple in colour |
| TPRC533 | SPR533001 | 1 | Quaternary sand | Fine grained light brown sand |
| | SPR533002 | 2 | Possible laterite | Fine grained light brown powder with small rock chips |
| | SPR533003 | 3-4 | Possible laterite | Fine powder with small rock chips, light brown/purple |
| TPRC535 | SPR535000 | 0 | | |
| | SPR535001 | 1-2 | Quaternary sand | Fine grained sand with coarse gravel. Red brown in colour |
| | SPR535002 | 3-4 | Logged as tertiary sand | White powder, small rock fragments, possible calcrete |
| TPRC538 | SPR538000 | 0 | | |
| | SPR538001 | 1-2 | Quaternary sand | Very fine sand and medium coarse gravel, dark red/brown in colour |
| | SPR538003 | 4 | Possible laterite | Very fine dark brown powder with small rock chips, possible laterite |

## Appendix F

## Tropicana topsoil assessment area



Proposed Operational Area
6768000 mN
6767000 mN
6766000 mN
6765000 mN
6764000 mN
6763000 mN
6762000 mN
6761000 mN
6760000 mN
6759000 mN
6758000 mN
646000 mE
647000 mE
648000 mE
649000 mE
650000 mE
651000 mE
652000 mE
653000 mE
ANGLOGOLD ASHANTI AUSTRALIA LIMITED
A.B.N. 42 008 737 424
TROPICANA PROJECT
Topsoil Assessment
Operational Area
0 250 500 1000 m
Workspace:
Coord System: MGA Zone 51 (GDA 94)
Drawn: BB
Date:30/8/2007
Scale: 1:40000
Author: BB
Office: PERTH
Enclosure No:
ANGLOGOLD ASHANTI