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## UMCEBO MINING (Pty) Ltd

# PROPOSED DEVELOPMENT OF AN UNDERGROUND COAL MINE AND ASSOCIATED INFRASTRUCTURE NEAR HENDRINA, MPUMALANGA

## Soil & Land Capability Assessment Report

DMR Reference Number:
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Compiled For

DIGBY WELLS ENVIRONMENTAL

July 2016

SPECIALIST SOILS

Earth Science Solutions

Sustaining the Environment

# UMCEBO MINING (Pty) Ltd

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# SOIL AND LAND CAPAPABILITY ASSESSMENT REPORT

**Compiled for**

DIGBY WELLS ENVIRONMENTAL PTY LTD

**Report Number: Soils and Land Capability Specialist Studies – EIA/EMP**

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# DECLARATION OF INDEPENDENCE

This specialist report has been compiled in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended (NEMA) and its associated Environmental Impact Assessment (EIA) Regulations, 2014, and forms part of the overall impact assessment, both as a standalone document and as supporting information to the overall impact assessment for the proposed development.

The Specialist Soils and Land Capability Baseline Studies, where managed and signed off by Ian P.C. Jones (Pr. Sci Nat 400040/08) and Certified EAP, an Earth Scientist with 34 years of experience in the these specialist fields.

I declare that both, Ian Jones, and Earth Science Solutions (Pty) Ltd, are totally independent in this process, and have no vested interest in the project.

The objectives of the study were to:

- Provide a permanent record of the present soil resources in the area that are potentially going to be affected by the proposed development – Pre construction environment,
- Assess the nature of the site in relation to the overall environment and its present and proposed utilization, and determine the capability of the land in terms of agricultural utilization, and
- Provide a base plan from which long-term ecological and environmental decisions can be made, impacts of construction can be determined, and mitigation and rehabilitation management plans can be formulated.

The Taxonomic Soil Classification System and Chamber of Mines Land Capability Rating Systems in combination with the Canadian Land Inventory were used as the basis for the soils and land capability investigations respectively. These systems are recognized nationally.

**Signed:** **10 July 2016**

**Ian Jones** **B.Sc. (Geol) Pr.Sci.Nat 400040/08, (EAPASA Certified)**

# EXECUTIVE SUMMARY

Umcebo Mining (Pty) Ltd (Umcebo) are considering the possibility of mining coal by underground bord and pillar methods at their Hendrina Project situated in the Highveld Region of the Mpumalanga Province – South Africa.

The proposed development covers significant areas of land that fall within the Klein-Olifants River catchment, the river forming a distinctive divide to the proposed mining areas. The Klein Olifants River flows from south to north through the area of concern forming a distinct floodplain, river channel and associated terraces, with significant secondary and tertiary catchments, all of which are very significant in understanding the complex of hydromorphic soils within these land forms.

This soils and land capability assessment is part of the larger environmental assessment and assimilation of scientific input needed in assessing the impacts.

The sites being considered are all greenfields sites in terms of their mining development. They are however all impacted by farming development to some degree or other, and as such rank as brownfield sites in terms of their environmental status when considering soils and land capability. The degree of alteration of these areas from their original or natural condition varies across the area of study. The baseline studies have captured the pre mining/construction conditions, the point of departure for the impact assessment.

The geomorphology (geology, soil, climate, topography, landform, ground roughness, aspect etc.) is significant to an understanding of how the activities of a development of this nature might impact on the overall biodiversity and the soils and land capability in particular. The complex inter-relationships require that a full and scientifically defendable baseline of information is available before any impact assessment can be undertaken and any management or mitigation measures can be formulated.

The combination of underground bord and pillar mining and surface infrastructure (i.e. Shaft Complex, Waste Storage, Conveyencing and Run of Mine Stockpiles etc.) require a study and understanding of the surface resources prior to any development plan being formulated (refer to Figure 1-2).

A scoping assessment was completed, and has been used as the basis for this detailed assessment. The soil characteristics considered in this evaluation comprise, soil depth, soil structure, texture and soil wetness, while the climate, topographic slope and relative steepness of the terrain combined with aspect and ground roughness are all considerations that have been taken into account. The assessment has been considered in terms of the existing/pre development soil utilisation potential or land capability, and places a significant weighting on the utilisation of the soil in terms of rehabilitation and workability, factors that are considered important to the overall sustainability of the project.

The characterisation (mapping) and classification of the soils have been undertaken using the Taxonomic Soil Classification – a system developed for Southern African, and a system recognised nationally in terms of best practise guidelines.

As part of the impact assessment a more comprehensive walk over investigation was carried out of the three sites that will be impacted at the surface. These areas comprise the Shaft and Office Complex and associated mining infrastructure.

Observations from the baseline include:

- A strong correlation is noted between the underlying lithologies and the soil forms mapped;
- Topography plays a significant role in the soil forms noted;
- Geomorphology is important in the delineation and rating of the land capability;
- Significantly large areas of colluvial and alluvial derived soils associated with the wide open drainage lines;
- Marked differences in soil depths across the study area; and
- Differences in the texture and structure of the soils across the study areas.

The soils are highly influenced by the parent materials from which they are derived (fine to medium grained sediments for the most part, with areas of quartzite and dolerite intrusives) and by the subtle but variable topography that results in a net positive erosive environment.

The attitude of the underlying lithologies (generally flat lying/horizontal) and the negative water balance (evaporation is higher than rainfall) has also had an influence on the weathering processes at work and the pedogenetic mechanisms (soil forming) that contribute to the soil forms mapped.

The soils vary in texture and structure, from apedal and single grained silty and sandy loams to sandy clay loams with slightly stronger structure (crumby to slight blocky) to strongly structure gley and gleycutanic soil forms associated predominantly with the topographic low lying areas and colluvial/alluvial derived soils.

Variation in the wet based hydromorphic soils was also noted, with lower mid-slope transitional form soils that comprise sandy clay to loamy and stratified sub soils and sandy topsoil on the alluvial outwash plains, to highly saturated gley and gleycutanic wetland soil forms that are characterised by topsoil's with better than average organic carbon contents well developed hydromorphic characteristics.

It is important to note that the present land use also varies, from areas with little to no cultivation but with some commercial grazing, to areas with intensive commercial cropping and livestock grazing. There is little to no subsistence farming or grazing. These aspects have been taken into account when considering the merits of the proposed mining plan and developments on the surface.

The following summary details the findings of the impacts that development may have on the study area in general:

- A greater proportion of the areas being considered for development returned soils that are of a moderate grazing land potential, with average soil depths, moderate to poor nutrient status and better than average water holding capabilities;

- The percentage of the overall study area associated with wet based soils is significant, with the associated wetland status being of concern to some of the proposed surface development (Wetland and Associated Report, 2016);
- The wet based soils mapped on the midslope (midslope seeps) have for the most part been impacted by cultivation or livestock grazing;
- The soils are moderately easily worked and stored, albeit that erosion is an issue to be considered and managed;
- The land capability is considered to be of a moderate potential “grazing” to low potential “arable” status/rating, with significant areas of wet based soils and transition zone “wetland” status; and
- Commercial livestock grazing and agriculture are the dominant commercial activity.

# TABLE OF CONTENTS

# LIST OF FIGURES



# LIST OF TABLES

# LIST OF APPENDICES



# GLOSSARY OF TERMS

**Alluvium:** Refers to detrital deposits resulting from the operation of modern streams and rivers.

**Base status:** A qualitative expression of base saturation. See base saturation percentage.

**Black turf:** Soils included by this lay-term are the more structured and darker soils such as the Bonheim, Rensburg, Arcadia, Milkwood, Mayo, Sterkspruit, and Swartland soil forms.

**Buffer capacity:** The ability of soil to resist an induced change in pH.

**Calcareous:** Containing calcium carbonate (calcrete).

**Catena:** A sequence of soils of similar age, derived from similar parent material, and occurring under similar macroclimatic conditions, but having different characteristics due to variation in relief and drainage.

**Clast:** An individual constituent, grain or fragment of a sediment or sedimentary rock produced by the physical disintegration of a larger rock mass.

**Cohesion:** The molecular force of attraction between similar substances. The capacity of sticking together. The cohesion of soil is that part of its shear strength which does not depend upon inter-particle friction. Attraction within a soil structural unit or through the whole soil in apedal soils.

**Concretion:** A nodule made up of concentric accretions.

**Crumb:** A soft, porous more or less rounded ped from one to five millimetres in diameter. See structure, soil.

**Cutan:** Cutans occur on the surfaces of peds or individual particles (sand grains, stones). They consist of material which is usually finer than, and that has an organisation different to the material that makes up the surface on which they occur. They originate through deposition, diffusion or stress. Synonymous with clayskin, clay film, argillan.

**Desert Plain:** The undulating topography outside of the major river valleys that is impacted by low rainfall (<25cm) and strong winds.

**Denitrification:** The biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

**Erosion:** The group of processes whereby soil or rock material is loosened or dissolved and removed from any part of the earth's surface.

**Fertilizer:** An organic or inorganic material, natural or synthetic, which can supply one or more of the nutrient elements essential for the growth and reproduction of plants.

**Fine sand:** (1) A soil separate consisting of particles 0,25-0,1mm in diameter. (2) A soil texture class (see texture) with fine sand plus very fine sand (i.e. 0,25-0,05mm in diameter) more than 60% of the sand fraction.

**Fine textured soils:** Soils with a texture of sandy clay, silty clay or clay.

**Hardpan:** A massive material enriched with and strongly cemented by sesquioxides, chiefly iron oxides (known as ferricrete, diagnostic hard plinthite, ironpan, ngubane, ouklip, laterite hardpan), silica (silcrete, dorbank) or lime (diagnostic hardpan carbonate-horizon, calcrete). Ortstein hardpans are cemented by iron oxides and organic matter.

**Land capability:** The ability of land to meet the needs of one or more uses under defined conditions of management.

**Land type:** (1) A class of land with specified characteristics. (2) In South Africa it has been used as a map unit denoting land, mapable at 1:250,000 scale, over which there is a marked uniformity of climate, terrain form and soil pattern.

**Land use:** The use to which land is put.

**Mottling:** A mottled or variegated pattern of colours is common in many soil horizons. It may be the result of various processes *inter alia* hydromorphy, illuviation, biological activity, and rock weathering in freely drained conditions (i.e. saprolite). It is described by noting (i) the colour of the matrix and colour or colours of the principal mottles, and (ii) the pattern of the mottling.

The latter is given in terms of abundance (few, common 2 to 20% of the exposed surface, or many), size (fine, medium 5 to 15mm in diameter along the greatest dimension, or coarse), contrast (faint, distinct or prominent), form (circular, elongated-vesicular, or streaky) and the nature of the boundaries of the mottles (sharp, clear or diffuse); of these, abundance, size and contrast are the most important.

**Nodule:** Bodies of various shapes, sizes and colour that have been hardened to a greater or lesser extent by chemical compounds such as lime, sesquioxides, animal excreta and silica. These may be described in terms of kind (durinodes, gypsum, insect casts, ortstein, iron, manganese, lime, lime-silica, plinthite, salts), abundance (few, less than 20% by volume percentage; common, 20 – 50%; many, more than 50%), hardness (soft, hard meaning barely crushable between thumb and forefinger, indurated) and size (threadlike, fine, medium 2 – 5mm in diameter, coarse).

**Overburden:** A material which overlies another material difference in a specified respect, but mainly referred to in this document as materials overlying weathered rock

**Ped:** Individual natural soil aggregate (e.g. block, prism) as contrasted with a clod produced by artificial disturbance.

**Pedocutanic, diagnostic B-horizon:** The concept embraces B-horizons that have become enriched in clay, presumably by illuviation (an important pedogenic process which involves downward movement of fine materials by, and deposition from, water to give rise to cutanic character) and that have developed moderate or strong blocky structure. In the case of a red pedocutanic B-horizon, the transition to the overlying A-horizon is clear or abrupt.

**Pedology:** The branch of soil science that treats soils as natural phenomena, including their morphological, physical, chemical, mineralogical and biological properties, their genesis, their classification and their geographical distribution.

**Slickensides:** In soils, these are polished or grooved surfaces within the soil resulting from part of the soil mass sliding against adjacent material along a plane which defines the extent of the slickensides. They occur in clayey materials with a high smectite content.

**Sodic soil:** Soil with a low soluble salt content and a high exchangeable sodium percentage (usually EST > 15).

**Swelling clay:** Clay minerals such as the smectites that exhibit interlayer swelling when wetted, or clayey soils which, on account of the presence of swelling clay minerals, swell when wetted and shrink with cracking when dried. The latter are also known as heaving soils.

**Texture, soil:** The relative proportions of the various size separates in the soil as described by the classes of soil texture shown in the soil texture chart (see diagram on next page). The pure sand, sand, loamy sand, sandy loam and sandy clay loam classes are further subdivided (see diagram) according to the relative percentages of the coarse, medium and fine sand subseparates.

**Vertic, diagnostic A-horizon:** A-horizons that have both, a high clay content and a predominance of smectitic clay minerals possess the capacity to shrink and swell markedly in response to moisture changes. Such expansive materials have a characteristic appearance: structure is strongly developed, ped faces are shiny, and consistence is highly plastic when moist and sticky when wet.

# 1 INTRODUCTION

Umcebo Mining (Pty) Ltd (Umcebo), a subsidiary of Glencore Operations South Africa (Pty) Ltd (Glencore) is proposing the development and operation of a new underground coal mine and associated infrastructure at a site situated approximately 10-22 kilometres (km) south east of Hendrina in the Mpumalanga Province of South Africa (the project).

Umcebo currently holds two Prospecting Rights (PRs), namely, MP 1265 PR and MP 1266 PR, located within the Ermelo Coal Field. The total extent of MP 1265 PR (referred to as Mooivlei East and Mooivlei West) is 3 923 hectares (Ha) and comprise the following farms and portions:

- Mooivlei 219 IS – Potions 2, 4, 5 and Remaining Extent (RE) of the farm;
- Tweefontein 203 IS – Portions 2, 15, 16, 17 and Portion of Portion 14;
- Uitkyk 220 IS – Portions 2 and 3; and
- Orange Vallei 201 IS – Portions 1 and RE of the farm.

The total extent of MP 1266 PR (referred to as Hendrina South) is 2 787 ha and comprises the following farm and portions:

- Elim 247 IS - RE of the farm;
- Geluksdraai 240 IS – 1 and 2;
- Orpenskraal 238 IS – RE of the farm; and
- Bosmanskrans 217 IS – Potions 1, 3, 4, 6, 8, 9 and RE of the farm.

The project area proposed to be mined (underground) has a combined footprint of 6714 ha and is located within the Steve Tshwete Local Municipality (STLM) and Msukaligwa Local Municipality (MLM).

Three separate sites are being considered (Refer to Figure 1-1), with access to the underground workings being planned from a number (3) of shafts on each of the sites (Refer to Figure 1-2). Mooivley West and Hendrina South will be mined at the same time. Once completed, Mooivley East mining activities will commence. The infrastructure utilised for the mining of Hendrina South and Mooivley West will be relocated to Mooivley East once mining has been completed.

The Run of Mine (RoM) will be transported, via conveyor, to a Crushing and Screening Plant (625 $m^2$), which will be located within the footprint of the product stockpile.

The initial site evaluation was undertaken during March 2016, with additional site visits in May 2016 to complete work on the northern sections that had not been accessible initially.

This document deals with the Soils and Land Capability assessment for the overall area that is planned for mining and the development of the required surface infrastructure inclusive of the shaft complexes, access roads and haulage ways/conveyencing systems, soil and soft overburden stockpiles, RoM Stockpiles, the crushing and screening plant and any waste storage facilities.

The study has been structured so as to satisfy the requirements of the Mineral and Petroleum Resources Development Act, 2002 (Act No. 20 of 2002) (MPRDA), as well the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and the Environmental Impact Assessment (EIA) Regulations, 2014.

To this end, a number of soil parameters were mapped and classified using the standard *Taxonomic Soil Classification, a System for South Africa (Mac Vicar et al, 2$^{nd}$ edition* 1991**)** and the Chamber of Mines Land Classification System of rating.

The objectives of the study were to:

- Provide a permanent record of the present soil resources in the areas that are potentially going to be affected by the proposed developments;
- Assess the nature of the sites in relation to the overall environment and its present and proposed utilisation, to determine the capability of the land in terms of agricultural utilization (arable, grazing, wilderness or wetland), and
- To provide a base plan from which long-term ecological and environmental decisions can be made, impacts of construction and operation can be determined and planned, and mitigation and rehabilitation management plans can be formulated.

Historically, the project area has been confined to cultivation of annual crops and low intensity grazing of livestock. Little to no previous mining or industrial development has taken place, with the town of Hendrina being the closest centre.

The advent of coal mining in this particular area has been mooted for many years as part of the Highveld Coal Fields, and the possibility of mining for coal resources has been known to exist. Areas to the south – close to Ermelo (Approximately 25km south), and areas to the west around Kriel are all well-known and established coal mining areas.

The proposed underground mining and its associated infrastructure will require that limited surface area is affected, with the conveyencing of raw materials, the stockpiling of RoM coal, the crushing and screening of the coal and the transportation of the product to market all contributing to impacts on the natural environment. The loss and sterilisation of resource (soils), erosion and compaction of disturbed land and the potential for contamination of soil resources are all negative impacts that can be expected for the duration of the project.

The land proposed for the infrastructure facilities is existing farmland that has been zoned as such and is already disturbed by these activities (cultivated land or livestock grazing). The proposed linear features (conveyer lines, haulage ways and pipelines will traverse a number of differing land types, with the majority of the length of the features being planned over existing agricultural land (arable and grazing) land and two waterways, while the soil stockpiles and materials handling facilities are generally associated with farmlands.

Mining and the development of support infrastructure is a feature of the landscape in the vicinity, and mining as an activity in the Hendrina area has been accepted as a way of life for generations. However, with the ever-increasing competition for land, it has become imperative that the full scientific facts for any particular site are known, and the effects on the land to be used by any other proposed enterprise must be evaluated, prior to the new activity being implemented.

This document describes the in-field methods used to classify and describe the *in-situ* soils, using a well-documented rating system to classify and rank the land capability based on the soils assessment, regional climate information and topographic variables, and records the pre mining/construction land use as a baseline to the proposed planning. This information will be invaluable in determining the end use and rehabilitation plans for the closure phase of the developments.

The findings of this investigation are based on a pedological survey involving a number of specialists in differing fields of expertise and the interpretation of the resulting data.

This study was aimed at describing the physical and chemical properties of the soils that are to be disturbed, to identify the soil forms and characterise the pedological status of the areas that are to be utilised for development, and to determine the effect that the proposed mining project will have on the land capability and sustainability of the area.

This includes an evaluation of the hydromorphic nature of the soils, their effective rooting depths, nutrient status, the potential erodibility, and the soil utilisation potential. In addition, the investigation required that the impacts be assessed, and mitigation methods recommended where possible, and the status of the proposed mining area understood.

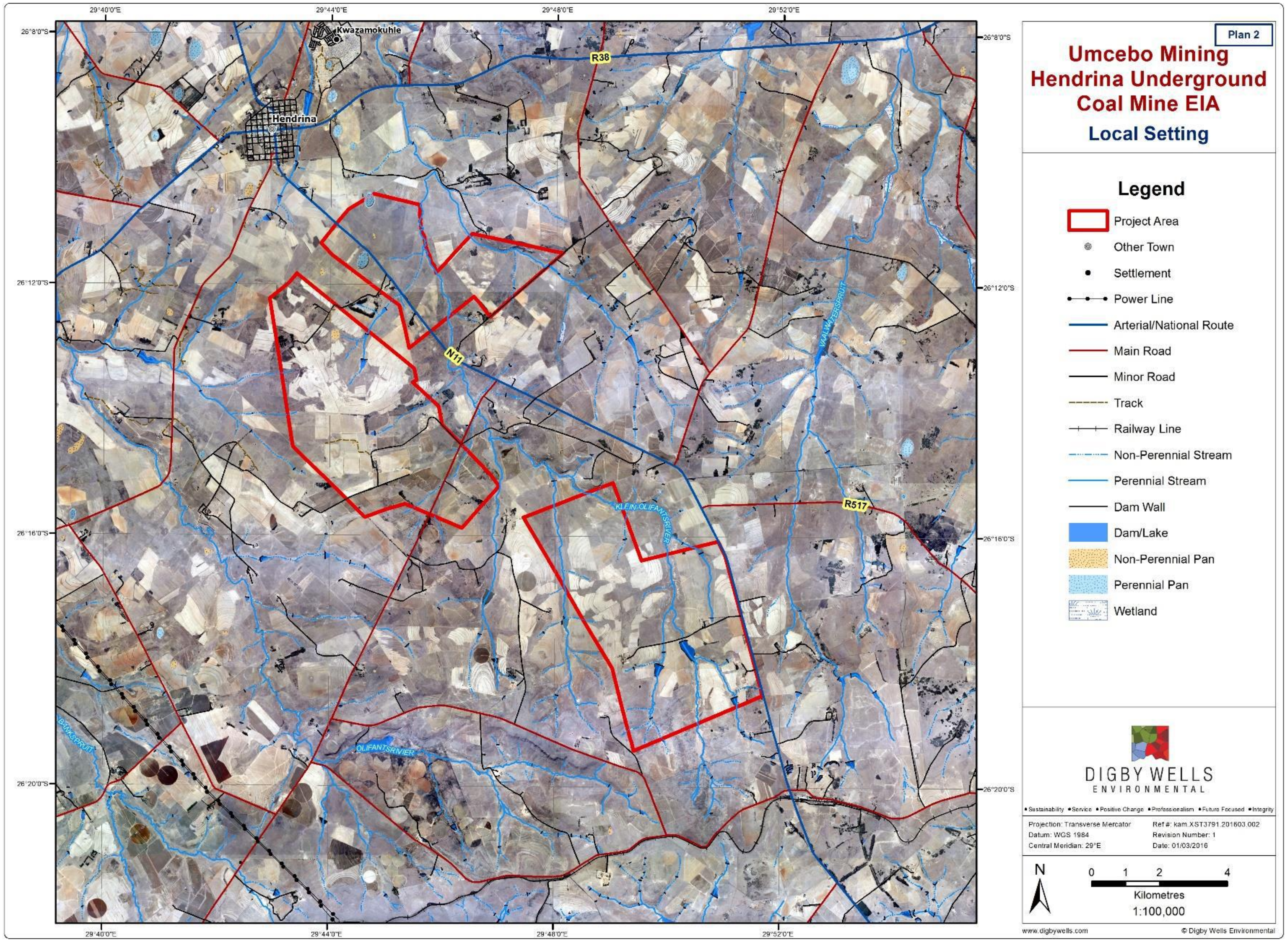


**Figure 1-1: Locality Plan**

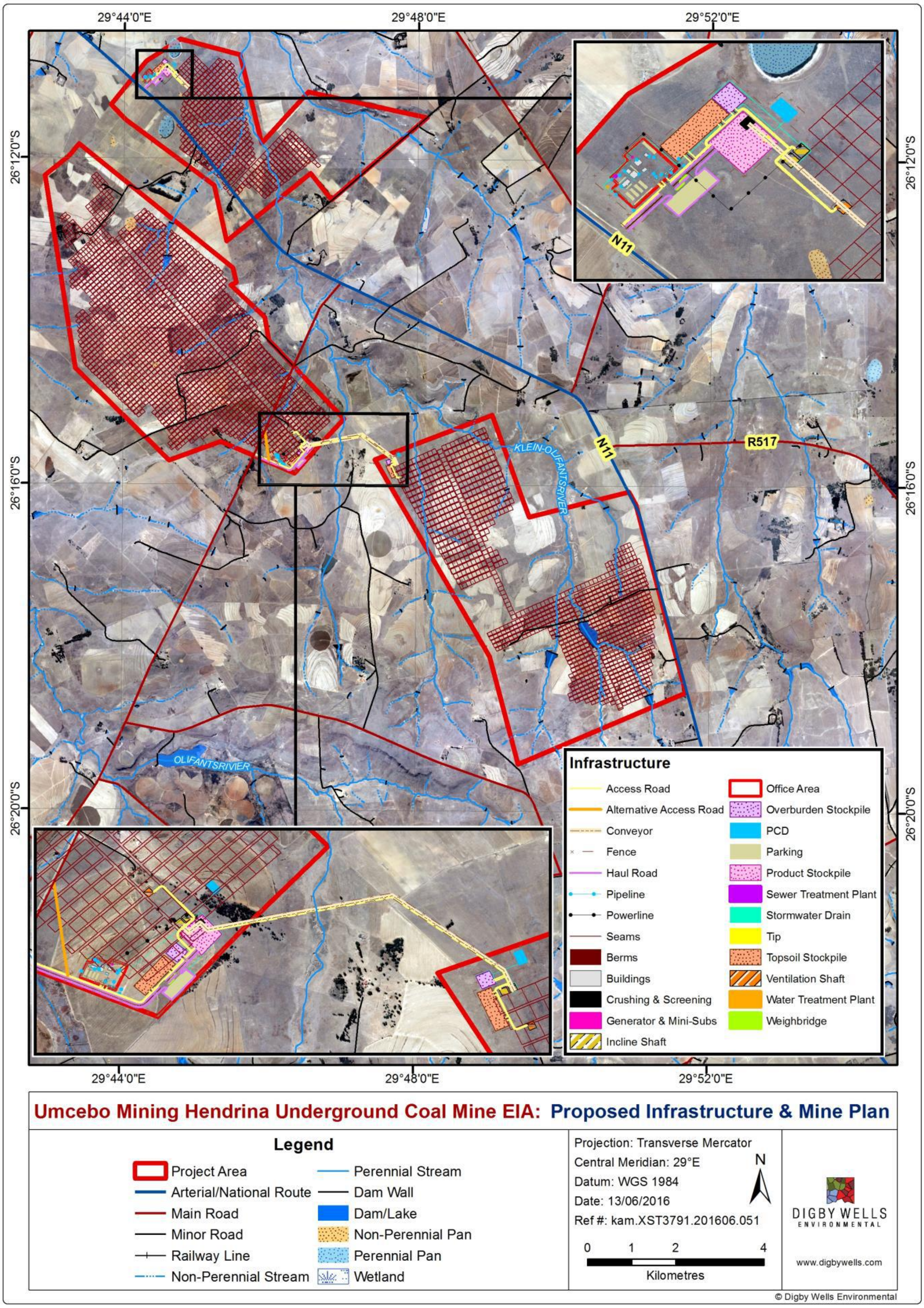


**Figure 1-2: Proposed Mine Plan**

# 2 DESCRIPTION OF THE PRE-MINING/CONSTRUCTION ENVIRONMENT

## 2.1 Soils

### 2.1.1 Data Collection

#### *2.1.1.1 Review of Published Reports and Maps*

The area proposed for development is in close proximity to a number of existing mining ventures, and forms part of the greater coal mining regions of the eastern and central Highveld coal fields of South Africa. Extensive geological and geotechnical information is available for this area, and a substantial amount of existing information is available with regard to the geology and geochemistry of the sedimentary formations that make up the major portion of the materials that are to be affected by mining or infrastructure development. The proponent has undertaken a detailed economic and geological/geotechnical investigation over the area of prospect, and has a proven resource that underlies the area. With the economic viability of the resource understood, and with a mine plan on the table, it remains only for the socio economic and environmental aspects of the site to be assessed and the impacts understood.

The Land Type Mapping of S.A. (1:250000 scale), the Geological Map of S.A. and local knowledge of the soils and land capability where made available for the study and used in understanding the regional aspects. However, no existing detailed mapping was available.

The soils of the study area and footprint materials for the proposed areas of underground mining have been assessed on a reconnaissance grid base, with a more detailed specialist investigation being undertaken for the baseline information required as part of the planning for the surface infrastructure.

Additional information was also obtained from the exploration and geotechnical data where it was available (drilling logs etc.), while the wetland delineation study and hydrology were included as part of a better understanding of the general geomorphology of the site.

The underlying geology is used as the basis for the soil study, the lithological units reflecting the general chemistry and physical components of the resultant soils produced. The moderately complex suite of rocks that make up the geological sequence is reflected in the variation in soil pedogenisis.

It is these complexes of lithologies combined with the topographic changes that produce the complex of differing soil polygons noted across the study site.

In its simplicity, the major portion of the area studied is underlain by the Ecca sediments and younger intrusives.

The Department of Agriculture requires that the agricultural potential of the soils in South Africa is considered for any areas that are going to be impacted by new developments.

#### *2.1.1.2 Field Work*

The pedological study was performed based on a variable grid bases with the understanding that the differences in soil forms, site sensitivity, the impact of surface infrastructure and the possibility of subsidence due to underground mining collapse will affect the surface features to differing degree.

The soil classification/characterisation and mapping has delineated the broad soil patters for the total mining right area, the dominant soils map produced reflecting the spatial distribution of the different soil groupings.

The survey was undertaken during March and May of 2016.

The fieldwork comprised a site visit during which profiles of the soil were examined and observations made of the differing soil extremes. Relevant information relating to the climate, geology, wetlands and terrain morphology were also considered at this stage. This information was obtained from the project applicant or from other consultants involved in these areas of speciality.

In addition to the grid point observations, a representative selection of the soil Forms mapped was sampled to determine the chemistry and physical attributes of the soils. The soil mapping was undertaken on a 1:10 000 scale (Refer to Figure 2-1).

The majority of observations used to classify the soils were made using a hand operated Bucket Auger and Dutch (clay) augers with any and all natural exposures (road cuttings etc.) being used to obtain a better understanding of the in-situ characteristics of the soils.

In all cases, the observation points were excavated to a depth of 1 500 mm or until refusal was obtained. Immediately after completing the classification of the profiles, the excavations were backfilled for safety reasons.

Standard mapping procedures and field equipment were used throughout the survey. Initially, geological map of scale 1:250 000 and top cadastral maps at a scale of 1:50 000 were used to provide an overview of the area, while Ortho photographs at a scale of 1:10,000 being used as the base map for the soil survey.

The pedological study was aimed at investigating/logging and classifying the soil profiles. Terrain information, topography and any other infield data of significance was also recorded, with the objective of identifying and classifying the area in terms of:

- The soil types to be disturbed/rehabilitated;
- The soil physical and chemical properties;
- The soil depth;
- The erodibility of the soils;
- Pre-construction soil utilisation potential, and
- The soil nutrient status.

#### *2.1.1.3 Soil Profile Identification and Description Procedure*

The identification and classification of soil profiles were carried out using the *Taxonomic Soil Classification System (Mac Vicar et al, 2nd edition 1991*).

The Taxonomic Soil Classification System is in essence a very simple system that employs two main categories or levels of classes, an upper level or general level containing soil forms, and a lower, more specific level containing soil families. Each of the soil forms in the classification is a class at the upper level, defined by a unique vertical sequence of diagnostic horizons and materials.

All forms are subdivided into two or more families, which have in common the properties of the Form, but are differentiated within the Form on the basis of their defined properties.

In this way, standardised soil identification and communication is allowed by use of the names and numbers given to both form and family.

The procedure adopted in field when classifying the soil profiles is as follows:

- Demarcate master horizons (Refer to Figure 2-1)
- Identify applicable diagnostic horizons by visually noting the physical properties such as:
    - Depth (below surface);
    - Texture (Grain size, roundness etc.);
    - Structure (Controlling clay types);
    - Mottling (Alterations due to continued exposure to wetness);
    - Visible pores (Spacing and packing of peds);
    - Concretions (cohesion of minerals and/or peds); and
    - Compaction (from surface).
- Determine from i) and ii) the appropriate Soil Form
- Establishing provisionally the most likely Soil Family

### Table 2-1: Typical Arrangement of Master Horizons in Soil Profile

| | | Arrangement of master horizons | | | | | Comments on Layers |
|---|---|---|---|---|---|---|---|
| SOLUM | (Zone in which the soil forming processes are maximally expressed) | O - Organic | C - Regic Sands (C), Stratified Alluvium (C), Man - Made Soil Deposits (C). | A | Humic,Vertic, Melanic, Orthic | G | Loose leaves and organic debris, largely undecomposed |
| | | | | | | | Organic debris, partially decomposed or matted |
| | | | | B | Red Apedel, Yellow-brown Apedel, Soft Plinthic, Hard Plinthic, Prismacutanic, Pedocutanic, Lithocutanic, Neocutanic, Neocarbonate, Podzol, Podzol with placic pan | | Dark coloured due to admixture of humified organic matter with the mineral fraction |
| | | | | | | | Light coloured mineral horizon |
| | | | | | | | Transitional to B but more like A than B |
| | | | C | Dorbank, Soft Carbonate horizon, Hard Carbonate Horizon, Saprolite, Unconsolidated materials without signs of wetness, Unconsolidated materials with signs of wetness, Unspecified materials with signs of wetness | | | Transitional to A but more like B than A |
| | | | | | | | Maximum expression of B-horizon character |
| | | | | | | | Transitional to C |
| | | | | | | | Unconsolidated material |
| | | | R - Hard Rock | | | | Hard rock |

## 2.1.2 Description

### *2.1.2.1 Soil Forms Identified*

The dominant soil forms encountered during the site investigation include those of the orthic phase Hutton, Clovelly, Griffin, Shortlands and shallow Mispah and Glenrosa, with sub dominant forms that include the Shortlands, Valsrivier and Glencoe forms. In addition, and of importance to the area in question, is the significantly large proportion of the area that comprises wet based soils and materials that classify as “wetlands” in terms of the wetland delineation guidelines.

These hydromorphic form soils are extremely prevalent and of significance to the overall EIA, the low angled topographic slopes and resulting wide expansive drainage lines resulting in proportionately much larger areas of transition zone moist grasslands and wet based soils that meet the wetland classification both pedologically as well as ecologically.

The hydromorphic soils are primarily associated with the Klein Olifants River catchment and its tributaries, The horizontal bedding of the sedimentary lithologies (Sandstone, siltstone and shales) that underlie the site, and the presence of significant hard sandstone partings have resulted in large expanses of ouklip/hard plinthic horizons both in the lower lying drainage lines, as well as relic land forms at lower midslope and midslope positions in the landscape.

The hydromorphic soils range from extremes of deep Avalon, Bainsvlei, Bloomsdale, Glencoe and Pinedene forms on the transition zone terries slopes, and shallow Avalon, Westleigh, Kroonstad and Sepane Forms associated with the lower slopes and midslope seeps, to highly structured prismacutanic and gleycutanic form soils (Katspruit, Rensburg etc.) associated with the alluvial floodplains.

The dominant soil forms classified in the area are discussed below (Refer to Figure 2-1), the physical and chemical attributes of each being important to an understanding of how the materials might be impacted and effected by the development being proposed.

This information along with the geomorphology of the site was also used in rating the land capability (Chamber of Mines Land Capability Rating System and the Canadian Land Inventory System) and assessing the site sensitivity.

The soils have been categorised and mapped into a number of groups, each group comprising soils of similar characteristics that can be handled and managed in a similar way. The soil structure, texture and depth along with the soil wetness characteristics are the main attributes used to characterise the different groups.

The dominant groups include, the deep sandy loams (generally >700mm) with no signs of wetness, moderately deep sandy loams and silty clay loams, shallow soils and very shallow materials, and a number of groups of hydromorphic soil forms that vary in depth and underlying plinthite character (Refer to Figure 2-1).

The **deep sandy loams and silty clay loams** are characterised by a variety of pale red and yellow brown topsoil colours on brown and orange to red subsoil, exhibit an apedal to single grained structure and are for the most part well drained. The clay contents vary from as low as 10% and 15% in the sandy topsoil's, rising as high as 25 % in some of the more basic (dolerite) derived soils.

The subsoil clay percentages range from about 15 % to 45 % depending on the position that they occupy in the topographic sequence and the host geology from which they are derived.

In almost all cases mapped, the soils classify as having a mesotrophic leaching status (moderately leached) and are luvic in character.

These soil forms generally occupy the upper and upper midslopes, and returned effective rooting depths (ERD) that vary from as shallow as 400mm to greater than 1 200 mm.

This group comprises deep (Generally >700 mm) Hutton and Clovelly form soils, with sub dominant Clovelly, Griffin and deep Glenrosa forms for the most part.

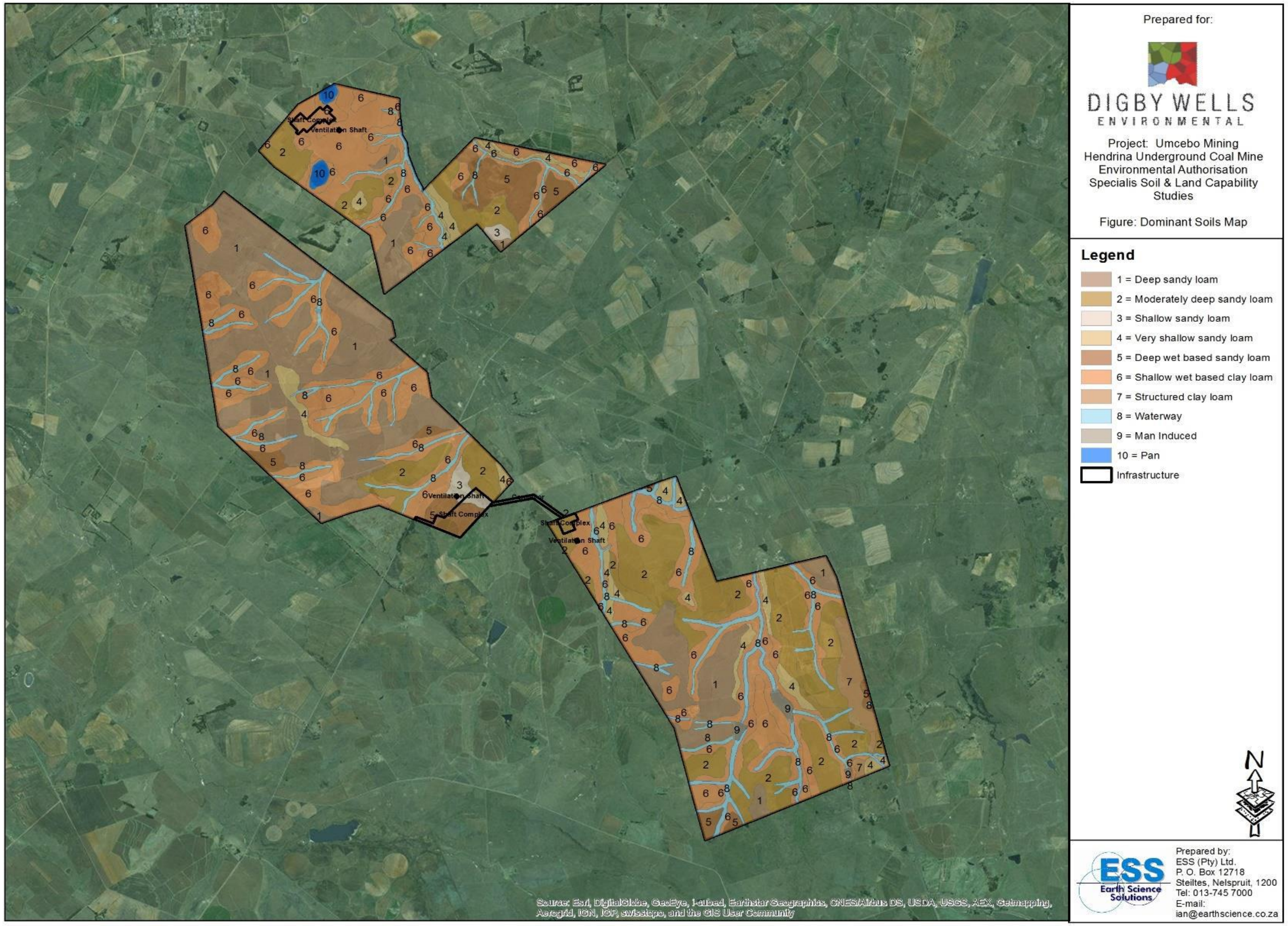


**Figure 2-1: Dominant Soil Map**

The **moderately deep sandy loams and silty clay loams** have been mapped out from the deep materials based solely on their effective rooting depth. Their structure and texture are similar or the same as for the deep soils described above. Depths to hard rock and or saprolite will restrict the depth of soil stripping (if required), a factor that is important in maintaining the soil viability for future use. The inclusion of hard rock or saprolite into the soil utilisable soil stockpiles will reduce the soils viability (dilutes the nutrient pool and water holding capability). The dominant soil forms in this group include the Hutton, Clovelly and deeper Glenrosa forms soils.

Compaction and erosion are physical hazards to be aware of and catered for when working on and with these soil types.

The **shallow and very shallow** sandy loams and clay loams have again be separated out based on their depth to an inhibiting horizon, the ability of these soils to be managed posing a much more difficult issue in terms of the materials sensitivity and vulnerability to erosion. The site sensitivity mapping has been used as a management tool in this regard, with soil depths of less than 400mm being regarded as sensitive sites (Refer to Figure 2-1). The major soil forms included in this group include the Glenrosa (Gs) and Mispah forms with sub dominant forms including the shallow Hutton, Clovelly and Dresden (Dr) forms.

These soil returned effective rooting depths of between 150mm and 400mm. The major constraint envisaged with these soils will be tillage, sub surface hindrance and erosion. The restrictive layer associated with these soils is a hard lithocutanic layer in the form of weathered parent material (Gs), hard plinthite (Dr) or hard rock (Ms).

The effective soil depth is restricted, resulting in reduced soil volumes and as a result, depletion in the water holding capacity as well as nutrient availability.

Geophysical characteristics of these soils include moderate clay percentages (12% to 20%), moderate internal drainage and low water holding capabilities.

These materials are of the poorer land capability units mapped. It is imperative that good management of these soils is implemented, both from the erosion as well as the compaction perspective.

The **wet based soils** vary somewhat in depth and degree of wetness, with a significant proportion of the area mapped comprising soils that classify as transitional moist grasslands and wetland soil forms in terms of the wetland delineation classification.

The wet based materials are generally confined to the lower mid-slope, lower slope and bottom land positions, and are found associated with the transition zone and wetland areas that are regularly influenced by the soil water and surface accumulations of runoff within the vadose zone.

These soil forms are indicative of a resistant wetting of the subsoil and the effects of evaporation, and the formation of a hard plinthic horizon at the base of the profile (evaporites). These soils are associated with lithologies that are rich in iron and magnesium and often form relic land forms within the mid and upper midslopes due to their resistant nature.

Physically these soils returned fine to medium grained, pale red to brown, apedal structure in the topsoil's ("A" horizon), with moderate to low clay contents (12 % – 18 %) and moderate to low water holding capabilities (40 – 60 mm/m). The subsoil is generally pale yellow/red to pale red in colour, returning moderate clays (12 % – 22 %), fine to very fine-grained sand fractions, with a concretionary layer at the interface between the "B" horizon and the hard plinthic "C" horizon.

Chemically, the soils are similar to the Avalon, Pinedene and Westleigh soil Forms described herein.

Hazards to be managed on these soils include the impeded drainage caused by the hard plinthic layer, compaction in the wet state, and erosion.

The dominant soil forms associated with these soils include the Glencoe (Gc), Bainsvlei (Bv), Bloemdale (Bd), Pinedene (Pn) and Avalon (Av).

The **wetlands soils** are of much more sensitive nature and are considered of greater risk in terms of both their contribution to biodiversity and the ecology of an area as well as their ability to be worked on.

By definition, these soils vary in the degrees of wetness at the base of their profile. i.e. the soils are influenced by a rising and falling water table, hence the mottling within the lower portion of the profile and the pale background colours.

Depths of utilizable agricultural soil (to top of mottled horizon) vary from 300 mm to 500 mm. The deeper rooting depths (>700 mm) are considered potentially utilizable soils, with those less than 500mm being considered to have a wetland or wilderness/conservation status. In general, these soils are high in transported clay in the lower "B" horizon with highly leached topsoil's and pale denuded horizons at shallow depths. The nutrient status is variable, but due to excessive leaching is generally low.

These materials will be more difficult to work due to the wetness factor, both during the construction phase and operation, as well as on rehabilitation. Compaction is a problem to contend with if these soils are to be worked during the wet months of the year. Stockpiling of these soils should be done separately from the dry soils and greater care is needed with the management of erosion problems during storage. Any strong structure that develops during the stockpiling stage will need to be dealt with prior to the use of this material for rehabilitation.

The dominant soil forms include the Avalon, Westleigh, Longlands, Katspruit and Rensburg forms, all of which by definition show strong hydromorphic characteristics at shallow depths.

In general, these soils are high in transported clay in the lower "B" horizon with highly leached topsoil's and pale denuded horizons at shallow depths. The nutrient status is generally low.

These soils will be more difficult to work due to the wetness factor, both during the construction and operation of the facility.

Compaction is a problem to contend with if these soils are to be worked during the wet months of the year.

Stockpiling of these soils should be done separately from the dry soils and greater care is needed with the management of erosion problems during storage.

Any strong structure that develops during the stockpiling stage will need to be dealt with prior to the use of this material for rehabilitation.

### 2.1.3 Soil Chemical and Physical Characteristics

A suite of composite and representative samples from the differing soil forms/types were taken and sent for analyses for both chemical as well as physical parameters (Refer to Table 2-2 for the results). A select number of samples were submitted, each sample containing a number of sub samples, thus forming a composite sample, which is representative of the soil polygon rather than just the point sampled.

#### *2.1.3.1 <u>Soil Chemical Characteristics</u>*

Sampling of the soils for nutrient status was confined where possible to areas of uncultivated land. However, some of the land being used for grazing may have been fertilized in the past, and thus these results may not be truly representative of the soils in their natural state.

These results represent the pre mining/construction conditions, and will give a baseline from which to compare the soils at closure. However, due to the possible loss of nutrients from the soils during stockpiling and storage, additional sampling and analysis of the soils will be needed prior to their use for rehabilitation.

The results of the analysis returned moderate to light textured soils with a pH (KCl) of between 4.2 and 7.5, a base status ranging from 2.2me% to 10.6me%, and nutrient levels reflecting generally acceptable concentrations of calcium and magnesium, but deficiencies in the levels of potassium, phosphorous and zinc, with predictably low organic carbon matter.

The structured and basic derived soils returned values that are indicative of the higher reserves of calcium and magnesium. They are inherently low in potassium reserves, and returned lower levels of zinc and phosphorous for economically acceptable agricultural growth.

The nutrient status indicates a need for fertiliser applications of “Zn” “P” and “K”.

It should be noted however, that the addition of “P”, “K” and “Zn” in the form of commercial fertilisers are potential pollutants to the riverine and groundwater environment if added in excess. This must be taken into account when applying these additives. Small amounts of fertilizer should be added on a regular/more frequent basis, rather than adding large quantities in one application.

##### 2.1.3.1.1 Soil acidity/alkalinity

In general, it is accepted that the pH of a soil has a direct influence on plant growth. This may occur in a number of different ways, which include:

- The direct effect of the hydrogen ion concentration on nutrient uptake;
- Indirectly through the effect on major trace nutrient availability; and by
- Mobilising toxic ions such as aluminium and manganese, which restrict plant growth.

A pH range of between 6 and 7 most readily promotes the availability of plant nutrients to the plant. However, pH values below 3 or above 9, will seriously affect, and reduce the nutrient uptake by a plant.

## Table 2-2: Analytical Soils Results

| Obs Pt | Soil Fm | pH (Water) | Res (ohms) | Ca mg/kg | Mg mg/kg | K mg/kg | Na mg/kg | P (Bray1) | Al mg/kg | Ca/Mg | Ca+Mg/K | Zn mg/kg | C% | Org Mat% | Sand% | Silt% | Clay% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H1 | Hu | 7.52 | 1146 | 2774 | 218 | 4 | 10 | 7 | 0.8 | 12.72 | 748.00 | 1.20 | 0.32 | NA | 68 | 13 | 19 |
| H2 | We | 5.55 | 2100 | 3089 | 1327 | 220 | 21 | 0.3 | 10 | 2.33 | 20.07 | 4.29 | 2.52 | 4.33 | 62 | 14 | 24 |
| H3 | Av | 5.93 | 840 | 3632 | 1473 | 217 | 171 | 0.5 | 9 | 2.47 | 23.53 | 3.52 | 1.01 | 1.73 | 60 | 6 | 34 |
| H4 | Cv | 4.96 | 500 | 537 | 149 | 225 | 8 | 10.7 | 51 | 3.60 | 3.05 | 2.92 | 1.01 | 1.73 | 82 | 4 | 14 |
| H5 | Cv/Gf | 5.02 | 1400 | 1626 | 470 | 322 | 132 | 0.6 | 11 | 3.46 | 6.51 | 1.25 | 1.19 | 2.04 | 60 | 16 | 24 |
| H6 | Bd | 5.33 | 990 | 734 | 373 | 107 | 61 | 0.3 | 15 | 1.97 | 10.35 | 1.25 | 0.86 | 1.49 | 68 | 12 | 20 |
| H7 | Rg | 4.2 | 940 | 353 | 85 | 253 | 4 | 43.7 | 17 | 4.15 | 1.73 | 5.52 | 1.44 | 2.48 | 77 | 3 | 20 |
| H7a | Lo | 4.7 | 622 | 122 | 34 | 12 | 3 | 7 | 6 | 3.59 | 13.00 | 0.90 | 0.04 | NA | 74 | 24 | 2 |
| H7b | Lo | 6.85 | 842 | 1946 | 728 | 12 | 20 | 7 | 1.2 | 2.67 | 222.83 | 1.10 | 0.33 | NA | 55 | 6 | 39 |

The dominant soils mapped in this area are neutral to acid (4.20 to 7.60), generally within the accepted range for good nutrient mobility albeit that lime is often a requirement for some of the commercial crops grown. However, some of the soils derived from intrusive material will tend to be more alkaline than indicated by these results due to the potential buffering capacity of the moderately high levels of calcium carbonate. This may affect the pH of the soils to some extent. It is unlikely however, that they will be dramatically impaired.

#### *2.1.3.1.2 Soil salinity/sodicity*

In addition, to the acidity/alkalinity of a soil, the salinity and/or sodicity are of importance in a soils potential to sustain growth.

Highly saline soils will result in the reduction of plant growth caused by the diversion of plant energy from normal physiological processes, to those involved in the acquisition of water under highly stressed conditions. Salinity levels of <60mS/m will have no effect on plant growth. From 60 – 120mS/m salt sensitive plants are affected, and above 120mS/m growth of all plants is severely affected.

In addition soil salinity may directly influence the effects of particular ions on soil properties. The sodium adsorption ratio (SAR) is an indication of the effect of sodium on the soils. At high levels of exchangeable sodium, certain clay minerals, when saturated with sodium, swell markedly.

With the swelling and dispersion of a sodic soil, pore spaces become blocked and infiltration rates and permeability are greatly reduced. The critical SAR for poorly drained (grey coloured) soils is 6, for slowly draining (black swelling as found in this site) clays it is 10 and for well drained, (red and yellow) soils and recent sands, 15.

Generally, the soils mapped in this area tend toward being non-saline in character, but could become susceptible to an increase in salinity if their water regime is not well managed, particularly on the more clay rich materials (Rensburg and Arcadia).

#### *2.1.3.1.3 Soil fertility*

The soils mapped in this area returned moderate to high levels of some of the nutrients required for good plant growth, although Zn, P and K are generally lower than the optimum required, and the soil depths are inhibiting due to the extreme soil structure.

Significantly large areas of soil with an acceptable level of plant nutrition where mapped on soils that are not generally considered to be of an arable rating. These results can possibly be ascribed to either a natural anomaly in nutrient levels within the soil profile sampled, or to residual levels of fertiliser within the soil due to farming activities in the area.

There are no indications of any toxic elements that are likely to limit natural plant growth in the soils mapped within the study area.

Fairly standard fertiliser treatments will be needed for optimum agricultural production of crops on areas that have previously been planted, with good water management being of paramount importance on both dry-land as well as irrigated lands.

##### *2.1.3.1.4 Nutrient Storage and Cation Exchange Capacity (CEC)*

The potential for a soil to retain and supply nutrients can be assessed by measuring the "cation exchange capacity" (CEC) of the soils.

The low organic carbon content is balanced to some extent by the relatively high clay content which naturally provide exchange sites that serve as nutrient stores. These conditions will result in a moderate retention and supply of nutrients for plant growth.

Low CEC values are an indication of soils lacking organic matter and clay minerals. Typically a soil rich in humus will have a CEC of 300 me/100g (>30 me/%), while a soil low in organic matter and clay may have a CEC of 1-5 me/100g (<5 me/%).

Generally, the CEC values for the soils mapped in the area are moderate to low, due to the moderate clay contents but poor organic matter content.

#### *2.1.3.2 Soil Physical Characteristics*

The majority of the soils mapped exhibit apedal to weak structure, moderate clay contents and mesotrophic to dystrophic characteristics.

Due to the texture and structure inherent in these soils, compaction within the "A" horizon is likely to occur if heavy machinery is used during the wet summer months over unprotected ground, while the sensitivity of the soils to erosion is a factor to be considered during the rehabilitation process (refer to section on Soil Handling and Removal and Mitigation and Management Measures).

A large proportion of the overall area to be affected by the construction operations and its associated infrastructure is underlain by soils with a more sensitive nature to heavy traffic. This will affect both compaction and erosion of the materials if not well managed.

The area is flat to undulating, with wide open drainage lines and active water ways. The natural movement of eroded materials has resulted in the distribution of differing soils associated with the midslopes and lower midslope positions. The upper slopes and midslopes are dominated by erosion platforms and old land surfaces, while the lower slopes are dominated by recent accumulations of transported materials (colluvial) from the upslope positions in the alluvial floodplains of the Klein Olifants River and its tributaries.

The end result is a complex of differing soil forms within a relatively small spatial area.

#### *2.1.3.3 Characteristics of different Soil Groups*

##### *2.1.3.3.1 The Heavy Clay Rich Soils*

The colluvial derived soils and those derived from the more basic parent materials (intrusive diabase and dolerite) returned structures within the soil profile that are expansive, with notable cracking within the soil profile in the dry state, and indications of slicken-slides in the wet state.

Generally the C-horizons that underlie these horizons are composed of moderately hard and shallow weathering rock (saprolite). Intake rates and drainage of these soils are poor, while the erosion hazard is moderate.

These soils generally have a moderate to low nutrient status, and are subject to serious physical limitations if the soils are worked too wet or too dry.

The major soils that fit this category include the Rensburg, Arcadia and to some degree the Swartland and/or Sterkspruit soil Forms. These soils are characterised by dark brown to black vertic or melanic (crumbly) topsoil's and moderate blocky to massive and vertic structured, clay rich "B" horizons. These soils are poorly drained and will pose a problem to handling and re-working during the construction as well as the rehabilitation phases.

Erosion and compaction are the main problems that will need to be managed on these soil types. This is due to the sensitivity of the soils to mechanical disturbances during/after the removal of surface vegetation. The existing and established vegetation binds and stabilises the soils ensuring fair growing conditions and good soil retention.

These same conditions will need to be emulated as soon after storage/stockpiling and/or rehabilitation of the soils has been undertaken.

#### *2.1.3.3.2 Light Textured -Yellow-brown and Red Apedal Soils*

More extensive areas of lighter textured soils are found generally across the site and will be the major soil forms affected by the proposed infrastructure and surface development.

The lighter textured soils (Hutton, Clovelly and Glencoe) are characterised by an orthic A-horizon overlying a red or orange to brown apedal "B", with possible indications of a ferricrete layer in the B/C-horizon.

The lithologies encountered are generally resistant, massive, intrusive geologies, resulting in shallow weathering within the saprolitic zone.

The working of these soils as well as the storage (stockpiling) will need to be well managed.

#### *2.1.3.3.3 Shallow soils*

The generally shallow rooting depths of the soils that dominate the area (<500 mm) are associated with the hard and resistant lithologies that underlie the site.

### 2.1.4 Soil Erosion and Compaction

The erosion potential of a soil is expressed by an erodibility factor ("K"), which is determined from soil texture, permeability, organic matter content and soil structure.

The Soil Erodibility Nomograph of (*Wischmeier et al,* 1971) was used to calculate the "K" value. An index of erosion (I.O.E.) for soils is then determined by multiplying the "K" value by the slope percentage. Erosion problems may be experienced when the Index of Erosion is greater than 2.

The “K” value is used to express the “erodibility” of a particular soil form. Erodibility is defined as the vulnerability or susceptibility of a soil to erosion. It is a function of both the physical characteristics of that soil as well as the treatment of the soil.

The average “Erosion Indices” for the dominant soil forms on the study site can be classified as having a moderate erodibility index. This is largely ascribed to the generally low organic carbon content and the sensitivity of the soils to solution weathering. These factors are offset by the generally gentle to flat topography and the moderate clay contents. The vulnerability of the “B” horizon to erosion once/if the topsoil is removed must not be under estimated.

The wet and structured soils are susceptible to compaction due to the swelling clays that are common in the majority of the materials classified. These soils will need to be managed extremely well, both, during the stripping operation, as well as during the stockpiling/storage and rehabilitation stages.

The concerns around erosion and compaction are directly related to the fact that the protective vegetation cover and topsoil will be disturbed during any mining or construction operation. Once disturbed, the actions of wind and water are increased. Loss of soil (topsoil and subsoil) is extremely costly to any operation, and is generally only evident at closure or when rehabilitation operations are compromised.

Well planned management actions during the construction and operational phases will save time and money in the long run, and will have an impact on the ability to successfully “close” an operation once completed.

### 2.1.5 Dry Land Production Potential

The dry land production potential of the shallow soils and the more structured forms, are poor.

The deeper, and apedal soil are easier to cultivate and have a better propensity to both drainage as well as the holding of moisture within the soil that is available to the plant. These soils are more productive dry land materials that are also easier to manage.

### 2.1.6 Irrigation Potential

The irrigation potential for the soils is “moderate to good” in terms of the soil structure and drainage capability. With good water management, and adequate drainage, the deeper (>700 mm) soils could be economically cultivated to irrigated crops. The spatial distribution and occurrence of these soils is limited and it is unlikely that sufficiently large enough areas of soil are available to make the use of irrigation viable on anything other than highly intensive market gardening tunnel gardening.

Irrigation is practice to some extent in the area of study. Again, the spatial distribution of the soils with adequate soil rooting depths will limit the size of the areas that can be cultivated, thus limiting the potential for economic irrigation farming. In addition, for any irrigation to be undertaken in the area on a large (sustainable) scale, it would require the installation of a number of surface water impoundments as storage during the dry months. A more detailed study would be needed if irrigated farming is to be considered as an "End Use" for the rehabilitated areas.

### 2.1.7 Soil Utilisation Potential

In general, the soils that will be disturbed and that will require rehabilitation, are moderately deep to shallow, (ERD = 400 mm to 800 mm), moderately well drained, with a susceptibility to erosion and compaction and in a significant proportion of the study area show signs of wetness at depth (shallow or perched water table).

The wet based and structured soils will be difficult to work, both from a trafficability, workability, storage and rehabilitation point of view.

Compaction must be considered carefully as the working of the wet based and structured soils when wet (rainy season), will be detrimental and compaction will occur.

The structure of the soil will affect their workability, and provision will need to be made for the timing of the stripping and rehabilitation works to be undertaken if the structural integrity of these soils are to be maintained.

The potential for the use of the hydromorphic soils for economic crop production and/or market gardening is at best poor, and should not be considered for anything other than as wilderness/conservation lands (preferred option), while the potential for economic farming of the structured soils is considered at best to be "low intensity grazing land". The less structured and non-hydromorphic soils are that cover a substantial portion of the site are considered arable class soils, and as such can be considered for use in low intensity livestock grazing and or arable crop production.

## 2.2 Pre-Construction Land Capability

### 2.2.1 Data Collection

The land capability of the study areas was classified into four classes (wetland, arable land, grazing land and wilderness/conservation) according to the *Chamber of Mines Guidelines*, 1991. The criteria for this classification are set out in Table 2-3.

**Table 2-3: Criteria for Pre-Construction Land Capability (Chamber of Mines 1991)**

**Criteria for Wetland**

- Land with organic soils or supporting hygrophilous vegetation where soil and vegetation processes are water determined.

**Criteria for Arable Land**

- Land, which does not qualify as a wetland.
- The soil is readily permeable to a depth of 750 mm.
- The soil has a pH value of between 4.0 and 8.4.

- The soil has a low salinity and SAR
- The soil has less than 10 % (by volume) rocks or pedocrete fragments larger than 100 mm in the upper 750 mm.
- Has a slope (in %) and erodibility factor ("K") such that their product is <2.0
- Occurs under a climate of crop yields that are at least equal to the current national average for these crops.

**Criteria for 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.
- Supports, or is capable of supporting, a stand of native or introduced grass species, or other forage plants utilisable by domesticated livestock or game animals on a commercial basis.

**Criteria for Wilderness/Conservation Land**

- Land, which does not qualify as wetland, arable land or grazing land.

### 2.2.2 Description

The "land capability classification" as described above was used to classify the land units identified during the pedological survey. In conjunction with the soils classified, the climate, ground roughness and topography (Geomorphology) were assessed and used in the determination of the Land Capability Rating. Figure 2-2 illustrate the spatial distribution of land capability classes.

#### *2.2.2.1 Arable*

Significantly large portions of the study area have been cultivated and are being economically farmed to annual crops under dry land and irrigation. The percentage area of soil that classify as "arable" land is however somewhat smaller, with some of the farming being undertaken on soils that are either less than 700mm in depth, rocky and inhibited in rooting depth, are associated with the transition zone wetlands or in some cases cultivation is being undertaken in the wetland zone. The area of actual cultivated land use is therefore not the same as the "arable" land capability delineated on the map.

#### *2.2.2.2 Grazing*

A significant portion of the study area rates as grazing land potential , and is used as such. These areas are generally confined to the shallower (500 mm to 700 mm) and transitional hydromorphic soil Forms that are moderately well drained. These soils are generally darker in colour, and are not always free draining to a depth of 750 mm, but are capable of sustaining palatable plant species on a sustainable basis, especially since only the subsoil's (at a depth of 500 mm) are periodically saturated. In addition, there should be no rocks or pedocrete fragments in the upper horizons of this soil group. If present it will limit the land capability to wilderness/conservation land.

#### *2.2.2.3 Wilderness/Conservation*

The areas that classify as either conservation or wilderness land are found associated with the more structured, and shallower rocky soils (Glenrosa and Mispah) that are associated with non-hydromorphic soils. These are for the most part evident as outcrop or shallow sub-outcrop on the lower mid-slopes, or occasionally on the crest slopes. This land capability unit is not prevalent in the area of concern.

#### *2.2.2.4 Wetland*

The wetland areas are defined in terms of the wetland delineation guidelines, which use both soil, topography as well as vegetation criteria to define the domain limits.

These zones are dominated by hydromorphic soils that are often structured, and have plant life that is associated with aquatic processes.

The soils are generally dark grey to black in the topsoil horizons, high in transported clays, and show pronounced mottling on gleyed backgrounds (pale grey colours) in the subsoil's. These soils occur within the zone of groundwater influence.

This land capability unit is very prevalent in the study area and makes up a significant proportion of the area that could potentially be impacted by the proposed development.

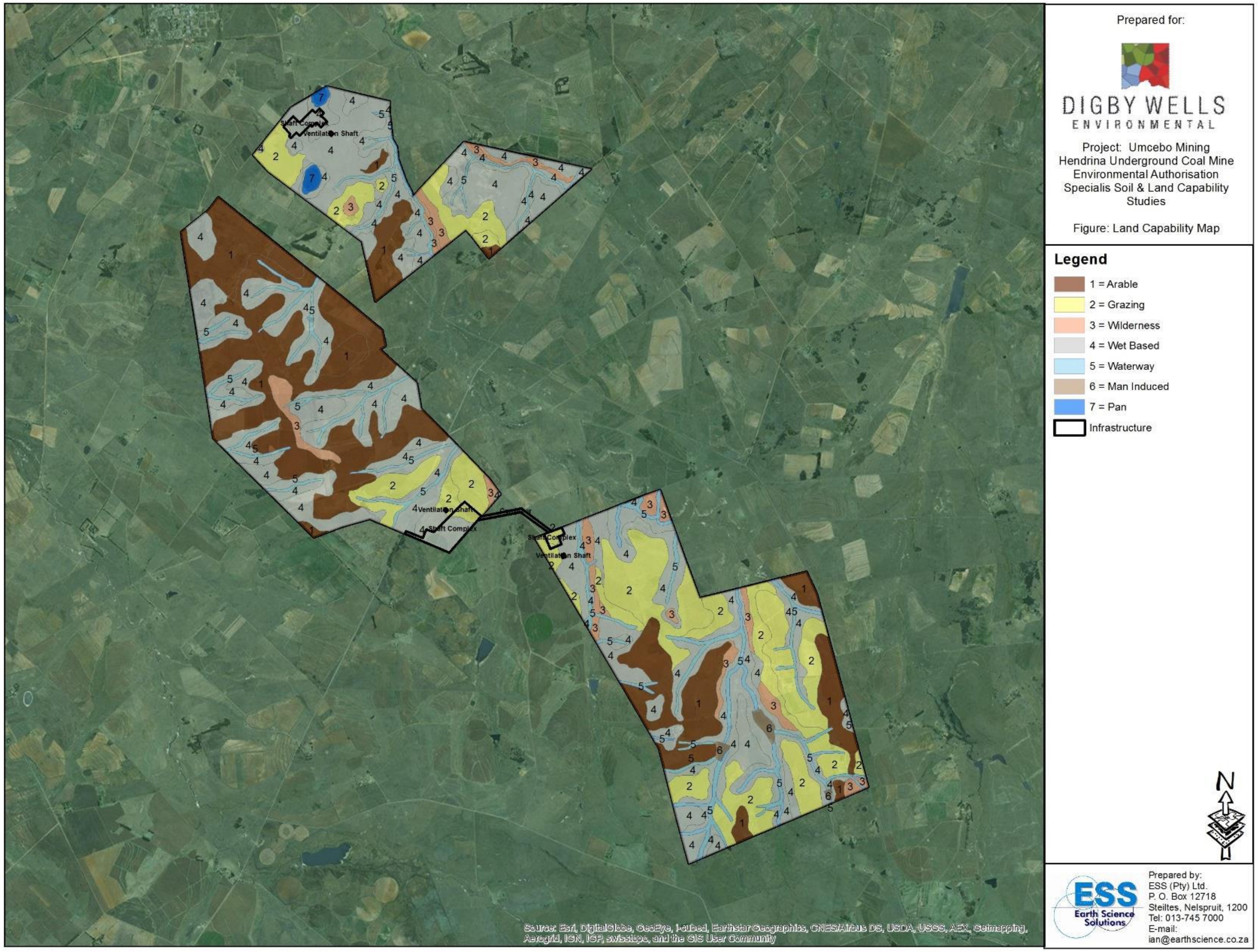


**Figure 2-2: Land Capability Plan**

# 3 ACTIVITIES BEING ASSESSED

A list of project activities to be assessed for the project has been discussed in Table 3-1

**Table 3-1: Description of Activities to be assessed**

<table>
<tr><th>Project Phase</th><th>Project Activity</th><th>Project Structures</th></tr>
<tr><td rowspan="6">Construction</td><td>Site Clearance</td><td>Topsoil Stockpiles</td></tr>
<tr><td>Blasting and Excavation</td><td>Two Shafts per mining right area</td></tr>
<tr><td>Construction of Surface Infrastructure</td><td>Crushing and Screening Plant<br>Mine Offices<br>Change House<br>Workshop<br>Overburden and Product Stockpiles<br>Site Fencing<br>Access and Service Roads (with weighbridge)<br>Overland Conveyor<br>Sewage Treatment Plant<br>Three Pollution Control Dam<br>Water Treatment Plant<br>Diesel Storage Tanks<br>Ventilation Shaft per mining right area</td></tr>
<tr><td>Water Abstraction and Use</td><td>Water Tanks and Pipes</td></tr>
<tr><td>Waste Generation and Disposal</td><td>Waste Skips</td></tr>
<tr><td>Power Generation</td><td>Diesel Generator</td></tr>
<tr><td rowspan="6">Operations</td><td>Underground Blasting and Mining</td><td>Heavy Machinery and Equipment</td></tr>
<tr><td>Stockpiling</td><td>Waste Rock Berms<br>Product Stockpile</td></tr>
<tr><td>Hauling/Conveying of Coal</td><td>Overland Conveyor Belt<br>Haul and Access Roads</td></tr>
<tr><td>Plant and Equipment Operations</td><td>Crushing and Screening Plant<br>Workshop and Diesel Storage Tanks</td></tr>
<tr><td>Water Use and Storage</td><td>Pollution Control Dam and Jo Jo Tanks</td></tr>
<tr><td>Waste Generation and Storage</td><td>Sewage Treatment Plant<br>Waste Skips</td></tr>
</table>

| Project Phase | Project Activity | Project Structures |
|---|---|---|
| | Power Generation | Diesel Generator |
| **Mine Decommissioning and Closure** | Removal of infrastructure and surface rehabilitation | Crushing and Screening Plant<br>Mine Offices<br>Change House<br>Workshop<br>Overburden and Product Stockpiles<br>Site Fencing<br>Access and Service Roads (with weighbridge)<br>Overland Conveyor<br>Sewage Treatment Plant<br>Three Pollution Control Dam<br>Water Treatment Plant<br>Diesel Storage Tanks<br>Ventilation Shaft per mining right area |
| | Waste Generation and Disposal | Waste Skips |

# 4 ENVIRONMENTAL IMPACT ASSESSMENT

The system used for the rating and ranking of impact is based on the Hacking Methodology, a system recognised and accepted by the authorities and the industry in general.

The system considers the significance of an impact in terms of its probability, duration, extent or scale and magnitude or sensitivity.

The impacts are assessed based on the impact's magnitude as well as the receiver's sensitivity, culminating in an impact significance which identifies the most important impacts that require management.

Based on international guidelines and South African legislation, the following criteria are taken into account when examining potentially significant impacts:

- Nature of impacts (direct/indirect, positive/ negative);
- Duration (short/medium/long- term, permanent(irreversible)/temporary (reversible), frequent/seldom);
- Extent (geographical area, size of affected population/habitat/species);
- Intensity (minimal, severe, replaceable/irreplaceable);
- Probability (high/medium/low probability); and
- Possibility to mitigate, avoid or offset significant adverse impacts.

The significance rating process follows the established impact/risk assessment formula:

**Significance** = Consequence x Probability x

Where

**Consequence** = Intensity + Extent + Duration

And

**Probability** = Likelihood of an impact occurring

And

**Nature** = Positive (+1) or negative (-1) impact

**Note:** In the formula for calculating consequence, the type of impact is multiplied by +1 for positive impacts and -1 for negative impacts

The matrix calculates the rating out of 147, whereby Intensity, Extent, Duration and Probability are each rated out of seven as indicated in Table 4-1. The weight assigned to the various parameters is then multiplied by +1 for positive and -1 for negative impacts.

Impacts are rated prior to mitigation and again after consideration of the mitigation measures proposed.

The significance of an impact is then determined and categorised into one of eight categories, as indicated in Table 4-2, which is extracted from Table 4-1. The description of the significance ratings is discussed in Table 4-3.

It is important to note that the pre-mitigation rating takes into consideration the activity as proposed, i.e. there may already be certain types of mitigation measures included in the design (for example due to legal requirements). If the potential impact is still considered too high, additional mitigation measures are proposed.

## Table 4-1: Impact Assessment Parameter Ratings

| RATING | INTENSITY/REPLICABILITY | | EXTENT | DURATION/REVERSIBILITY | PROBABILITY |
|---|---|---|---|---|---|
| | Negative impacts | Positive impacts | | | |
| 7 | Irreplaceable damage to highly valued items of great natural or social significance or complete breakdown of natural and / or social order. | Noticeable, on-going natural and / or social benefits which have improved the overall conditions of the baseline. | International<br>The effect will occur across international borders. | Permanent: The impact is irreversible, even with management, and will remain after the life of the project. | Definite: There are sound scientific reasons to expect that the impact will definitely occur. >80% probability. |
| 6 | Irreplaceable damage to highly valued items of natural or social significance or breakdown of natural and / or social order. | Great improvement to the overall conditions of a large percentage of the baseline. | National<br>Will affect the entire country. | Beyond project life: The impact will remain for some time after the life of the project and is potentially irreversible even with management. | Almost certain / Highly probable: It is most likely that the impact will occur. <80% probability. |
| 5 | Very serious widespread natural and / or social baseline changes. Irreparable damage to highly valued items. | On-going and widespread benefits to local communities and natural features of the landscape. | Province/ Region<br>Will affect the entire province or region. | Project Life (>15 years): The impact will cease after the operational life span of the project and can be reversed with sufficient management. | Likely: The impact may occur. <65% probability. |

| RATING | INTENSITY/REPLICABILITY | | EXTENT | DURATION/REVERSIBILITY | PROBABILITY |
|---|---|---|---|---|---|
| | Negative impacts | Positive impacts | | | |
| 4 | On-going serious natural and / or social issues. Significant changes to structures / items of natural or social significance. | Average to intense natural and / or social benefits to some elements of the baseline. | Municipal Area<br>Will affect the whole municipal area. | Long term: 6-15 years and impact can be reversed with management. | Probable: Has occurred here or elsewhere and could therefore occur. <50% probability. |
| 3 | On-going natural and / or social issues. Discernible changes to natural or social baseline. | Average, on-going positive benefits, not widespread but felt by some elements of the baseline. | Local<br>Local extending only as far as the development site area. | Medium term: 1-5 years and impact can be reversed with minimal management. | Unlikely: Has not happened yet but could happen once in the lifetime of the project, therefore there is a possibility that the impact will occur. <25% probability. |
| 2 | Minor natural and / or social impacts which are mostly replaceable. Very little change to the baseline. | Low positive impacts experience by a small percentage of the baseline. | Limited<br>Limited to the site and its immediate surroundings. | Short term: Less than 1 year and is reversible. | Rare / improbable: Conceivable, but only in extreme circumstances. The possibility of the impact materialising is very low as a result of design, historic experience or implementation of adequate mitigation measures. <10% probability. |
| 1 | Minimal natural and / or social impacts, low-level replaceable damage with no change to the baseline. | Some low-level natural and / or social benefits felt by a very small percentage of the baseline. | Very limited<br>Limited to specific isolated parts of the site. | Immediate: Less than 1 month and is completely reversible without management. | Highly unlikely / None: Expected never to happen. <1% probability. |

## Table 4-2: Probability/Consequence Matrix

| Probability | Significance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | -147 | -140 | -133 | -126 | -119 | -112 | -105 | -98 | -91 | -84 | -77 | -70 | -63 | -56 | -49 | -42 | -35 | -28 | -21 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 | 84 | 91 | 98 | 105 | 112 | 119 | 126 | 133 | 140 | 147 |
| 6 | -126 | -120 | -114 | -108 | -102 | -96 | -90 | -84 | -78 | -72 | -66 | -60 | -54 | -48 | -42 | -36 | -30 | -24 | -18 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 | 78 | 84 | 90 | 96 | 102 | 108 | 114 | 120 | 126 |
| 5 | -105 | -100 | -95 | -90 | -85 | -80 | -75 | -70 | -65 | -60 | -55 | -50 | -45 | -40 | -35 | -30 | -25 | -20 | -15 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 105 |
| 4 | -84 | -80 | -76 | -72 | -68 | -64 | -60 | -56 | -52 | -48 | -44 | -40 | -36 | -32 | -28 | -24 | -20 | -16 | -12 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 | 80 | 84 |
| 3 | -63 | -60 | -57 | -54 | -51 | -48 | -45 | -42 | -39 | -36 | -33 | -30 | -27 | -24 | -21 | -18 | -15 | -12 | -9 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 | 45 | 48 | 51 | 54 | 57 | 60 | 63 |
| 2 | -42 | -40 | -38 | -36 | -34 | -32 | -30 | -28 | -26 | -24 | -22 | -20 | -18 | -16 | -14 | -12 | -10 | -8 | -6 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 |
| 1 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |

**Consequence**

### Table 4-3: Significance Rating Description[1]

| Score | Description | Rating |
|---|---|---|
| 109 to 147 | A very beneficial impact that may be sufficient by itself to justify implementation of the project. The impact may result in permanent positive change | Major (positive) |
| 73 to 108 | A beneficial impact which may help to justify the implementation of the project. These impacts would be considered by society as constituting a major and usually a long-term positive change to the (natural and / or social) environment | Moderate (positive) |
| 36 to 72 | An positive impact. These impacts will usually result in positive medium to long-term effect on the natural and / or social environment | Minor (positive) |
| 3 to 35 | A small positive impact. The impact will result in medium to short term effects on the natural and / or social environment | Negligible (positive) |
| -3 to -35 | An acceptable negative impact for which mitigation is desirable. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in negative medium to short term effects on the natural and / or social environment | Negligible (negative) |
| -36 to -72 | A minor negative impact requires mitigation. The impact is insufficient by itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in negative medium to long-term effect on the natural and / or social environment | Minor (negative) |
| -73 to -108 | A moderate negative impact may prevent the implementation of the project. These impacts would be considered as constituting a major and usually a long-term change to the (natural and / or social) environment and result in severe changes. | Moderate (negative) |
| -109 to -147 | A major negative impact may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are immitigable and usually result in very severe effects. The impacts are likely to be irreversible and/or irreplaceable. | Major (negative) |

[1] It is generally sufficient to only monitor impacts that are rated as negligible or minor

## 4.1 Impact Assessment Rating

### 4.1.1 Construction Phase

**Issue:** **Loss of Utilisable Soil Resource due to – Erosion, Compaction and possible Contamination during construction**

The relative differences between the soils classified (structure, texture and hydromorphy), their position in the landscape and their pedogenisis (soil forming systems and characteristics – in-situ versus transported materials etc.) will have an influence on the impact significance, which in turn will have an influence on the mitigation measures that will need to be manage the impacts to a reasonable and acceptable level. The extent of impact will be confined to a relatively small spatial area (shaft area, crushing and screening plant and support infrastructure).

| **Construction for Project** |
|---|
| Stripping of utilisable soil, preparation (levelling and compaction) of lay-down areas and pad footprint for stockpiling and stormwater berms, opening up of foundations, mining voids (shafts), stockpiling of soft overburden, and slope stability where required. Haulage and access road construction and stockpiling of utilisable soils.<br>Control of dust and loss of materials to wind and water erosion, and protection of materials from contamination (chemical, hydrocarbons and sewage). |

The construction phase will impact on all of the infrastructural activities and areas of disturbance on surface, inclusive of:

- The construction/preparation of the footprint for the overall lay down of the materials stockpiles (removal of vegetation and utilisable soil (A Horizon and portion of B2/1 horizon);
- Stockpiling of the utilisable soils needed to secure a viable cover for the areas to be rehabilitated at decommissioning and closure;
- The opening up of the shafts to the underground workings, and the raise boring for the ventilation shafts for the underground sections;
- The construction of the starter walls for the storm water control dams;
- Construction of pipelines for water reticulation;
- Construction of access and haulage roads;
- Conveyer routes;
- Stockpiling of the soils and overburden (softs and cover material) from construction footprints;

- Design and construction of dirty water control dams, channels and berms (storm water control facilities) to cater for all dirty water and diversion of clean water around the facility;
- Design and construction of site offices and related infrastructure (workshops, change house etc.), and
- Clearing and removal of vegetation and the stockpiling of the utilisable soil prior to the lay down of soft overburden materials from the shafts and deep excavations.

Soils will need to be stockpiled in different locations throughout the construction and operational phases, with the materials stripped from the areas of infrastructure, roads and pad footprint construction being best stockpiled as close as possible to these features in the form of berms upslope of the facilities, and the shaft complex soils being stored as low level dumps and/or berms close to the voids to which they are planned to be used.

#### *4.1.1.1 Description of Impacts*

The loss of the soil resource to the overall environment due to stripping of footprint areas to mining infrastructure, construction of the water management facilities, crushing and screening plants, the conveyencing system and support infrastructure (Workshops, Offices etc) will definitely occur and be of significance for the life of mine and restricted to the immediate mining area. The overall loss of the soil resource to the environment if un-mitigated will result in a Moderate Significant Rating.

Disturbance of the surface restrictive layers associated with the relatively more sensitive soils (Ferricrete and soft plinthic layers) will occur for all founding areas, and particularly those associated with the relict land forms that occupy the upper portions of the transition zone/moist grasslands that are going to be affected in some cases by the surface infrastructure and mine entrance, while the deeper foundations required for the heavier structures (Plant, PCD etc.) requiring that the underlying restrictive layers (inhibiting barrier layer) is broken through.

The majority of the infrastructure, and all of the proposed structures associated with the mining development are outside of the alluvial/riverine environment and are for the most part associated with the moderately shallow to shallow soils of the sedimentary host rock, with only small areas of transitional zone soil forms affected.

The variation in soil sensitivity is marked, with the dry friable sandy loams and silty loams being far easier to manage than the hydromorphic soils that comprise the transition zone upslope of the wetlands.

The impact of removing the topsoil's and upper portion of the subsoil horizon (Utilisable soil) will destroy any surface capping that might be in place, will remove all vegetative cover, and will expose the subsoil's to wind and water affects and induce possible erosion and compaction if not well managed and protected.

The sensitive and highly sensitive soils (friable soils) will be susceptible to erosion and compaction once disturbed, and will be difficult to manage, or lost if left unprotected.

It must be emphasised, that the failure to manage the soils will result in the total loss of this resource, with a resultant moderate to major significance.

#### *4.1.1.2 Mitigation/Management Actions*

With management, the loss of this primary resource can be reduced and mitigated to a level that is more acceptable.

The impacts on the soils may be mitigated with a number of management procedures, including:

- Effective soil stripping during the dryer and less windy months when the soils are less susceptible to erosion and compaction. This will assist the stockpiling and vegetative cover to propagate before the following wet season;
- Effective cladding of any stockpiles, dumps and berms, and the minimising of the height of all stockpiles wherever possible will help to reduce wind erosion and the loss of materials;
- Soil replacement to all areas (temporary) that are not required for the operational phase, and the preparation of a seed bed to facilitate the re-vegetation program for these areas will limit potential erodibility during the operational phase and into the rehabilitation and closure phases;
- Soil amelioration (cultivation) to enhance the growing capability of the stockpiled soils so that they can be used for rehabilitation at closure and to maintain the soils viability during storage;
- Backfilling of any voids and deep excavations with rock, soft overburden, and the creation through compaction of a barrier layer at the soil backfill interface using the relatively more impermeable clay rich subsoil and soft overburden. This is recommended as the ferricrete layer and any hard impermeable sedimentary layers will have been destroyed and will not be available to re-create this barrier;
- Replacement of the growing medium (Utilisable soil) in the correct order and as close as possible to its original position in the topography will help to maintain the soil pedogenisis and utilisation potential relative to the ecology and biological constraints; and
- Soil replacement and the preparation of a seed bed to facilitate the re-vegetation program and to limit potential erodibility during the rehabilitation process.

Care will need to be taken to keep any wet based soils separated from the dry soils, and to keep all stockpiled soils that are in storage vegetated and protected from contamination and erosion.

These soils will be stripped as “Utilisable Soil” stored in a position that will be convenient for the final rehabilitation of the facilities during the decommissioning and closure phases – reduce distances to be hauled and negate the need for double handling.

Only if these materials are available can rehabilitation possibly be executed successfully. It is suggested that an average "Utilizable Soil Depth" (USD) of 500 mm be stockpiled where present/available.

#### *4.1.1.3 Residual Impact*

The above management procedures will probably reduce the significance of the impacts to negligible in the long term.

**Table 4-4: Construction Phase – Impact Significance**

| Dimension | Rating | Motivation | Significance |
|---|---|---|---|
| **Description of Impact:** Loss of utilisable soil as a resource through sterilisation, compaction, erosion, and salinisation/contamination | | | |
| ***Prior to mitigation/ management*** | | | |
| **Duration** | Project Life (5) | Utilisable soil will be stripped and stockpiled. If this is done without following the mitigation measures the impact will have a long term affect. | Moderate (negative) – 84 |
| **Extent** | Local (3) | Loss of soil will only occur within and immediately around the Project site. | |
| **Intensity** | Medium (4) | Loss of soil may result in loss of land capability and land use. Soil regeneration takes a very long time. | |
| **Probability** | Certain (7) | By excavating the soil it will certainly impact on the soil. | |
| ***Mitigation/ Management actions*** | | | |
| • Soils are to be stripped as per the stripping guidelines (contained within the soil utilisation and management section of this report) and erosion of stockpiles should be minimized by establishing vegetation on the stockpiles.<br>• Compaction should be avoided. | | | |
| ***Post- mitigation*** | | | |
| **Duration** | Project Life (5) | Loss of utilisable soil makes land less productive. Effects will occur long after the project life. | Minor (negative) – 54 |
| **Extent** | Very Limited (1) | Loss of topsoil will only occur within and immediately around the Project infrastructure area. | |
| **Intensity** | Moderate (3) | Loss of topsoil may result in loss of land capability and land use. | |
| **Probability** | Highly Probable (6) | If the mitigation is followed then it is unlikely that the impacts will occur. | |

### 4.1.2 Operational Phase

**Issue: Loss of Soil Usability/Utilisation Potential**

| **Operation of Project – Cumulative** |
|---|
| Loss of soil utilisation – Shaft complex, surface collapse and ponding of water due to underground subsidence, raw materials conveyencing and the possible contamination by spillage and dirty water interaction, dust and/or hydrocarbon spillage, loss of resource/sterilisation due to covering of the soils by infrastructure, by-product stockpiles, storage facilities and dumps, compaction by vehicle movement, and erosion and loss of materials due to wind and water interaction with unprotected soils. |

#### *4.1.2.1 Description of Impacts*

During the operational phase, all of the construction activities for the infrastructure and major by-product storage structures will have been completed, the crushing and sizing of materials and the deposition of by-product will have begun along with the continuous opening up of additional mining areas (underground 30 m to 120 m deep).

The loss of the soil utilisation due to surface collapse, ponding and/or the covering of materials for extended periods of time will lead to both the loss of the utilisable resource as well as salinisation, compaction and sterilisation. If this occurs it will result in a major negative impact that will last for the duration of the mine activities. The consequence is major with an overall significance of minor.

The movement of vehicles, the conveyencing of the raw product, the use of access roads and the on-going additions of by-product to the stockpiles and storage facilities will all impact on the size of area being affected, and ultimately on the area of soil affected.

Un-managed soil stockpiles and soil that is left uncovered/not vegetated will be lost to water and wind erosion, and will be prone to compaction.

All of these soils will be impacted upon to differing degrees, while the stockpiled materials will be available for future use during the rehabilitation phase and at closure.

The significance of the impact during the operational phase will differ both in intensity and duration, with the soils associated with the shaft complex, infrastructure and stormwater management remaining in a stockpile/stored state for the full life of the mining and processing operations.

It is inevitable that the soils utilisation potential will be lost during the operational phase, and possibly for ever if they are not well managed and a mitigation plan is not implemented.

#### *4.1.2.2 Mitigation/Management Action*

The impacts on the stockpiled and stored soils may be mitigated with management procedures including:

- Minimisation of disturbed areas;
- Timorous replacement of the soils so as to minimise the area of disturbance (concurrent rehabilitation where possible);
- Adequate protection from erosion (wind and water);
- Effective vegetative and soil cover and protection from wind (dust) and dirty water contamination;
- Servicing of all vehicles on a regular basis and in well-constructed and bunded areas, well-constructed and maintained oil traps and dirty water collection systems;
- Cleaning of all roadways and haulage/conveyencing ways, drains and storm water control facilities;
- Containment and management of spillage;
- Soil replacement and the preparation of a seed bed to facilitate and accelerate the re-vegetation program and to limit potential erosion; and
- Soil amelioration to enhance the growth capability of the soils and sustain the soils ability to retain oxygen and nutrients, thus sustaining vegetative material during the storage stage.

Of consequence during the operational phase will be the minimising of the area that is being impacted by the operation and its related support structures and activities, and maintenance of the integrity of the stored soils. This will require that the soils are kept free of contamination (dust and dirty water), and stabilised and protected from erosion and compaction. The action of wind on dust generated and the loss of materials downwind will need to be considered, while contamination of the soils used on the roads and workshop areas will need to be managed.

If the soils are stripped to a “utilisable” depth, and replaced in the correct sequence and as close as possible to their original position in the topography, the chances of nature being able to restore the systems present prior to disturbance will be more easily achieved.

#### *4.1.2.3 Residual Impact*

In the long term, the above mitigation measures will probably reduce the impact on the utilisable soil reserves from a minor significance rating to one of negligible significance.

## Table 4-5: Operational Phase – Impact Significance

| Dimension | Rating | Motivation | Significance |
|---|---|---|---|
| **Description of Impact:** The operation and maintenance of the utilisable soil and stockpiles will require the minimisation of compaction and erosion and the on-going management of contamination. | | | |
| ***Prior to mitigation/ management*** | | | |
| Duration | Project Life (6) | When the soil has eroded the impact will be permanent and is potentially irreversible even with management. | Minor (negative) – 52 |
| Extent | Limited (2) | Compaction and erosion will occur on a limited scale and in the unmitigated situation the erosion will extend beyond the direct infrastructure. | |
| Intensity | Very Serious (5) | Loss of soil may result in loss of land capability and land use. Soil regeneration takes a very long time. | |
| Probability | Probable (4) | The maintenance of all vehicles will be confined to the workshop area. | |
| Nature | Negative | | |
| ***Mitigation/ Management actions*** | | | |
| • Maintenance on the soil stockpiles must be done regularly to check for compaction and erosion. Where prevalent corrective measures must be taken so as to minimise the loss of utilisable soil as a resource and minimise the effects of sedimentation on the receiving water bodies. These would include keeping a soil balance, inspection for erosion and loss of soil, fertility of stockpiles and vegetation establishment on these stockpiles. | | | |
| ***Post- mitigation*** | | | |
| Duration | Short term (2) | If the mitigation measures are implemented the impact will be for less than a year. | Negligible (negative) – 18 |
| Extent | Very limited (1) | Compaction and erosion will occur on a very limited scale. | |
| Intensity | Moderate (3) | The intensity of the impact will be reduced if mitigation is implemented. | |
| Probability | Unlikely (3) | If mitigation is followed the impact will rarely occur | |
| Nature | Negative | | |

### 4.1.3 Decommissioning & Closure Phase

**Issue: Net loss of soil potential due to change in materials (Physical and Chemical) and loss of nutrient base.**

| **Decommissioning and Closure – Cumulative** |
| --- |
| Loss of the soils original nutrient store by leaching, erosion and de-oxygenation while stockpiled. Impact of vehicle movement, dust contamination and erosion during soil replacement and demolishing of infrastructure, slope stabilisation and re-vegetation of disturbed areas. Possible contamination by dirty water interaction (use of mine water for irrigation of re-vegetation), dust and/or hydrocarbon spillage from vehicles. Positive impacts of reduction in areas of disturbance and return of soil utilisation potential, uncovering of areas of storage and rehabilitation of compacted materials. |

#### *4.1.3.1 Description of Impact*

The impact will remain the net loss of the soil resource if no intervention or mitigating strategy is implemented. The impact will be of a negative intensity, local extent, permanent over the area of disturbance, with a moderate consequence and resultant minor significance rating. Un-managed closure will result in a long term depletion of soil utilisation potential.

#### *4.1.3.2 Management/Mitigation Actions*

Ongoing rehabilitation during the decommissioning phase of the project will bring about a net long-term positive impact on the soils.

The initial impact will be negative due to the necessity for vehicle movement while rehabilitating the open voids, moving of softs and soils, the demolishing of storm water controls, dams etc and the demolishing of buildings and infrastructure. Dust will be generated and soil will be contaminated and eroded.

The positive impacts of rehabilitating an area are the reduction in the area previously disturbed, the amelioration of the affected soils and oxygenation of the growing medium, the stabilising of slopes and revegetation of areas decommissioned with a reduction in areas previously subjected to wind or water erosion.

#### *4.1.3.3 Residual Impacts*

On mine closure the long-term negative impact on the soils will probably be of a minor to negligible significance if the management plan set out in Environmental Plan is effectively implemented to reinstate current soil conditions.

Chemical amelioration of the soils will possibly have a low but positive impact on the nutrient status (only) of the soils in the medium term.

### Table 4-6: Decommissioning Phase – Impact Significance

| Dimension | Rating | Motivation | Significance |
|---|---|---|---|
| **Description of Impact:** Decommissioning and rehabilitation phase of the project could cause compaction and erosion if rehabilitation is not done correctly. This could be as a result of poor vegetation establishment which would result in exposed surfaces and increase the risk of erosion. Heavy machinery driving continuously over rehabilitated areas may result in compaction, which would impact on plant rooting depth which then would have a further impact to vegetation establishment. | | | |
| ***Prior to mitigation/ management*** | | | |
| Duration | Project Life (6) | When the soil has eroded the impact will be permanent and is potentially irreversible even with management. | Minor (negative) – 39 |
| Extent | Limited (2) | Compaction and erosion will occur on a limited scale and in the unmitigated situation the erosion will extend beyond the direct infrastructure. | |
| Intensity | Very Serious (5) | Loss of topsoil may result in loss of land capability and land use. Soil regeneration takes a very long time. | |
| Probability | Unlikely (3) | Vehicles will remain on existing access routes | |
| Nature | Negative | | |
| ***Mitigation/ Management actions*** | | | |
| • Rehabilitate according to the approved rehabilitation plan. | | | |
| ***Post- mitigation*** | | | |
| Duration | Short term (2) | If the mitigation measures are implemented the impact will be for less than a year. | Negligible (negative) – 12 |
| Extent | Very limited (1) | Compaction and erosion will occur on a very limited scale. | |
| Intensity | Moderate (3) | The intensity of the impact will be reduced if mitigation is implemented. | |
| Probability | Rare (2) | If mitigation is followed the impact will rarely occur | |

## 4.2 Cumulative Impacts

One of the negative impacts associated with long term development is the disturbance of the soil environment, the naturally occurring layers of decomposed rock and accumulations of eroded materials as soil horizons.

Rehabilitation of disturbed areas aims to restore land capability to as close as possible its original state. Experience has however shown that the post development land capability is often of a lesser utilisable rating and compromises the end land us potential. The primary reason for this is poor management.

Soil formation is determined by a combination of naturally occurring geomorphological processes and actions. These include factors such as time, climate, slope, presence or lack of organisms and the type of parent material.

Soil formation is generally quite slow (geological time) rendering soil a non-renewable resource.

Soil quality deteriorates during storage and stockpiling, with nutrient and carbon loss due to leaching and the sterilisation of the resource by de-nitrification. Replacement of these soil materials into soil profiles during rehabilitation cannot replicate pre-construction conditions with the effective loss being of a financial consequence to the project if not well managed.

Depth however can be replicated if sufficient soil is tripped at the construction phase and it is retained and managed against erosion.

The resultant net loss of land capability due to these changes will forces a change in land use.

The loss of this natural resource is considered high and negative, with the loss of Eco System Services being detrimental to the long term sustainability of both the physical and socio economic environments.

The utilisable soil is considered the upper portion of the vadose zone, and comprises the materials which naturally holds water, are able to liberate nutrients and contain the major rooting system for plants. These layers comprise the conventional topsoil or “A” horizon and a significant portion of the upper portion of the subsoil “B2/1” horizon. This is the layer that needs to be stripped, stored and well managed throughout the project if any meaningful rehabilitation is to be considered at closure.

# 5 ENVIRONMENTAL MANAGEMENT PLAN

Based on the studies undertaken, and with the development plan made available, it has been possible to assess the impacts that the proposed mining and beneficiation could potentially have on the soils and their resultant utilisation potential, and has aided in the development of a meaningful soil utilisation and management plan for the development.

The management and mitigation measures proposed have been tabled (Refer to Table 5-1, Table 5-2 and Table 5-3 respectively) for the different stages of the project in line with the system used to assess and rate the impacts, and gives recommendations on the soil utilisation (stripping and handling of the soils) during the construction and operational phases, and details the systems and actions for the rehabilitation and ultimate closure of the facility as part of the "End Use" planning.

It is important that a management plan is implemented if the economics of mine closure are to be met, and the relative positioning and timings of materials handling are to be aligned with the mining plan. Table 5-4 to Table 5-6 summaries the proposed management objectives and activities and lists the designated department and personnel responsible for their implementation.

The management planning is considered from the stand-point of "No Net Loss" (NNL), a concept that is admittedly difficult to achieve when dealing with the soils and vadose zone and mining, but a premise none the less that sets the goals at a level of sustainability that meets with best practice guidelines and international standards. This concept (NNL) will be tested by both the development on surface as well as by the activities associated with the underground mining (surface subsidence due to collapse of underground workings).

For the management plan to succeed it will be essential that sufficient "utilisable" soil material is removed and saved/stored from the footprint of development prior to any construction taking place.

All materials/soils that are going to be impacted by the mining and/or its associated activities will require that the utilisable soil (top 500 mm to 700 mm) are stripped and stored ready for re-emplacement and rehabilitation at closure

## 5.1 Construction Phase

### 5.1.1 Soil Stripping and Handling

In considering any management plan for soils it is important that both the physical and chemical composition are known as these will be important in obtaining a utilisable material at decommissioning and/or during rehabilitation. The method of stockpiling and general handling of the soil will vary depending on its composition.

The relatively more sandy topsoil's (low clay contents) along with the upper portion of the subsoil's (B2/1 Horizon) within which the majority of the nutrient store occurs **(Utilisable Soil)** will need be stripped and stockpiled ready for use at closure.

**The concept of stripping and storage of all UTILISABLE soil is tabled as a minimum requirement and as part of the overall Soil Utilisation Guidelines.**

In terms of the "Minimum Requirements", usable soil is defined here as ALL soil above an agreed subterranean cut-off depth defined by the project soil scientist, depths that will vary for different types of soil encountered as well as for the different activities that being planned in a project area. It does not differentiate between topsoil (orthic horizon) and other subsoil horizons.

Soil stripping requirements are set to enable the mining company to achieve post mining land capabilities wherever possible, and are based on the pre-mining land capability assessment as detailed in the baseline study. Pre-mining grazing land capability is the norm that is aimed for in most situations post mining in this area. However, in this sensitive environment, although a low intensity grazing land status is tabled as the minimum requirement, it is likely that moderate grazing could be achieved with the possibility of economic crop production if the rehabilitation plan is well managed and implemented.

The following requirements should be considered wherever possible:

- Over areas of DEEP EXCAVATION *strip all usable soil* as defined (700 mm). Stockpile alluvial/colluvial (transported wet based) soils separately from the *in-situ* materials, which in turn should be stored separately from the underlying overburden. Store the soils in berms or stockpile dumps of no more than 1,5m high if space allows.
- At *rehabilitation* replace soil to appropriate soil depths in the correct order, and cover areas to achieve an appropriate topographic aspect and attitude so as to achieve a free draining landscape that is as close as possible the pre-mining land capability rating.
- Over area of STRUCTURES (Offices, Workshops, Haul Roads) AND SOFT OVERBURDEN STOCKPILES *strip the top 300 mm* of usable soil over all affected areas including terraces and *strip remaining usable soil* where founding conditions require further soil removal. Store the soil in stockpiles of not more than 3 m around infrastructure area for closure rehabilitation purposes. Stockpile hydromorphic soils separately from the dry materials. At *rehabilitation* strip all gravel and other large material and place to form terraces or recycle as construction material or place in open voids below the soft overburden of soil horizon. Remove foundations to a maximum depth of 1m. Replace soil to appropriate soil depths, and cover areas in appropriate topographic position to achieve pre-mining land capability and a free draining land form.
- Over area of CONSTRUCTION OF STORAGE FACILITIES AND HARD OVERBURDEN STOCKPILES *strip usable soil* to a *depth of 700 mm* in areas of *arable soils* and *between 300 mm and 500 mm* in areas of *soils with grazing land capability.* Stockpile hydromorphic soils separately from the dry and friable materials. *For rehabilitation* strip all gravel and other material places to form terraces and recycle as construction material or place in open voids. Remove foundations to a maximum depth of 1m. Replace soil to appropriate soil depths, and over areas and in appropriate topographic position to achieve pre-mining land capability.
- Over area of ACCESS ROADS, LAY-DOWN PADS AND CONVEYOR SERVITUDES *strip the top 150 mm* of usable soil over all affected areas and stockpile in longitudinal stockpile within the mining lease area.

In general, the depth of the topsoil's material for the site is between 450 mm and 800 mm. However, due to the shallow soil depths on the more rocky slopes, and the need to rehabilitate these areas with sufficient materials to induce growth at closure, it is recommended that a minimum of 500mm is stripped and stockpiled from all areas where it is available.

The positioning of these storage facilities will need to be assessed on the basis of the cost of double handling, distances to the point of rehabilitation need, and the potential for use of the materials as storm-water management facilities (berms). Suggestions include the use of materials in positions upslope of the mining infrastructure and any/all areas as clean water diversion berms, and/or as stockpiles close to, but outside of the final voids that are to be created by the mining operations.

Soils removed from areas that require deep foundations, dam footprints, lay-down pads for by-product facilities and the processing facility, all access and haulage roads and their associated support infrastructure must be stockpiled as close as possible to the facilities as is possible without the topsoil's becoming contaminated or impacted by the operations.

The vegetated soils should be stripped and stockpiled without the vegetation having been cleared/stripped off wherever practical, while any grassland/natural veld that has not been cultivated or disturbed should be fertilized with super phosphate prior to being stripped (wherever practical). This will ensure that the fertilizer is well mixed into the soil during the stripping operation and will aid in a more rapid cover to the stockpiles, while reducing the amount of fertilizer required during the rehabilitation program. All utilisation of the land for any other purpose will need to stop before mining begins.

The lower portions of the subsoil's (>500 mm) and the soft overburden material (where removed) can be stored as separate stockpiles close to the areas where they will be required for backfilling and final rehabilitation.

The base to all of the proposed structures to be constructed should be founded on stabilised materials, the soils having been stripped to below the topsoil contact (200mm to 300mm) and or to 500mm as the depth of utilisable soil might dictate.

It is proposed that prior to soil stripping, an appropriate (to be determined by local experts) fertilizer (super phosphate) should be added to the sandy loams and silty clay loams at a rate of about 200 kg/ha if they have not previously been fertilized. This will help to enhance the seed pool and encourage growth within the stored materials.

The stripping and handling of materials during the construction phase or while opening up of the shafts and decline roadways to the underground workings is highlighted, because the correct removal, storage and reinstatement of the materials will have a significant effect on the costs and the final success or failure of the rehabilitation plan at closure.

Of importance to the success and long term sustainability of rehabilitating these sensitive environments will be the replacement of the materials in their correct order and topographic position, and the ability of the rehabilitation team to re-create the soil profile and landscape so that soil water is retained and surface water does not pond.

This will be no mean feat, as the natural materials that are achieving this function at present (pre-mining and development) will have been disturbed or destroyed.

Long term and forward planning for the utilisation of the materials to their best advantage and the understanding of the final “End Land Use” will need to be well understood if the optimum utilisation of the materials is to be achieved. Please refer to the recommendations of materials replacement under the decommissioning and closure plan section.

The consequences of not achieving these goals will need to be assessed and quantified in terms of the long term ecological impacts and biodiversity loss, and will require the input of the specialist ecologists, wetland scientist, hydrogeologists and engineers in the final formulation of the overall management plan. Table 5-1 is a summary of the soil handling and management plan for the construction phase.

**Table 5-1: Construction Phase – Soil Conservation Plan**

| Phase | Step | Factors to Consider | Comments |
|---|---|---|---|
| Construction | Delineation of areas to be stripped | | Stripping will only occur where soils are to be disturbed by activities that are described in the design report, and where a clearly defined end rehabilitation use for the stripped soil has been identified. |
| | Reference to biodiversity action plan | | It is recommened that all vegetation is stripped and stored as part of the utilizable soil. However, the requirements for moving and preserving fauna and flora according to the biodiversity action plan should be consulted. |
| | Stripping and Handling of soils | Handling | Soils will be handled in dry weather conditions so as to cause as little compaction as possible. Utilizable soil (Topsoil and upper portion of subsoil B2/1) must be handled and stockpiled separately from the lower "B" horizon and all softs (decomposed rock). |
| | | Stripping | mThe "Utilizable" soil will be stripped to a depth of 500cm to 700mm or until hard rock is encountered. These soils will be stockpiled together with any vegetation cover present (only large bushes to be removed prior to stripping). The total stripped depth should be at least 500mm, wherever possible. |
| | Delineation of Stockpiling areas | Location | Stockpiling areas will be identified in close proximity to the source of the soil to limit handling and to promote reuse of soils in the correct areas. |
| | | Designation of Areas | Soils stockpiles will be demarcated, and clearly marked to identify both the soil type and the intended area of rehabilitation. |

## 5.2 Operational Phase

### 5.2.1 Soil Stockpiling and Storage

Based on the findings of the baseline studies the sensitivity of the soil materials has been evaluated and site specific recommendations are made that are relevant to the unique conditions that pertain to this Highveld environment.

It is proposed that the construction of any berms needed and soil storage stockpiles are limited to a height of 3 m. For soils that are to be stored for any length of time (greater than three years) it is recommended that all utilisable soil should be stockpiled, while the heavier subsoil’s and any ferricrete/calcrete (evaporite) materials should be stored as separate stockpiles. Storing the soil in this manner will maximize the beneficial properties of each material, and render them available for use at closure in the best position. Separation of these layers at the time of utilising these soils is a matter for management, as the mixing and dilution of the soil properties is not recommended.

The utilisable soil stockpiled must be adequately vegetated as soon after emplacement on the storage pads as possible and maintained throughout the life of mining.

It is important, where possible, that the slopes of the stockpile berm facility are constructed to 1:6 or shallower. This will minimize the chances of erosion of the soils and will enhance the growth of vegetation. However, prior to the establishment of vegetation, it is recommended that erosion control measures, such as the planting of Vetiver Grass hedges, or the construction of benches and cut-off drains be included in the stockpile/berm design. These actions will limit the potential for uncontrolled run-off and the subsequent erosion of the unconsolidated soils, while the vegetation is establishing itself, and throughout the life of the mining operation. Vetiver is a recognised and certified natural grass specie in South Africa, and after many years of trials and testing has been given a positive record of decision as a non-invasive material that can be used as a hedging grass in the development of erosion control. The advantages to the use of Vetiver and Couch Grass, are documented in the attached brochure (Refer Appendix 3 - The Vetiver Network International - www.vetiver.org).

Erosion and compaction of the disturbed soils and the management of the stored or stockpiled materials are the main issues that will need to be managed on these sensitive soil forms. This is due to the sensitivity of the soils to mechanical disturbances during/after the removal of surface vegetation and the difficulties in replacing the disturbed materials.

Working with or on the differing soil materials (all of which occur within the areas that are to be disturbed) will require better than average management and careful planning if rehabilitation is to be successful. Care in removal and stockpiling or storage of the “Utilisable” soils, and protection of materials which are derived from the “hardpan ferricrete” layer is imperative to the success of sustainable rehabilitation in these areas. The sensitivity of the soils is a factor to be considered during the rehabilitation process (Refer to section on Soil Handling and Removal – Construction Phase (5.1) and Mitigation and Management Measures – Decommissioning and Closure Section (5.3)).

Table 5-2 summaries the management and handling of the soils during the operational phase of the mining project.

**Table 5-2: Operational Phase – Soil Conservation Plan**

| Phase | Step | Factors to Consider | Comments |
|---|---|---|---|
| Operation | Stockpile management | Vegetation establishment and erosion control | Rapid growth of vegetation on the Soil Stockpiles will be promoted (e.g. by means of watering or fertilisation). The purpose of this exercise will be to protect the soils and combat erosion by water and wind. |
| | | Storm Water Control | Stockpiles will be established with storm water diversion berms to prevent run off erosion. |
| | | Stockpile Height and Slope Stability | Soil stockpile heights will be restricted where possible to <1.5m so as to avoid compaction and damage to the soil seed pool. Where stockpiles higher than 1.5m cannot be avoided, these will be benched to a maximum height of 15m. Each bench should ideally be 1.5m high and 2m wide. For storage periods greater than 3 years, vegetative cover is essential, and should be encouraged using fertilization and induced seeding with water. The stockpile side slopes should be stabilized at a slope of 1 in 6. This will promote vegetation growth and reduce run-off related erosion. |
| | | Waste | No waste material will be placed on the soil stockpiles. |
| | | Vehicles | Equipment movement on to of the soil stockpiles will be limited to avoid topsoil compaction and subsequent damage to the soils and seedbank. |

## 5.3 Decommissioning and Closure

### 5.3.1 Soil Replacement and Land Preparation

During the decommissioning and closure phase of any mining project there will a number of actions being undertaken or completed. The removal of all infrastructure and the demolishing of concrete slabs, the backfilling of open voids and the compaction of the barrier layer, and the topdressing of the disturbed and backfilled areas with utilizable soil ready for re-vegetation are all considered part of a successful closure operation.

The order of replacement, fertilisation and stabilisation of the backfilled materials and final cover materials (soil and vegetation) are all important to the success of the decommissioning plan and final closure.

There will be a positive impact on the environment in general and on the soils in particular as the area of disturbance is reduced, and the soils are returned to a state that can support low to moderate intensity grazing or sustainable agriculture.

*Fertilizers and Soil Amendments*

For any successful soil amelioration and resultant successful vegetative cover, it is necessary to distinguish between the initial application of fertilizers or soil amendments and maintenance dressings. Basal or initial applications are required to correct disorders that might be present in the in-situ material and raise the fertility status of the soil to a suitable level prior to seeding. The initial application of fertilizer and lime to the disturbed soils is necessary to establish a healthy plant cover as soon as possible. This will prevent erosion. Maintenance dressings are applied for the purpose of keeping up nutrient levels. These applications will be undertaken only if required, and only after additional sample analysis has been undertaken.

Fertilizer requirements reported herein are based on the sampling of the soils at the time of the baseline survey and will definitely alter during the storage stage.

The quantities of additives required at any given time during the storage phase or after rehabilitation has been established will potentially change due to physical and chemical processes. The fertilizer requirements should thus be re-evaluated at the time of rehabilitation.

It is recommended that a qualified person (agronomist or plant ecologist) be employed to establish the possible need or not for lime, organic matter and fertilizer requirements that will be applied, prior to the starting of the rehabilitation process.

It will be necessary to re-evaluate the nutrient status of the soils at regular intervals to determine the possibility of needing additional fertilizer applications. In addition, it is important that only small amounts of fertilizer are added on a more frequent basis, rather than adding large quantities in one application.

Table 5-3 summaries the management and handling of the soil resource during the decommissioning and closure phase.

**Table 5-3: Decommissioning and Closure Phase – Soil Conservation Plan**

| Phase | Step | Factors to Consider | Comments |
|---|---|---|---|
| Decommissioning & Closure | Rehabilitation of Disturbed land & Restoration of Soil Utilization | Placement of Soils | Stockpiled soil will be used to rehabilitate disturbed sites either ongoing as disturbed areas become available for rehabilitation and/or at closure. The utilizable soil (500mm) removed during the construction phase or while opening up of open cast workings, shall be redistributed in a manner that achieves an approximate uniform stable thickness consistent with the approved postmining land use (Low intensity grazing), and will attain a free draining surface profile. A minimum layer of 300mm of soil will be replaced. |
| | | Fertilization | A representative sampling of the stripped soils will be analysed to determine the nutrient status of the utilizable materials. As a minimum the following elements will be tested for: EC, CEC, pH, Ca, Mg, K, Na, P, Zn, Clay% and Organic Carbon. These elements provide the basis for determining the fertility of soil. based on the analysis, fertilisers will be applied if necessary. |
| | | Erosion Control | Erosion control measures will be implemented to ensure that the soil is not washed away and that erosion gulleys do not develop prior to vegetation establishment. |
| | Pollution of Soils | In-situ Remediation | If soil (whether stockpiled or in its undisturbed natural state) is polluted, the first management priority is to treat the pollution by means of in situ bioremediation. The acceptability of this option must be verified by an appropriate soils expert and by DWA, on a case by case basis, before it is implemented. |
| | | Off site disposal of soils. | If in situ treatment is not possible or acceptable then the polluted soil must be classified according to the Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste (DWAF 1998) and disposed at an appropriate, permitted, off-site waste facility. |

The following maintenance is recommended:

- The area must be fenced, and all animals kept off the area until the vegetation is self-sustaining;
- Newly seeded/planted areas must be protected against compaction and erosion;
- Traffic should be limited were possible while the vegetation is establishing itself;
- Plants should be watered and weeded as required on a regular and managed basis;
- Check for pests and diseases at least once every two weeks and treat if necessary;
- Replace unhealthy or dead plant material;
- Fertilise, hydro seeded and grassed areas 4-6 weeks after germination, and
- Repair any damage caused by erosion.

**Table 5-4: Impacts and Mitigation Measures**

| Activities | Phase | Size and scale of disturbance | Mitigation Measures | Compliance with standards | Time period for implementation |
|---|---|---|---|---|---|
| Site clearance and topsoil removal prior to the commencement of physical construction activities. | Construction | Shaft Complex Footprint(s), Conveyer Servitude and associated Support Infrastructure Footprint | • Ensure proper storm water management designs are in place;<br>• If any erosion occurs, corrective actions (erosion berms) must be taken to minimize any further erosion from taking place;<br>• If erosion has occurred, soil should be sourced and replaced and the area shaped and protected to reduce the recurrence of erosion;<br>• Only the designated access routes are to be used so as to reduce any unnecessary compaction;<br>• Compacted areas are to be ripped to loosen the soil structure;<br>• The utilisable soil should be stripped by means of an excavator bucket, and loaded onto dump trucks;<br>• Soil stockpiles are to be kept to a maximum height of 3 m where possible;<br>• Soil is to be stripped when the soil is dry, so as to reduce compaction;<br>• Bush clearing contractors will only clear bushes and trees larger than 1 m the remaining vegetation will be stripped with the utilisable soil to conserve as much of the nutrient cycle, organic matter and seed bank as possible;<br>• The handling of the stripped soil will be minimized to ensure the soil’s structure does not deteriorate significantly;<br>• Compaction of the removed soil must be avoided by restricting traffic on stockpiles;<br>• Stockpiles should only be used for their designated final purposes; and<br>• The stockpiles will be vegetated (details contained in rehabilitation plan) in order to reduce the risk of erosion, prevent weed growth and to reinstitute the ecological processes within the soil. | Chamber of Mines Guidelines | Construction |
| Operation and maintenance of the Soil and Overburden Stockpiles. | Operational | Shaft Complex Footprint(s), Conveyer Servitude and associated Support Infrastructure Footprint | • Ensure proper storm water management designs are in place and managed (kept clean);<br>• If erosion occurs, corrective actions (erosion berms) must be taken to minimize any further erosion from taking place;<br>• Only the designated access routes are to be used to reduce any unnecessary impacts (contamination and sterilisation); and<br>• Compacted areas are to be ripped to loosen the soil structure and vegetation cover re-instated. | Chamber of Mines Guidelines | Operational |

| Activities | Phase | Size and scale of disturbance | Mitigation Measures | Compliance with standards | Time period for implementation |
|---|---|---|---|---|---|
| Demolition of infrastructure will take place and Rehabilitation of the Project area will be undertaken. Rehabilitation activities will cover the extent of the infrastructure footprint areas and will include the ripping of the compacted soil surfaces, spreading of soil and re-establishment of vegetation. | Decommissioning & Rehabilitation Phase | Shaft Complex Footprint(s), Conveyer Servitude and associated Support Infrastructure Footprint | • Ensure proper storm water management designs are in place and that it is functional at all times;<br>• If erosion occurs, corrective actions (erosion berms) must be taken to minimize any further erosion from taking place;<br>• If erosion has occurred, utilisable soil should be sourced and replaced and shaped to reduce the recurrence of erosion;<br>• Only the designated access routes are to be used to reduce any unnecessary compaction and/or contamination;<br>• Compacted areas are to be ripped to loosen the soil structure and vegetation cover re-instated;<br>• Implement land rehabilitation measures as defined in rehabilitation report.<br>• Follow rehabilitation guidelines;<br>• The utilisable soil should be moved by means of an excavator and loaded onto trucks;<br>• Soil should be moved when dry wherever possible;<br>• On completion of the project disturbed areas need to be cleared of all infrastructure;<br>• Foundations need to be removed;<br>• Utilisable soil needs to be replaced for rehabilitation purposes;<br>• The handling of the stripped soil will be minimized to ensure the soil's structure does not deteriorate; and<br>• Stockpiles should only be used for their designated final purposes. | Chamber of Mines Guidelines | Decommissioning and Rehabilitation Phase |
| Post-closure monitoring and rehabilitation will determine the level of success of the rehabilitation, as well as identify any additional measures that have to be undertaken to ensure that the disturbed areas are restored to an adequate state. Monitoring will include soil fertility and erosion control. | Post-Closure Phase | Shaft Complex Footprint(s), Conveyer Servitude and associated Support Infrastructure Footprint | • The rehabilitated area must be assessed once a year for compaction, fertility, and erosion;<br>• The soils fertility must be assessed by a soil specialist yearly ( during the dry season so that recommendations can be implemented before the start of the wet season) so as to correct any nutrient deficiencies;<br>• Compacted areas are to be ripped to loosen the soil structure, and vegetation cover re-instated;<br>• If erosion occurs, corrective actions (erosion berms) must be taken to minimize any further erosion from taking place;<br>• If erosion has occurred, soil should be sourced and replaced and landscaped to reduce the recurrence of erosion; and<br>• Only the designated access routes are to be used to reduce any unnecessary compaction. | Chamber of Mines Guidelines | Post-Closure Phase |

**Table 5-5: Objectives and Outcomes of the EMP**

| Activities | Potential impacts | Aspects affected | Phase | Mitigation Type | Standard to be achieved/objective |
|---|---|---|---|---|---|
| Site clearance and soil removal prior to the commencement of physical construction activities. | Loss of utilisable soil as a resource – Disturbance, Erosion, Sterilisation, Salinisation, Contamination and Compaction as well as loss of Land capability, and Land Use | Soils | Construction | • Stormwater Management Plan;<br>• Site Clearing Procedures;<br>• Rehabilitation Plan. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Construction of surface infrastructure. | Loss of soil as a resource – Disturbance, Erosion, Sterilisation, Salinisation, Contamination and Compaction as Well as Loss of Land capability, and Land Use | Soils | Construction | • Stormwater Management Plan; and<br>• IWWMP. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| The construction of stockpiles. | Loss of utilisable soil as a resource – Disturbance, Erosion, Compaction and Contamination. | Soils | Construction | • Rehabilitation Plan. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Operation and maintenance of the stockpiles. | Loss of utilisable soil as a resource – Sterilisation, Salinisation, Contamination, Erosion and Compaction | Soils | Operational | • Stormwater Management Plan;<br>• IWWMP; and<br>• Rehabilitation Plan. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Demolition of infrastructure and Rehabilitation of the Project area. Rehabilitation activities will cover the extent of the infrastructure footprint areas. | Loss of utilisable soil as a resource – Disturbance, Sterilisation, Salinisation, Contamination, Erosion, and Compaction as well as loss of Land capability, and Land Use | Soils | Decommissioning & Rehabilitation Phase | • Rehabilitation Plan; and<br>• Closure Plan. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Post-closure monitoring of rehabilitated areas. Monitoring will include soil fertility and erosion. | Re-instatement of soil as a resource. | Soils | Post-Closure Phase | • Rehabilitation Plan; and<br>• Closure Plan. | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |

**Table 5-6: Mitigation**

| Activities | Potential Impacts | Aspects Affected | Mitigation Type | Time Period for Implementation | Compliance with Standards |
|---|---|---|---|---|---|
| Site clearance and removal of utilisable soil prior to the commencement of physical construction activities. | Loss of utilisable soil as a resource – Disturbance, Contamination, Salinisation, Sterilisation, Erosion, Compaction and loss of Land capability, and Land Use | Soils | • Stormwater Management Plan;<br>• Site Clearing Procedures;<br>• Rehabilitation Plan. | Construction | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Construction of surface infrastructure. | Loss of utilisable soil as a resource – Disturbance, Sterilisation, Salinisation, Contamination, Erosion, Compaction and loss of Land capability, and Land Use | Soils | • Stormwater Management Plan; and<br>• IWWMP. | Construction | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| The construction of stockpiles. | Loss of utilisable soil as a resource – Disturbance, Erosion, contamination and Compaction. | Soils | • Rehabilitation Plan. | Construction | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |

| Activities | Potential Impacts | Aspects Affected | Mitigation Type | Time Period for Implementation | Compliance with Standards |
|---|---|---|---|---|---|
| Operation and maintenance of the topsoil and overburden stockpiles. | Loss of utilisable soil as a resource – Erosion, Compaction, sterilisation and salinisation | Soils | • Stormwater Management Plan;<br>• IWWMP; and<br>• Rehabilitation Plan. | Operational | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Demolition of infrastructure and Rehabilitation of the Project area. | Loss of utilisable soil as a resource – Disturbance, Sterilisation, Contamination, Erosion, Compaction and loss of Land capability, and Land Use | Soils | • Rehabilitation Plan; and<br>• Closure Plan. | Decommissioning and Rehabilitation Phase | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |
| Post-closure monitoring of rehabilitated areas. Monitoring will include soil fertility and erosion. | Re-instatement of utilisable soil as a resource. | Soils | ▪ Rehabilitation Plan; and<br>▪ Closure Plan. | Post-Closure Phase | Soil Management in terms of the Chamber of Mines Guidelines for Rehabilitation |

# 6 SOIL SAMPLING

During the rehabilitation exercise preliminary soil sampling should be carried out to determine the fertilizer requirements more accurately. Additional soil sampling should also be carried out annually until the levels of nutrients are at the required level. Once the desired nutritional status has been achieved, it is recommended that the interval between sampling be increased. An annual environmental audit should be undertaken. If growth problems develop, ad hoc, sampling should be carried out to determine the problem.

Sampling should always be carried out at the same time of the year and at least six weeks after the last application of fertilizer.

All of the soil samples should be analysed for the following parameters:

- pH ($H_2O$);
- Electrical conductivity;
- Calcium mg/kg;
- Magnesium mg/kg;
- Potassium mg/kg;
- Sodium mg/kg;
- Cation exchange capacity;
- Phosphorus (Bray I);
- Zinc mg/kg;
- Clay% and;
- Organic matter content (C %)

# 7 CONSULTATION UNDERTAKEN

Spontaneous interaction with the land owners was undertaken and introductions made at the time of entering the areas of concern.

# 8 COMMENTS AND RESPONSE

Comments will be addressed as part of the next round of consultation, during the EIA Phase.

# 9 CONSCLUSION AND RECOMMENDATION

Based on the baseline of information and the impact assessment ratings of significance, it is the opinion of the specialist earth sciences that this project is feasible and could be considered if the management measures tabled are rigorously adhered to for both the Shaft Complex areas as well as the proposed conveyencing servitude, while more detailed site placement of the conveyer plinths is considered necessary based on the wetland delineation and a more detailed assessment of the wet base soils as part of the pre-construction planning.

# 10 LIST OF REFERENCES

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# Appendix 1: A3 Drawings


Prepared for:

DIGBY WELLS
ENVIRONMENTAL

Project: Umcebo Mining
Hendrina Underground Coal Mine
Environmental Authorisation
Specialis Soil & Land Capability
Studies

Figure: Dominant Soils Map

## Legend

- 1 = Deep sandy loam
- 2 = Moderately deep sandy loam
- 3 = Shallow sandy loam
- 4 = Very shallow sandy loam
- 5 = Deep wet based sandy loam
- 6 = Shallow wet based clay loam
- 7 = Structured clay loam
- 8 = Waterway
- 9 = Man Induced
- 10 = Pan
- Infrastructure

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Project: Umcebo Mining
Hendrina Underground Coal Mine
Environmental Authorisation
Specialis Soil & Land Capability Studies

Figure: Land Capability Map

**Legend**

- 1 = Arable
- 2 = Grazing
- 3 = Wilderness
- 4 = Wet Based
- 5 = Waterway
- 6 = Man Induced
- 7 = Pan
- Infrastructure

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# Appendix 2: Ferricrete Classification

# Petrological and Geochemical Classification of Laterites

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*Abstract*

*In this classification of lateritic covers four major types are distinguished: ferricretes, latosols, conakrytes and bauxites.*

*In ferricretes, hematite is associated with kaolinite, forming mottles, nodules and metanodules. When, at the top of profiles, goethite and sometimes gibbsite develop at the expense of hematite and kaolinite, protopisolitic and pisolitic dismantling facies are formed. Ferricretes, in which hematite and kaolinite form concretions, are widespread and are the most common iron accumulations.*

*Latosols are soft lateritic covers with a microglaebular structure. Red latosols, like ferricretes, are essentially formed by an association of hematite and kaolinite, but with larger proportions of goethite and with the presence of gibbsite.*

*Lateritic bauxites are concentrations of aluminium with which iron is very often associated. Four major types of lateritic bauxites: protobauxites, orthobauxites, metabauxites and cryptobauxites are defined as a function of the nature of iron and aluminium minerals as well as their relative distributions in profiles.*

*Protobauxites are lateritic soils where gibbsite and goethite form together under very humid climates. Orthobauxites are allites or alferrites, rich in gibbsite and red in colour, which do not exhibit a concretionary structure. Iron may be concentrated in hard caps called conakrytes and located close to the top of the bauxitic profiles. Conakrytes are reticular and non nodular ferrites or ferrallites in which hematite and goethite dominate and where gibbsite could be present in small proportions. The presence of kaolinite at the bottom of the profiles is not necessary. Metabauxites are boehmitic and show a concretionary or pisolitic structure; iron is dissociated from aluminium and is frequently concentrated as hematite in a kaolinitic ferricrete located at the bottom of the bauxitic profile. Kaolinite always appears at the bottom of metabauxite profiles and less frequently at the base of orthobauxites. In cryptobauxites, kaolinite is abundant at the top and at the bottom of the profiles so that the gibbsitic layer is embedded between two kaolinitic horizons.*

*This petrological and geochemical classification of laterites is based on reactions of hydration–dehydration and of silication–desilication regulated by temperature, water activity and chemical composition of the parent material. Lateritic bauxites, ferricretes and latosols are witnesses of the succession of paleoclimates throughout the last 150 million years, since the Atlantic opening.*

*Keywords:* laterites, ferricretes, latosols, conakrytes, bauxites, hematite, goethite, kaolinite, gibbsite, boehmite

## Introduction

Bauxites (massive or pisolitic, and often indurated), conakrytes (massive or reticulated and often indurated), latosols (soft and microglaebular) and ferricretes (nodular and always indurated) are lateritic covers, widely distributed in North and South America, in West, Central and East Africa, as well as in Australia, India and South East Asia. These laterites form under tropical climates depending on rainfall, temperature, length of the dry season and on the nature of the parent material. Their geographic distribution is larger than the latitudinal zones of climates under which they normally form or develop. Almost all of them are very old: some are fossil, others are still active, but most of them are polygenic.

Some bauxites formed under humid conditions and later evolving under a drier climate, may generate ferricretes localised at the bottom of profiles, while ferricretes formed under seasonally contrasted climate, later evolving under wetter conditions may generate a new bauxitic horizon within a soft kaolinic latosol (Tardy *et al.*, 1991; Tardy and Roquin, 1992; Tardy, 1993).

## CLASSIFICATION OF IRON-RICH LATERITES

Tardy (1993) distinguishes two mechanisms of iron accumulation: concretion and excretion as well as four kinds of iron-rich lateritic formations: (i) mottled horizon and nodular ferricretes, (ii) microglaebular latosol, (iii) conakrytes of massive structures and (iv) plinthites and petroplinthites.

### Ferricretes: nodular iron-rich accumulations

Ferricretes or 'cuirasses ferrugineuses' *stricto sensu* are indurated iron concentrations, showing generally a noticeable nodulation. The words ferricrete, calcrete and silcrete are formed like concretion with 'the formant crete' which etymologically comes from Latin *con-crescere* signifying to cement or to grow together. Although these features may exhibit a concentric structure (Pettijohn, 1957) the definition of concretions does not include that they are concentric as proposed by Brewer (1964) but are only indurated or cemented accumulations. Concretion also designates the mechanism of cementation and induration, by centripetal accumulation of material, in pores of small size (Tardy, 1993). In ferricretes, the mechanism of concretion leads to the formation of indurated nodules by accumulation of hematite in the very fine porosity developed by kaolinite crystal assemblages.

In a sequence of ferricrete development from mottles (diffuse accumulations) to subnodules (nodules with diffuse edges), nodules (with distinct edges), and to metanodules (anastomosed), iron content increases, quartz content decreases drastically, while kaolinite content decreases slowly or even increases moderately. In mottles goethite dominates hematite, but in well developed nodules the contrary is observed. The ratio hematite/(hematite + goethite) increases from the mottled zone to the ferricrete zone.

Concretion and nodulation, the fundamental process of ferricrete formation, is based on the association of hematite and finely crystallised kaolinite.

Compared to hematite ($Fe_2O_3$), goethite is hydrated ($Fe_2O_3.H_2O$). Gibbsite ($Al_2O_3.3H_2O$) is more hydrated than kaolinite ($SiO_2.Al_2O_3.2H_2O$). The stability of hematite–kaolinite nodules is ensured as long as hematite and kaolinite are stable, i.e. they are not rehydrated or desilicated.

Tardy (1993) has shown that this association of dehydrated or poorly hydrated minerals is very stable and develops under tropical climates with a long dry season. This paragenesis hematite–kaolinite, when previously formed under contrasted tropical climates, is even stabilised in more arid conditions. In contrast, nodules of hematite and kaolinite are destabilised in humid tropical conditions, particularly under the great equatorial forest (Beauvais and Tardy, 1991).

### Latosol: a microglaebular iron-rich laterite

Beauvais (1991) and Beauvais and Tardy (1991) have shown that, under a humid climate, the transformation of a ferricrete into a microglaebular latosol corresponds to the transformation of a part of kaolinite into gibbsite by desilication and hydration, and to the transformation of hematite into goethite by hydration. During this process, the size of nodules is reduced and they are transformed into microglaebules.

Tardy and Roquin (1992) and Tardy (1993) have delineated the climatic limits of formation of latosols and ferricrete by taking into account their distribution in both Brazil and Africa.

Finally, ferricretes form under tropical climates which are warm, humid and seasonally contrasted (T $\approx$ 25°C; 1100 < P < 1700 mm $y^{-1}$).

An increase in humidity to above 1700 mm $y^{-1}$ or a decrease of temperature to below 25°C act in favour of the dismantling of ferricretes and their transformation into latosols (Tardy and Roquin, 1992).

### Conakrytes: massive and non-nodular iron accumulations

There are non aluminous iron accumulations which develop from non aluminous parent rocks, such as dunites, similar to those described by Bonifas (1959), in Conakry (Guinea). They are widely distributed lateritic products formed by weathering of ultramafic rocks and are characterised by massive or crystalliplasmic structures and the absence of concretions or nodules. Consequently they cannot be called ferricretes even if indurated. They were called *conakrytes* (Tardy, 1993)

Orthobauxitic profiles (discussed later) are very often capped by ferruginous hardcaps (Grubb, 1971) which were improperly named laterites by Balasubramanian *et al.* (1987). As in Mali (Tardy, 1993), these ferruginous horizons are often gibbsitic and of massive structure and, consequently, do not exhibit concretions. The absence of concretion is due to the fact that under very humid climates gibbsite forms instead of kaolinite. Hardcaps are not ferricretes in the sense of Nahon (1976) but aluminous conakrytes associated with ferruginous bauxites.

### Plinthite: a cutanic and reticular iron-rich laterite?

Camargo *et al.* (1988), in the Brazilian soil classification, referring to the FAO soil classification (FAO-UNESCO, 1975), and numerous other researchers describe a plinthite as an iron accumulation showing laminar, reticular or polygonal organisation. An iron accumulation principally characterised by mottles or nodules, which result from concretion, must be classified as a mottled horizon (soft material) or a ferricrete (hardened material).

Consequently, if the reading of the term reticular is correct, an iron accumulation characterised by iron-rich reticular cutans more abundant than nodules may be classified as a plinthite (soft material) or petroplinthite (hardened material). The first should correspond to a gley, the second should correspond to a pseudo-gley.

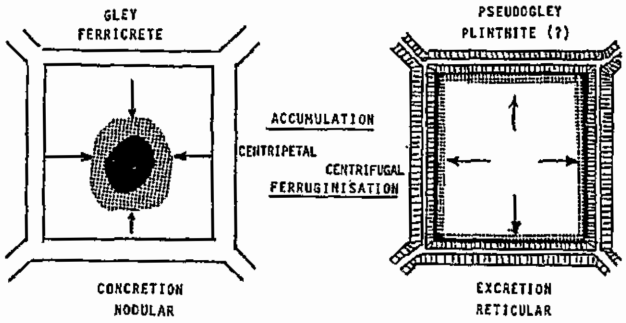


**Fig. 1** Concretion (mottle and nodule formation) versus excretion (cutan formation): two processes of iron accumulation which may allow, if acceptable, the distinction of ferricretes from plinthites. (from Tardy, 1993).

Tardy (1993) has shown that what he called *excretion* and *incrustation*, which appear as cutanic accumulations, have to be clearly distinguished and separated from *concretions*. A cutan of excretion results from a centrifugal transfer of the argillaceous matrix with a porosity of small size towards the voids and the porosity of large size. A cutan of incrustation results in a transfer of matter which goes from voids and the porosity of large size towards the soil matrix. *Excretion* and *concretion* are opposite with respect to features (cutan versus nodule) and to processes (centrifugal versus centripetal). *Excretion* and *incrustation* are similar with respect to features (cutans in both cases) but are of opposite polarity (centrifugal versus centripetal). *Incrustation* and *concretion* are opposite with respect to feature (cutan versus nodule) but similar with respect to the polarity of processes (centripetal towards the porosity of fine size). The process of excretion corresponds to the leaching of iron from kaolinitic domains and to the cutanic accumulation of hematite in the voids. Excretion is clearly distinguished from concretion which corresponds to a leaching in domains close to the voids and an accumulation of hematite in domains rich in kaolinite.

Obviously this distinction was not taken into consideration so that plinthite and ferricrete are both indistinctly used to designate all kinds of iron accumulations. It is suggested here that plinthites and petroplinthites, defined as iron cutanic and reticular accumulations resulting from a process of excretion, have to be clearly separated from mottled horizons and ferricretes which are iron accumulations resulting from a process of concretion (Fig. 1). Climates of development are distinct. Mechanisms of formation are different.

## CLASSIFICATION OF LATERITIC BAUXITES

The bauxitisation of very thick lateritic profiles is slow, requiring millions to tens of millions of years to form. This is the reason why bauxitic profiles have been evolving under different types of climatic and morphological situations which do not necessarily correspond to their conditions of formation.

### Protobauxites

Protobauxite is the name of a gibbsitic soil that could be considered as the precursor of a lateritic bauxite. It is rather difficult to determine with precision the time required for transformation and what is the type of soil which could be the precursor of thick bauxitic profiles. Tardy (1993) admitted that among the different types of oxisols (sols ferrallitiques, in the French classification) the most sensitive to bauxitisation are the red or the yellow oxisols in which gibbsite, goethite and hematite dominate and where kaolinite and quartz are, at least originally, subsidiary (Sieffermann, 1973).

### Orthobauxites

The prefix *ortho* in Greek means normal. Orthobauxites are products of evolution of gibbsitic protobauxites, developed under an annual rainfall greater than 1700 mm $y^{-1}$ (Tardy, 1993).

A typical orthobauxitic profile is made of three major horizons (Valeton, 1972, 1981; Aleva, 1979, 1981, 1982, 1989; Bardossy, 1989; Bardossy and Aleva, 1990). From the top to the bottom one finds:

- a ferruginous, hematitic and gibbsitic horizon, red in colour, located close to the surface;
- a bauxitic horizon, less coloured, less ferruginous and more aluminous, with gibbsite and hematite;
- an argillaceous horizon, rich in kaolinite, poorly ferruginous and red-yellow in colour.

Typical orthobauxitic profiles are those of Mounts Bakhuis, Surinam (Aleva, 1981), Jarrahdale in the Darling Range, Australia (Grubb, 1971), Mount Tato at Lakota in the Ivory Coast, Africa (Boulangé, 1983, 1984) and some profiles of Famansa in Mali, Africa (Tardy, 1993), which are of Cretaceous age (Michel, 1973).

There are two types of bauxites in Famansa: orthobauxites and metabauxites. The orthobauxites are homogeneously red, and do not exhibit nodules, concretions or pisolites. Over thicknesses of about 10 m they are constituted of gibbsite, hematite and goethite. From the bottom to the top of profiles, typical orthobauxites show an increase in iron (goethite and hematite) versus aluminium (gibbsite) content, an increase in the hematite/goethite ratio and a decrease in the content of quartz and kaolinite (Tardy, 1993).

An orthobauxite is dominantly gibbsitic in the thick intermediate horizon and does not show boehmite, pisolites or concretions. It is normally capped by a conakryte when developed from a ferruginous parent rock.

There are several orthobauxitic profiles which do not exhibit a kaolinitic layer at the base and where bauxite develops down to the contact with the unaltered parent rock. The volume and the architecture of the parent rock are preserved and that is the reason why Boulangé *et al.* (1973, 1975) and Boulangé (1984) call these formations isalteritic bauxites.

### Cryptobauxites

In Amazonia, bauxites are widespread. Lucas *et al.* (1986) and Lucas (1989) have presented an interesting synthesis concerning the ore deposits of Juriti and Trombetas. The parent rocks are sandstones and argillites of Alter-do-Chão from the later Cretaceous or the early Tertiary (Daemon, 1975). All bauxitic profiles are capped by an argillaceous horizon, very rich in kaolinite and poor in quartz, called Clays of Belterra and considered by Sombroek (1966) and Tricart (1978) as a Quaternary sedimentary lacustrine formation; by Grubb (1979), Kotschoubey and Truckenbrodt (1981) as a Pliocene lacustrine or desertic deposit; and finally by Aleva (1981, 1989) as a sedimentary cover. Chauvel *et al.* (1982) and Lucas *et al.* (1984) first called attention to a pedogenetic origin, while Tardy (1993) proposed that the pedogenetic phase takes place in a biogenic formation. The peculiarity of this type of bauxite comes from the fact that a gibbsitic horizon is interbedded between two kaolinite-rich horizons.

It is also interesting to remark that hematite is associated with gibbsite in the bauxitic horizon while goethite is the iron mineral dominant in the superficial layer. We agree with Lucas (1989) that bauxites of Amazonia are polygenic. They are similar to gibbsitic soils of Cameroon such as those described by Muller (1987). Both were considered by Tardy (1993) to be ancient ferricretes, formed under seasonally contrasted tropical climates and later dismantled under a more humid tropical climate. Gibbsite forms in place of the ancient ferricrete, and continues to develop in situ, close to the water table (Lucas, 1989) but below a thick kaolinic soft horizon, so that the bauxite layer is called cryptobauxite. This peculiar distribution implies a strong necessity of supplying silica from the lower to the upper part of the profile. Several biological processes can be responsible for that: termites (Truckenbrodt *et al.*, 1991) or phytolites (Lucas *et al.*, 1993). Cryptobauxites are common in equatorial forests and, if really polygenic, characterise a paleoclimatic succession which has been moving from arid to humid. The opposite is observed for the metabauxite evolution.

### Metabauxites

Metabauxites are orthobauxites, initially formed under a tropical humid climate and later transformed under warmer and drier climates. *Meta* in Greek means which comes later. Metabauxites are diagenetised bauxites (Tardy, 1993).

### Typical metabauxite profiles

Some of the most typical profiles that we can classify as metabauxites, are those of Weipa and Pera Head, in the Cape York Peninsula, N.E. Australia. They were described by Loughnan and Bayliss (1961) and Loughnan (1969). Over a thickness of 10 m, a quartz–argillaceous sandstone is transformed into an aluminium-rich bauxite. From the bottom to the top of the profile, quartz and kaolinite, always present, diminish while gibbsite and boehmite increase. In the lower part, goethite dominates while in the higher part, hematite becomes the dominant iron mineral.

The metabauxite profile of Famansa in South Mali was described by Tardy (1993). This so-called white bauxite profile exhibits, over 10 m of thickness, an increase in aluminium, gibbsite and boehmite and a decrease in silicon towards the profile surface. The three ratios boehmite/(boehmite + gibbsite), hematite/(hematite + goethite) and gibbsite/(gibbsite + kaolinite) rise constantly from the bottom to the top of the profile. In this profile, iron does not accumulate in the superficial horizon but at depth, between 6 and 8 m, forming a typical kaolinite–hematite rich nodular ferricrete.

Metabauxites are deferruginised at the top but ferruginised at the bottom of profiles. The massive gibbsitic structure is replaced by a boehmitic, pisolitic structure. In orthobauxites, iron in hematite and aluminium in gibbsite are associated at the top of the profile forming conakrytes of massive structure. In metabauxites, at the surface of profiles, iron and aluminium in boehmitic pisolites separate, while in the ferricrete located at the bottom, iron in fine grained hematite and aluminium in kaolinite are again associated.

### Regional metabauxitisation

Balkay and Bardossy (1967) first pointed out that the amounts of boehmite in bauxites of Western Africa, increase from the south to the north.

Seven regions were distinguished by Bourdeau (1991), who studied 3750 analyses of samples collected by Pechiney-Sarepa

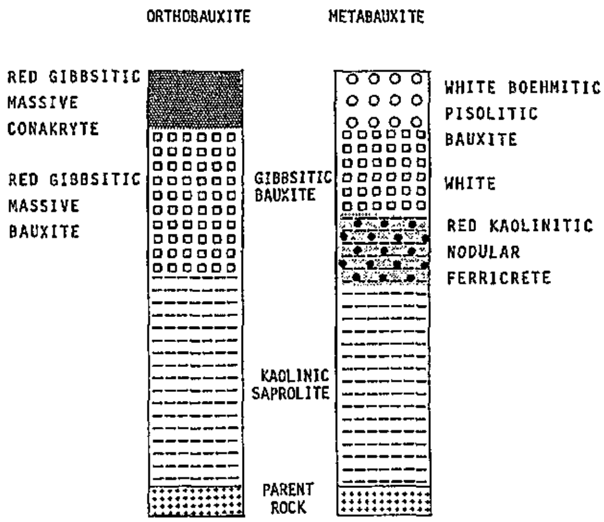


**Fig. 2** Schematic distribution of boehmite, gibbsite, kaolinite and hematite in conakrytes associated with orthobauxites on one hand and in ferricretes associated with metabauxites on the other hand (from Tardy and Roquin, 1992; Tardy, 1993).

**Table 1** Elements of classification of iron and aluminium laterites

| Name | Structure | Al (contents) | Fe (contents) | Hematite (size) | Goethite | Gibbsite (contents) | Boehmite (contents) | Kaolinite (contents) |
|---|---|---|---|---|---|---|---|---|
| Conakryte | crystalliplasmic | poor | abundant | large | present | present | absent | absent |
| Ferricrete | nodular | moderate | abundant | very small | present | possible | absent | abundant |
| Orthobauxite | massive | abundant | moderate | large | present | abundant | absent | absent |
| Metabauxite | pisolitic | very rich | poor | very small | absent | present | abundant | present |
| Latosols | microglaebular | medium | medium | small | moderate | frequent | absent | abundant |

*Note that hematite is always present but in different sizes and gibbsite is always present but in different proportions*

**Table 2** Geochemical and mineralogical classification of laterites

| Name | Geochemical process | Mineral constituents | Geochemical composition |
|---|---|---|---|
| Conakryte[1] | hydro-ferrallite | goethite, hematite, gibbsite | $Fe_2O_3.H_2O.Al_2O_3$ |
| Conakryte[2] | ferrite | hematite, goethite | $Fe_2O_3.H_2O$ |
| Ferricrete | xero-fersiallite | hematite, kaolinite | $Fe_2O_3.SiO_2.Al_2O_3.H_2O$ |
| Orthobauxite | hydro-alferrite | gibbsite, goethite, hematite | $H_2O.Al_2O_3.Fe_2O_3$ |
| Metabauxite | xero-allite | boehmite, hematite | $Al_2O_3.Fe_2O_3$ |
| Red latosol | xero-sialferrite | kaolinite, hematite, goethite | $SiO_2.Al_2O_3.H_2O.Fe_2O_3$ |
| Yellow latosol | hydro-sialferrite | goethite, kaolinite, gibbsite | $H_2O.Al_2O_3.SiO_2.Fe_2O_3$ |
| Podzol | sillite | quartz | $SiO_2$ |

*[1] conakrytes on aluminous rocks, [2] conakrytes on ultramafic rocks*

in bauxites of Guinea and Mali: (I) Fouta Djalon in Guinea, (II) Balea, North of Guinea, (III) Bamako-West in South Mali, (IV) Falea, (V) Kenieba in South-West Mali, (VI) Koulikoro, West Mali and (VII) Bafoulabe North-West Mali. In each region, the upper or superficial and the lower horizon of the profile, were distinguished.

It is clear that from the south (humid) to the north (dry and hot) i.e. from the humid Guinea to the Sahara

water content diminishes;

- iron content decreases in the superficial horizon;
- in the deep horizon, iron content increases and aluminium decreases;
- gibbsite and goethite contents diminish, while hematite and boehmite increase;
- kaolinite content increases;
- the contrast between ratios: $Al_2O_3/Fe_2O_3$ in the upper horizon versus $Al_2O_3/Fe_2O_3$ in the lower horizon increases significantly.

From the south to the north, bauxites dehydrate, more so in the upper than in the lower horizon. Accompanying the dehydration process, a migration of iron proceeds from the top (conakryte) to the bottom of the profile (ferricrete) (Tardy, 1993) (Fig. 2).

## CONCLUSION

Tables 1–3 summarise the elements of classification of iron-rich and aluminium-rich lateritic formations. They are conakrytes, ferricretes, orthobauxites, metabauxites and latosols. As well as the nature of the parent rock, climatic and paleoclimatic influences are major factors controlling the nature of laterites.

Aluminous conakrytes and orthobauxites are associated in humid conditions. Ferricretes form under seasonally contrasted climates. Ferricretes and metabauxites can be associated in semi-arid or arid conditions because metabauxites are ancient orthobauxites formed under humid climates and further dehydrated and deferruginised.

Hematite is less hydrated than goethite:

$$Fe_2O_3 + H_2O \rightarrow 2FeO(OH) \tag{1}$$

Boehmite is less hydrated than gibbsite:

$$AlO(OH) + H_2O \rightarrow Al(OH)_3 \tag{2}$$

and finally, kaolinite contains more Si but is less hydrated than gibbsite:

$$Al_2Si_2O_5(OH)_4 + 5H_2O \rightarrow 2Al(OH)_3 + 2H_4SiO_4 \tag{3}$$

Reactions of hydration–dehydration and silication–desilication are the processes of laterite climatic formation and paleoclimatic evolution. Dehydration favours concretion and formation of nodules while hydration favours excretion and development of crystalliplasmic structures. In ferricretes hydration of hematite into goethite favours the dismantling of previously formed nodules. In contrast, hydration of bauxites, favours the induration of crystalliplasmas of gibbsite. Dehydration works in the

**Table 3** Climatic conditions (H: humidity; T: temperature) and paleoclimatic evolution ($H_1$–$H_2$; $T_1$–$T_2$) for controlling the laterite evolution

| | Tropical climate | Parameter H | Parameter T | Paleoclimatic evolution | Parameters $H_1$ | Parameters $H_2$ | Parameters $T_1$ | Parameters $T_2$ |
|---|---|---|---|---|---|---|---|---|
| Conakryte(1) | humid | medium | high | constantly humid tropical | > | | | > |
| Conakryte(2) | undifferent. | — | — | undifferent. | — | | | — |
| Ferricrete | tropical contrasted | high | medium | constantly contrasted | — | | | — |
| Latosol | cool humid | high | medium | from contrasted to humid | | / | \ | |
| Orthobauxite | humid | high | medium | constantly humid | > | | | > |
| Metabauxite | arid | low | very high | from humid to arid | | \ | / | |
| Cryptobauxite | humid | high | medium | from arid to humid | | / | \ | |

*[1] from ferrioluminous rocks; [2] from ultramafic rocks.*
*$H_1$, $H_2$: humidity stage 1 or 2; $T_1$, $T_2$: temperature stage 1 or 2.*

direction of aggradation and induration. Hydration works in the direction of degradation and dismantling (Tardy, 1993).

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# Clays

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# A Geotechnical classification of calcretes and other pedocretes

F. Netterberg and J. H. Caiger

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# A geotechnical classification of calcretes and other pedocretes

F. Netterberg & J. H. Caiger

SUMMARY: Authigenic calcareous accumulations within regoliths can be simply classified for geotechnical purposes as calcareous soils, calcified soils, powder calcretes, nodular calcretes, honeycomb calcretes, hardpan calcretes, and calcrete boulders and cobbles. Each of these categories represents a particular stage in the growth or weathering of a calcrete horizon and possesses a significantly different range of geotechnical properties. A similar classification can be applied to other pedocretes.

Development of the arid and semi-arid zones has increasingly involved the use of non-traditional materials such as calcretes for construction and foundation materials. Such exploitation has often revealed inadequacies in certain geotechnical procedures developed in temperate zones as well as the necessity for studies on these materials. This paper outlines a simple, descriptive classification suitable for geotechnical use on calcretes and similar materials based on approximately 20 years of personal experience of both the authors with these materials. The classification is the latest of several earlier studies (Caiger 1964; Netterberg 1967, 1969a, 1971), and largely represents a very condensed and simplified geotechnical version of one of them (Netterberg 1980) embracing all the known morphogenetic forms of calcrete formation and weathering processes. Although based largely upon southern African experience, perusal of the literature, together with the authors' limited experience in Australia, Israel and Texas, suggests that this classification is applicable to calcretes everywhere and, with minor modifications, to other pedocretes such as ferricretes and silcretes.

## Necessity for and requirements of a calcrete classification

The necessity for a calcrete classification stems from the inability of temperate zone soil classifications of the Casagrande (British Standards Institute (BSI) 1957; Bureau of Reclamation 1974; American Society for Testing and Materials (ASTM) 1980) and American Association of State Highway and Transportation Officials (AASHTO) (1978) types adequately to describe and predict the engineering performance of materials composed of cemented particles of clay, silt, sand, etc. or almost pure carbonate, and ranging in consistency from loose silt to very strong rock and in thickness from millimetres to 100 m. Some of these materials are not rock, but they do not slake or soften greatly in water, and when excavated and broken down during compaction, they behave as soils. Only then can they be said to possess a particle size distribution and Atterberg limits. Descriptive methods intended for use on undisturbed material such as those of the ASTM (1980b), BSI (1957, 1972), Geological Society (1970, 1977a,b), Jennings, Brink & Williams (1973), and the Core Logging Committee (1978) are better in this respect, but often require lengthy descriptions to convey an adequate picture. As calcretes frequently present unusual geotechnical properties and performance, it is necessary to distinguish them from other materials (Netterberg 1969a, 1971, 1980, 1982; Horta 1980).

A calcrete classification suitable for geotechnical use should be of both geological and engineering significance, and must be applicable in the field by relatively untrained personnel, as well as satisfying certain other requirements (Netterberg 1969a, 1980). Previous calcrete classifications (reviewed by Netterberg 1980) appear to be either too simple for modern use or too complicated for geotechnical use. The most recent (Horta 1980) only considers calcrete gravels and sands.

## Definitions

The extensive calcrete literature has been reviewed in recent years by Netterberg (1969a), Goudie (1973) and Reeves (1976). It is clear that the terms 'calcrete' and 'caliche' have been applied to almost any material of almost any consistency and carbonate content formed by the *in situ* cementation and/or replacement of regolith material by (dominantly) calcium carbonate precipitated from the soil water or ground water. Calcified cave soils, spring tufas, aeolianites, and beachrocks are usually excluded, largely for the sake of convention, although they could be included for geotechnical purposes. The term 'calcrete' has also been used in more restricted senses for indurated materials only or for materials containing more than about 50% $CaCO_3$ equivalent, i.e. the lower limit for the term 'limestone'. This somewhat conflicting usage is accommodated here by the use of the unqualified term 'calcrete' for the widest usages only and the application of qualifying adjectives when more restricted use is intended. In the more restricted usage, calcretes generally possess more than about 50% $CaCO_3$ equivalent and, with one exception, are also indurated, more or less in accordance with the recommendation of the Speciality Session on Pedogenic Materials (1976).

The term 'soil' is used here in its wide engineering sense for practically any geological material which the engineer does not classify as rock, which requires blasting for excavation.

## The classification

### Basis of the classification

The classification suggested here is a simple, morphogenetic one based upon secondary (chemical) structure and sequence of development. It employs a combined geological and engineering approach, in its simplest form consisting of a genetic term such as 'calcrete', 'calcified', 'ferricrete', 'ferruginised', etc., plus a traditional engineering soil or rock term such as 'sand', 'gravel', etc., e.g. 'calcified sand', 'calcrete gravel', 'calcrete rock', as recommended by the Speciality Session on Pedogenic Materials (1976). This scheme is not dissimilar to that of Fookes & Higginbottom (1975) for the geotechnical classification of near-shore carbonate sediments. As material is often classified simply as 'rock' (requires blasting or consists of large boulders), 'hard' (requires pneumatic tools) and 'soft' (other materials) for

TABLE 1. *Stages in the development and weathering of calcretes (Netterberg 1969b, 1980)*

| Stage | | Host material | | | |
|---|---|---|---|---|---|
| 0 | | Weathered rock | Shattered clay | Mixed texture | Clean sand or gravel |
| 1 | DEVELOPMENT | Calcrete soluans in cracks | Calcrete powder soluans in cracks | Scattered calcrete glaebules in host soil | Calcrete-coated grains |
| 2 | DEVELOPMENT | Calcified weathered rock | Powder calcrete (sandy silt or silty sand) | Glaebular calcrete (clayey, silty or sandy gravel) | Calcified sand or gravel (massive) |
| 3 | DEVELOPMENT | | | Honeycomb calcrete (partially coalesced nodules or soluans) | |
| 4 | DEVELOPMENT | | | Hardpan calcrete (rock-like horizon) | |
| 5 | WEATHERING | | | Calcrete boulders, cobbles or gravel (discrete fragments formed by weathering) | |

excavation payment purposes, the addition of such terms would represent the final descriptor in the simplest form of the classification. However, it is often necessary to use the classification together with more detailed geotechnical descriptive and particle size-plasticity classifications. The applicability and modifications required of such classifications have been considered (Netterberg 1969a, 1980, 1982; Horta 1980). Horta's (1980) suggestion of adding calcrete gravels and sands and gypcrete sands to Casagrande-type classifications should be taken even further.

Calcretes are thus classified simply into calcareous soils, calcified soils, powder calcretes, nodular calcretes, honeycomb calcretes, hardpan calcretes, and calcrete boulders and cobbles. As calcretes form more or less in this sequence (Table 1) (Netterberg 1969a,b, 1980; Goudie 1973) this classification should cover all the basic forms possible. Each of the forms listed in Table 1 represents an easily recognizable stage of growth or weathering and possesses a significantly different range of geotechnical properties. Possible correlations between this and other classifications have been discussed by Netterberg (1980). Calcrete profile log symbols have also been suggested by him, as well as a standard method for describing calcrete profiles.

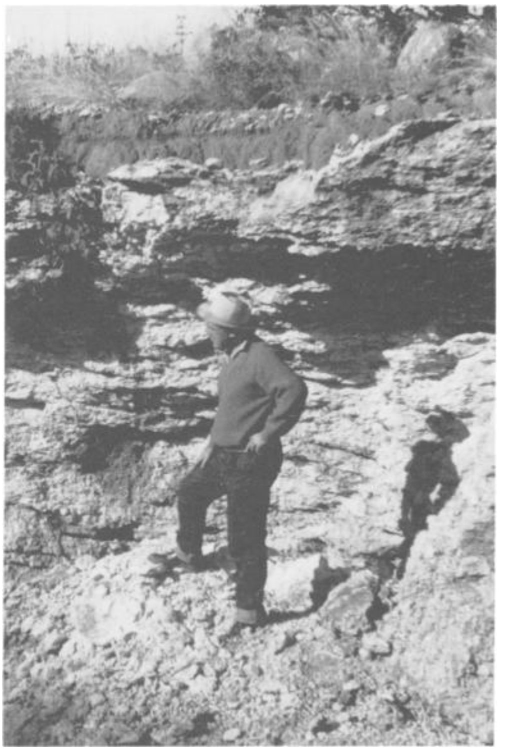

FIG. 1. Pseudobedded calcified alluvial sand (Netterberg 1980) with slight overlying hardpan development.

**Calcareous soil**

Calcareous soils (further described as sand, gravel, etc.) are soils with little or no cementation or development of carbonate concentrations such as nodules, but which effervesce with dilute hydrochloric acid. As, apart from ion exchange effects, the geotechnical properties of the original host soil have not been significantly altered by the carbonate (usually only 1–10% $CaCO_3$ equivalent), it is probably not necessary to distinguish this category (Stage 1, Table 1) unless the presence of even small amounts of carbonate are of significance to the works in question.

**Calcified soil**

A calcified soil (further described as sand, gravel, etc.) is a soil horizon (mass) cemented by carbonate usually to a firm of stiff consistency. Although often just friable, it does not usually slake in water. The carbonate is usually evenly distributed throughout the horizon as in calcified sands (Fig. 1) and gravels, but may occur as fissure-fillings as in calcified weathered rocks, although nodules are few. The amount of carbonate (usually 10–50% $CaCO_3$ by mass) is sufficient to have significantly altered the geotechnical properties of the original soil. Calcified soils can generally be dug with a pick or a face shovel (although particularly well-cemented gravels may require more drastic methods) and compacted with rollers to yield sandly or gravelly pavement layer material. Only after excavation and processing can most calcified soils be said to possess a particle size distribution, which is very dependent on the type and amount of such processing. Most aeolianites could be classified as calcified sands with some calcrete hardpan horizons.

**Powder calcrete (calcrete silt or calcrete sand)**

Powder calcretes are chiefly composed of loose silt-sized and fine sand-sized carbonate with few or no visible host soil particles or calcrete nodules. Any nodules present are generally weak and friable. Powder calcrete horizons are occasionally cemented to a consistency of up to stiff but break down on working (Fig. 2). Carbonate contents often

FIG. 2. Unsuccessful use of powder calcrete as gravel road material.

exceed 70% $CaCO_3$ equivalent. Powder calcretes may develop into nodular calcretes, from which they are distinguished by having more than 75% of particles by mass finer than 2 mm (Fig. 3) or a grading modulus of less than 1.5. (The grading modulus (Kleyn 1955) is the sum of the cumulative mass percentages retained on each of the 2.00, 0.425 and 0.075 mm sieves divided by 100. A minimum value of 1.5 is often specified for rural road sub-bases in southern Africa.) Most powder calcretes also possess more than 55% finer than 0.425 mm. Many powder calcrete possess sub-base California bearing ratios (CBR). However, they are generally troublesome materials to compact and best avoided (Von Solms 1976).

Powder calcretes can also be called calcrete silt or calcrete sand (*not* silty calcrete or sandy calcrete), but the use of the term 'powder calcrete' may be more appropriate for use by unsophisticated road workers, and Fig. 3 actually represents the limiting particle-size distributions of powder and nodular calcretes visually classified in the field.

**Nodular calcrete (calcrete gravel or calcrete sand)**

Nodular calcretes are natural mixtures of silt-sized to gravel-sized particles of carbonate-cemented host soil particles in a matrix of usually calcareous soil (Fig. 4). More than 25% of the particles by mass are coarser than 2 mm (Fig. 3) or the grading modulus has a minimum value of 1.5. The overall consistency of the horizon is generally loose, but the nodules may vary from firm and friable to very strong. Calcrete nodules vary in shape and texture from nearly spherical and smooth, through botryoidal to irregular and rough, while platy, elongated

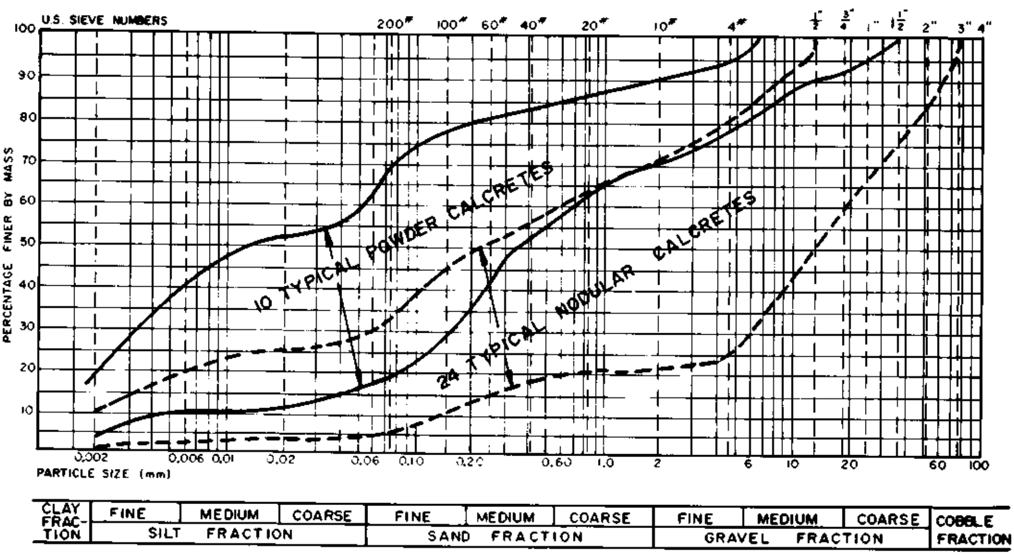


FIG. 3. Grading envelopes of typical powder and nodular calcretes.

FIG. 4. Nodular calcrete (Netterberg 1980). Calcrete cobble in lower right hand corner is a weathering relic of an older hardpan calcrete and not a nodule.

and cylindroidal forms also occasionally occur. The maximum size of individual or compound nodules very rarely exceeds 50 or 60 mm. Nodular calcretes can usually be scraper-loaded or bulldozed without ripping, and compacted to produce a good pavement layer material. Most calcretes display gap gradings by mass (Fig. 3) even after compaction. These are at least partly due to variations in particle bulk density with size and disappear or are reduced if gradings are calculated on a volumetric basis (Netterberg 1969a, 1971). The best nodular calcretes have properties comparable to those of graded crushed stone.

Geologically, the best term for nodular calcretes is really 'glaebular calcretes' (Brewer 1964). However, since calcrete glaebules other than nodules are rare (Netterberg 1969a, 1980), use of the more common term for geotechnical purposes seems sensible. Similarly, other non-glaebular, secondary structures such as pedotubules and small crotovinas can also be included under the term 'nodular calcrete' for geotechnical purposes.

Geotechnically, the best term for nodular calcrete is 'calcrete gravel'. However, many materials called nodular calcretes by field personnel classify as calcrete 'sands' according to a Casagrande type of classification (e.g. BSI 1957; ASTM 1980a) (Fig. 3). For this reason, as well as the one that, with experience, it is easy to estimate in the field when a material has a grading modulus of 1.5 or more and is thus potential road sub-base or base material, the term 'nodular calcrete' has been retained, especially at a less sophisticated level. Proper geotechnical descriptions should, however, also use the terms 'calcrete gravel' etc. as estimated by the usual criteria for the Casagrande-type classification employed.

**Honeycomb calcrete**

As the nodules in a nodular calcrete grow larger and more numerous, they may become partially cemented together to form a honeycomb calcrete (Fig. 5). A honeycomb calcrete is thus a stiff to very hard, open, honeycomb-textured calcrete horizon with the interstitial voids often filled with loose or soft soil. Both the voids and the individual nodules seldom exceed a diameter of about 30 mm, and are usually interconnected. Honeycomb calcretes can usually be ripped and grid-rolled to yield an excellent pavement base comparable to or even better than graded crushed stone in quality.

Another less common type of honeycomb calcrete can be formed from carbonate fissure-fillings in a weathered rock to result in a box-work structure. In both forms the soil filling the voids may be quite plastic.

FIG. 5. Honeycomb calcrete.

Although honeycomb (and boulder) calcretes can be geologically regarded as forms of hardpan, their geotechnical properties are sufficiently different to warrant classifying them separately.

### Hardpan calcrete

A hardpan calcrete (Fig. 6) is formed when most of the voids in a honeycomb calcrete become cemented or the upper part of a calcified soil horizon becomes more heavily cemented than the rest of the horizon (Table 1). It is a usually stiff to very strong, relatively massive and impermeable, sheetlike horizon which normally overlies a weaker material such as nodular or powder calcrete or calcified soil. Hardpans may vary from millimetres to several metres in thickness, although individual horizons more than 500 mm in thickness are not common. They may be sandy or gravelly or nearly pure limestone, and may be nearly structureless, or pseudobedded, tufaceous, jointed, veined, brecciated or laminated, and may contain voids of various kinds. Many are capped with a thin, very hard laminated 'rind'.

Many calcrete hardpans can be ripped and grid-rolled to yield a good to excellent pave-

TABLE 2. *Summary of some properties of calcretes in comparison with calcareous and calcified soils*

| Material type | Total carbonate[a] as $CaCO_3$ % | Grading modulus[b] | Classification: AASHTO M 145–73 (1978) Group | Index | BSI CP 2001 (1957) | Mod. AASHO soaked CBR[b] % | <0.425 mm: PI[a,b,c] % | Electric. conductivity[a,b,c,d] $Sm^{-1}$ at 25° C |
|---|---|---|---|---|---|---|---|---|
| Calcareous soil | 1–10?[b] | Variable | Variable | Variable | Variable | Variable | Variable | Variable |
| Calcified sand | 10? – 50 | 1.0 – 1.8? | A–1–b to A–2–7 | 0–2 | GF, GP, SU, SF | 25? – 100 | NP–20 | 0.02–0.23 |
| Calcified gravel | 10? – 50 | >1.8? | A–1–a to A–1–b | 0–1? | GF to GW? | >80? | <8? | <0.1? |
| Powder calcrete | 70 – 99 | 0.4 – 1.5 | A–2–4 to A–7–5 | 0–13 | ML to GF | 25? – 70? | SP–22 | 0.1–2.1 |
| Nodular calcrete | 50 – 75 | 1.5 – 2.3 | A–1–a to A–6 | 0–3 | GF, GP, GU | 40 – >120 | NP–25 | 0.02–0.74 |
| Honey-comb calcrete | 70 – 90 | >2.0 | Rock? | – | – (Hard, h or Rock, r)[i] | >100 | SP–16 | 0.01–0.1? |
| Hardpan calcrete | 50 – 99 | >1.5? | Rock? | – | (Hard, h or Rock, r)[i] | 10? – >100 | NP–7 | 0.01–0.06 |
| Calcrete boulders and cobbles | 50 – 99 | >2.0 | Boulders | – | Boulders and cobbles[l] (B) | >100 | NP–3 | 0.01–0.02 |

[a]Without the soil between calcrete boulders and cobbles.
[b]After excavation and rolling or crushing in the case of hardpans, honeycombs, boulders, calcified gravels and some calcified sands.
[c]On the fines produced in the Los Angeles Abrasion test in the case of honeycombs, hardpans and boulders.
[d]Saturated paste method (Netterberg 1970).

ment layer material. Those which require blasting and crushing are probably best described as 'calcrete rock'. Such materials may occasionally be several metres thick.

**Calcrete boulders and cobbles**

Calcrete hardpans weather to boulders, cobbles and smaller fragments, usually in a matrix of non- or only slightly calcareous soil (Fig. 7). The shape and sphericity of the fragments vary from subrounded and subspherical to subangular and blocky, depending upon whether dissolution or disintegration was the dominant mode of weathering. Such fragments are generally strong to very strong and are often confused with nodules, from which they can usually be distinguished by their greater strength, sphericity and size, lower grain/matrix ratios, sharper and smoother boundaries, and a frequent partial or complete skin of laminated rind. Significant amounts of gravel-sized fragments have not been observed.

Calcrete boulders and cobbles are relatively useless as pavement materials. In their natural state they are usually too coarse and gap-graded for uses other than as fill, and are generally uneconomic to crush. However, in parts of

TABLE 2 (Continued)

| Natural or crushed aggregate | | | | | Whole mass *in situ* | | | |
|---|---|---|---|---|---|---|---|---|
| | | APT[e] | | | | | | |
| ACV % | 10% FACT kN | AFV[e] % | APV[e] % | Mohs hardness[f] | Overall consistency[g] | Seismic velocity m $sec^{-1}$ | Workability | Usual max. thickness m |
| Variable | Variable | Variable | Variable | Variable | Variable | 300–900? | Variable | Variable |
| 35? – 55? | 18? – 70? | 70? – 95? | 20? – 50? | 2–3 | Med. dense —dense or firm–stiff | 600? – 1200 | Bulldoze, shovel, or rip and grid-roll | 5 |
| 25? – 35? | 70? – 135? | 90? – 100? | 50? – 90? | ≥3? | Med. dense —very dense or firm to very stiff | 1200 – 2450? | Rip and grid-roll or blast and crush | 10 |
| 33? – 55 | 18 – 90? | 25 – 95 | 5 – 65 | 2–3 | Loose – stiff | 400 – 1070 | Bulldoze, shovel, or scraper | 5 |
| 20 – 57 | 9 – 178 | 0 – 100 | 0 – 90 | 1–5 | Loose – med. dense | 600 – 900 | Bulldoze, shovel, or scraper | 5 |
| 16 – 35 | 80? – 205 | 90? – 100 | 60? – 100 | 3–6 | Stiff – very stiff | 900 – 1200 | Rip and grid-roll | 1 |
| 19 – 53 | 27 – 196 | 75? – 100 | 30? – 100 | 2–6 | Stiff—very strong | 900 – 4500 | Rip and grid-roll or blast and crush | 1, rarely 10 |
| 20 – 33 | 98 – 205 | 95? – 100 | 70? – 100 | 3.5 – 5 | Very stiff— very strong | Erratic | Rip and crush | 1 |

[e]APT = Aggregate Pliers Test; AFV = Aggregate Fingers Value; APV = Aggregate Pliers Value (Netterberg 1969a, 1978)
[f]Of the carbonate or silicified carbonate cement (aggregate or mass).
[g]According to methods of BSI (1957, 1972) and Geological Society (1977b).
[h]Up to 50% when many nodules present.
[i]Suggested term and symbol.

FIG. 6. Hardpan calcrete overlying nodular calcrete (Netterberg 1980).

Australia they are gathered by means of 'rock pickers' and crushed with travelling 'rock busters' for base coarse.

### Geotechnical properties

The geotechnical properties of calcretes (Netterberg 1969a, 1971, 1982; Reeves 1976; Weinert 1980) depend largely upon the nature of the original host soil (e.g. whether it was sand or clay) and the extent to which it has been cemented and/or replaced by carbonate. They thus vary from those of soil to those of rock (limestone), improving in a general fashion with the stage of development (Table 2).

FIG. 7. Calcrete boulders and cobbles.

### Application to other pedocretes

Like calcretes, other pedocretes such as ferricrete and silcrete are also simply soils which have been cemented and/or replaced to a varying degree by (in this case) iron oxides and amorphous silica respectively. They therefore pass through similar stages of growth and weathering and, with minor modifications, a similar classification can be applied to them (Netterberg 1975, 1976; Weinert 1980).

### Classification for other purposes

With minor modifications and amplifications the scheme suggested here should be suitable for most purposes (Netterberg 1980).

## Conclusions

Traditional geotechnical classifications developed for temperate zone materials require modification and amplification in order to adequately describe the non-traditional materials of other areas. In particular, an indication of the type of geological material (e.g. calcrete, weathered dolerite, ferricrete, etc.) is essential.

Authigenic calcareous accumulations in the regolith can be simply classified for geotechnical purposes into calcareous soils, calcified soils, powder calcretes, nodular calcretes, honeycomb calcretes, hardpan calcretes, and calcrete boulders and cobbles. Each of these categories represents an easily recognizable stage in the growth or weathering of a calcrete horizon and possesses a significantly different range of geotechnical properties. A similar classification scheme can be applied to other pedocretes such as ferricretes and silcretes.

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## Appendix 3: Vetiver Grass - Publication

# THE VETIVER SYSTEM
## A PROVEN SOLUTION

The Vetiver Network International - www.vetiver.org

# VETIVER GRASS
## A HEDGE AGAINST EROSION

The Vetiver Network International - www.vetiver.org

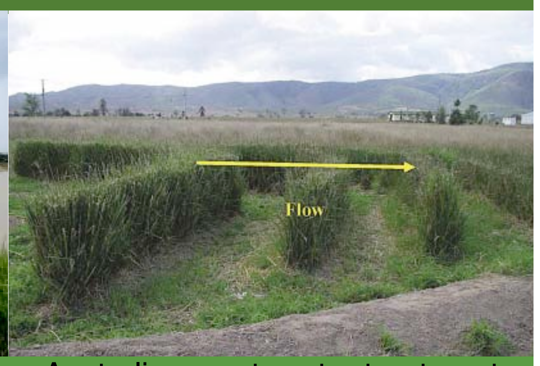

Malaysia - highway stabilization


India - beach stabilization


Fiji - 2m high vetiver created terrace


Ethiopia - soil conservation


Cambodia - river bank stabilization



Australia - wastewater treatment

### The problems we face are growing at a pace that challenges our ability to solve them

- Soil loss results in physical, chemical, and biological degradation and loss of ability to produce food.
- Land slides, unstable slopes and flooding destroy agricultural land and valuable infrastructure.
- Siltation of drains, lakes, reservoirs, and rivers reduce storage capacity and can result in flooding.
- Overuse and misuse of large areas of land, and contamination by toxic runoff from mine dumps, landfills, feedlots, salinization, etc.., require extensive reclamation programs.
- Water polluted by mineral or organic sediments as well as the pollutants mentioned above detrimentally affect drinking water supplies, fresh and saltwater fisheries, and coral reefs.
- Decreased groundwater recharge in watersheds results in local water shortages.
- Inattention to site stabilization and maintenance results in infrastructure failure and losses.

### Solutions are often too complex or costly given existing resources and capacity

- The complexity and high cost of engineering and structural designs; ambitious and impracticable environmental protection and remedial practices - often due to over demanding design engineers and supervisors - and unnecessary high-end quality control measures; as well as, amongst others, bureaucratic accounting and bidding procedures.
- Low potential for sustainability due to lack of funds for maintenance, unsuitability to local conditions/ capacity, or need for continuous subsidies to maintain effectiveness.

### Many of these problems share a common solution in THE VETIVER SYSTEM

### The Vetiver System (VS)

- Consists of a simple vegetative barrier (a hedge) comprising upright, rigid, dense, and deeply-rooted clump grass, that slows runoff, allowing sediments to stay on site, eventually forming natural terraces.
- Vetiver grass is already found in more than 120 countries throughout the tropics and sub-tropics.
- It has been used for more than a century in many Asian, African, and Caribbean countries as a traditional "soil binding" technology.
- Today, the VS is used for soil and moisture conservation, bioengineering, and for bioremediation.

#### It is not weedy or invasive

- Hedges are propagated and established vegetatively. **Analyses show that recommended cultivars of *Chrysopogon zizanioides* (south India type) are sterile and are not invasive.**

#### Deep, tough roots

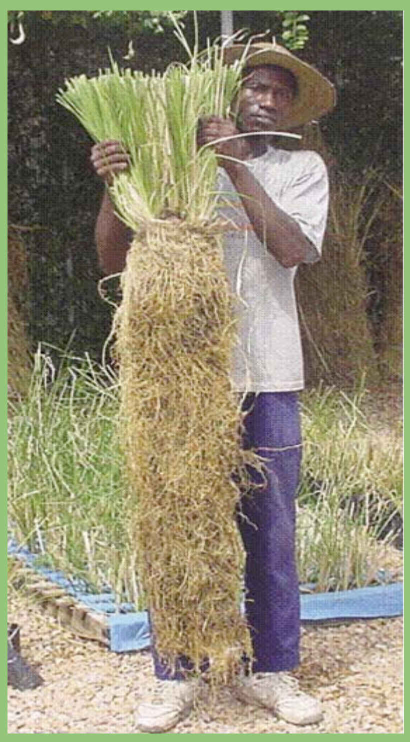
- Vetiver's deep, massive fibrous root system can reach down to two to three meters in the first year.
- This massive root system is likened to "*living nails*", binding the soil together.
- The measured maximum resistance of vetiver roots in soils is equivalent to one-sixth that of mild steel (75 Mpa); stronger than most tree roots; improves soil shear strength by as much as 39%
- The fibrous mat of roots strengthens earthen structures and removes many contaminants from soil and soil water.
- Closely planted slips grow into dense hedgerows with a deep, tough root systems. They can withstand inundation, and effectively reduce flow velocities, forming excellent filters that prevent soil loss.

### THE PLANT -- VETIVER GRASS -- *Vetiveria zizanioides L (Nash) recently reclassified* ***Chrysopogon zizanioides L (Roberty)***

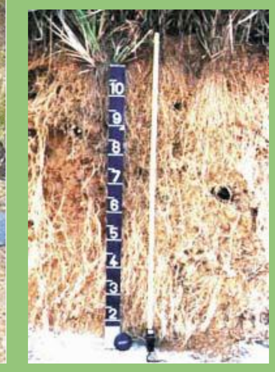

*Chrysopogon zizanioides L (Roberty)* previously named *Vetiveria zizanioides L (Nash)* common name: ***Vetiver Grass***


Planting slip


*Tissue cultivation of vetiver grass*


6 month vetiver root grown in Senegal


Cross section through a two year old hedgerow. Note sediment build up over original top soil (brown line)


*Longitudinal section through hedgerow*


*Newly planted vetiver hedgerow*

Large differences occur between the roots of vetiver grass species and cultivars. Compare *C. zizanioides* (upper) with *C. nemoralis* (lower)


*Indian vetiver nursery of containerized plants*


*Planting containerized vetiver on steep highway fill slope in Malaysia*


Vetiver inflorescence. In many cases vetiver never flowers, but when it does, it produces rather beautiful non-fertile flowers

### WHY VETIVER GRASS

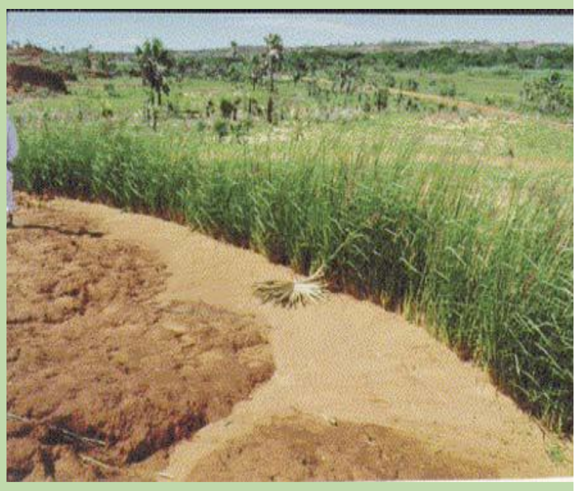
For a plant to be useful for agriculture and biological engineering, and be accepted as safe, it should have as many as possible of the following characteristics:

- Its seed should be sterile, and the plant should not spread by stolons or rhizomes, and therefore not escape and become a weed.
- Its crown should be below the surface so it can resist fire, over grazing, and trampling by livestock.
- It should be capable of forming a dense, ground level, permanent hedge, as an effective filter, preventing soil loss from runoff. Apparently only clones will grow 'into' each other to form such a hedge.
- It should be perennial and permanent, capable of surviving as a dense hedge for decades, but only growing where we plant it.
- It should have stiff erect stems that can, at minimum, withstand flowing water of 1 foot (30 cm) depth that is moving at 1 foot per second (0.3 meters/second).
- It should exhibit xerophytic and hydrophytic characteristics if it is to survive the extremes of nature. Vetiver grass, once established, is little affected and highly tolerant of droughts or floods.
- It should have a deep penetrating root system, capable of withstanding tunnelling and cracking characteristics of soils, and should the potential to penetrate vertically below the plant to at least three meters.
- It should be capable of growing in extreme soil types, regardless of nutrient status, pH, sodicity, acid sulphate or salinity, and toxic minerals. This includes sands, shales, gravels, mine tailings, and even more toxic soils.
- It should be capable of developing new roots from nodes when buried by trapped sediment, and continue to grow upward with the rising surface level, forming natural terraces.
- It should not compete with the crop plants it is protecting.
- it should not be a host (or intermediate host) for undesirable pests or diseases of any other plants.
- It should be capable of growing in a wide range of climates -- from 300 mm of rainfall to over 6,000 mm -- from air temperatures of -15º C (where the soil does not freeze) to more than 55º C. It should be able to withstand long and sustained droughts (>6 months).
- It should be cheap and easy to establish as a hedge and easily maintained by the user at little cost.
- It should be easily removed when no longer required.

**Vetiver Grass cultivars used around the world for essential oil production, originating from south India, have all these characteristics.**


Dense crown of a vetiver grass clump from which roots and shoots emerge


After a fire vetiver hedge remains vertical and quickly recovers with new growth


Erosion sediment trapped by a vetiver hedgerow in Madagascar.

Closely spaced (15 cm between plants at planting) hedgerow at left assures a properly dense hedge

Very dense and very effective vetiver hedgerow

### VS FOR AGRICULTURE

- **On-farm** - in modern and traditional agriculture VS is used to trap sediments, control runoff, increase soil moisture recharge, and stabilize soils during intense rainfall and floods. There is only minimal competition with adjacent perennial and annual crops for moisture or nutrients. VS is used for wind erosion control, forage, and pest control.
- **On-farm** - VS protects rural structures such as roads, ponds, drains, canals and building sites. Also used for land and gully rehabilitation.
- **Off-farm** - VS plays a vital role in watershed protection at large scales - slowing down and spreading rainfall runoff, recharging groundwater reserves, reducing siltation of drainage systems, lakes and ponds, reducing agrochemical loading into groundwater and watercourses, and for rehabilitation of misused land.






Top left: Vetiver hedgerows protecting farm crops on steep slopes in the highlands of N.E. Thailand

Top center: Vetiver hedgerow on Darling Downs, Australia, used to reduce erosive power of flooding on flat land -- as a result more land can be cropped each year

Top right: Farmers from Gundalpet, India, have used vetiver for centuries to reduce soil loss, conserve moisture, provide forage, and increase groundwater recharge

Bottom left: Vetiver hedgerow used to protect crops from high winds in Pintang Island, China

Bottom center: Vetiver used to stabilize a farm road in Malaysia

Bottom right: A irrigation drain/canal stabilized by vetiver hedgerow

# THE VETIVER SYSTEM
## A PROVEN SOLUTION
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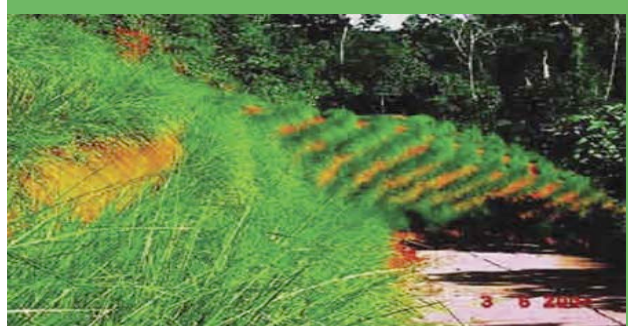
### VS FOR BIO-ENGINEERING

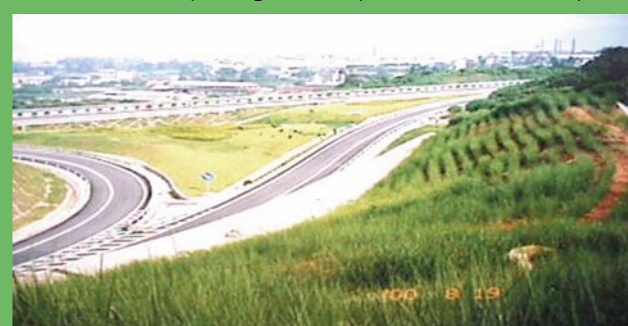
- For the stabilization and protection of infrastructure (roads, railroads, and building sites) VS is proven effective, efficient, and low cost when compared to other 'hard' engineering alternatives using cement, rock, and steel. Vetiver grass roots have an Mpa of 75 (1/6 the strength of mild steel) and will improve soil shear strength at a depth of 0.5 meters by as much as 39%. VS costs from 55% to 85% less than traditional engineering systems. **For successful applications cultivars of *Chrysopogon zizanioides* originally from south India should be used.** These cultivars are of the same genotype as Monto and Sunshine, and are **non-invasive.** They have a more massive root structure than non sterile *C.zizanioides* accessions from north India, Africa (*C.nigratana*) and Thailand (*C.nemoralis*)



The KEY to successful VS applications for infrastructure is the availability of large quantities of good quality vetiver planting material. Above, from left to right, are nurseries from Senegal (containerized), China (bare rooted) and Thailand (from in vitro plantlets)

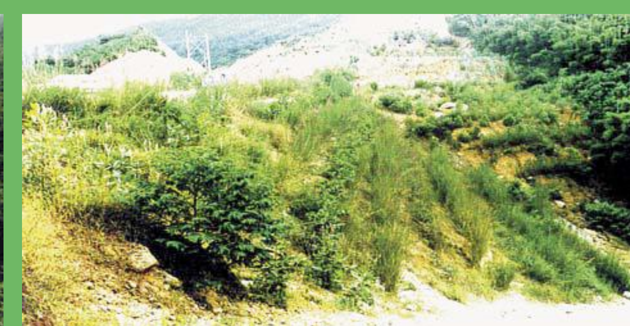


Venezuela - rehabilitation of bauxite mine tailings. The soils are very acid and prone to slippage. High levels of fertilizer assure good growth

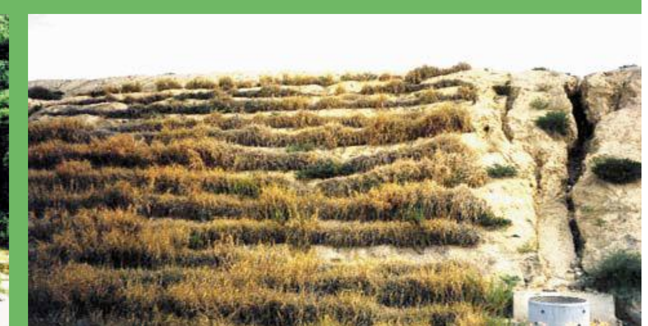


China - expressway stabilization. This cut was prone to massive slip. Stabilization with VS has given complete protection

China - unstable highway fill prior to VS treatment. Road stability was so bad in untreated state that major lateral cracks in the pavement occurred



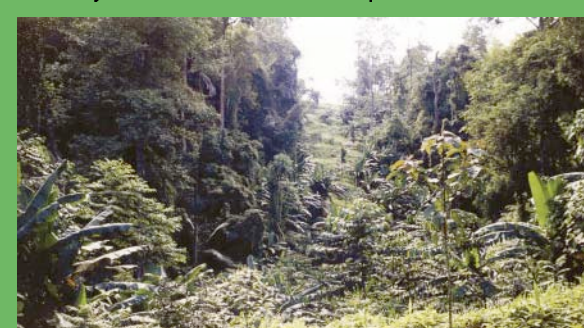
China - same fill less than a year later. After another two years this fill became fully forested. Untreated cut in background



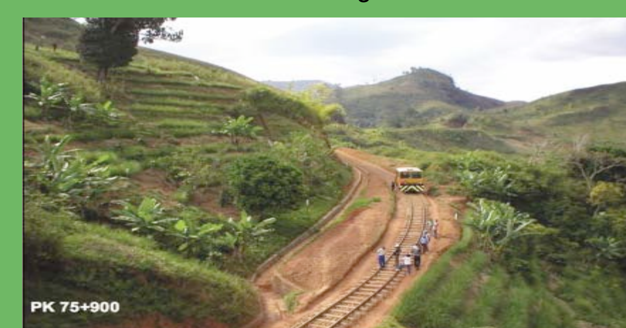
Spain - unstable and eroding highway fill treated with VS. Untreated eroded fill on right. VS grows well under low rainfall Mediterranean climate

Vietnam: the Ho Chi Minh Highway has been stabilized with vetiver grass. The batters and fills are stable and withstand cyclonic rainfall events


Vietnam - Ho Chi Minh Highway - with and without vetiver stabilization



Thailand - a gas pipeline was laid through tropical forest. On steep slopes the right of way was stabilized with vetiver - native plants regenerated




Disaster mitigation - this railroad in Madagascar was closed down by frequent cyclone damage. Stabilization with vetiver was vital in its rehabilitation

Congo D.R. - huge gullies that destroy urban areas and houses can be rehabilitated and stabilized using the Vetiver System.

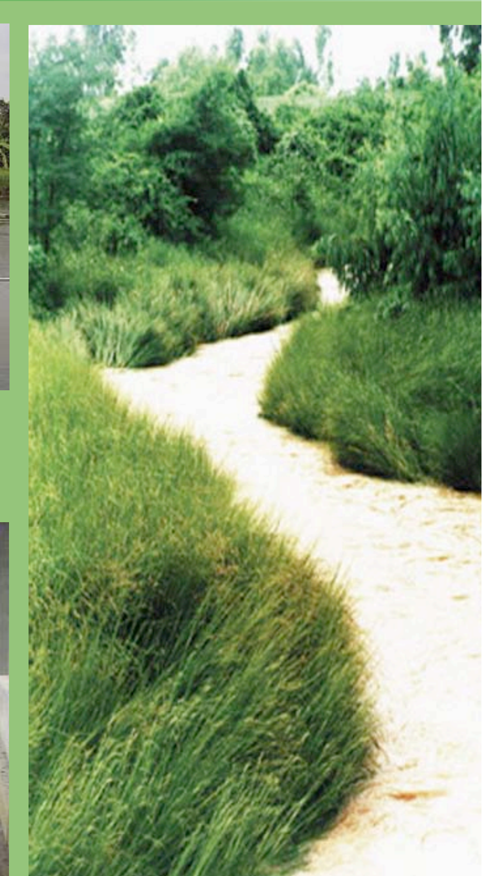
### VS FOR WATER RELATED APPLICATIONS

- VS protects ponds, reservoirs, and rivers banks from erosion caused by wave action, it strengthens earthen dams against collapse, and it reduces maintenance costs and ensures the integrity of dam walls, canal and river banks, and drains.
- VS improves groundwater recharge through improved infiltration and reduced rainfall runoff, and the quality of water by removing sediments and chemicals.

Venezuela - Vetiver withstands flooding for long periods. This grass was flooded for 8 months. Vetiver one month after flood receded

China - VS used to stabilize a small river bank located behind hedge allowing the safe production of crops

Vietnam - Vetiver is increasingly used to stabilize the banks of fishponds and to purify pond water

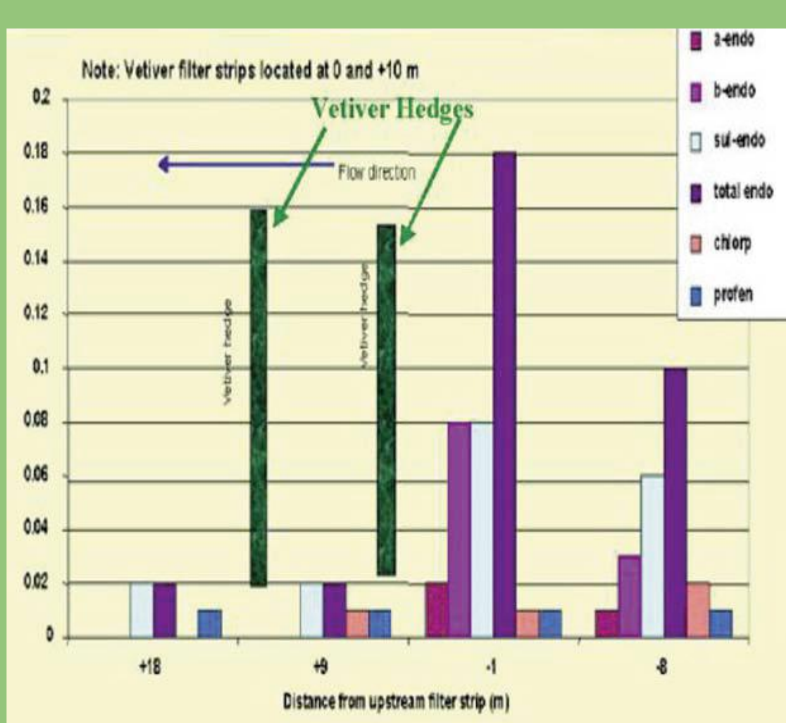


Zimbabwe - a fast flowing stream protected from stream bank erosion using VS application

Australia - VS protects the right hand bank of a drain cut through acid sulphate soils of Queensland. Note left hand bank is devoid of any vegetation

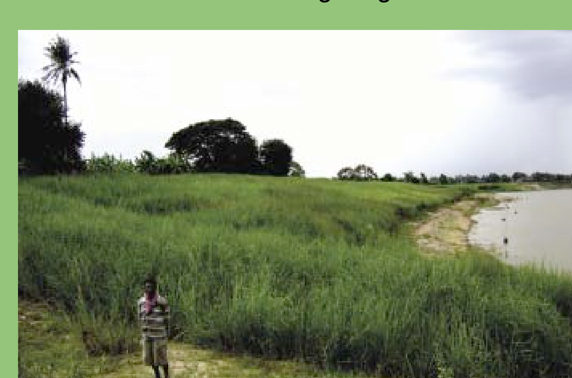
China - partially submerged vetiver grass used to stabilize the draw-down slope of a reservoir in Guangdong Province

Australia - this river bank and bridge abutment have been stabilized with vetiver. Vetiver is an excellent interface for concrete and soil

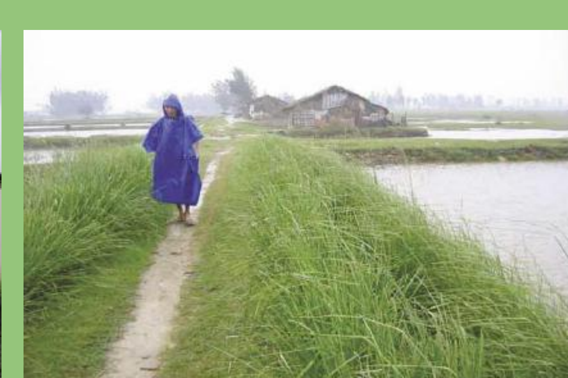



Australia - schematic of research results showing dramatic drop of pesticide levels as pesticide laden water moves through vetiver hedges from right to left. (Green columns = hedges - all other columns pesticide levels)

Cambodia - This very large bank on the Mekong River has been under continuous erosion. The land owner with assistance from TVNI is stabilizing using vetiver hedgerows.



Cambodia - the bank in the previous image has been reshaped and planted with vetiver hedgerows. Very good growth seven months after planting.



Vietnam - cyclone damage to sea dykes is a major problem. VS has been applied successfully for disaster mitigation

Vietnam - the left hand bank of the canal has been reshaped and stabilized with vetiver, the right bank has yet to be treated.

### VS FOR BIO-REMEDIATION

- Onsite and offsite pollution control from wastes and contaminants is a breakthrough application of VS for environmental protection. Vetiver is being used to rehabilitate a large copper mine in China, coal mines in Indonesia, diamond mine spoils in South Africa, to control erosion and leachate from municipal landfills in China…. and more.
- Research has clearly established vetiver's tolerance to extremely high levels of Al, Mn, As, Cd, Cr, Ni, Cu, Pb, Hg, Se, and Zn.
- Vetiver has been used to reclaim soils and increase site productivity in places that were previously believed to be totally unproductive.

Vetiver grass will remove phosphate and nitrate from polluted water. The beaker on the left is before treatment; on the right 4 days later 90% P and 94% N removed

Australia - VS used as a buffer to absorb seeping sewage from this holiday camp site thus reducing runoff and smells

Australia - VS used to stabilize a gold slimes waste area. The hedges reduce the incidence of wind-blown, cyanide-polluted dust

Australia - VS used hydroponically on a pig effluent pond to reduce high levels of phosphate and nitrate

### VS FOR OTHER USES

- In disaster mitigation and vulnerability reduction, VS has a crucial role to play…. "*The storms were terrible. [Afterward there were] landslides, roads destroyed, agricultural lands washed away; but, where there were vetiver barriers, everything seemed normal*". (pers. comm. Mr. E. Mas, USDA/NRCS after Hurricane George, Puerto Rico)
- For handicrafts, perfumes, and medicinal purposes.
- For paper making, mulch, thatch, reinforcing bricks, biofuel, pest control, carbon sequestering, and many other uses.

Thailand - a selection of handicrafts, including handbags, vases, lamp shades, book covers, hats and other crafts from vetiver grass leaves and stems

Zimbabwe - a nicely thatched meeting house using vetiver grass thatch. The thatch will last three times as many years due to its resistance to insects and fungus attack

### ACT NOW! **Contact TVNI for additional technical information.**


**The Vetiver Network International**
709 Briar Rd., Bellingham, WA 98225 USA

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**E-mail:** coordinator@vetiver.org

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**Vetiver Clients Gallery:** http://picasaweb.google.com/VetiverClients
**Vetiver Picture Gallery**:http://picasaweb.google.com/VetiverNetwork
**Blog:** http://vetivernetinternational.blogspot.com


The Vetiver Network (TVNI) is a nonprofit foundation under United States code 501 (c) (3). It is a volunteer organization that promotes the use of the Vetiver System through dissemination of information and networking worldwide. TVN has helped established over 25 regional and country-based affiliated networks.

**Contact your local vetiver network at:**

FOR SUCCESSFULL VETIVER SYSTEMS APPLICATION ONLY USE CULTIVARS OF *CHRYSOPOGON ZIZANIOIDES* WITH CHARACTERISTICS OF SOUTH INDIAN GENOTYPES - SUCH AS SUNSHINE, MONTO, KARNATAKA, FIJI, MADUPATTY. THESE NOT ONLY HAVE GOOD ROOT SYSTEMS, BUT ARE KNOWN TO BE NON-INVASIVE AND ARE EXTENSIVELY RESEARCHED