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14th February 2018

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Attention : Paul Jorgensen

Re: SIERRA RUTILE ENVIRONMENTAL, SOCIAL AND HEALTH IMPACT ASSESSMENT PROJECT (515234_SR Area 1 ESHIA)
SPECIALIST SOILS AND LAND CAPABILITY STUDIES

Dear Paul,

Attached herewith for your consideration is a draft of the baseline studies, environmental impact assessment and soil utilisation plan, part of the Sierra Rutile Environmental, Social & Health Impact Assessment (ESHIA) being undertaken by Iluka Resources Limited on their mining area in Sierra Leone.

The specialist studies cover the soils and land capability aspects of the proposed new mining areas associated with Area 1.

Yours faithfully,
Earth Science Solutions (Pty) Ltd

Ian Jones B.Sc. (Geol) Pr.Sci.Nat (400040/08), *EAPASA Certified*
Director Earth Science Solutions (Pty) Ltd

Earth Science Solutions

Project No: SRK.SRL.S.14.03.00.

SIERRA RUTILE PROJECT - AREA 1

ENVIRONMENTAL, SOCIAL & HEALTH IMPACT ASSESSMENT

SPECIALIST SOILS AND LAND CAPABILITY ASSESSMENT

Compiled for

srk consulting

SRK Consulting (South Africa) (Pty) Ltd.

FINAL REPORT

February 2018

Sustaining the Environment

LEAD CONSULTANTS: SRK Consulting (South Africa) (Pty) Ltd.

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Copyright	**ESS (Pty) Ltd.**			
Title	**Name**	**Capacity**	**Signature**	**Date**
Author	Ian Jones	Director		14th February 2018
EIA manager				
Technical Review				

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Declaration

This specialist baseline report has been compiled in terms of the Sierra Leone Environmental Legislation and the International Finance Corporation (IFC) Performance Standards, and forms part of the Environmental, Social and Health Impact Assessment (ESHIA) being updated and amended for Iluka Resources Limited on the Sierra Rutile Project - Area 1, both as a standalone baseline document and as supporting information to the overall impact assessment and management plan.

The specialist Soils and Land Capability studies were managed and signed off by Ian Jones (Pr.Sci.Nat. 400040/08) who is an Earth Scientist with 39 years of experience in these fields of expertise.

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 baseline studies are to:

- Provide a permanent record of the present soil resources in the areas that are potentially going to be affected by current and future mining and associated activities;
- Assess the nature of the site in relation to the overall environment and its present and proposed utilisation, and determine the capability of the land in terms of its utilisation potential; and
- Provide a base line of information from which long-term ecological and environmental decisions can be made, impacts of the development on the environment can be assessed and measured, and mitigation measures can be formulated.

The Taxonomic Soil Classification System (TSCS) in combination with the World Reference Base for Soil Naming – International Soil Classification System (ISCS) were consulted in classifying and characterising the soils of the study area, while the Canadian Land Inventory System in association with the British Land Capability Rating Systems were used in the assessment and rating of the land capability. These systems are recognised nationally and internationally and meet the World Bank Environmental Health and Safety (EHS) Guidelines and International Finance Corporations (IFC) Performance Standards.

Signed: 14th February 2018

Ian Jones B.Sc. (Geol) Pr.Sci.Nat 400040/08
Director – Earth Science Solutions (Pty) Ltd

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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.
Calcrete:	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 (Figure 3.3).
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. The attraction within a soil structural unit or through the whole soil as found in apedel soils.
Concretion:	A nodule made up of concentric accretions.
Crumb:	A soft, porous more or less rounded ped from 1mm to 5mm in diameter. Refer Texture, 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.
Diagnostic horizons:	A system of classify the soils based on changes in the different layers that make up the soil profile. The horizons have defined criteria that classify them as different from all others. These are also referred to as “Master Horizons” in the Taxonomic System (Table 2.3a).
Dystrophic	Three classes of base status are defined and referred to in terms of the sum of the ratio of major nutrient cations (Ca, Mg, K and Na) to the clay % in the soil. If the sum is less than 5 (indicating low inherent fertility and/or strongly weathered profile); **mesotrophic** - if the sum is between 5 and 15 inclusive (indicating moderate inherent fertility and/or moderately weathered profile); and **eutrophic** if it is greater than 15 (indicating relatively high inherent fertility and/or low degree of profile weathering).
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) representing more than 60% of the sand fraction.
Fine textured soils:	Soils with a texture of sandy clay, silty clay or clay (Refer to Texture).
Hardpan:	A massive material enriched with and strongly cemented by sesquioxides, chiefly iron oxides (known as ferricrete, diagnostic hard plinthite), silica (silcrete, dorbank) or lime (diagnostic hardpan carbonate-horizon, calcrete). Ortstein hardpans are cemented by iron oxides and organic matter.
Hydromorphy:	A term describing the wetness of soils.
Illuviation:	The accumulation of dissolved or suspended soil materials in one area or horizon as a result of eluviation from another.
Hygrophilous:	Growth of plants in moist places.

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

Land type: A class of land with specified characteristics.

Land use: The use to which land is put by the local population. The use of land for anything other the natural occurring condition.

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 to 50%; many, more than 50%), hardness (soft, hard meaning barely crushable between thumb and forefinger, indurated) and size (threadlike, fine, medium 2 to 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 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.

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.

Soil sensitivity: Soil sensitivity is the estimate of a soil's ability to maintain its original strength when impacted or disturbed.

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

Sodium adsorption ratio (**SAR**): A measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. It is also a measure of the **sodicity** of soil, as determined from analysis of water extracted from the soil.

Soil horizon: A soil horizon distinguishes between layers within a soil profile that have distinguishable characteristics that are different from those above or below. These horizons are generally given an alphabetic nomenclature, with "A" "O" representing the organic layer (normally on top, with "A", above "B" over "C" – Figure 2.3a.

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 Figure 2.3b). The pure sand, sand, loamy sand, sandy loam and sandy clay loam classes are further subdivided according to the relative percentages of the coarse, medium and fine sand - Figure 2.3b.

Vertic, diagnostic A-horizon: A-horizons that have both, 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 and ped faces are shiny.

Vulnerability: Susceptibility to physical change.

1. INTRODUCTION

1.1 Introduction

Sierra Rutile Limited (SRL), a wholly owned subsidiary of Iluka Resources Limited (Iluka), is an existing mining operation located in the Bonthe and Moyamba Districts of the Southern Province of Sierra Leone. The mine has been in operation for over 50 years and produces rutile, ilmenite and zircon rich concentrate. SRK Consulting (South Africa) (Pty) Ltd (SRK) was appointed by SRL to undertake an Environmental, Social and Health Impact Assessment (ESHIA) and develop an Environmental, Social and Health Management Plan (ESHMP) for Area 1 that meets the Sierra Leonean legal requirements, Iluka's corporate policies, and is aligned with good international industry practice (GIIP). The ESHIA being undertaken also serves as an update to the previously undertaken Environmental and Social Impact Assessments (ESIA's) and associated management plans to include the dry mining process and associated activities, as well as community health aspects.

Earth Science Solutions (ESS) (Pty) Ltd was appointed by SRK to undertake the soils and land capability assessments for the on-going and future mining activities for the Project (Area 1).

The information provided in this baseline report presents the basis for assessment of potential impacts by the mining project and also informs soil utilisation and "End Land Use" planning

The principal component of this study includes:

- The mining areas and associated support infrastructure - The mining areas (existing, inferred, measured and indicated resources), supporting infrastructure such as internal haulage roads and stockpile footprint areas of utilisable soil storage.

The study was confined to areas that will be disturbed by the additional mining that is being planned as part of the on-going development and extraction of the heavy mineral sands in Area 1.

The area of concern includes both measured and inferred resource blocks, the areas having been drilled and delineated (Figures 1.1) as part of the on-going exploration for added resource.

The relative size and spatial extent of the study area was established based on the project description and planned activities.

The intensity of assessment varied depending on the complexity of the materials being mapped, and the degree of possible impact that could be expected based on the information available at the time of study.

This report describes the in-field methods used to classify and describe the soils, rates land capability based on the soil characteristics and related geomorphological information (climate, ground roughness, and topography), and gives details of the present state of the soil environment.

The results are important to the baseline information and give a pre-development record from which planning decisions can be made in terms of the soil workability and site sensitivities as well potential impact to the eco system services and the requirements for rehabilitation.

Rehabilitation and the closure of any mining development is important in terms of the overall sustainability of a project, a factor that is best considered earlier rather than later in a projects planning.

A major part of any closure strategy involves the reinstatement of the soils, and the vegetative cover. As part of this equation are an understanding of the depth of soil or soil rooting depth and the soil water retention properties of the utilisable soil retained and made available for use in the rehabilitation process.

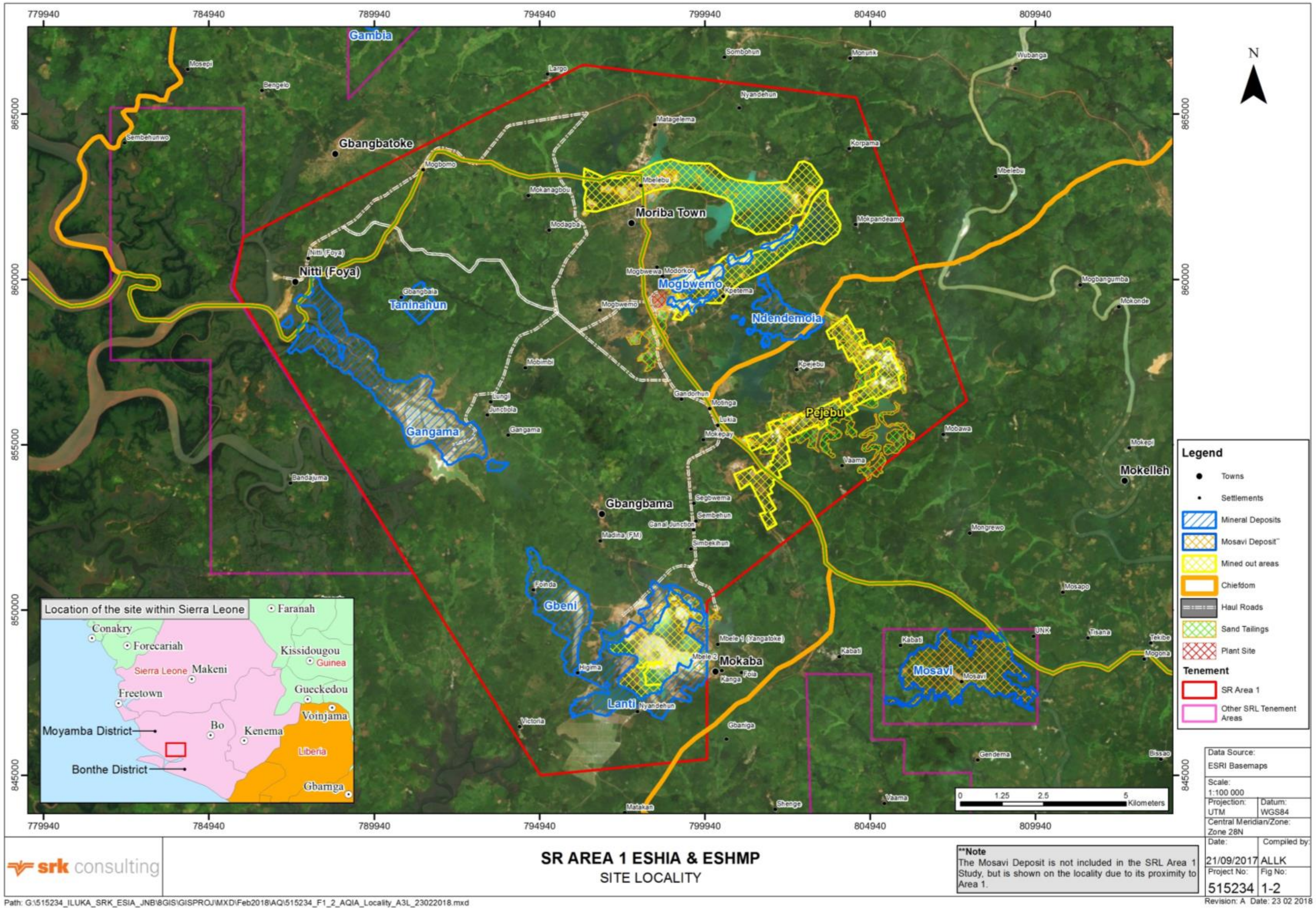

Figure 1.1 Project location and study area

These specialist assessments (soil and land capability) are guided by the principles and standards of the World Bank Guidelines (Equator Principles and International Finance Corporation (IFC) Performance Standards), and the general rights and obligations of the company in terms of the Sierra Rutile Act 2002.

This report has been written as a standalone document. However, it should be read in conjunction with the ESHIA report being compiled by SRK.

1.3 Scope of Work

The Scope of Work (SoW) was based on the Terms of Reference (ToR) and consideration of the existing and expected activities and their associated risks and impacts. To this end, a number of geomorphological parameters (climate, geology, topography, ground roughness etc.) and soil characteristics were considered and classified using the Taxonomic Soil Classification System *(*Mac Vicar *et al,* 1991) and cross referenced with the International Soil Classification System (World Reference Base for Soil Naming).

This information was in turn used to rate the land capability of the study area using a combination of the British Land Capability System and the Canadian Land Inventory (CLI) System.

The SoW included the:

- Assessment and characterisation (classification/rating) of baseline, soils and land capability conditions;
- Classification of soil forms and dominant soil groups based on physical and chemical properties;
- Production of a “dominant soils” map for the study area as an aid to project planning;
- Rating of existing/present land capability;
- Development of soil utilisation principles based on the site-specific information obtained; and
- Interpretation of the above information as inputs to impact assessment and rehabilitation planning.

It was assumed for the purpose of this study, that:

- The study area covers the measured and inferred resources;
- The base plan issued to the team is the most recent available, and that it is accurate and geo-referenced, and
- Any/all previous information have been made available.

1.4 Legal

The legal requirements specified by the government of Sierra Leone are aligned to the Mines and Minerals Act, 2009, the Environmental Protection Agency Act, 2008, the Environmental Protection (Mines and Minerals) Regulations 2013 and The Sierra Rutile Agreement (Ratification) Act, 2002.

2. APPROACH AND METHODOLOGY

2.1 Introduction

The approach to the study was tailored to the understanding of the different elements of:

- The existing mining operation;
- The future mining operations;
- How these elements may impact soils and land capability; and
- Management and mitigation measures that could be considered as part of the soil utilisation and management plan.

The existing mining areas have been considered as part of the proposed management plan, albeit that many of the roads and buildings would potentially be left to the communities on closure.

The baseline assessment needed to provide robust data that would enable:

- Identification of potential project-related impacts; and
- Address the land capability issues that have been raised by stakeholders and/or affected parties.

The level of study and intensity of observations was guided by a number of practical variables. These included the:

- Accessibility of sampling sites;
- Type and severity of potential impact anticipated, and
- Complexity and sensitivity of the soils encountered during the site evaluation.

Interaction with SRK, the client's representative and on-site personnel was invaluable in accessing and understanding the areas to be disturbed and the types of activity to be undertaken, while the accessibility to the areas of concern levelled some minor restrictions to the studies and determined the intensity of study possible.

2.2 Data Sources

At the outset, existing geological and topocadastral maps of Area 1 were used to gain an overview of the study area. Colour imagery (LiDAR) was only obtained from the client while on site and the site assessment base map used was confined to the most recent Google Imagery during the field studies.

The LiDAR image was used as the final base map onto which the field information was mapped and the final interpretation was carried out.

The logs of the geotechnical test pits undertaken on each of the areas were used to obtain a better profile and understanding of the soil profile and catena across the study area.

The local geology is described in a report entitled "Geology of the Sierra Rutile Deposit" compiled by MTG Button (August 2011), and catalogues the history of the heavy mineral bearing sands and their discovery in 1920 by the Gold Coast Geological Survey. The first exploration was undertaken in 1955 and mining commenced in 1961.

The heavy mineral deposits of SRL are proximal alluvial placers in origin, with the primary source of mineralisation derived from the quartzo-feldspathic gneisses of the Precambrian (2.1ba) Kasila Group (refer to Figure 3.1a). The heavy mineral suite is hosted within the Bullom Group, the onset of which marked the end of the late Tertiary marine regression.

Sea levels at this time were approximately 100m below the present levels, exposing the basement rocks of the Kasila Group to erosion. Mechanical and chemical degradation of the Kasila gneisses to form kaolinite and other clay minerals subsequently liberated the heavy minerals where they were eroded and deposited into pre-incised channel systems. It is these systems that have been mined and exploration is concentrated on for the on-going mining of the heavy mineral sands.

Existing soils information is limited to the regional descriptions given in the 2001 and 2012 ESIA and the Scoping Study that was made available by SRK. This information provides a high-level understanding of the land capability and associated earth sciences variables for the area.

Other information sources consulted included the studies done by R. Hatting h *et al.* on Mine Closure, R. Hattingh and C. Viljoen on soil water retention properties as the key driver for rehabilitation**,** and H. Kotzé, R. Hattingh and C Ballot on Economic Viability of Rehabilitated Sugarcane Agriculture.

Important from these studies and outcomes for this investigation are:

- The soil water balance and how a soil depends on effective rainfall, surface water run-off, ease of infiltration, water holding capacity, percolation, and losses by transpiration through plants and by evaporation from the soil surface;
- The retention properties of the utilisable soil, and
- The effective rooting depth requirements for natural vegetative sustainability and the economic viability of any rehabilitation design.

2.3 Soil Characterisation and Classification

The majority of observations used to classify the soils were made using a hand operated Bucket Auger or Dutch (clay) Auger to expose the soil profile. A Tractor Loader (TLB) was employed where practical to better expose the soil profile to depth and obtain relatively undisturbed samples from the different soil horizons.

The geomorphology of the study area was also used, the climate, geology, ground roughness, wetland status and terrain morphology all considered important in understanding the pedogenesis (soils formation) and the land capability status.

Approximately 180 observations were made as part of the field investigation and 65 samples were taken, with 45 site-specific samples submitted for physical and chemical analysis, five of these submitted for bulk sample and engineering tests (Refer to Figure 3.3.2b).

The soil samples were taken from the active zones within the profile, distinction being made between the top soil "A" horizon, upper portion of the sub soil ("B2/1" horizon) and the underlying saprolite or plinthite "C" horizons. Sampling was confined to the "A" and "B2/1" horizons. This zone has been characterised as the "utilisable soil" horizon or "Effective Rooting Depth" (ERD), the area in which most/the majority of the plant requirements are obtained (nutrient and water reserves).

The soil characterisation and classification were confined by the depth of observation (soil auger and/or excavation using TLB), the majority of the classification being undertaken using the hand auger. The effective root depths are a function of the root density as observed in the hand augering, a characteristic that is difficult to estimate as these aspects are disturbed by augering, while the test pits were for the most part confined to roadways and tracks outside of the natural forest or cultivated lands. This was a necessity as a result of social and compensation considerations.

The soil observations were tailored to the accessibility to the land, the grid-based approach being used to guide the study and obtain scientifically meaningful data based on the Project Design as detailed in the Scoping report (515234_Sierra Rutile Scoping Report Area 1_20170530).

The identification and classification of soil profiles were carried out using a Taxonomic Soil Classification System (Mac Vicar *et al*, 1991) and the World Reference Base (WRB) for Soil Resources 2014 (International Soil Classification System for naming soils and creating legends for soil maps – Updated 2015) – Food and Agricultural Organisation of the United Nations – Rome 2015.

The soil forms described in the Taxonomic Classification, a System for South Africa (Macvicar 1991) may not be entirely relevant to Sierra Leone, but the systematic identification of diagnostic soil horizons using this Taxonomic System (or the FAO system) is relevant, and has been used as the mapping methodology.

The Taxonomic System 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/master horizons (Refer to Figure 2.3a).

The soil forms are then subdivided into two or more soil families, each of which have in common the properties of the Soil Form but are differentiated within the major division (Soil 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.

In addition to classifying and characterising the soil the physical and chemical characteristics (nutrient and metals) of the materials are used to highlight any site-specific sensitivities. For ease of interpretation and to assist the management team with soil utilisation and management, the soil forms are further combined into "dominant soil groups", each group having similar characteristics and sensitivities to being disturbed, producing mapping units that can be used in designing a practical soil utilisation and management plan.

The assessment of sensitivity includes consideration of the sites susceptibility to erosion, removal of vegetative cover, the chemical nature of the materials and their vulnerability to being taken into solution as well as the structural integrity of the materials when disturbed by mechanical means.

The field procedure for classifying a soil profiles includes:

i. Demarcation of master horizons;
ii. Identify applicable diagnostic horizons by visually noting the physical properties:
    - 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);
    - Compaction (from surface);
iii. Determine from i and ii the appropriate soil form; and
iv. Establish provisionally the most likely soil family.

<table>
<tr><td rowspan="11">SOLUM</td><td rowspan="11">(Zone in which the soil forming processes are maximally expressed)</td><th colspan="6">Arrangement of master horizons</th><th>Comments on Layers</th></tr>
<tr><td rowspan="10">O - Organic</td><td rowspan="5">G = Regic Sands (C), Stratified Alluvium (C), Man - Made Soil Deposits (C).</td><td rowspan="2">A</td><td rowspan="2">Humic,Vertic, Melanic, Orthic</td><td rowspan="10">G</td><td>Loose leaves and organic debris, largely undecomposed</td></tr>
<tr><td>Organic debris, partially decomposed or matted</td></tr>
<tr><td rowspan="3">B</td><td rowspan="3">Red Apedel, Yellow-brown Apedel, Soft Plinthic, Hard Plinthic, Prismacutanic, Pedocutanic, Lithocutanic, Neocutanic, Neocarbonate, Podzol, Podzol with placic pan</td><td>Dark coloured due to admixture of humified organic matter with the mineral fraction</td></tr>
<tr><td>Light coloured mineral horizon</td></tr>
<tr><td>Transitional to B but more like A than B</td></tr>
<tr><td rowspan="4">C</td><td colspan="2" rowspan="4">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</td><td>Transitional to A but more like B than A</td></tr>
<tr><td>Maximum expression of B-horizon character</td></tr>
<tr><td>Transitional to C</td></tr>
<tr><td>Unconsolidated material</td></tr>
<tr><td colspan="3">R - Hard Rock</td><td>Hard rock</td></tr>
</table>

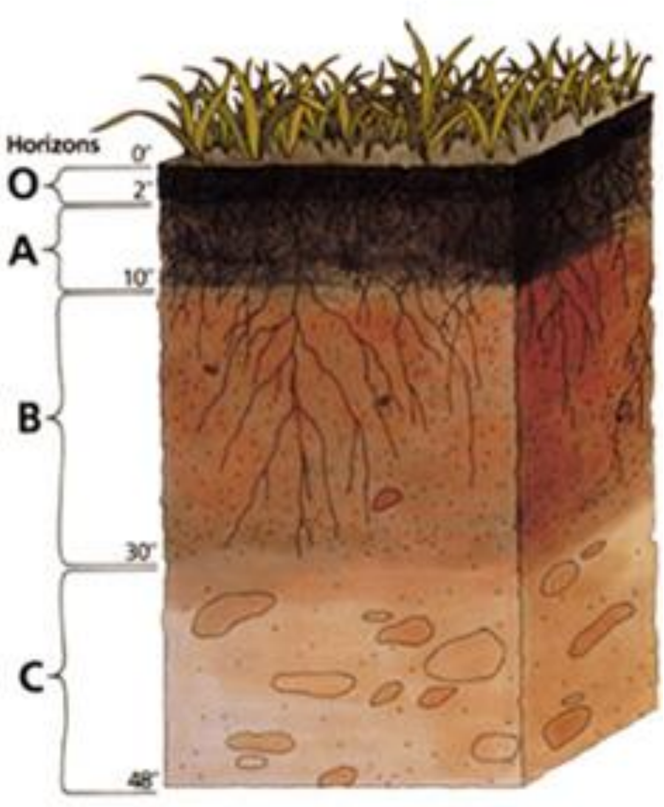

Figure 2.3a Typical Arrangement of Master Horizons in Soil Profile

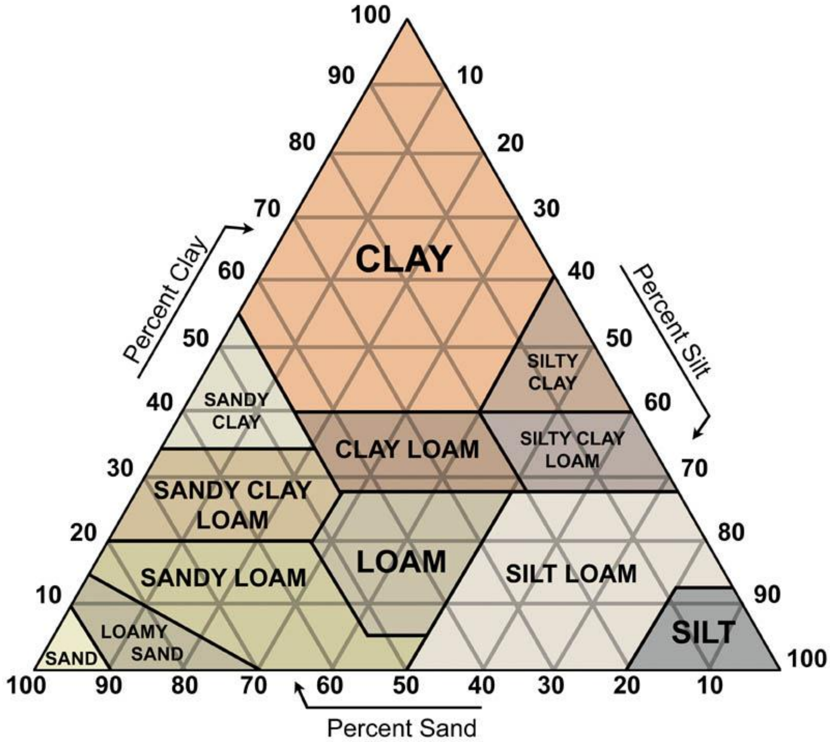

Figure 2.3b Soil Textural Classes

2.4 Soil Sampling

The soil survey was undertaken during June and early July of 2017. The study area was assessed on a variable grid base intensity of between 200 m^2 and 450 m^2 depending on the complexity of the soil patterns, the accessibility to the areas and the degree of potential impact.

In addition to the grid point observations (Refer to Figure 3.3.2b and Appendix 3), a representative selection of the soil forms mapped were sampled and analysed to determine their chemical and physical attributes (Refer to Table 3.3.3a – Soil Chemical Analysis, and 3.3.3b for the Physical Analysis).

The samples (top 300mm "A" horizon and 300mm to 600mm "B2/1" horizon) were bagged and packed for transportation to an accredited laboratory for analysis (NviroTek Labs – 2007/029712/07). The sample results are representative of the point from which they were taken and not necessarily of the soil form in general. However, the results do indicate a degree of similarity and show consistency within the soil groups as mapped.

Specific sampling and analysis of specific sites should only be considered during the design phase if considered necessary, and possibly more importantly during the rehabilitation phase when the soils are being reinstated.

Section 3 (refer to Table 3.3.2) provides the results of laboratory analyses of the soils sampled.

2.5 Data Analysis

The methods used for analysis of the soils and sediments included (Refer to Appendix 3 for Certification methods used by the laboratory):

- Spectro Atomic Analyser for the determination of the basic elements;
- Titration method for the determination of Organic Matter content;
- Density meter for the determination of the clay content;
- Sieve analysis for determination of the grading characteristics; and
- Engineering tests for the soil physical attributes.

Laboratory analytical parameters included:

- Determination of pH;
- Exchangeable bases;
- Cation exchange capacity (CEC);
- Texture (% clay); and
- Nutrient status.

2.6 Land Capability Classification and Rating

A number of systems were considered in classifying and rating of the land capability. Most of the systems are area or country specific, and although the parameters considered are relevant, the system needed to be adapted for the unique conditions that a site presents.

In the case of Sierra Rutile Limited, the depth of the soils and their inherently silty to sandy nature coupled with the variable geomorphology require a versatile approach. In achieving this versatility both the British Land Capability (BLC) methodology (adapted from the US Department of Agriculture) and the Canadian Land Inventory System were consulted, with a simplified version of the BLC system being adopted.

The classification is based on an assessment of the capability of the land from known ecosystem relationships (local crop production yields and management) and the physical characteristics of the soil, topography, climate etc.

The system is essentially a negative approach in which land is graded according to mixed qualitative and quantitative measures of limitations to land capability. In the BLC System there are seven land capability classes.

The upper class (1) has a wide range of uses with few (if any) limitations, while the remaining six classes suffer from increasingly severe limitations and are progressively less flexible in the range of their potential land uses. Land capability subclasses are defined on the basis of one or more permanent or semi-permanent physical factors that limit production. Each of these subclasses is denoted by a letter (w, s, g, e, c) attached to the relevant class number (e.g. 2w or 6gs). These are outlined in Table 2.1 below.

Table 2.1 Defined classes

Class	Description	Suitable uses
1	Land with very minor or no physical limitations to use.	Any, esp. arable
2	Land with minor limitations that reduce the choice of crops and interfere with cultivations.	Any, esp. arable
3	Land with moderate limitations that restrict the choice of crops and/or demand careful management.	Arable/pasture
4	Land with moderately severe limitations that restrict the choice of crops and/or require very careful management practices.	Pasture/arable
5	Land with severe limitations that restrict its use to pasture, forestry and recreation	Pasture/forestry
6	Land with very severe limitations that restrict use to rough grazing, forestry and recreation	Rough pasture/forestry/rec.
7	Land with extremely severe limitations that cannot be rectified	Recreation only

Subclass limitations:

Wetness (w)
This includes interactions between soil properties, relief and climate resulting in wet soils which cause problems of delayed spring growth, compaction and puddling by farm machinery, poor root development, asphyxiation, denitrification, etc. Wetness may result from:

- Low permeability (especially in fine textured soils such as clays);
- Impermeable layers (e.g. indurated layers and ferricretes/ironpans);
- High groundwater table;
- Flushing by springs;
- Flooding from streams and rivers; and
- High rainfall.

Soil limitations (s)
These include shallowness, stoniness, poor soil texture and structure or inherent low fertility. Shallow soils can have low available water capacities and restrict rooting and adequate nutrient uptake. Ploughing may be impractical if the bedrock is too near the surface. Stony soils affect plant growth and farm operations depending on the size and number of stones. Stones hinder growth and mechanised harvesting of root crops whilst reducing water capacity and nutrient uptake depending on their geology. Soil texture and structure affect drainage and permeability. Water capacity is determined largely by soil texture (i.e. clay = high and sandy = low). Naturally low soil fertility can be difficult to correct by management and so is included as a physical limitation.

Gradient and soil pattern limitations (g)
Gradient (or slope) has a marked effect on mechanised farming as presented in Table 2.2.

Table 2.2 Gradient and soil pattern limitations (g)

Gradient	g Class	Problems
0-3	Gently sloping (1)	None
03-Jul	Moderately sloping (2)	Difficulties with weeders, precision seeders and some mechanised root crop harvesters
07-Nov	Strongly sloping (3)	Use of combine harvester restricted
Nov-15	Moderately steep (4)	Limit of use of combine harvester and of two-way ploughing (depending of field configuration)
15-25	Steep (5)	Not suitable for arable crops, with slopes over 20 being difficult to plough, lime or fertilise
>25	Very steep (6)	Mass movement occurs, animal tracks across slope appear and mechanisation impossible without specialised equipment

Soil pattern can affect capability in that small and intricate variations can mean that a mixture of land of poor capability prevents the cultivation or land of good capability (e.g. variation in soil depth can be marked).

Liability to erosion (e)
Two major forms of erosion are recognised: wind and water. Wind erosion is prevalent on sandy or light peat soils in exposed conditions, especially when the vegetation cover is removed. Water erosion includes coastal erosion, sheet, rill and gully erosion on steep bare slopes (or even gentle slopes after very heavy rainfall) and river bank erosion.

Climatic limitations (c)
Differences in macroclimate influence land capability. Emphasis is placed on water balance and temperature during the main part of the growing season (i.e. April - September) to delineated three climatic groupings as defined in Table 2.3 below.

Table 2.3 Climatic groupings for land capability

Group	Definition
I	R-PT < 100mm and T(x) > 15C - No or only slight climatic limitations imposed on crop growth.
II	R-PT < 300mm and T(x) > 14C - Moderately unfavourable climate which restricts choice of crops.
III	R-PT > 300mm or T(x) < 14C - Moderately severe to extremely severe climatic which further limits the range of crops.

where R = average rainfall (mm)
PT = average potential transpiration (mm)
T(x) = long term average of mean daily maximum temperature

Assumptions:
The object of the classification is to present the results of soil surveys and limitations data in a form which is of use to farmers, agricultural advisors, planners and other land users. There are a number of important assumptions associated with this method. These are:

1. The classification is primarily for agricultural purposes;
2. Land is assessed on its capability under a moderately high level of management and not necessarily under its present use;
3. Land which suffers from limitations that can be removed or reduced at acceptable cost is graded on the basis of the remaining limitations;
4. The capability classification may be changed by major reclamation projects which permanently alter previous limitations;
5. Within classes soils may differ in their management and fertiliser requirements but are grouped together because they possess similar limiting factors (i.e. the classification is not affected by profitability);
6. Within specific subclasses are soils with different management requirements (e.g. in an area classified as 3w the wetness may result from either slow infiltration or a high water table; each of which require different management);
7. The system is based on permanent or semi-permanent physical limitations but where a severe chemical limitation is present this may be recognised as a soil limitation;
8. Distance to markets, road access and farm structure are not considered although they will affect decisions about land use;
9. The interpretive nature of the system means that when new data and/or knowledge is acquired then the classification may change; and
10. The system is not a soil suitability classification for specific crops (e.g. for dairy farming or forestry) further interpretations of soil maps are required for such purposes.

Table 2.4 Guidelines for the recognition of capability classes

Class	Description, subclass and comment	
Class 1	Land with very minor or no physical limitations to use: - Soils are usually well drained, deep (more than 75cm) loams, sandy loams or silty loams, related humic variants or peat, with good reserves of moisture or with suitable access for roots to moisture; they are either well supplied with nutrients or responsive to application of fertilisers. The land is level or gently sloping (usually less than 3) and climate favourable; altitude below 150m.	
	Comment: A wide range of crops can be grown, and yields are good with moderate inputs of fertiliser.	
Class 2	Land with minor limitations that reduce the choice of crops and interfere with cultivation.	
	Subclass	Limitations may include, singly or in combination, the effects of:
	W	- Moderate or imperfect drainage;
	s	- Less than ideal rooting depth (not less than 50cm) and/or slightly unfavourable soil structure and texture;
	g	- Moderate slopes (not greater than 7);
	e	- Slight erosion;
	c	- Slightly unfavourable climate (altitude usually below 230m).
	Comment: A wide range of crops can be grown though some root crops and winter harvested crops may not be ideal choices because of harvesting difficulties.	
Class 3	Land with moderate limitations that restrict the choice of crops and/or demand careful management.	
	Subclass	Limitations may result from the effects of one or more of the following:
	w	- Imperfect or poor drainage;
	s	- Restriction in rooting depth (not less than 25cm) and/or unfavourable structure and texture;
	g	- Strongly sloping ground (not greater than 11);
	e	- Slight erosion;
	c	- Moderately unfavourable to moderately severe climate (more than 1000mm annual rainfall and altitudes usually below 380m).
	Comment: The limitations affect the timing of cultivation and range of crops which are restricted mainly to grass, cereal and forage crops. Whilst good yields are possible, limitations are more difficult to correct.	

Class	Description, subclass and comment	
Class 4	Land with moderately severe limitations that restrict the choice of crops and/or require very careful management practices.	
	Subclass	Limitations are due to the effects of one or more of the following:
	w	- Poor drainage difficult to remedy and/or occasionally damaging floods;
	s	- Shallow and/or very stony soils but capable of being ploughed;
	g	- Moderately steep gradients (not greater than 15);
	e	- Slight erosion, especially loose or sandy soils in exposed areas;
	c	- Moderately severe climate (more than 1270mm annual rainfall and altitudes usually below 460m).
	Comment: Climatic disadvantages combine with other limitations to restrict the choice and yield of crops and increase risks. The main crop is grass, with cereals and forage crops as possible alternatives where the increased hazards can be accepted.	
Class 5	Land with severe limitations that restrict its use to pasture, forestry and recreation.	
	Subclass	Limitations are due to one or more of the following defects which cannot be corrected:
	w	- Poor or very poor drainage and/or frequent damaging floods;
	s	- Soils too shallow or stony to plough satisfactorily;
	g	- Steep slopes (not greater than 25 and usually less than 20);
	e	- Severe risk of erosion;
	c	- Severe climate (altitude usually below 530m).
	Comment: High rainfall, exposure and a restricted growing season prohibit arable cropping although mechanised pasture improvements are feasible. The land has a wide range of capability for forestry and recreation.	
Class 6	Land with very severe limitations that restrict use to rough grazing, forestry and recreation.	
	Subclass	Of the following limitations one or more cannot be corrected:
	w	- Very poor drainage and/or liable to frequent damaging floods;
	s	- Shallow soil, extremely stony or boulder strewn;
	g	- Very steep slopes (greater than 20);
	e	- Severe erosion;
	c	- Very severe climate (usually below 610m).
	Comment: The land has limitations which are sufficiently severe to prevent the use of machinery for pasture improvement. Very steep ground which has some sustained grazing value is included. On level or gently sloping upland sites wetness is closely correlated with peat or humus flush soils.	
Class 7	Land with extremely severe limitations that cannot be rectified.	
	Subclass	Limitations result from one of more of the following defects:
	w	- Very poor drainage; boggy soils;
	s	- Extremely stony, rocky or boulder strewn soils, bare rock, scree or beach sands and gravels; untreated waste tips;
	g	- Very steep gradients (generally greater than 25);
	e	- Severe erosion;
	c	- Extremely severe climate (altitude over 610m).
	Comment: Exposed situations, protracted snow cover and a short growing season preclude forestry though a poor type of rough grazing may be available for a few months.	

With the site-specifics of climate soil and geomorphology at hand, the system has been simplified for ease of use, combining some of the classes so that there are four dominant classes used to describe/classify and rate the capability of the study area.

Combining the class 1 and 2 categories in the definitions given above as “Arable”, while classes 3 and 4 are considered of a “Subsistence/Grazing” land capability, classes 5 and 6 as “Wilderness/Natural Conservation” status, and class 7 as having a “Wetland” rating.

The criteria have further been simplified (refer to Table 2.5) and described in terms of the site-specific conditions, with climate being one of the variables that is quite different to that used in the cool temperate to cold climates associated with Britain and the European states.

Table 2.5 Simplified - Criteria for Land Capability Classification & Rating

Criteria for Wetland Status

- Land with organic soils or supporting hygrophilous vegetation where soil and vegetation processes are water dependent. This rating requires both soil and ecological inputs (fauna and flora) as part of the classification.

Criteria for Arable Land Status

- Land, which does not qualify as wetland status;
- The soil is readily permeable to a depth of 750mm;
- The soil has a pH value of between 4.0 and 8.4;
- The soil has a low salinity and Sodium Absorption Ratio (SAR);
- The soil has less than 10% (by volume) rocks or pedocrete fragments larger than 100mm in the upper 750mm;
- Has a slope (in %) and erodibility factor ("K") such that their product is <2.0; and
- The land is able to support crop yields that are at least equal to the current national average for the particular crops being considered.

Criteria for Subsistence/Grazing Land Status

- 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 250mm thick and contains less than 50% by volume of rocks, or pedocrete fragments larger than 100mm; and
- 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/Natural Conservation Land Status

- Land, which does not qualify as wetland, arable land or palatable grazing land, and as a result is regarded as requiring conservation practise/actions.

3. DESCRIPTION OF THE BASELINE ENVIRONMENT

3.1 Geology

Knowledge of the overall geomorphology and the regional and local geology in particular is helpful in better understanding the origin of the soils and their associated land capability, the extrapolation and use of site-specific information (soil and core sampling and logging undertaken by the mine geologists) being invaluable.

The lithological sequence and generally similar geological structures that define the mining areas and the depositional environment that characterises the emplacement and genesis of the mineral deposit, all have an influence on the soil formation and characteristics.

Regionally, the geology comprises two tectonic-stratigraphic units, the stable Precambrian West African Craton that forms the majority of the eastern side of the country, and comprises elements of an orogenic belt that was deformed during the Pan-African tectono-thermal event, and a 20 – 40 km wide coastal strip to the west comprising Pleistocene to Recent sediments (refer to Figure 3.1a – Regional Geology, and Figure 3.1b – More Localised Geological Map).

The origin of the heavy mineral deposits at Sierra Rutile Limited (SRL) are proximal alluvial placers in origin, with the primary source of mineralisation derived from the quartzo-feldspathic gneisses of the Precambrian (2.1ba) Kasila Group (refer to Figure 3.1b). The heavy mineral suite is hosted within the Bullom Group, the onset of which marked the end of the late Tertiary marine regression.

Sea levels at this time were approximately 100 m below the present levels, exposing the basement rocks of the Kasila Group to erosion. Mechanical and chemical degradation of the Kasila gneisses to form kaolinite and other clay minerals, subsequently liberated the heavy minerals where they were eroded and deposited into pre-incised channel systems. It is these systems that have been mined and identified for further exploration.

The earliest drainage pattern probably followed the regional structural fabric, draining to the Jong River in the southeast. A secondary drainage pattern, orientated to the north-northeast was superimposed over the basement fabric, while the current day drainage is the result of a marine transgression and the Bullom sedimentation during the Cenozoic uplift.

Surface geology in the project area consists of laterite derived from weathered bedrock exposed in the Gbangbama and Imperi Hills. The local bedrock is a Precambrian aged high-grade quartzo-feldspathic-garnet gneiss (charnockites) with accessory rutile, ilmenite, zircon, and monazite.

Concentrations of these heavy resistate accessory minerals in the laterites and associated clay soils surrounding the hills, constitute the ore bodies that are being mined by SRL within the alluvial deposits. The mineral assemblage reported in SRL gravity concentrates is typical for titanium-rich placers of similar origin.

The alluvial-laterite/bedrock contact is often marked by a sharp change in slope, often at the swamp/upland interface. The alluvial deposits, found mainly in or near the tidal creek areas, have been protected from erosion by the general rise in sea level and burial by the marine sediments. Valley walls of more resistant but weathered gneiss also protect the alluvium and heavy laterisation of the alluvium, giving rise to massive iron cemented sands.

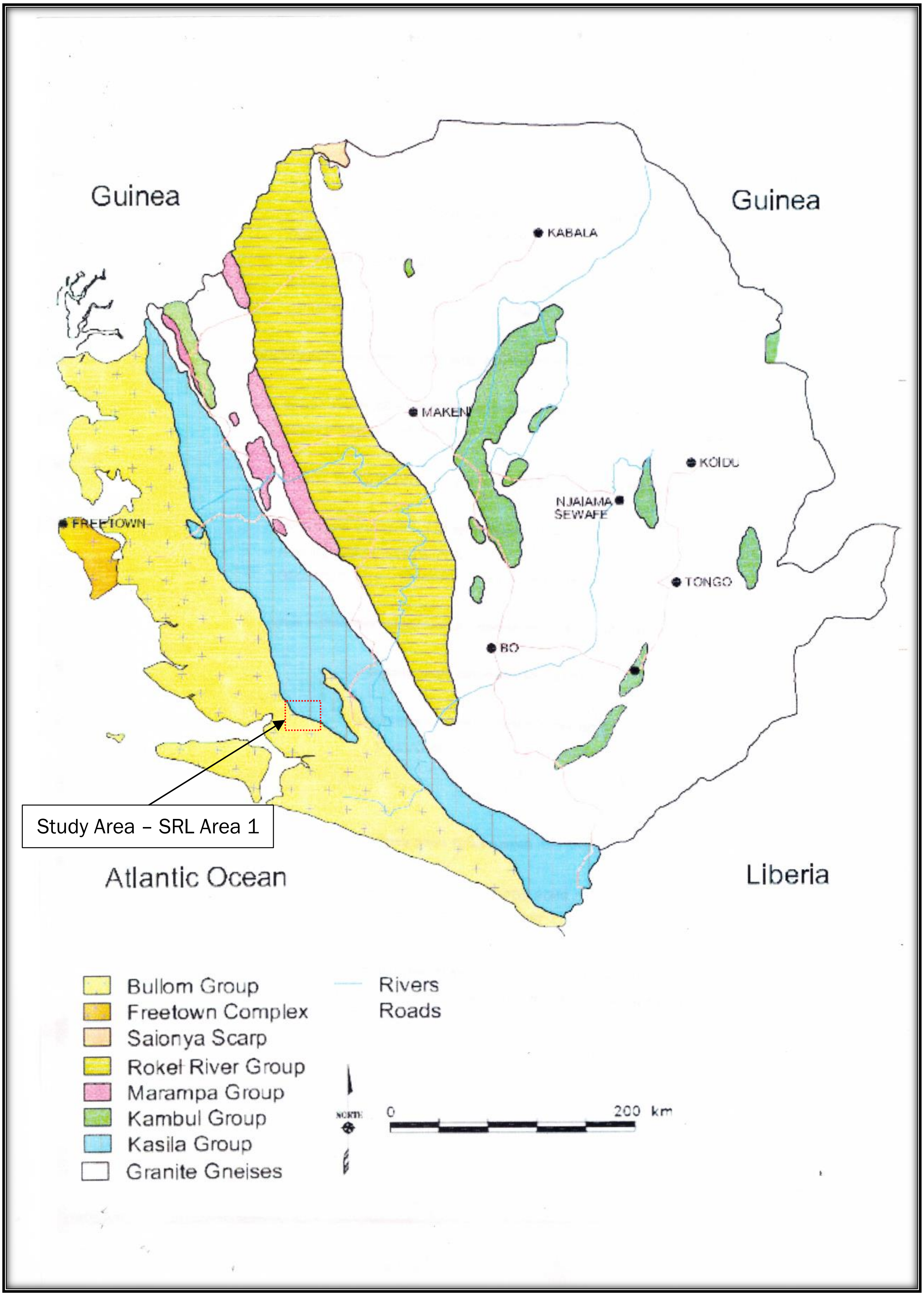

Figure 3.1a Regional Geological Map

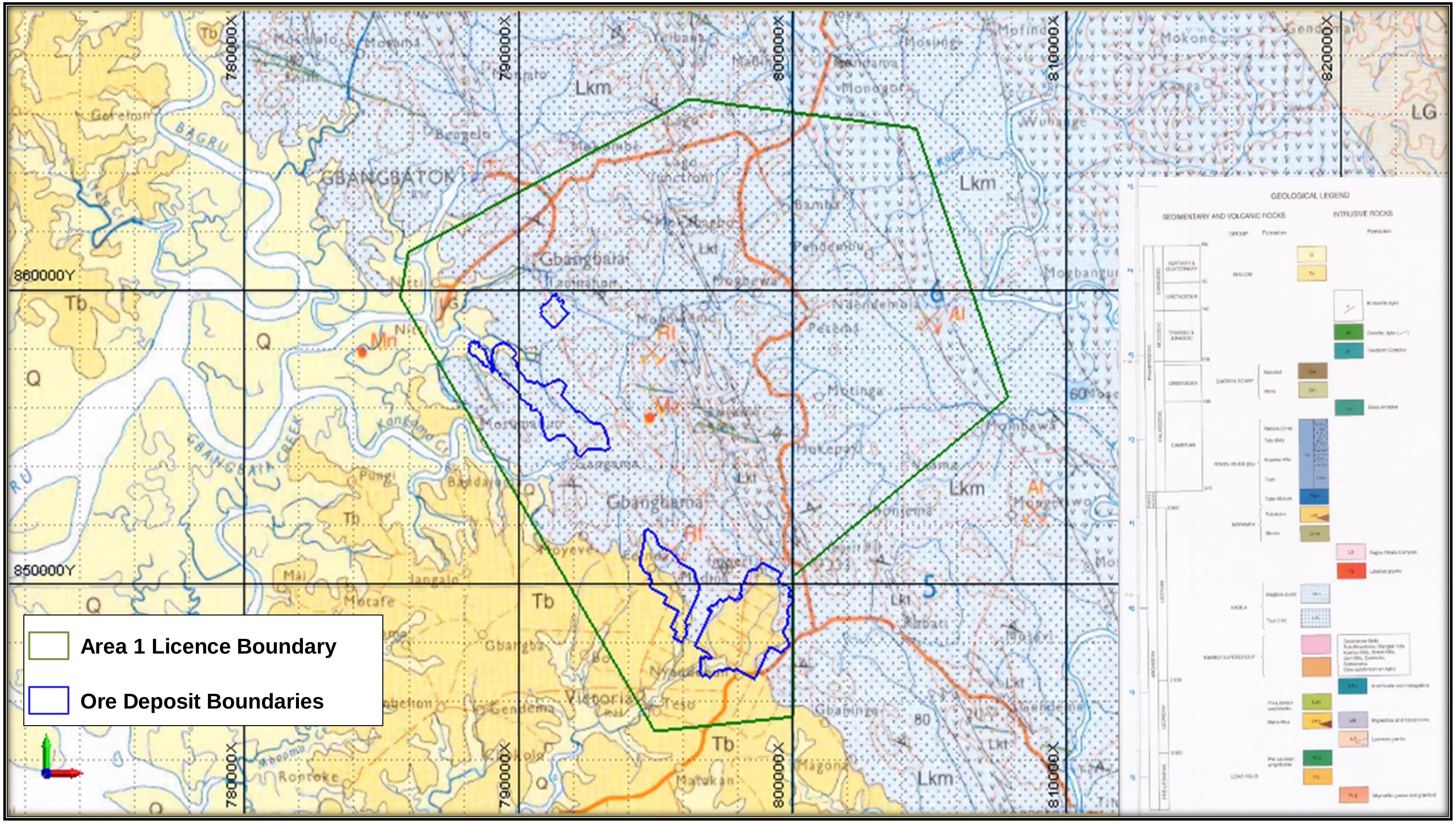

Figure 3.1b Localised Geological Map

3.2 Topography

The study area consists of a series of prominent hills and slight undulations with an elevation range of 0.9 meters above sea level (masl) along the mangroves to 322 masl with the highest point being at Gbangbama Hill. The existing dredge ponds and rutile deposits are situated around the Imperi Hills region on the western and south western extent, with the Lanti and Gangama expansion situated within the alluvial plains and mangrove swamps to the northwest.

The hills in the region have relatively steep slope angles and form prominent features in the landscape. The majority of the area adjacent to the hills comprise undulating, broad expansive fluvial plains, becoming increasingly flat towards the mangrove swamp areas.

3.3 Climate and meteorology

The climate is that typical of the tropics being hot and moist during summer and dry in winter. The average rainfall is estimated to be around 2,800 mm/year. The wet season typically begins in May and ends in November, with the highest average monthly rainfall reading of 651 mm in August. The dry season, beginning in December and ending in April, is characterised by low rainfall. The average rainfall during the dry season varies from a minimum of 6 mm in January to a maximum of 97 mm in April. The annual average A Pan evaporation rate is slightly in excess of 1,100 mm/year, with the highest evaporation rates occurring during the dry season. The climate of SR Area 1 is one that experiences a distinct wet season and a distinct dry season, where rainfall is more than twice evaporation.

The average monthly temperatures ranged between 25.3 °C - 27.9 °C, with the maximum reaching 33.4 °C and minimum reaching 22.7 °C. Daily temperatures during the rainy season are up to 5 °C lower than in the dry season.

It is these conditions of extended dry spells within the otherwise wet conditions that make the soils water retention capability important. The mining areas in general comprise soils with a low water holding capability, the sandy loam character returning clays of less than 10% in almost all cases analysed.

With these aspects considered, the timing of any rehabilitation plan will be important if the plants utilised are to be given a chance to establish themselves ahead of the dry season. The extent of the areas that will need to be rehabilitated will negate artificial watering, and require careful use of the soil clays that are available to enhance the silty sands that are going to form the bulk of the rehabilitation materials used.

3.4 Soils Study

3.4.1 Historical Background Information – Previous Studies

Previous studies undertaken by Knights Piésold in 2001 [Sierra Rutile Environmental and Social Impact Assessment – Knights Piésold (2001) and Co. and Cemmats Group Ltd. (June 2012)] describe the soils noted in previous studies. These include the Lunsar and Makondu systems.

The Lunsar system is found associated with the gentle, undulating plains that form the foot slopes to the more hilly terrain that forms the water divide. These soils are characterised by dark to moderately dark red brown soils and gravelly clay loams, soils classified as Hard Plinthite, Oxisols or Laterites that are generally acidic with low fertility and low water-holding capacity.

The crest slopes are characterised by moderately deep brownish sandy clay loams, while the soils of the foot slopes and lower colluvial terraces are generally deeper, and returned yellowish-brown sandy clay and silty loams with nodular plinthite or ironstone gravel at depth.

The valley and swamp areas comprise both colluvial and alluvial derived soils that are deep, highly variable in character and locally often poorly drain and waterlogged with peat formation.

The acidic conditions and low fertility described are common characteristics of soils that evolve in tropical areas with high rainfall. The leaching of the exchangeable cation bases (e.g. calcium, sodium, potassium, and magnesium) and associated nutrients, results in a land capability rating for the majority of these sites of wilderness (poor agricultural potential) or low intensity grazing land capability status (Birkeland, 1984 and Langmuir, 1997). Under such extreme conditions, exchangeable cation sites are generally occupied by exchangeable aluminium (Al^{3+} or $Al(OH)^{2+}$), possibly iron, and protons (H+) derived from natural organic acids and carbonic acid. The concentration of aluminium is often of a level toxic to many plant spices.

The Makondu system is a series of undulating plains found between the foothill slopes and the Lunsar system. Soils that range in depth from shallow to moderately deep and comprise gravelly loams to clay loams and clays. The soils of Makondu system located on the crest slopes range are generally shallow, with areas of moderately deep rooting profiles. These soils comprise gravelly clay loams which are well drained. In contrast, the mid and lower midslopes are reported to comprise a range of soil rooting depths, with moderately shallow to deep gravelly loams and clay loams. The valley swamps and alluvial floodplains report deep rooting depths with a range of silty gravels, less clay and generally less well developed drainage.

3.4.2 Site Assessment

3.4.2.1 – Baseline Field Investigation

The mining areas considered as part of these studies are confined almost exclusively to the lower foot slopes and topographic lows of the colluvial/alluvial floodplains and riverine/swampland environments, the accumulation of transported materials within the depositional environment being targeted as the source of the heavy mineral deposit.

The proposed new mining areas as delineated were investigated using a combination of hand augering and test pitting to expose the soil profile, the taxonomic system of classification used to characterise and capture the physical attributes of the soil horizons, while selective sampling and laboratory analysis of the rooting horizon (A and B2/1 horizons) was undertaken to obtain the chemical and physical attributes of the utilisable soil.

This information was then cross referenced with the World Reference Base for Soil Resources 2014, an internationally recognised soil naming system, and used as the nomenclature for naming the soil groups for this study.

Using the soil and geomorphological information (climate, topography, geology and ground roughness) obtained from this site investigation in conjunction with the laboratory results and historical information, a number of trends are apparent that can, and have been used to better define and group the soils, rate the land capability and better understand the site sensitivities. The Scoping Report supplied has been used as the basis for the project description.

In addition to the soil investigation, note was made of the geomorphology (geology, topography and climate) of the site, aspects that are used in rating both the land capability as well as site sensitivity.

The geology (parent materials), climate and topography (slope and attitude) are some of the drivers for soil formation and contribute to the variation in soil forms across the study area. Climate (rainfall) and the effects of mechanical weathering (erosion) have a significant influence on the weathering, transportation and depositional processes, while the geology has an influence on the soil chemistry and structural characteristics.

The climate is typically described as a tropical environment comprising hot and humid conditions with high rainfall for the majority of the year. The high rainfall is significant to the erosion and depositional conditions that effect pedogenisis.

Four topographic zones were identified across the area of study (Area 1). These include:
- The marshes and swamplands associated with the coastal plains – Gleysols and saturated Gleycutanic materials;
- The sandy and silty clay loams and fluvial derived alluvial/colluvial deposits associated with the lower slopes and alluvial plains (Fluvisols) ;
- The in-situ derived ferricretes/laterites and shallow plinthic soils on the lower midslopes and midslopes; and
- The ridge or crest slope and shallow to deep soils on saprolitic crystalline bed rock.

3.4.2.2 Soil Characterisation

The soil study returned a range of soil depths, texture and structure across the catena, a strong correlation being noted between the position of the observation in the topography, the geology and the resultant soil form. (Refer to Figure 3.3.2a observation point map and 3.3.2b – Dominant Soil Map as well as Appendix 3 – Field Data).

The soil depth, effective rooting depth (restrictions to rooting noted), soil colour, texture and structure were all noted along with ground roughness and an estimate of the soil permeability (in-field estimation) and water holding capability. Restrictions to rooting and the testing of the soil permeability (field test) were important in better understanding the potential of the soils as an Eco System Service and growth medium, while also considering the how well the soils will react to being disturbed.

Laboratory analysis of both the "A" horizon and "B2/1" horizons were obtained for soil chemical constituents and soil physical properties, while a number (5) of geotechnical samples representative of the main soil groupings were submitted for Bulk Density analysis and foundation indicators.

Available Water Capacity (AWC) of the soils was estimated (Identification & Management of the Soils of the South African Sugar Industry – South African Sugar Association Experiment Station – Third Edition 1999) based on the effective soil depth and texture. The low clay percentages and fundamental to the high infiltration and high leaching status of the majority of the soils mapped (alluvial/colluvial derived materials).

Field observations returned a variation in soil form, ranging from shallow sub-outcrop and outcrop of laterite and hard plinthite (Ferralsols), to shallow rooting wet based and saturated mangrove swampland soils (strong hydromorphic character - Gleysols), and moderate to deep (600mm to 1,200mm) sandy loams, sandy to silty clay loams, and silty sand profiles with a colluvial/alluvial origin (Fluvisols).

The majority of the area of interest is associated with the deep sandy to silty loams grouped as Fluvisols, and saturated gleycutanic mangrove swamplands grouped as Gleysols.

A typical soil profile section through the Fluvisols would have the following components:

- A grit or gravel layer on surface, varying across the catena from almost absent to areas with upwards of 30% surface cover;
- An "A" Horizon with varying percentages of clay (8% to 12%) and organic matter (0.75% to 1.8%);
- A "B" Horizon, that reflects varying texture (clay percentage) and degree of sorting, with a weak but discernable stratification, a chemical character consistent with the host materials from which they are derived, albeit altered in the case of the highly leached materials; and
- A "C" Horizon comprising a highly weathered saprolitic layer of decomposed ferricrete or weathered country rock. The decomposed nature of the ferricrete/laterites is typical of the tropics and geomorphology of the area.

Based on the field studies (2017) and assimilation of the historic soil studies and assessments, the soils can be broadly categorised into three (3) dominant reference groups, each group reflecting similar physical and chemical characteristics.

The dominant soils groupings include:

- Fluvisols:
  Fluvisols accommodate genetically young soils in fluvial, lacustrine or marine deposits. Despite their name, *Fluvisols* are not restricted to *river* sediments (Latin *fluvius*, river); they also occur in lacustrine and marine deposits. Many Fluvisols correlate with *Alluvial Soils, Stratified Alluvium, Stratic Rudosols*, *Fluvents or Auenböden*. The Fluvisols mapped are confined almost exclusively to the colluvial accumulation of transported soils within the alluvial plains.

Plate 1 and 2 - Example of Fluvisols

- Ferralsols:
  Ferralsols represent the classical, deeply weathered, red or yellow soils of the humid tropics. These soils have diffuse horizon boundaries, a clay assemblage dominated by low-activity clays (mainly kaolinite) and a high content of sesquioxides.

  Ferralsols are also known as *Oxisols, Laterites or Hard Plinthite*, are associated with strongly weathered material on old, stable geomorphic surfaces, and develop faster in material weathered from basic rock than from siliceous material. This soil group is typically found on level to undulating land of Pleistocene age or older, and are less common on younger, easily weathering rocks.

The deep and intensive weathering results in a residual concentration of resistant primary minerals (e.g. quartz) along with sesquioxides and kaolinite. This mineralogy and the relatively low pH explain the stable microstructure (pseudo-sand) and yellowish (goethite) or reddish (hematite) soil colours.

Plates 3 and 4 - Example of Ferralsols

- Gleysols:
  Gleysols comprise soils saturated with groundwater for long enough periods to develop reducing conditions resulting in *gleyic* properties, including underwater and tidal soils. This pattern is essentially made up of reddish, brownish or yellowish colours at aggregate surfaces and/or in the upper soil layers, in combination with greyish/bluish colours inside the aggregates and/or deeper in the soil.

  Gleysols with a *thionic* horizon or *hypersulfidic* material (a*cid sulphate soils*) are common in these reducing environments as reported in the studies undertaken by Knights Piésold 2001). Redox processes may also be caused by up-moving gases, like CO_2 or CH_4. Gley or gleycutanic soils with clear signs of groundwater influence are derived from the Russian - *gley* (a mucky mass) (a soil name introduced by G.N. Vysotskiy in 1905). These soils cover a wide range of unconsolidated materials, mainly fluvial, marine and lacustrine sediments that are found in bottom lands and low lying topographic positions in landscapes with a high groundwater table, tidal zones, shallow lakes or sea shores. These soils were confined almost exclusively to the mangrove swamplands in the northwest of the study area.

Plates 5 and 6 - Example of Gleysols

3.4.2.3 Interpretation of soil classification and site evaluation

The site assessment and soil mapping of the proposed new mining areas was undertaken during late June 2017.

The soil structure of the interfluves returned apedel to single grained friable loamy sands, with occasional weak crumby laminated structure and well-defined peds, with better than average permeability and moderate to poor water holding characteristics. These soils are for the most part well drained and returned effective rooting to depths of between 650 mm and 900 mm. These soils are of the more productive soils in the area, albeit that the highly leached nature and associated poor nutrient levels render these soils of a low potential grazing/sub arable (subsistence) to poor arable land capability.

The Fluvisols that dominate these areas are derived from the crystalline rocks of the more mountainous hinterland (Kasila Group and Granite Gneisses) to the east of the study area (refer to Figure 3.4.2a – Dominant Soil Group Map and Figure 3.4.2b for Soil Observation points).

In contrast, the marshlands and tidal zone (Gangama) comprises moderately shallow to shallow saturated gleycutanic and gleyed profiles (Gleysols), a significant area of hydromorphic and wet based soils that occupy the tidal zone and mangrove swamp lands. The anaerobic conditions and tidal nature of this environment renders these sites of low productivity and of a wetland status in terms of their land capability rating. These soils range from shallow saturated sandy clays and gley's, to moderately deep silty clay loams on a hard plinthic "C" horizon.

Inland of the coastal plains the soils are representative of *in-situ* processes and comprise for the most part shallow rooting depths on deeply weathered sandy loam of varying colour and structure underlain by on a hard plinthic base ("C" horizon). This zone is characterised by soils with a more variable texture and structure and comprises more gravelly sandy loams and silty sand loams with highly variable rooting depths (200 mm to over 1200 mm). The soil water holding capability (AWC) is at best moderate to poor 80mm/m-100mm/m. These soils are generally red brown to yellow or orange/red in colour and show little evidence of redoximorphic characteristics within the profile. Mapping on these sites was limited, the mining areas associated almost exclusively with the alluvial flood plains, tidal zone and low lying colluvial depositional sites.

Across the catena the soils grade inland from the coastal swamp lands to the colluvial/alluvial derived sandy loams and silty clay loams associated with the fluvial/riverine areas and on upslope through the Ferralsols and shallower rooted soils associated with the lateritic sub base and steeper hill slopes.

The interfluves and shallow wide open valleys that characterise the south and central portions of the proposed mining include the Lanti, Gbandei, Gbeni, Bondavei and Gangama South dry mining deposits, which contrast with the mangroves and marshland environment in the north western portion of Gangama (Refer to Figure 1.2). The soils of these areas are generally characterised by deeper and sandier Fluvisols returning clay fractions between 8% and 16% and a significant sand fraction (upwards of 65% to 75%).

The differing soil groupings (dominant forms) are depicted in Figure3.3.2b. This system groups the soils based on their physical and chemical similarities, a system that helps in the formulating of a meaningful soil utilisation and management plan for the materials that are to be disturbed.

In addition, the sensitivity or vulnerability of a site to being disturbed, uses the physical and to some extent chemical attributes of the soils as a measure. The sensitivity/vulnerability rating is a tool used to better understand the potential impact that an activity might have on the site, and assists in the development of the soil utilisation plan (stripping depths, stockpiling methods and general mitigation of impacts).

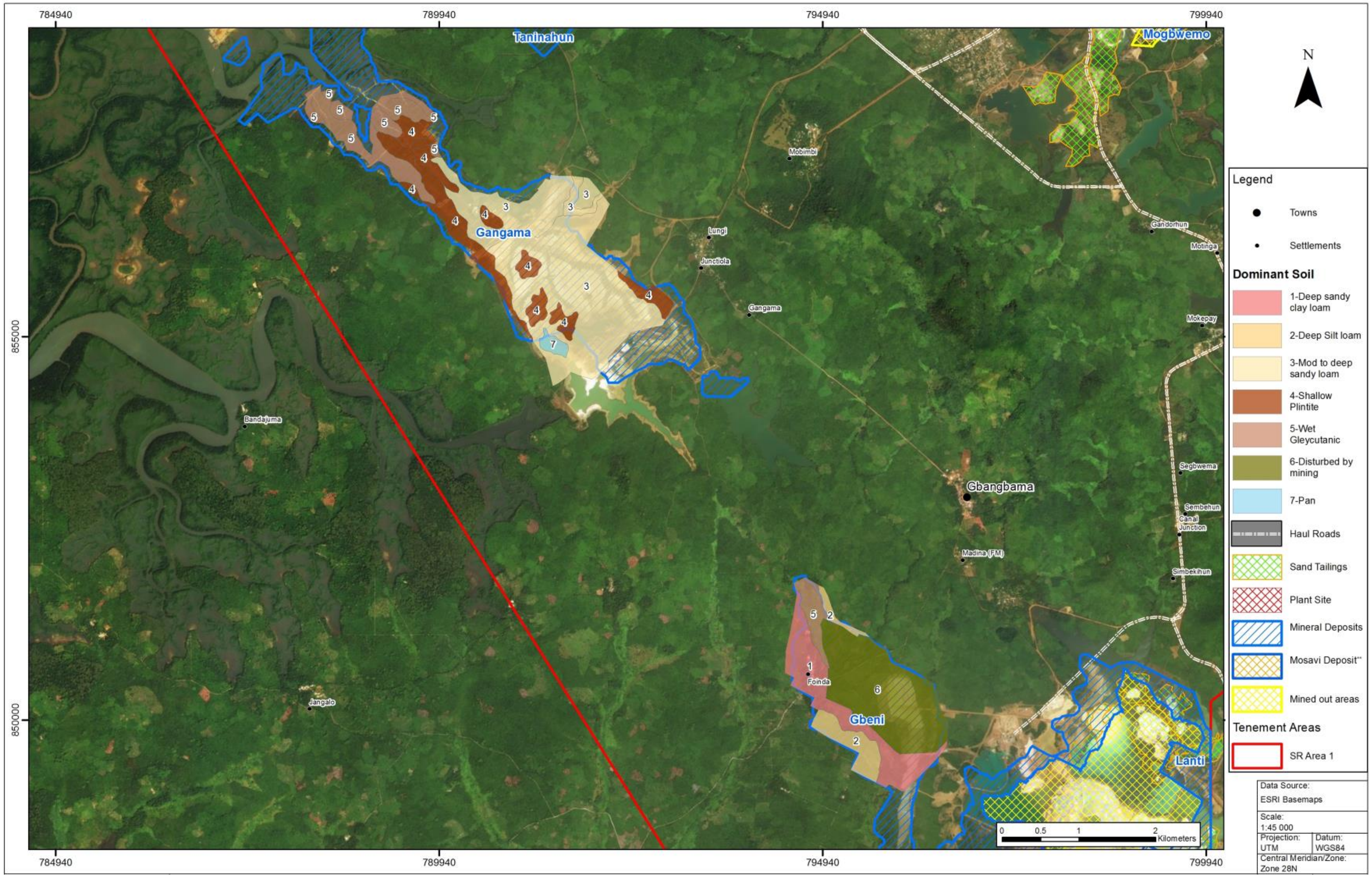

Figure 3.4.2a Dominant Soils in the Study Area (refer to Appendix 1 for larger scale maps)

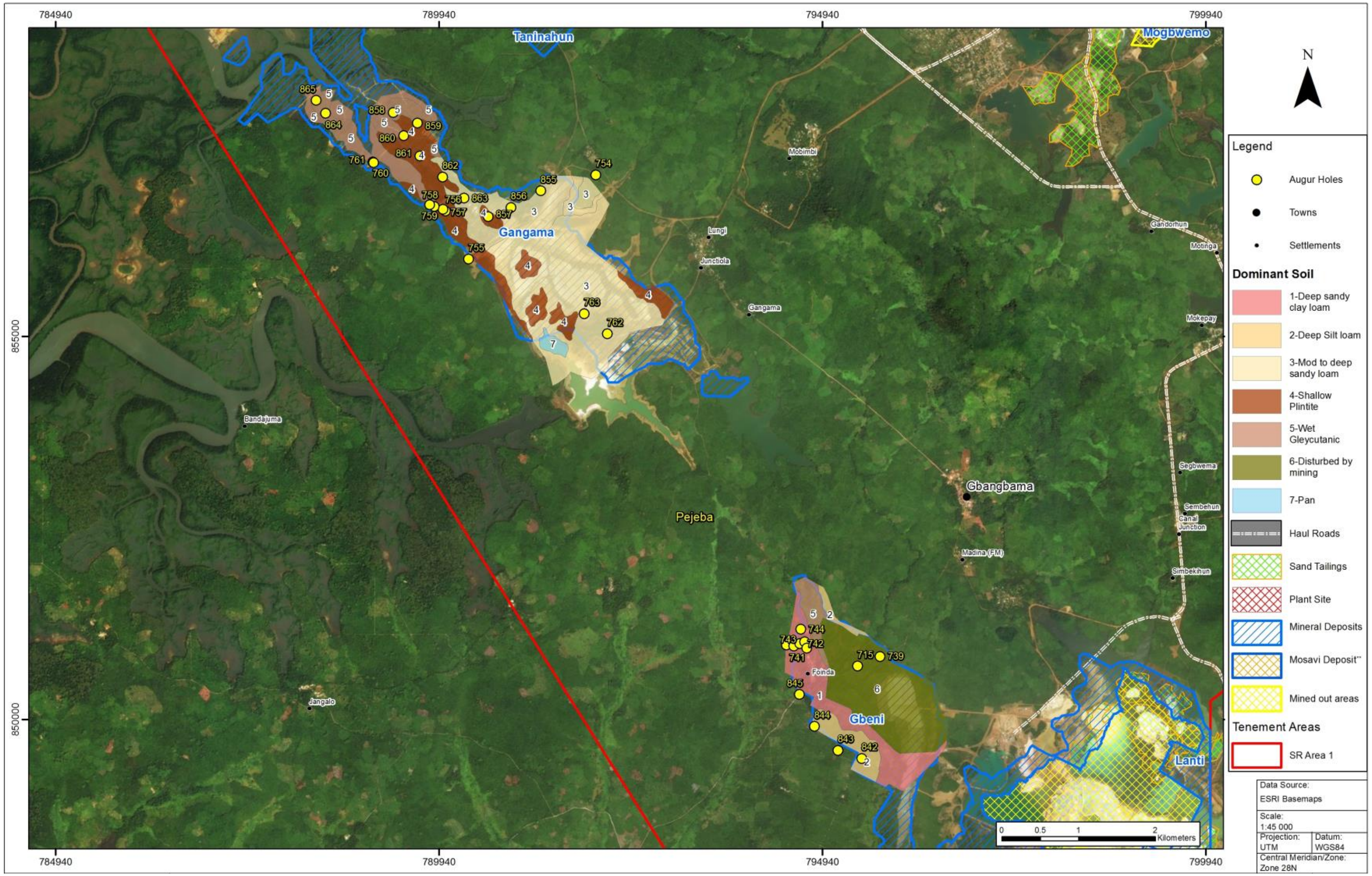

Figure 3.4.2b Soil Observations

3.4.3 Laboratory Analysis

A number of soil samples were taken as part of the site assessment and analysed for chemical and physical parameters at an accredited laboratory (refer to Appendix 3 for certification certificate). Soil samples were taken from a number of auger point observations, the "A" horizon and the "B2/1" horizon, collectively regarded as the "utilisable" portion of the soil profile, while bulk density and physical parameters were assessed from representative samples taken for selective test pits.

The laboratory results are indicative of the point source from which they are taken and considered representative of the soil form for areas of *in-situ* development. However, the variable nature of the more recent and transported materials associated with the fluvial/alluvial derived soils, is more questionable, and the point source sampling is statistically less likely to be representative of the soil group due to the transported nature of the materials. The results are important to the baseline information and give a pre-development record from which planning decisions can be made in terms of the soil workability and site sensitivities.

Information obtained from the laboratory results includes, the soil chemistry as well as soil texture, and nutrient status, information that is needed when considering how the materials will react to being disturbed, stockpiled and stored, and how productively they can be used during rehabilitation.

These information sets combined with the field observations (soil depths, topographic slope, attitude, ground roughness and geology) to compile a baseline of information (Refer to Table 3.4.3a – Soil Chemistry and 3.4.3b – Soil Physical Parameters).

The majority of the soils mapped are associated with the colluvial derived Fluvisols. This soil group returned apedel to single grained texture, moderately low to low clay content (<12%), and a dystrophic to mesotrophic leaching status. The structure ranges from very friable single grained to apedel and/or stratified alluvium, a reflection of the pedogenetic processes involved.

The effective rooting depths are generally deep (>600mm), with restriction based primarily on wetness features and/or sub base saprolite, plinthite or hard rock inhibiting layers (refer to Appendix 3).

The north western extent of the mining area being considered is dominated by saturated soils with a significantly much higher clay component and tidal marine influences. These sites returned primarily Gleysols.

The analytical results returned results consistent with the host materials and soil forming processes active in these environments, with erosion (water primarily), climate (rainfall and temperature) and tidal action dominating the weathering processes.

The sample depths, effective rooting depths and water holding characteristics are detailed in Appendix 2 – Soil Observation.

Table 3.4.3a Analytical Results

										MEHLICH III																	
Lab No	Sample No.	pH(H2O 1:1)	Density	TEC/CEC	Org Mat	Available N	Bray II	K	Na	Ca	Mg	P	Fe	Mn	Cu	Zn	S	B	Ca	Mg	K	Na	H	Other	Clay	Silt	Sand
		-	g/ml	ME/100g	%	kg/ha	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	Base Saturation						%	%	%
	Norms	5.2 - 6.5		5-15	>0.75			> 40	> 2.0	> 200	> 60	> 20													15-25		
12909	SRL270a	5.20	1.09	1.02	6.00	117.58	1	17	9	76	10	4	53.79	1.31	0.63	0.55	10.85	0.00	37.43	8.36	4.37	3.84	39.00	7.00	4	20	76
12910	SRL270b	5.45	1.17	0.43	0.89	40.00	1	8	7	34	6	3	26.20	1.05	0.65	0.57	6.12	0.00	38.62	11.78	4.93	6.67	31.50	6.50	8	21	71
12911	SRL271a	5.22	1.09	2.53	0.67	29.91	1	19	9	204	33	6	56.42	1.65	0.70	0.76	7.36	0.00	40.40	10.62	1.95	1.63	38.43	6.96	6	15	79
12912	SRL27b	4.98	1.27	1.22	0.96	43.15	1	6	5	94	9	10	38.73	0.63	0.57	0.45	5.14	0.00	38.42	5.88	1.26	1.64	45.36	7.44	8	18	74
12913	SRL278a	5.01	0.99	1.29	0.69	30.96	1	32	8	69	19	6	47.06	1.18	0.73	0.52	22.63	0.00	26.68	12.25	6.30	2.68	44.70	7.38	14	20	66
12914	SRL278b	5.35	0.96	0.98	1.28	50.98	2	12	13	73	16	3	50.91	0.73	1.00	0.61	14.03	0.00	37.06	12.93	3.08	5.76	34.47	6.70	18	19	63
12915	SRL733a	5.22	1.05	2.08	0.85	37.90	1	24	10	153	33	5	74.36	1.73	0.80	0.61	10.03	0.00	36.80	12.88	2.95	2.00	38.40	6.96	4	7	90
12916	SRL733b	5.03	1.30	0.37	1.20	49.26	1	7	3	20	6	2	28.01	0.37	0.51	0.41	17.89	0.00	27.13	12.69	4.91	3.90	44.04	7.34	10	20	70
12917	SRL735a	4.96	1.04	0.92	0.72	32.22	1	20	6	51	12	4	62.14	0.88	0.67	0.53	6.58	0.00	27.67	10.43	5.67	2.95	45.80	7.48	4	17	79
12918	SRL735b	5.17	1.31	0.63	0.78	34.89	1	14	6	41	8	3	36.95	0.67	0.60	0.43	9.22	0.00	32.30	10.85	5.84	4.18	39.78	7.05	4	19	77
12919	SRL736a	5.29	1.15	1.46	0.99	44.34	2	20	8	112	22	6	74.91	1.65	0.69	0.58	5.90	0.00	38.52	12.52	3.43	2.40	36.30	6.82	2	13	85
12920	SRL736b	5.31	1.06	0.90	0.75	33.41	1	11	9	70	12	5	47.57	1.33	0.80	0.71	11.69	0.00	38.93	11.05	3.27	4.27	35.70	6.78	16	17	67
12921	SRL739a	5.08	1.11	0.68	0.90	40.42	1	12	5	45	7	2	49.33	1.36	0.64	0.47	19.34	0.00	33.13	8.79	4.69	3.49	42.66	7.24	4	20	76
12922	SRL739b	5.01	1.09	0.53	0.60	26.90	1	10	4	31	7	2	20.96	1.19	0.62	0.44	31.59	0.00	29.05	10.44	4.97	3.46	44.70	7.38	8	21	71
12923	SRL744a	5.17	1.18	1.34	1.18	48.74	1	16	8	92	21	2	82.64	0.99	0.80	0.45	9.32	0.00	34.53	12.72	3.03	2.75	39.90	7.06	18	15	67
12924	SRL744b	5.45	1.30	0.66	1.88	64.47	1	12	5	45	15	2	111.46	2.35	0.66	0.42	7.10	0.00	34.38	19.34	4.82	3.30	31.65	6.51	22	15	63
12925	SRL745a	5.19	1.22	0.85	2.08	69.05	2	17	10	61	8	3	83.85	0.77	0.71	0.44	6.40	0.00	36.00	7.81	4.98	4.89	39.30	7.02	10	19	71
12926	SRL745b	5.22	1.30	0.47	1.02	45.27	2	9	4	31	7	2	63.04	0.52	0.56	0.40	4.00	0.00	33.27	12.46	4.85	4.12	38.34	6.96	8	20	72
12927	SRL747a	4.99	0.93	2.68	0.67	30.12	2	89	10	140	36	8	91.63	1.62	1.04	0.74	32.35	0.00	26.17	11.03	8.51	1.67	45.20	7.42	6	20	74
12928	SRL747b	5.18	1.01	0.98	1.69	60.16	1	18	8	57	19	4	75.08	1.23	0.78	0.53	10.26	0.00	29.26	16.00	4.73	3.40	39.57	7.04	20	15	65
12929	SRL748a	5.29	1.17	1.75	1.25	50.32	1	19	9	146	22	5	58.95	2.60	0.73	0.55	6.48	0.00	41.57	10.39	2.71	2.21	36.30	6.82	4	15	81
12930	SRL748b	5.37	1.22	0.73	0.73	32.71	1	8	6	60	11	2	70.69	1.13	0.59	0.43	4.94	0.00	40.95	12.26	2.95	3.28	33.90	6.66	4	16	80
12931	SRL751a	5.34	0.96	1.39	0.50	22.49	2	24	8	107	22	5	58.09	3.28	0.79	1.06	14.17	0.00	38.44	13.18	4.39	2.40	34.86	6.72	16	15	69
12932	SRL751b	5.22	1.01	0.71	1.20	49.23	1	8	6	48	12	1	23.67	1.36	0.63	0.47	6.61	0.00	34.27	13.71	3.01	3.55	38.49	6.97	22	14	64
12933	SRL750a	5.10	0.97	0.87	0.83	37.41	1	11	7	56	13	1	39.45	0.85	0.74	0.55	13.18	0.00	32.11	11.74	3.29	3.66	42.00	7.20	18	15	67
12934	SRL750b	5.29	1.01	0.62	0.95	42.59	1	10	10	40	10	3	20.98	0.59	0.65	0.55	9.27	0.00	32.23	13.53	4.01	7.24	36.18	6.81	14	22	64
12935	SRL752 1	5.76	1.30	0.49	0.84	37.76	1	3	7	49	8	2	9.14	0.49	0.52	0.41	13.57	0.00	50.67	13.15	1.58	6.51	22.20	5.88	1	4	95
12936	SRL759a	4.99	1.12	1.52	2.48	78.06	2	22	11	99	15	3	79.05	1.16	0.71	0.55	7.52	0.00	32.47	8.16	3.71	3.10	45.14	7.41	2	37	61
12937	SRL759b	5.15	1.05	0.72	1.81	63.03	1	9	6	54	7	0	42.36	1.01	0.41	0.46	17.45	0.00	37.79	7.73	3.35	3.53	40.50	7.10	34	29	37
12938	SRL760	5.67	1.06	44.11	Empty	Empty	1	329	4010	662	1075	5	332.47	3.46	0.61	1.44	850.17	4.09	7.50	19.98	1.91	39.52	25.02	6.07	8	49	43
12939	SRL763a	5.31	1.05	1.10	1.03	45.55	2	6	13	97	9	3	156.00	0.72	1.02	0.52	33.26	0.00	44.36	6.66	1.45	5.04	35.70	6.78	4	19	77
12940	SRL763b	5.45	1.12	1.12	1.10	47.02	1	7	12	112	8	4	113.48	0.77	0.90	0.55	34.98	0.00	50.02	5.74	1.56	4.68	31.50	6.50	6	20	74
12941	SRL765a	5.21	1.09	2.85	1.63	58.86	3	51	8	215	37	6	47.96	4.08	1.02	1.08	11.01	0.00	37.75	10.67	4.54	1.20	38.85	6.99	6	19	75
12942	SRL765b	5.13	1.19	1.50	1.15	48.21	1	12	5	100	27	2	46.90	1.52	1.04	0.45	9.65	0.00	33.40	14.66	2.11	1.53	41.16	7.14	4	31	65
12943	SRL766a	5.13	1.01	1.56	1.01	44.96	2	15	8	131	9	4	52.08	1.58	0.86	0.52	6.61	0.00	42.04	4.86	2.54	2.32	41.10	7.14	4	16	80
12944	SRL766b	5.30	1.13	0.87	0.88	39.30	1	7	6	79	7	2	44.18	1.01	0.79	0.44	6.14	0.00	45.52	6.44	2.18	2.94	36.12	6.81	8	18	74
12945	SRL778a	5.80	0.91	8.78	2.83	85.87	3	83	15	1011	134	9	52.68	6.12	1.19	0.92	8.78	0.00	57.57	12.48	2.42	0.73	21.00	5.80	6	18	76
12946	SRL778b	5.36	1.00	3.92	2.02	67.55	2	31	8	345	59	5	51.57	2.78	1.00	0.61	6.54	0.00	44.03	12.25	1.99	0.91	34.14	6.68	4	31	65
12947	SRL786a	5.85	1.01	8.64	3.54	95.68	2	38	7	1151	71	4	47.55	13.35	1.46	1.03	5.63	0.00	66.60	6.71	1.13	0.36	19.50	5.70	4	22	74
12948	SRL786b	6.33	1.00	2.48	2.47	77.64	1	47	11	305	50	2	23.32	6.03	1.03	0.57	32.22	0.00	61.65	16.40	4.86	1.89	10.13	5.08	8	40	52
12949	SRL790a	5.96	0.90	11.48	3.32	93.18	3	69	12	1423	201	8	59.84	12.71	1.78	1.28	6.37	0.00	61.98	14.33	1.54	0.47	16.20	5.48	8	18	74
12950	SRL790b	6.14	1.04	5.21	2.93	88.11	2	36	7	624	125	4	42.09	6.92	1.31	0.83	6.27	0.00	59.83	19.63	1.76	0.62	12.90	5.26	10	21	69

CEC - Cation Exchange Capacity
Mehlich III - Extraction Protocol (Determination of macro and micro nutrients in soil - agrochemical testing

Table 3.4.3b Geotechnical Results

Geotechnical Information																													
		Sieve Analysis (mm)											Soil Mortar Analysis % of mat < 2.00mm								Atterberg Limits			Classification				Bulk Density	
Sample No.	Description	37.5	26.5	19.0	13.2	4.75	2.00	0.4250	0.0750	0.0500	0.0050	0.0020	Coarse sand	Fine Sand	Silt	Clay	Effective Size	Uniformity Coef	Curvature Coef	Grading Modulus	Liquid Limit	Plasticity Index	Linear Shrinkage	Unified Soil	COLTO	US . Highway	Group Index	Loss Bulk density	Compacted Bulk Density
764	drk olive Inorganic Clay					100	99	79	57	47.70	28.80	21.90	20.10	31.9	19.10	28.90	0.002	92.10	0.40	0.64	22	7	3.6	CL	N/A	A-4	4	1.264	1.334
765	drk Grey Silty/Cleyey sand	100.00	98.00	93.00	82.00	57.00	51.00	41.00	13.00	11.30	5.40	4.10	18.80	59.10	11.40	10.70	0.030	177.60	0.30	1.95	22	5	2.4	sm/c	N?A	A-1-B	0	1.445	1.538
748	drk Olive Silty sand					100.00	100.00	86.00	21.00	15.40	9.50	8.10	13.80	70.70	5.90	9.60	0.006	25.20	7.00	0.93		NP	0	SM(d)	N?A	A-2-4	0	1.354	1.445
751	drk Olive Cleyey sand						100.00	76.00	36.00	32.00	21.70	17.90	23.30	44.60	10.40	21.80	0.002	210.50	4.80	0.88	28	11	5.4	SC	N?A	A-6	0	1.211	1.294
750	drk Olive Cleyey sand						100.00	66.00	30.00	26.60	18.30	14.10	34.20	39.10	8.30	18.30	0.002	323.80	17.70	1.05	30	10	4.8	SC	N?A	A-2-4	0	1.212	1.275

The physical characteristics include:

- Topsoil clay percentages ranging from as low as 4% on the alluvial derived sands, to more than 15% on the sandy loams, with a weak correlation with their position in the landscape/topography. The wet based and in places saturated Gleysols returned higher clay percentages, a distinguishing aspect that is significant;
- Subsoil clay content ranges from less than 8% on the Fluvisols and alluvial derived stratified alluvium, to as high as 48% on the clay rich Gleysols;
- Moderate to high infiltration/permeability rates, are associated with the sandy loams and well sorted alluvial/colluvial materials, which form the present day cover materials to the lower slopes and riverine environs upslope of the mashes and mangroves;
- The wetlands and swamplands, which predominate within the tidal zone downslope of the coastal plains and fluvial riverine environment returned a range of hydromorphic soils with a higher silt and clay content. The sensitivity of this zone is important to a range of ecological aspects and ecosystem services.

The Fluvisols exhibit well defined topsoil (A) and subsoil (B) horizons, with significant organic matter accumulation within the lower A and B2/1 zone (0.72% and 1.2%), are generally well vegetated and considered stable in the natural state. However, if the vegetation cover is disturbed and the soils are exposed they are vulnerable to dispersion and erosion. Impacts to downstream users will need to be considered as part of the impact assessment.

In contrast, the *in-situ* derived Ferralsols are associated with the mid and upper slopes down gradient of the Gbangbama Hills and associated hard rock geology (granite gneisses) in the area. These soils returned a variety of rooting depths and soil depth to hard rock, with the weathering profile (saprolite) reported to depths of greater than 12 m in places. This soil group is characterised by a coarser gravel fraction and plinthic horizon at the base of the soil profile. These soils are markedly different from the Fluvisols and Gleysols and form the boundary to the mining areas, and are most often associated with more undulating and steeper topography.

The Ferralsols are characterised by stronger soil structure (apedel to weak crumby) and higher clay texture, comprising sandy clay loams and silty clay loams with better water holding capabilities (restricted somewhat by soil depth) and moderate permeability. This soil group is more resistant to erosion than the Fluvisols, however where exposed by vegetative clearing or where the soils are exposed, the erosion index will increase. Care will need to be taken wherever the vegetation and soils are disturbed, by implementing relevant management / mitigation measures.

While compaction is a concern to be noted and managed in the natural (undisturbed) environment, it is of greater consequence to the successful implementation of any rehabilitation plan, and will need to be managed throughout the mining phases.

In summary, field observations and laboratory analysis results returned better than average organic matter content, generally low clay percentages for all but the gleyed materials within the mangroves and swamplands, with limited structure and textural variation. The contrast in soil structure and clay texture (saturated silty clay loams) of the tidal mangrove swamplands in the northwest, will influence the management recommendations for soil storage and utilisation during the operation and rehabilitation.

The ecosystem services associated with these areas are considered sensitive in terms of the ecological biodiversity and connectivity between the marine environment and the coastal plains.

The soil mapping and associated site sensitivity will need to be linked with the findings of the wetland sciences, hydrological studies and terrestrial assessments.
The chemical characteristics include:

- The chemistry of the soils reflects the weathered product of the underlying (in-situ) geology (Ferralsols) and/or transported materials of the upslope environs from which they are derived (Fluvisols and Gleysols). The physical and chemical characteristics of the materials are shown in Table 3.3.3a, and typify the acidic characteristics and low fertility of soils that evolve in tropical areas of high rainfall. The highly leached status of all exchangeable cation bases (e.g. calcium, sodium, potassium, and magnesium) and nutrients (Birkeland, 1984 and Langmuir, 1997) evident in the results;
- The fluvial zone returned chemistry that is indicative of the highly leached and better sorted transported materials, and reflects the pedogenetic character and structure of younger deposited materials with less pronounced lamellae and ped formation. These soils are nutrient poor, lower in clay mineralisation, have generally more sand, higher infiltration rates and permeability, as well as lower water holding capabilities. These are important factors when considering the utilisation potential of the soil for rehabilitation;
- In contrast the Ferralsols are rich in iron, returning red and yellow orange coloured soils with a distinctive ferricrete/laterite forming a hard resistant gravel to the base of the soil profile. The inherent structure is more pronounced with an apedel to weak crumby structure and stronger ped formation, a distinguishing characteristic. These soils are generally shallower in rooting depth (<600 mm) and while they have slightly higher clay content (field observations), the relatively low clay percentages and poor nutrient stores are supportive of the dystrophic leaching status.

There are no indications of any toxic elements that are likely to limit natural plant growth in the soils mapped within the mining areas. It is however evident from previous studies (ESIA 2012) that with the dystrophic leaching conditions the exchangeable cation sites are largely occupied by exchangeable aluminium (Al^{3+} or $Al(OH)^{2+}$), iron and protons (H^{+}) derived from natural organic acids associated with decaying organic matter. When exposed and wet, the hydrolysis of aluminium and the equilibration with exchangeable iron and protons results in low pH conditions with a high buffering capacity.

In general, soil pH values tend to decrease with increasing annual rainfall amounts and better drainage (Rose *et al*. 1979). The better-drained soils exhibited lower pH values (paste), relative to the more poorly drained soils developed in the mangroves/swampy areas.

In terms of the essential nutrients required for plant growth, the soils are considered poor, with less than adequate supplies of potassium, calcium, magnesium and phosphate (refer to Table 3.4.3a).

The potential for soil to retain and supply nutrients was assessed by measuring the Total Exchange Capacity (TEC) and Cation Exchange Capacity (CEC) of the soils (CEC is the total capacity of a soil to hold exchangeable cations. CEC is an inherent soil characteristic and is difficult to alter significantly. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification). Generally, the TEC/CEC values for the soils mapped in the area are moderate to low, with the values being somewhat reduced due to the generally low clay percentages and the highly leached nature of the soils. 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/%).

In addition to a soil being able to retain a nutrient pool it also needs to retain water if it is going to be of use as a growing medium.

Available Water Capacity (AWC) of a soil is a function of the water which lands on the surface and infiltrates into the soil and is retained within the pour spaces, and the excess water that drains through the soil and is lost down profile into the groundwater environment.

The vadose water (water in the unsaturated soil profile) available to plants is held in the profile on the clay surfaces and taken up by the plants as needed. The percentage and types of clay determine the ease with which the soil water can be taken up by a plant.

The AWC has been based on the soil texture and clay percentages obtained from the soils analysis, and expressed as a function of utilisable soil depth. The Sugar Industry of South African published estimates of AWC for differing clay percentages (Refer to Identification & Management of the Soils of the South African Sugar Industry – South African Sugar Association Experiment Station – Third Edition 1999).

This measure along with the soil depth and nutrient availability are important considerations when debating and considering how much soil is needed for sustainable rehabilitation, the retention of soil water being one of the critical aspects in rehabilitation.

3.4.4 Soil Erodibility and Compaction

The physical attributes of the soils (structure and texture) coupled with the poor nutrient stores, the low clay content, the climate (high rainfall) and the generally flat to undulating topography (all but the hills and elevated ridges) result in an erosion index of moderate. This is tempered somewhat by the natural vegetative over of tropical bush and grasses to an index of Low.

The value of the vegetative cover must not be underestimated, as unprotected soil is noted to erode with ease under the extremes of rainfall common in the area during the wet season.

Exposure of the soils will need to be managed well, the removal of vegetative cover exposing the soil cover to rainfall and overland stormwater impacts, actions that will potentially erode the exposed materials downslope. The erodibility index varies for the different lithologies, soil forms and their position in the topography. In general, the Ferralsols are noted to have a lower erosion index than the Fluvisols.

Erodibility is defined as the vulnerability or susceptibility of a soil to erode. It is a function of both the physical and chemical characteristics of a material, the topographic slope as well as the treatment of the soil.

The resistance to, or ease of erosion of a soil, is expressed by an erodibility factor (“K”), which is determined from soil texture/clay content, permeability, organic matter content and soil structure. The Soil Erodibility Nomograph (Wischmeier *et al,* 1971) is used to calculate the “K” value.

The Index of Erosion (IOE) can be determined by multiplying the “K” value by the “slope” (measured as a percentage). Erosion problems may be experienced when the IOE is greater than 2.

Erodibility Ratings are expressed as:

- Resistant "K" factor = <0.15
- Moderate "K" factor = 0.15-0.35
- Erodible "K" factor = 0.35-0.45
- Highly erodible "K" factor = >0.45

The average IOE for the majority of the soils that are likely to be impacted (Fluvisols) fall within the moderate to erodible category. The low clay content and lack of meaningful structure rendering these soils moderately erodible to erodible. This rating is influenced by the moderate organic matter content and undulating to flat terrain, which reduces the index of erosion moderate.

The steeper slopes associated with the more resistant Ferralsols are the exception, with resistant to highly resistant erodibility indices, albeit that the potential for an increase in erodibility index will occur if vegetation is removed or the soils are disturbed.

The vulnerability of the "B" horizon (refer to Table 2.3a) to erosion once the topsoil and/or vegetation are removed, must not be under estimated when undertaking activities likely to disturb these soils.

3.5 Pre-Construction Land Capability

The mining areas and associated activities have been classified and rated in terms of a simplified version of the British Land Classification (BLC) System. The variables used have been described in Section 2.6, with the seven classes of the BLC system being reduced to four classes or rating categories. These four categories are considered to adequately describe and rate the site conditions that pertain to the areas under consideration.

Land capability is the ability of the land to sustain a land use given its geomorphological attributes (topography, climate, soil etc.).

Based on this rating system the mining areas were classified and rated for their land capability.

The land capabilities range from moderate to low intensity (carrying capacity) grazing or subsistence farming land, with poor or no commercial potential, to land with a natural conservation or wilderness status. The depth of most of the soils is well within the conditions suitable for arable land capability (>700 mm). However, the poor nutrient status, excess iron and moderate to poor water holding capabilities, reduce the rating of all of these sites to a moderate conservation status or low potential subsistence arable status.

3.5.1 Description

Arable Potential Land

There are no sites with an arable land capability rating associated with the study areas in terms of the definitions. The basic requirement for a crop to obtain a yield equal to or higher than the national average for commercial crops under natural conditions, is unlikely to be achieved on any of the sites assessed due to the highly leached nature of the soils and the associated low nutrient stores measured.

Although the soil depths are often adequate, and the high rainfall of this area increases the utilisation potential of the site, the soil chemistry negates the potential for anything better than moderate subsistence farming or low intensity grazing, with significant portions of the study area comprising wilderness/conservation status land capability.

The soil's natural state is acidic (pH of 5.5 on average) and nutrient poor, conditions that are not conducive to a commercial yield for any of the national food crops. Significant additions of both lime/gypsum and basic nutrient supplies, are required to enhance the utilisation potential and ecosystem service potential.

Sub Arable / Subsistence / Grazing Land Capability

The areas that classify as grazing land (subsistence farming) are generally associated with the poor quality and/or shallow rocky soils, as well as the transitional zones between the wetlands environment and the areas that are well drained.

However, in the study area, the deep sandy soils (free draining) are not capable of supporting commercial plant species on a sustainable basis, due primarily to the highly leached nature of the soils and resultant poor nutrient stores, and classify as sub arable or grazing land capability.

The majority of the soils associated with the Fluvisols grouping meet the requirements for subsistence agriculture or low intensity grazing land potential, with the water holding capabilities, poor nutrient stores and leached status rendering these soils poor arable sites.

Wilderness / Conservation Land

The shallow soils mapped in association with the Ferralsols and steeper portions of the rocky hill slopes rate as wilderness or conservation land capability. This is due mainly to the shallow depths of rooting, the occurrence of a gravel layer within the lower profile, the generally low clay contents and the leached nature of the soils. These are generally of the poorer soils mapped in the study area.

Wetland

Wetland areas are defined in terms of a set of wetland delineation guidelines, which use soil characteristics as well as vegetation criteria to define the domain limits.

These wetland zones are dominated by hydromorphic soils (wet based) that often show signs of structure, and have vegetation that is associated with seasonal wetting or permanent wetting of the soil profile.

The wetland soils are generally characterised by dark grey to black colours (organic matter) in the topsoil horizons, are often high in transported clays and show variegated signs of mottling on gleyed backgrounds (pale grey colours) in the subsoil. Wetland soils occur within the zone of soil water influence.

There are a number of very distinctive wetland areas that rate as true wetlands based on the soils and vegetative cover, with zones of slight wetness at depth - where the stratification and structure is able to hold water in the profile, or were the underlying lithologies are holding groundwater or perched soil water within the profile.

The mangrove swamps are a distinctive zone that classifies as a wetland, while the lower lying areas along some of the alluvial channels show signs of redoximorphic indicators within the prescribed upper 500 mm of the profile.

These zones are considered very important, sensitive and vulnerable in terms of their ecosystem services and ecological importance.

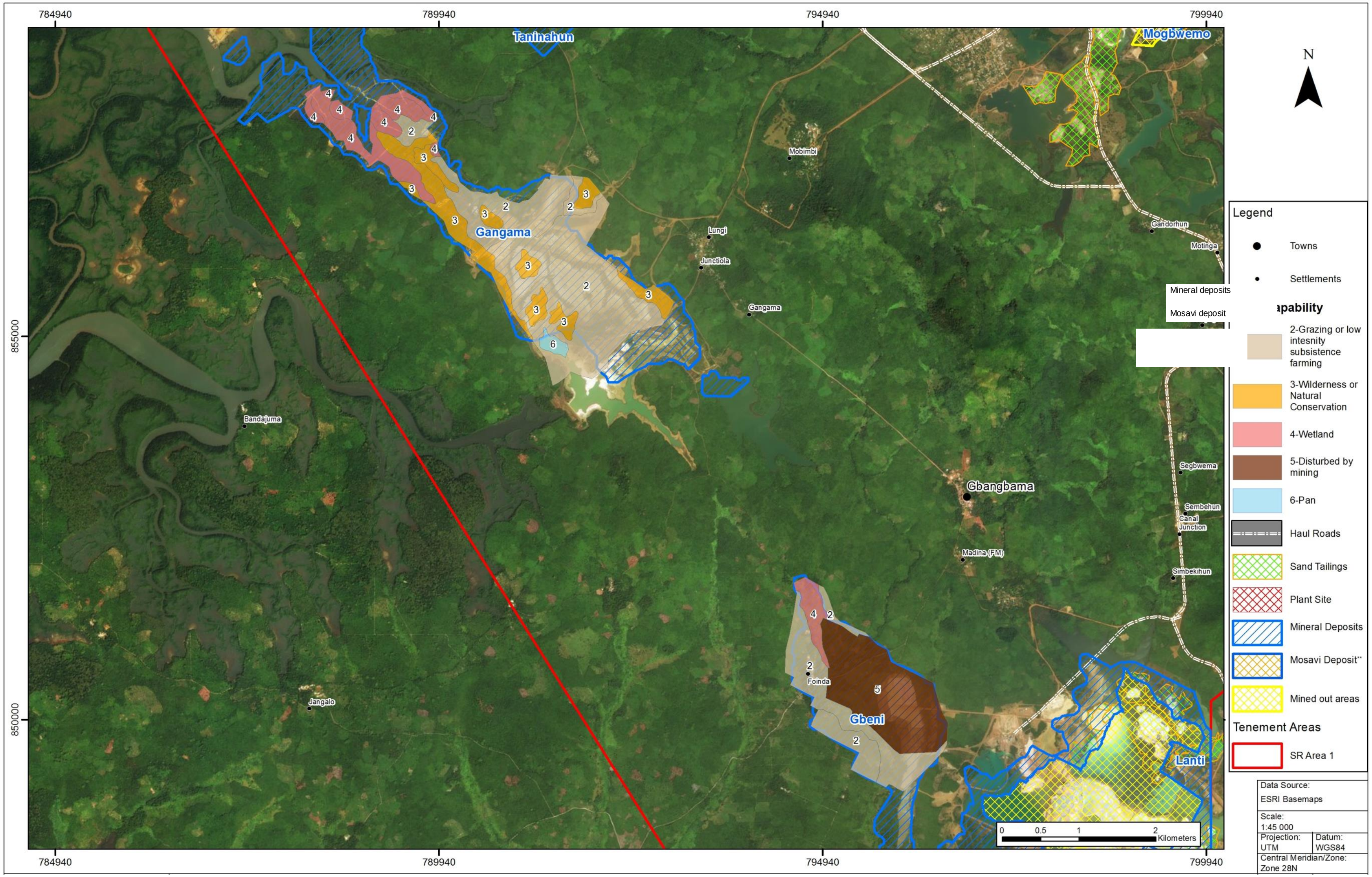

Figure 3.5 Land Capability in the Study Area (refer to Appendix 1 for enlarge scale maps)

4. ENVIRONMENTAL IMPACT ASSESSMENT AND MANAGEMENT PLAN

4.1 Baseline Information

With the mine having been in operation for over 50 years, the exiting impacts and current re-instatement are considered as the baseline conditions to this assessment. Dredge mining, processing and the deposition of tailings is a process that forms part of the cumulative effects on the local environment and the soils and land capability as well.

The purpose of this Environmental Social Health Impact Assessment (ESHIA) is to update the impact assessment and management measures within Area 1.

The potential impacts of significance associated with the mining activities on the soils and land capability include:

- The loss of soil resources and potential change in soil characteristics, land capability and land use as a result of site clearing ahead of the mining operation.
- The loss of soil resources and potential change in soil characteristics, land capability and land use from the open cast mining (dredge mining and dry mining);
- Contamination of soil resources from spillage of chemicals and seepage from waste; and
- The loss of future land use from mining and beneficiation of the mineral sands.

The activities that are considered as part of the current and planned mining include:

- Site clearing;
- Mining;
- Access road building and maintenance;
- Primary mineral processing;
- Tailings / overburden management;
- Transport of ore / product;
- Waste management;
- Power transmission;
- Potable water reticulation;
- Mine offices, workshops and stores; and
- Completed and future rehabilitation.

With the baseline assessment in hand, and the determination of the existing state of the environment covered, the relative sensitivities and areas of concern have been highlighted as the basis for the ESHIA.

The Impact Assessment philosophy and Significance Rating System aims to identify and quantify, where possible, the environmental, social and health aspects of the proposed activities, to assess how the aspects will affect the existing environmental state, and link the aspects to variables that have been defined in terms of the baseline study.

Based on the outcomes of the impact assessment, the site-specific management planning and mitigation measures can be defined and a rehabilitation strategy and design can be implemented with the End Land Use in mind.

This includes describing management and mitigation measures to reduce the intensity and probability of the impact, as well as specify a performance expectation for the mitigation / management proposed. In addition, and as part of the practical soils management plan, a monitoring system has been tabled.

The Project description, as outlined in the Scoping Study (SRK 2017) was used as the basis for the impact assessment. The soils and land capability are aspects of the physical environment that has been, and will potentially be affected by the current and future mining and its associated activities (e.g. mining, haulage and beneficiation).

In updating the current impact assessment and understanding the current, and planned future mining management and mitigation strategy, it is important that the activities and their related impacts are understood.

The current and planned dry mining areas have been delineated from the measured and inferred resource plans, which have been determined from intensive exploration drilling and sampling.

The majority of the support infrastructure and beneficiation activities already exist, with the addition of some access and haul roads that will be required for the proposed expansion areas.

Based on the information available (historic and current), the previous baseline studies undertaken, and information provided by SRL, the areas of concern have been assessed and the significance of the expected / potential impacts rated.

Management and mitigation measures proposed are based on a well-developed and researched rehabilitation strategy that has been well tested on a number of similar mineral sand projects (Refer to Hillendale Project -1998– Natal, South Africa).

The principle of "No Net Loss" was followed wherever possible. However, the historical and current mining and its associated development occupies a large surface area and has been on-going for over 50 years. The present land uses and land capabilities have been previously altered and impacted by dredge mining, flooding of the land and associated soil resource, with the soils being mined as part of the mineral resource. These impacts were inevitable, and will be continuous and negative for future mining if not managed and mitigated differently. These activities challenge the concept of "No Net Loss".

The legal requirement and implications for any development and the effects of the activities on the natural environment have been considered as part of the baseline studies, with soils being a consideration of both the local legislation (The Sierra Rutile Agreement, Act, 2002), as well as the best practice guidelines of the IFC Performance Standards. These guidelines and laws will, where applicable, dictate the acceptable levels of impact and will assist in setting the permissible standards and limits that should be considered.

In essence, the legal requirements as detailed in the IFC Performance Standards (Particularly standards 1 to 8) require that soils are considered as a "*prime resource that need to be managed and protected, and that the impacts of soils on the environment (erosion) need to be managed*".

In addition, The Sierra Rutile Agreement (Ratification) Act, 2002 Clause 10 (k) requires that "*reclamation and rehabilitation is undertaken for mined out areas".*

The IFC Performance Standard 1 establishes the importance of:

- **Integrated assessment** to identify the social and environmental impacts, risks, and opportunities of projects;
- Effective **community engagement** through disclosure of project-related information and consultation with local communities on matters that directly affect them; and
- The client's **management of social and environmental** performance throughout the life of the project.

Performance Standards 2 through 8, establish requirements to **avoid, reduce, mitigate or compensate** for impacts on people and the environment, and to improve conditions where appropriate. It is required that all relevant social and environmental risks and potential impacts should be considered as part of the assessment. The Performance Standards describe potential social and environmental impacts that require particular attention in emerging markets.

Where social or environmental impacts are anticipated, the client is required to manage them through its Social and Environmental Management System consistent with Performance Standard 1.

With regard to the application of relevant standards (either host country or other) there are no specific guidelines relating to soils and land capability. However, the World Bank's Mining and Milling guidelines make reference to:

- Minimising soil disturbance / vegetation clearance;
- Appropriate stockpiling of soils, maintaining soil integrity;
- In addition, the Plan to include measures appropriate to the situation to intercept, divert, or otherwise reduce the storm water runoff from exposed soil surfaces, tailings dams, and waste rock dumps; and
- Project owners are encouraged to integrate vegetative and non-vegetative soil stabilisation measures in the erosion control plan.

The variation in soil structure, texture and clay content of the soils, combined with the soil chemistry (low nutrient stores and high iron) make for complex natural conditions that, when combined with the climate and topographic variables, contribute to a complex of geomorphological and soil conditions that will be challenging to replicate during a rehabilitation exercise and/or at closure.

However, the concept of "**utilisable soil**" storage has been tabled as a management tool, a system that if combined with the well tested rehabilitation strategy being considered for this project, should prove to both enhance any rehabilitation effort while reducing costs in the long term.

Utilisable soil is classified as that soil which is important to the ecosystem services and ecological sustainability of an area. In soil terms, it is described as the combination of the "A" horizon and "B2/1" horizon - the soil horizons that support root development and store water.

4.2. Impact Assessment Philosophy

Based on the project information supplied, and using a well understood and recognised Impact Assessment philosophy the significance of the proposed activities in terms of impact have been described and rated.

The basis of the Impact Assessment system requires that that the impact "intensity" and its "probability" of occurrence are understood so that a relative "significance" can be determined. The impact intensity is a function of the "intensity potential" plus the "extent" plus the "duration" and the "frequency".

System Philosophy

The environmental impact assessment is designed according to a method developed by SRK.

All specialists working on the EIA have been asked to use a common, systematic and defensible method of assessing impact significance that will enable comparisons to be made between impacts across different disciplines. It also enables all parties to understand the process and rationale upon which impacts have been assessed.

Generally, impact assessment is divided into three parts:

- **Issue identification** - the evaluation and identification of the 'aspects' arising from the proposed project;
- **Impact definition** – defining of the positive and negative impacts associated with these issues (and any others not included). The definition statement includes the activity (source of impact), aspect and receptor as well as defining weather the impact is direct, indirect or cumulative. Fatal flaws are also identified at this stage; and
- **Impact evaluation** – this is not a purely objective and quantitative exercise. It has a subjective element, often using judgement and values as much as science-based criteria and standards.

In better understanding the impact evaluation, the sensitivity of the receiving environment, the effect on the receiving environment and the significance of the impacts needs to be clearly understood.

Impact significance rating

The impact significance rating system is presented in and involves three parts as detailed in Table 4.2:

Part A: Define impact consequence using the three primary impact characteristics of magnitude, spatial scale/population and duration;

Part B: Use the matrix to determine a rating for impact consequence based on the definitions identified in Part A; and

Part C: Use the matrix to determine the impact significance rating, which is a function of the impact consequence rating (from Part B) and the probability of occurrence.

Table 4.2 Method for determining significance of an impact

PART A: DEFINING CONSEQUENCE IN TERMS OF MAGNITUDE, DURATION AND SPATIAL SCALE *Use these definitions to define the consequence in Part B*		
Impact characteristics	**Definition**	**Criteria**
MAGNITUDE	Major -	Substantial deterioration or harm to receptors; receiving environment has an inherent value to stakeholders; receptors of impact are of conservation importance; or identified threshold often exceeded
	Moderate -	Moderate/measurable deterioration or harm to receptors; receiving environment moderately sensitive; or identified threshold occasionally exceeded
	Minor -	Minor deterioration (nuisance or minor deterioration) or harm to receptors; change to receiving environment not measurable; or identified threshold never exceeded
	Minor +	Minor improvement; change not measurable; or threshold never exceeded
	Moderate +	Moderate improvement; within or better than the threshold; or no observed reaction
	Major +	Substantial improvement; within or better than the threshold; or favourable publicity
DURATION	Short term	Up to 18 months.
	Medium term	18 months to 5 years
	Long term	Longer than 5 years
SPATIAL SCALE OR POPULATION	Site or local	Site specific or confined to the immediate project area
	Regional	May be defined in various ways, e.g. cadastral, catchment, topographic
	National/ International	Nationally or beyond

PART B: DETERMINING CONSEQUENCE RATING *Rate consequence based on definition of magnitude, spatial extent and duration*					
MAGNITUDE			**SPATIAL SCALE/ POPULATION**		
			Site or Local	**Regional**	**National/ international**
Minor	**DURATION**	**Long term**	Medium	Medium	High
		Medium term	Low	Low	Medium
		Short term	Low	Low	Medium
Moderate	**DURATION**	**Long term**	Medium	High	High
		Medium term	Medium	Medium	High
		Short term	Low	Medium	Medium
Major	**DURATION**	**Long term**	High	High	High
		Medium term	Medium	Medium	High
		Short term	Medium	Medium	High

PART C: DETERMINING SIGNIFICANCE RATING **Rate significance based on consequence and probability**				
		CONSEQUENCE		
		Low	**Medium**	**High**
PROBABILITY (of exposure to impacts)	**Definite**	Medium	Medium	High
	Possible	Low	Medium	High
	Unlikely	Low	Low	Medium

4.3 Impact Assessment Variables

The following sections describe the components and activities associated with the mining project, with a particular emphasis on those activities that may lead to significant (moderate or high) environmental or social impacts. The scoping study (SRK 2017) has been used as the reference document.

Mineral sands mining at SRL comprise a number of mining and associated activities of consequence to the impact assessment. The existing operations include:

- The Lanti Wet Mining (18 months);
- The Lanti Wet processing plant;
- The Lanti Dry processing plant;
- The Gangama processing plant;
- The Mineral Separation Plant (MSP), and
- Nitti Port.

While additional mining and expansion to the infrastructure is planned for:

- Lanti Dry Mining (including Gbeni) (4 years);
- Mogbwemo;
- Pejebu, and
- Gangama (4 years), and additions to the infrastructure at Gangama.

On-going mining will necessitate that additional areas of land are disturbed. The areas of impact include:

- The expansion into Dry Mining methods at Lanti (including Gbeni), Mogbwemo, Pejebu and Gangama;
- Access and haulage roads to the new mining areas;
- Addition to the processing facility, and
- Possible extension to the Nitti Port area.

The impact and management planning consider the expansion and on-going mining activities as part of the operational phase and consider the clearing of vegetation and stripping of soil ahead of the mining to be an operational function.

The general philosophy used in the scoping document has been used for ease of cross referencing and assimilation of data across the disciplines.

4.4 Operational Phase

During the operational phase the following activities are considered that could impact on the environment:

- Clearance of vegetation ahead of the mine path;
- Stripping and storage or concurrent reuse of utilisable soil, and
- Development of access and haulage roads where necessary to access the new mining areas.

A risk to soils use and land capability is associated with the actual mining operation itself. Ingress of storm water and/or vadose (soil) water into the system could potentially result in contamination and erosion of unprotected materials and the loss of this valuable resource from the system.

The impact of poor quality water (dissolved and suspended solids/sediments) on downstream uses caused by mining is also of concern if the sedimentary load is increased and sedimentation of water bodies (rivers and dams) increases.

Mining
Future mining will utilise a dry mining system, the use of mechanical shovels and articulated trucks, a method of mining that is to replace the present dredge mining. This mining method allows for the possible use of concurrent or progressive rehabilitation to occur.

The mining method/system involves the backfilling of the pit behind the mining face with the mixture of fine and coarse tailings and the top dressing of the final land form (landscaped) with a mixture of fine slit tails and the utilisable soil stripped and stored ahead of the mining. The utilisable soils have both a nutrient store as well as a seed pool that is invaluable for rehabilitation.

Erosion and the impacts of suspended solids on the environment are considered a significant risk based on the soil physical and chemical characteristics (low clay content, high leaching status), the climate (high rainfall) and variable geomorphology of the area. These concerns are important to both the loss of soil as a resource as well as the loss of land capability and the surface water ecology. The design of the storm water management system will be important in minimising and mitigating these aspects.

The impacts associated with these activities and actions, includes possible sterilisation of the soil resource, contamination of the soil resource and surrounding areas, salinisation and the potential loss of the resource due to erosion and compaction, while the potential for the siltation and/or contamination of the surrounding streams and rivers is raised as a significant risk.

Haul Roads
The extracted ore is transported from the mine void to the concentrator and processing plants along existing haul roads. Where additional access or haul roads are needed, they will conform to the same design standards as the existing system.

The impacts associated with these activities and actions, include sterilisation of the soil resource, loss of the soils utilisation potential, possible contamination of the soil resource and surrounding areas, salinization, and the possible loss of the resource due to erosion and compaction. The effects of erosion will potentially result in the siltation and/or contamination of the surrounding streams, mangroves and rivers.

Nitti Port
The on-going operation and any additions or changes at Nitti Port will impact the soils and land capability through the sterilisation of the utilisable resource, the potential for contamination and salinisation by spillage of product concentrate, hydrocarbons and/or reagents, and the loss of soil from the system due to unmanaged erosion.

The impact significance of these activities if not well managed is moderate to high.

However, if the management and mitigation measures are implemented, the negative impacts can be minimised to an acceptable level.

5. ASSESSMENT OF IMPACTS ON THE ENVIRONMENT

5.1 Impact Statement for Study Area

With the EIA methodology and philosophy addressed in the preceding sections, and with information available on what activities are undertaken, an assessment of the environmental impacts in terms of soils and land capability has been carried out and has been measured against the existing environmental state. The concept of "sensitivity" (measure of the natural environmental state) is introduced as a measure that management could considered when assessing the impact to the natural environment.

This section assesses and measures/quantifies the environmental aspects of the activities in terms of how they will affect the existing state, and details the maximum acceptable level of impact for each of the variables listed.

Based on these findings, the significance of the impact is discussed (not rated) in terms of its unmanaged and managed state, with the management recommendations forming the basis of the ESHMP, as it relates to soils and land capability.

5.2 Impact Assessment

Of significance to the study area is the group of moderately sensitive, deep sandy loams and silty loam soils (Fluvisols) that rate as moderate or slightly sensitive sites, as well as the much more sensitive Gleysols with which the wet based soils are associated. The marshlands and tidal wetlands along with the hydromorphic soils of the wetland capability rating, are considered the sites of greatest sensitivity.

Based on the site assessment it is clear that the mining development spans a range of site sensitivity ratings. These include:

- The colluvial/alluvial nature of the Fluvisols (low to very low clay percentages, and at best moderate to poor nutrient stores);
- The potential for flooding and inundation by storm water and/or tidal events render these sites sensitive if exposed and/or disturbed, and
- Erosion and the loss of soil materials coupled with the potential for contamination by dirty storm water and/or spillage of hydrocarbons and product are all considered impacts.

The potential for the soils to erode and impact the downstream environment and biodiversity with suspended solids and contaminants is possible if not well managed. In addition, during the Life of Mine (LoM), it will result in the loss of the soil resource, possible sterilisation of the soil as a resource and alter the lands capability and utilisation potential.

In terms of the wetland delineation guidelines (Manual for the assessment of a Wetland Index of Habitat Integrity for South African - Department of Water Affairs and Forestry Resource Quality Services August 2007) used, and the sensitive nature of wetlands, any soil that show signs of hydromorphic character at or close to surface (mottling and reduction in the ferrous concentrations within 50 cm of surface), need to be considered a sensitive site and treated with caution. Impacting wetland sites will potentially have negative consequences for downstream receptors and eco-system services.

The types of traffic expected will include the full range of light and heavy duty commercial and, in the case of SRL some private vehicles, Light Delivery Vehicles and heavy industrial supply trucks, albeit on a relatively small footprint.

Using the Scoping Document and proposed LoM plan as baseline information, and with an understanding of the mining methodology and relative areas that will be disturbed (de-bushed, cleared of vegetation, moved and/or utilised) considered, the major concerns and probable impacts that could affect the soils and associated land capability if not managed correctly include:

- The loss of the soil resource due to the **change in land use** and the removal of the resource from the existing system (sterilisation), as a result of the mining activities and the construction of related infrastructure. These activities will change land utilisation and its associated capability resulting in the loss of the soils resource for the life of the activity;
- The possible loss of the soil resource due to the **erosion** (wind and water) of unprotected soils and the possible contamination of the downstream receptors by sediment and/or other contaminants (hydrocarbons etc.);
- The possible loss of the utilisation potential of the soil and land capability due to **compaction** of areas adjacent to the mining pits and constructed facilities;
- Loss of the resource due to **removal** of materials for use in other activities such as borrow pits;
- The **contamination** or ***salinisation*** of stored or in-situ materials due to dust or emissions fallout from the open pit mining and transporting of the ore/HMC to the plant, and
- The **loss of the soil utilisation potential** due to the disturbance of the soils and potential loss of nutrient (seed pool) and organic carbon stores through infiltration and de-nitrification of the materials.

<u>Operational Phase (Current and Future)</u>

Issue ***Loss of utilisable resource (sterilisation and erosion), compaction, de-nutrification and contamination or salinisation.***

The operational phase involves the mining of the heavy mineral sands and the disturbance of the soils, leading to the potential loss of the soil resource and ecosystem services from the system as a result. The ability to rehabilitate and reinstate the lands to a sustainable end land use will be severely compromised and additions of both organic matter and nutrients will be required if the soils are not adequately managed.

In summary, the operation will result in:

- The loss and sterilisation of the soil resource and a resultant loss of ecosystem services from the system;
- The possible loss (through erosion) of utilisable soil down-slope / downstream, a resultant increase in sedimentary load/suspended solids, within the mangrove and river environments;
- The compaction of the in-situ and stored soils and the potential loss of utilisable materials from the system;
- The contamination of the soils by dirty water run-off and/or spillage of raw materials and/or hydrocarbons from vehicle and machinery;
- Contamination of soils by use of dirty water for road wetting (dust suppression);
- Potential contamination of soils by chemical spills of reagents being transported to site;

- Sterilisation and loss of soil nutrient pool, organic carbon stores, seed bank and fertility of stored soils while in storage,
- The creation of a new soil comprising tailings, sand and slimes, a mix that is generally poor in water holding capability and low in nutrients; and
- Impact on the soil structure and soil water balance.

Impact Significance

The result of the operations associated with the mining on the soil resource will have a high negative intensity potential that is permanent and confined to the immediate site.

In the un-managed scenario, the frequency is likely to be continuous. This result is of a high significance.

It is inevitable that some of the soils will be lost during the operational phase if they are not well managed and a mitigation plan is not made part of the general management schedule. However, the impacts on the soils during the operational phase can be mitigated with management procedures including:

- Stripping of larger vegetation and utilisable soil (top 300 mm to 600 mm) from the surface prior to mining commencing. Theses soils should be stored and managed (surveyed, demarcated and adequate records of their location and attributes to be kept) so that they are available for re-use at rehabilitation;
- Minimisation of the area that can potentially be impacted (eroded, compacted, sterilised or de-nutrified);
- Timely replacement of the soils so as to minimise/reduce the area of affect and disturbance using a system of concurrent rehabilitation;
- Effective soil cover and adequate protection from wind (dust) and dirty water contamination – re-vegetate all replaced and landscaped areas as soon as possible after replacement;
- Regular servicing of all vehicles in well-constructed and bunded areas;
- Regular cleaning and maintenance of all 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;
- The use of indigenous grasses to limit erosion on steeper areas that become available for rehabilitation (temporary servitudes);
- Soil amelioration (rehabilitated and stockpiled) including deep ripping and discing of the rehabilitated areas will be needed to enhance the growth capability of the soils and sustain the soils ability to retain oxygen and nutrients, and
- Optimisation of the water and nutrient holding capacity of surface tailings.

It will be necessary as part of the development plan to maintain the integrity of the stored soils, so that they are available for rehabilitation at decommissioning, rehabilitation and closure. If the soil (utilisable soils) quantities and qualities are available and managed through the operational phase, rehabilitation costs will be reduced, and natural attenuation will more easily and readily take effect and a sustainable “End Land Use” achieved.

Residual Impact

In the long term (LoM) and if implemented correctly, the above mitigation measures will reduce the impact on the utilisable soil reserves (erosion, contamination and sterilisation) to a significance rating of moderate or low.

However, if the soils are not retained/stored and managed, and a workable management plan is not implemented, the residual impact will definitely incur additional costs and result in the impacting of secondary areas (borrow pits etc.) in order to obtain cover materials for the rehabilitation process.

Loss of soil resource, potential change in soil characteristics while in storage and contamination by dirty water, dust and hydrocarbon spillage during the operational phases								
	Magnitude	**Duration**	**Scale**	**Consequence**	**Probability**	**SIGNIFICANCE**	**+ /-**	**Confidence**
Before Management	*Moderate*	*Medium-Long term*	*Site/local*	***High***	***Definite***	***High***	-	*Moderate*
Management Measures • Minimize the disturbed footprint as far as practically possible. • Timeous replacement of soils and concurrent rehabilitation where possible as per the Soil Management Plan. • Regular cleaning and maintenance (good housekeeping) of vehicles, erosion control by water and dust and on-going adherence to social and labour commitments to the loss of eco system services. • Implement the Closure and Rehabilitation Plan as described to support the proposed project as and when appropriate.								
After Management	*Minor*	*Medium-term*	*Site/local*	***Low***	***Definite***	***Medium -***	-	*Moderate*

<u>Decommissioning & Closure Phase</u>

Issue: ***Net loss of soil volumes and utilisation potential due to change in material status (physical and chemical) and loss of nutrient base.***

The impacts on the soil resource during the decommissioning and closure phase are considered to be both negative as well as positive, with:

- The loss of the soils original nutrient store (de-nutrification) and organic carbon by leaching of the soils during mining and/or while in storage;
- Erosion and possible de-oxygenation of materials while stockpiled;
- Compaction and contamination (spillage) due to vehicle movement while rehabilitating the area;
- Erosion due to slope stabilisation and re-vegetation of disturbed areas;
- Contamination of replaced soils by use of dirty water for plant watering and possibly dust suppression; and
- Positive impacts of reduction in areas of disturbance and return of soil utilisation potential, uncovering of areas of storage and rehabilitation of compacted materials.

Impact Significance

The impact will remain the net loss of the soil resource if no intervention or mitigating strategy is implemented. The intensity potential will remain moderate and negative for all of the activities if there is no active management (rehabilitation and intervention) in the decommissioning phase, and closure will not be possible. This will result in an irreversible impact that is continuous.

However, with mitigation and well-planned management, the impact significance can be meaningfully increased to a rating of positive moderate to high intensity as the utilisable soils are replaced and the sites are landscaped and re-vegetated.

Landscaping of the rehabilitated sites to be free draining, and the amelioration/fertilisation of the soils will assist in the implementation of a sustainable end land use.

On-going rehabilitation during the operational and decommissioning phases will bring about a net long-term positive impact on the soils, albeit that the land capability will likely only be returned to a status consistent with the present conditions (subsistence agriculture).

The significance rating associated with the re-instatement activities during rehabilitation and closure will be moderate and negative due to the necessity for vehicle movement while landscaping the operational footprint(s). Dust will potentially be generated, and soil will potentially be contaminated, compacted and eroded.

However, the positive impacts of rehabilitation and re-instatement on the area, include the reduction in the footprint of disturbance, the amelioration of the affected soils and oxygenation of the growing medium, the stabilisation of slopes and the re-vegetation of disturbed areas. All of these actions and outcomes will have a positive effect on the impact significance.

Residual Impacts

On closure, the long-term negative impact on the soils will be reduced from a significance of moderate to low if the management plan set out in the ESHMP (Section 6) is effectively implemented.

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

Compaction and possible contamination due to vehicle movement during rehabilitation, spillage of hydrocarbons and loss of soil resource by dirty water ingress to rehabilitated soils and restored vegetation, while positives associated with land use restoration, and land capability returned to wilderness status.								
	Magnitude	**Duration**	**Scale**	**Consequence**	**Probability**	**SIGNIFICANCE**	**+ /-**	**Confidence**
Before Management	*Moderate*	*Medium-term*	*Site/local*	***Low***	***Definite***	***Medium -***	-	*Low*
Management Measures • Reduction in area if impact, restriction on vehicle and animal movement over rehabilitated lands and maintenance of restored vegetation (monitoring etc.); • Equipment maintenance; and • Minimisation of dust and erosion by overland flow on unprotected areas.								
After Management	Minor	Medium-term	Site/local	Low	Possible	Low +	+	*Low*

6. ENVIRONMENTAL MANAGEMENT PLANNING

6.1 General Management Philosophy

It is incumbent on any mining operation to consider the possible impacts that the activities might have on the environment and to implement management measures that will aid in minimising and where possible mitigating the effects of the impacts to measurable and auditable standards. The IFC Performance Standards and local environmental laws [The Sierra Rutile Agreement (Ratification) Act, 2002, the Environmental Protection (Mines and Minerals) Regulations, 2013 and the Environmental and Social Regulations for Minerals Sector 2011] have been adopted as the guiding principles for impact and management objectives.

The management of the natural resources (soils and land capability) have been assessed on a phased basis (operation and decommissioning/closure) in keeping with the impact assessment philosophy, while the ESHMP has been assessed in consultation with the rehabilitation specialists (Mr. Rob Brown and Mr. James Lake), the Biodiversity Specialists and the Hydrologists.

The results tabled are based on site-specific soil characterisation and classification for the proposed new mining areas in conjunction with the geomorphology (topography, altitude, attitude, climate and ground roughness) and existing impacts and conditions associated with Area 1.

The soil utilisation plan has taken cognisance of the existing rehabilitation strategy as well as the strategy developed for similar heavy mineral sand projects in Southern Africa on which the client and members of staff have been intimately involved.

Consideration has also been given to recommendations on the stripping and handling of the soils along with recommendations for the utilisation of the soils for rehabilitation at closure.

It has been assumed that the infrastructure required is already available (existing), and that any new support infrastructure will be constructed within the already disturbed footprint. It is also assumed, that decommissioned or un-necessary infrastructure, and all mining areas will be rehabilitated and returned to as close as possible their pre-mining/development state as soon as possible after being decommissioned.

The concept of ***stripping and storage*** of "**Utilisable**" soil is recommended as a minimum requirement (IFC and Sierra Leone Act 2002) as part of the overall Soil Utilisation philosophy.

In terms of the "Minimum Requirements" (The Sierra Rutile Agreement (Ratification) Act, 2002 – Reclamation and Rehabilitation of Mined out areas Clause 10 k), the "study area needs to be rehabilitated according to a comprehensive master plan".

It is understood that the heavy mineral commodity being targeted occurs within the soil profile and colluvial/alluvial accumulations, and as such, the utilisable soil will be targeted as part of the process. It is however important that a compromise between maximum gain and rehabilitation success is achieved in terms of an environmentally sustainable outcome. In achieving these ends, it is proposed that the utilisable portion (A + B2/1 horizons) of the soil horizon be retained wherever possible, stored and used as part of the rehabilitation mix at closure.

The concept of usable or utilisable soil is defined here as all soil above an agreed subterranean cut-off depth defined by the project specialist scientists, a depth that will vary for different soil forms encountered in the project area.

The system does not differentiate between topsoil (orthic horizon) and other subsoil horizons necessarily but considers the utilisation potential of the vadose horizon as a whole and maximises on the depth of soil versus cost and practicality of storage (available open space).

From a sustainability perspective, any post-mining rehabilitated landform should be designed so that dryland agriculture can be practised under the range of normally occurring climatic conditions. The ability of the replaced soils to retain sufficient water through the dry season is considered an important factor in the soil utilisation mix.

The following soil utilisation guidelines should be considered wherever possible:

- Over areas of deep excavation (open pit mining or deep excavations/foundations where the majority or all of the soil profile is to be impacted), *strip all usable soil* as defined (300 mm to 450 mm) in terms of the soil classification, and store these fractions as berms (<1.5 m) or low, terraced dumps (<15 m). In the case of the SRL Project the following site-specific recommendations are considered:
    - ✓ Utilisable soil from the Fluvisols (alluvial and colluvial derived materials) should be stockpiled separately from the utilisable section of the hydromorphic and Gleysols (mangrove), which in turn should be separated from the utilisable portion of the *in-situ* derived materials or Ferralsols;
    - ✓ All of these soils should, in turn be protected from contamination and erosion using a combination of vegetation cover and storm water controls (berms and cut-off trenches), while concurrent reinstatement of the materials should be considered where practical;
    - ✓ At rehabilitation, backfill the open cast mining areas with any soft rock that might have been disturbed during the mining process, followed by the sand tailings from the beneficiation process and a sand/slimes (fine tails) mix;
    - ✓ Landscape the rehabilitated/re-instated area to a free draining land-form and top dress to the appropriate soil depth using the stored utilisable soils mixed with the slimes (Refer to Post Closure Land Use Guidelines – SRL Internal) as prescribed in the rehabilitation and closure plan, Ponding and the ingress of storm water should be avoided where possible, and
    - ✓ Cultivate and plant to a suitable vegetative cover (consult biodiversity specialists and Post Closure Land Use Guidelines – SRL Internal) that will emulate as close as possible the pre-mining/construction land capability.

- Over areas defined for residue/waste storage and any haulage and access roads - strip usable soil to a depth of 350 mm where possible. Following which:
    - ✓ Stockpile hydromorphic soils (Gleysols) separately from the dry and friable (fluvial soils) materials;
    - ✓ Before rehabilitation remove all gravel and other rocky material and recycle as construction material or place in open voids;
    - ✓ Remove foundations to a maximum depth of 1 m;
    - ✓ Replace soil to appropriate soil depths and in appropriate topographic position so as to achieve pre-mining land capability, and
    - ✓ Protect the stored materials from erosion and contamination.

- Over areas to be utilized for general access roads (light delivery vehicles), laydown pads and any conveyancing servitudes (above ground pipelines and power line servitudes), strip the top 350 mm of usable soil over all affected areas and stockpile in longitudinal stockpiles or berms upslope of the facilities. Protect these from erosion and contamination.

6.2 Environmental and Social Management Plan – Mine Site

6.2.1 Operational Phase – Pre-Mining

The mining design and techniques to be used for the extraction of the heavy mineral resource along with a well-developed “End Land Use” (ELU) are important in deciding at the outset if the utilisable soils need to be stripped and retained, and ultimately how much of the materials will be needed for rehabilitation.

Failure to remove and store the utilisable materials will result in the permanent loss of the growth medium.

Making provision for retention of utilisable material for rehabilitation will not only save significant costs at closure, but will ensure that a more sustainable ELU is achieved and that the ecosystem services are reinstated to an acceptable status (subsistence farming).

The depths of utilisable materials on the Fluvisols vary between 500 mm and greater than 800 mm with the wet based and saturated materials of the Gleysols returning rooting depths that are less than 500 mm in depth. These materials should be stockpiled separately wherever possible.

Where impacts extend onto the Ferralsols (haulage roads, support infrastructure and processing facilities), the utilisable soils are generally shallower with less than 400 mm of utilisable soil available. Adequate quantities of soil should be retained (top 400 mm) so that rehabilitation can be achieved at closure.

The alluvial and colluvial derived materials (Fluvisols) are sufficiently similar that they can be stripped and stored as one soil group. The more sensitive wet based materials (Gleysols) should be considered sensitive environments where they are going to be impacted and should therefore be stripped and stored separately. The mine plan considers the mining of the wet based materials in the north western portion of Gangama. The rehabilitation of these areas will require planning and considered inputs in relation to their original state (pre-mining surface levels and topography will need to be considered and recorded prior to mining commencing) if a sustainable end land use is to be achieved.

Table 6.2a describes the proposed utilisation plan for the soils during the pre-mining phase of the operation.

Table 6.2a Operational Phase – Soil Utilisation Plan

Phase	Step	Factors to Consider	Comments
Operational Phase - Pre-Mining	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 recommended that the larger timber is utilised by the local communities for fuels while the bushy vegetation is stripped and stored as part of the utilisable soil resource. 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	Utilisable soil (topsoil and upper portion of subsoil B2/1) should be stripped and stockpiled separately from any soft overburden or saprolitic materials (decomposed rock) that might be encountered. All stockpiles soils will need to be protected from erosion, either by promotion of natural vegetative cover, or through the use of rock cladding
		Stripping	The "Utilizable" soil will be stripped to a depth of 750cm or until hard rock is encountered. These soils will be stockpiled together with any vegetation cover present (only large bushes and trees to be removed prior to stripping). The total stripped depth should be 750mm, where possible.
	Delineation of stockpiling areas	Location	Stockpiling areas will be identified in close proximity to the source of the soil and to the area of end use so as 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.

This "Soil Utilization Plan" is intimately linked to the "development plan", and it should be understood that if the plan of construction changes, these recommendations will probably have to change as well.

6.2.2 Operational Phase – Open Cast Mining

The operational phase will involve open cast dry mining going forward. Very little change in the associated support activities is anticipated. This assumes that mining will be undertaken while concurrent rehabilitation is taking place behind the mining face. The backfilling of the mining voids with sand and tailings and the use of the utilisable soil in conjunction with the slimes (fine tails), will help in reducing the need for double handling of materials, and should reduce the quantities of utilisable material that need to be stockpiled in some areas.

Maintenance and care of the soil and land resources will be the main management activity and objective required during the operational phase, with the management of material loss, erosion, compaction, contamination and the creation of an acceptable mix of soil and slimes/tailings are the main issues of consideration. Table 6.2 details recommendations for the care and maintenance of the resource during the operational phase.

Working with or on the differing soil materials (all of which occur within the areas that are to be disturbed) will require effective management and careful planning if rehabilitation is to be successful, and it is important that the sensitive and highly sensitive materials are well managed if they cannot be avoided.

Table 6.2b Operational Phase – Soil Conservation/Maintenance Plan

Phase	Step	Factors to Consider	Comments
Operation - Care and Maintenance	Stockpile management	Vegetation establishment and erosion control	Where utilisable soils are to be stripped and stored, the berms/stockpiles should be vegetated and/or protected from impacts of soil erosion.
		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 the soil stockpiles and/or rehabilitated ground will be limited to avoid topsoil compaction and subsequent damage to the soils and seed bank.

6.2.3 Decommissioning and Closure

The decommissioning and closure phase will see:

- The removal of all infrastructure;
- The demolishing of all concrete slabs and ripping of any hard surfaces;
- The backfilling of any/all open voids and deep foundations with softs and/or tailings materials, and
- Topdressing (300 mm to 500 mm) of the disturbed areas with a mix of utilisable soil, slime and sand mix prior to, or as part of the landscaping (free draining topographic surfaces) and re-vegetation activities.

There will be a positive impact on the soil and land capability environments as the area of disturbance is reduced, and the soils are returned to a state that can support low intensity subsistence agriculture.

Table 6.2c is a summary of the proposed management and mitigation actions recommended

Table 6.2c 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 utilisable soil (750mm) removed during the pre-mining phase or while opening up of open cast workings should be redistributed in a manner that achieves an approximate uniform stable thickness consistent with the approved post mining land use, and will attain a free draining surface profile. A minimum layer of 400mm of sand and tails should be replaced, the area landscaped to a free draining topography, and the utilisable soils and slimes mix replaced prior to re-vegetation.
		Fertilization	A representative sampling of the stripped soils will be analysed to determine the nutrient status of the utilisable materials. As a minimum the following elements will be tested for: EC, CEC, pH, Ca, Mg, K, Na, P, Zn, Clay% and Organic Carbon. 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 carried 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 the local environmental agency on a case by case basis, before it is implemented.

7 MONITORING AND MAINTENANCE

Nutrient requirements reported herein are based on the sampling and monitoring of the soils and mangrove sediments at the time of the baseline survey. The results will definitely alter during the life of the project while the materials are in storage and will need to be re-evaluated before being used during rehabilitation. On-going evaluation of the nutrient status of the growth medium is recommended throughout the life of the project and into the rehabilitation phase.

Monitoring (annual) of soil from pre-selected positions around the site and from the soil stockpiles is recommended as part of the overall mine monitoring system (water, dust, air quality etc.)

During the rehabilitation exercise, preliminary soil quality sampling and analysis of the stockpiled materials should be carried out to accurately determine the nutrient requirements that will be needed. Additional soil sampling should also be carried out on the reinstated materials on a quarterly basis until the levels of nutrients, and base status are at the required levels for sustainable growth. One sample for every 1 hectare is recommended. Once the desired nutritional status has been achieved, it is recommended that the interval between sampling is increased.
An annual environmental audit should be undertaken at which time a decision can be made on the need for sampling and monitoring. If growth problems develop, ad hoc, sampling should be carried out to determine the problem.

Monitoring should always be carried out at the same times during the year and at least six weeks after the last application of fertiliser in the case of newly rehabilitated areas.

Monitoring for contamination should be considered if the audit findings warrant such action. Individual spills and accidental impacts will need to be assessed on a one on one basis and the degree of rehabilitation determined at the time.

The replaced soils and areas of rehabilitation should be sampled and analysed for the following parameters:

- pH (H_2O);
- Phosphorus (Bray I);
- Electrical conductivity;
- Calcium mg/kg;
- Cation exchange capacity;
- Sodium mg/kg;
- Magnesium mg/kg;
- Potassium mg/kgZinc mg/kg;
- Clay (soil texture);
- Organic matter content (C %); and
- Effective rooting depths.

The following maintenance is recommended:

- Newly seeded/planted areas must be protected against compaction and erosion as part of the landscaping of rehabilitated areas (keep slopes to less than 1:6 and free draining);
- Traffic should be limited where possible while the vegetation is establishing itself;
- Rehabilitation should be scheduled ahead of the annual rains so that water is retained and available for plant usage;
- Check for pests and diseases at least once every two weeks and treat if necessary;
- Replace unhealthy or dead plant material, and
- Repair any damage caused by erosion.

8 CONCLUSIONS

The findings from these specialist studies include:

- A broader understanding of the distribution of the various soil forms and their association to the geomorphology of the site obtained from the historical information and the baseline study;
- An appreciation of the soil physical and chemical attributes and how these could influence the rehabilitation strategy and End Land Use design for the existing and proposed mining activities. Information including consultation with the client and historical studies available;
- Consideration of the effective rooting depths and soil water characteristics of the dominant soil forms, and their use in planning the management of future mining, and an appreciation of what constitutes utilisable soil;
- An understanding of the existing rehabilitation effort and system and an appreciation of where improvements might be made based on existing research and case studies implemented by the client (similar projects). This information has been included in the amendment to the management plan;

- Current and future mining and its associated support activities are included in the amendment, and have been considered in terms of the affect that will be had on the soils and land capability;
- An understanding of the historic, current and future mining methods has informed the soil utilisation and management plan;
- An understanding that the dominant soils that will be disturbed by mining comprise:
  - ✓ moderately deep to deep profiles with effective rooting depths of between 500mm and 1,200mm, with fine textured sandy loams and silty clay loams with apedel to weak crumby laminated structure to the colluvial derived Fluvisols; and
  - ✓ moderately shallow clay and sandy clay loams and gleycutanic saturated profiles of the and Gleysols.

  These soil groupings returned significantly differing attributes in terms of soil texture, water holding capabilities and effective rooting depths, factors that will have a bearing on how the soils will react to be disturbed and how easily they can be handled (stripped and stored);
- A characterisation of the site and assessment of the sensitive. The moderate sensitivity of the sandy and silty loam soils that dominate the mining areas will require management in terms of erosion and compaction if they are to be useful as growth medium at rehabilitation and closure;
- The utilisation potential of the sandy loam and silty loam soils that constitute the soil rooting and water holding medium is considered an important resource for rehabilitation. The depth is considered moderate to good, with an average of 500mm of utilisable soil ("A" and "B2/1" horizon) that should be stripped and stored, while the water holding capacity is adequate and drainage good. The use of this material as a growth medium is recommended as part of the soil utilisation, and rehabilitation plan; and
- The current land capability is rated as wilderness potential, with a significant proportion of the area under consideration having been disturbed by subsistence farming.

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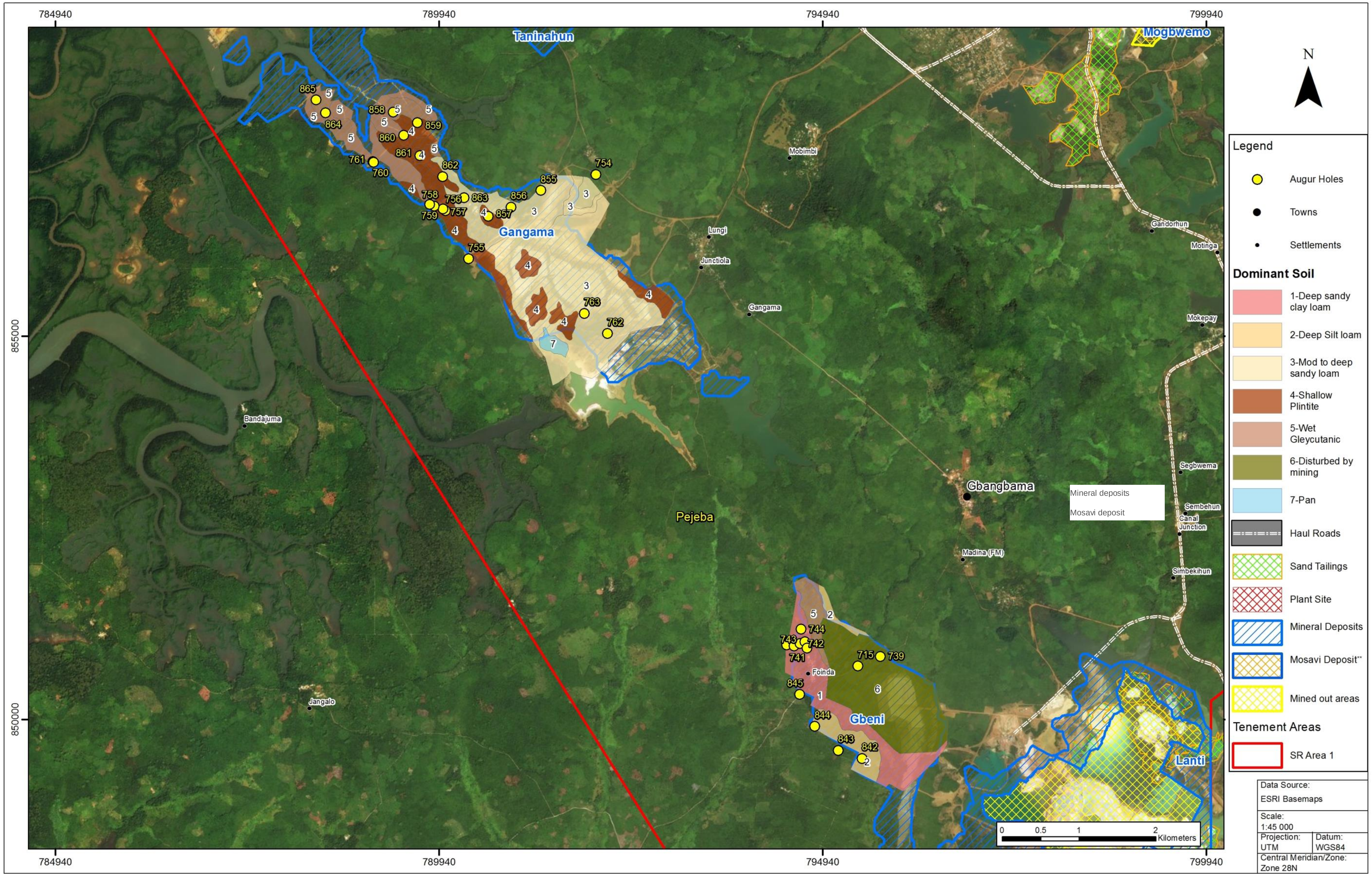
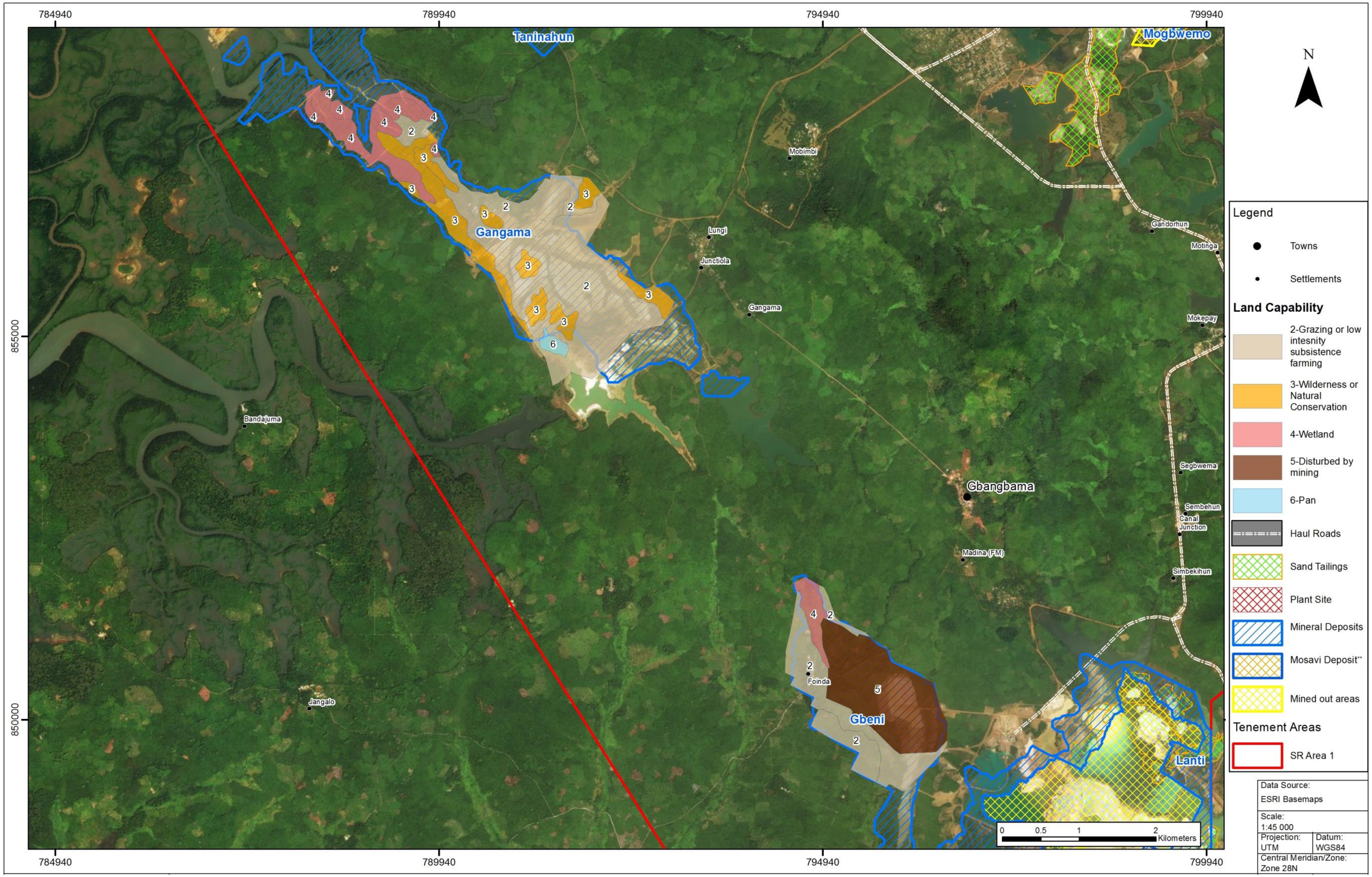
APPENDIX 1

A3 Maps



Appendix 1a: Dominant soils – Gbeni and Gangama



Appendix 1b: Land capability – Gbeni and Gangama

APPENDIX 2

Soil Observations

Soil Data Sheet - SRL 2017

Obs No	X	Y	Horizon	Depth cm	Clay %	Colour	Str	Wet	Cult Fact	ERD (cm)	Amel ERD (cm)	Comp-Min	Comp-Max	Org Mat %	"C" Horiz	TAM mm/m	Surf Feat	Rough	Tax	WR Base
712	799491	847688	A	25	8	pybr	a		g1	40	80	30	60	0.8	hp	70	r1	1	4-8 Dr/Gc	Ferralsol
			B	60	12	ybr	a													
713	797467	851577	A	30	8	pgbr/br	a		t1/g3/r1	45	60	40	50	0.8	hp	65	g2/r1	1	4-6 Dr/Gc	Ferralsol
			B	60	10	ybr	wc	w1												
714	796636	852161	A	40	10	ybr	a		t1	80	100	40	50	1	gn	80	g2	1	8-10 Cv/Gf	Fluvisol
			B	80	16	dybr	a													
715	795397	850701	A	35	10	ybr	a		t1	80	120	35	40	0.8	gn	100	g1/r1	1	8-12 Cv/Gf	Fluvisol
			B	120	18	rbr	a													
716	793328	854429	A	30	8	dyr	sg		g3/r1	40	40			0.6	hp	40	g3/r1	1	4 Gc	Ferralsol
			B	40	12	ybr	a	w1												
717	793888	857188	A	35	6	dybr	sg		g1/r1	50	60			0.8	hp	55	r3	2	6-8 Gc	Fluvisol
			B	80	12	hp	hp													
718	799275	847415	A	30	8	ybr	a		g2/r1	60	80			0.8	hp/sp	80	g2/r2	1	8-10 Gc	Fluvisol
			B	80	12	yr	a													
719	797578	846684	A	35	8	ybr	a			80	100			0.8	sp	100	g2	1	8-10 Gc/Cv	Fluvisol
			B	80	15	yr	a													
720	797791	846682	A	40	6	ybr	sg		r1/g1	80	100			2	so	110	g1	1	8-10 Gc/Cv	Fluvisol
			B	80	12	yr	wc													
721	798045	846612	A	35	10	pybr	a		r2/g1	50	80			0.8	hp	65	g3	1	4-10 Gc/Cv	Fluvisol
			B	80	15	ybr	wc	w1												
722	798356	846464	A	40	12	ybr	a		g1/t1	100	120	40	50	0.8	so	90	g1/r1	1	8-12 Cv	Fluvisol
			B	90	18	yr	a													
723	798556	846359	A	35	8	dbr	sg		t1	100	120	35	40	1	so	100	g1	1	10-12 Cv	Fluvisol
			B	100	12	ybr-r	wc													
724	798339	846713	A	35	10	pybr	a		g2/t1	80	100	35	50	1	so	90		1	10 Cv	Fluvisol
			B	80	15	ybr	wc													
725	798684	846560	A	35	12	dbr-bl	a		g2/t1	60	80	35	40	1.5	so	80		1	8-10 Cv/Av	
			B	80	22	dbr	wc	w1												
726	795232	849045	A	30	6	drbr	sg		g2/t1/r1	40		30	40	0.8	hp	50	g2r1	2	4-6 Dr/Gc	
			B	60	10	rbr	r													
727	794363	846738	A	35	12	br-ybr	a		t1	80	110	35	50	1	so	90	g1	1	12 Cv	Fluvisol
			B	100	18	ybr	wc													
728	794472	847425	A	40	15	ybr	a		t1	80	110	40	40	0.5	so	110		1	8-10 Gf	Fluvisol
			B	80	22	yr	wc													
729	794748	847309	A	40	12	ybr	a		t1	80	120	40	50	0.8	so	100		1	12 Cv	Fluvisol
			B	80	18	yr	wc													
730	794846	847266	A	35	10	dybr	a			100	120	35	50	0.8	so	110		1	12-15 Cv	Fluvisol
			B	100	15	ybr	wc													
731	795040	848048	A	40	10	dybr	a		g1/t1	110	140	40	50	0.8	so	120	g1	1	12-15 Cv/Fw	Fluvisol
			B	100	22	ybr-r	a													
732	794854	848134	A	35	10	dybr	a		t1	80	100	35	40	0.8	sp	80			8-10 Cv/Av	Fluvisol
			B	100	18	mybr	wc	w1												
733	794500	845000	A	35	8	dybr	sg		g2	60	80	35	40	1	hp	65	g2/r1	2	6-8 Gc/Cv	
			B	70	15	ybr	mb													
734	794500	8000	A	40	12	dybr	a		g1	60	80	40	50	0.85	hp	65	g2/r1	2	6-8 Gc/Cv	
			B	80	18	yr	mb													
735	794365	848475	A	40	6	ybr	sg		t1	80	100	40	50	0.8	so	90	g1/r1	1	8-10 Cv	Fluvisol
			B	80	10	ybr	wc													
736	794388	848685	A	40	12	br-ybr	a		t1	80	100	40	50	0.8	so	90	g1/r1	1	8-10 Cv	Fluvisol
			B	80	18	ybr	wc													
737	798426	859390	A	40	4	drbr	sg		g3/r1	20	40			1.2	hp	35	r3g4	3	2-6 Dr/Gc	Ferralsol
			B	60	10	rbr	hp													
738	797873	860741	A	40	8	rbr	a		r2/g2	40	60			1	hp	40	r2g3	2	4-6 Gc	Ferralsol
			B	60	15	dyr	r													
739	795692	850827	A	35	6	dybr	a		t1	80	120	35	40	1.1	so	100	g2	1	12 Cv/Gc	Fluvisol
			B	100	12	ybr-r	wc													

Obs No	X	Y	Horizon	Depth cm	Clay	Colour	Str	Wet	Cult Fact	ERD	Amel ERD	Comp-Min	Comp-Max	C-Cont	Lith	TAM	Surf Feat	Rough	Tax	
740	794470	850976	A	40	12	ybr	a		r4g2	30	40			0.8	sp	30	r3g2	3	4 Gc/Ms	
			B	40	18	br-ybr	sp													
741	794564	850961	A	20	12	rbr	a		r2/g3	20				0.8	r	25	r3	3	2 Ms	
742	794644	850995	A	35	12	ybr	a		t1	60	80	35	50	0.8	so	60		1	6-8 Cv	
			B	60	18	ybr-br	wc													
743	794708	851016	A	35	12	dybr	a		t1	80	100	40	70	0.5	so	80		1	8-10 Oa	Fluvisol
			B	100	15	ybr	wc													
744	794658	851181	A	25	15	rbr	a		r2/g3	30	40			1.2	hp	30	r4	3	4 Gc/Dr	Ferralsol
			B	40	25	r	hp													
745	793795	850919	A	30	12	g/ybr	a			20	30			1.8	gc	40		1	2-4 Rg/Lo	Gleysol
			B	40	20	myr	gc	w2/w3												
746	793980	850958	A	20	10	drbr	a		r1/g3	20	40			1	hp	35	r3	2	2-4 Dr/Gc	Ferralsol
			B	40	15	rbr	hp													
747	793670	851055	A	25	12	ybr	a	w2/w3		40	60			0.8	sp	45		1	4-6 We/Av	
			B	40	30	mybr	sp													
748	794736	850933	A	35	8	dybr	sg		t1	80	120	35	40	1.5	so	100		1	12 Cv	Fluvisol
			B	100	12	ybr/r	a													
749	797602	850115	A	35	12	dybr	a		r2/g2	40	60			1	hp	40	r2	2	4-6 Gc	Ferralsol
			B	60	18	yb	a													
750	794385	847191	A	45	12	dybr	a		t1	90	120	45	50	1	so	90		1	12 Cv/Fw	Fluvisol
			B	100	25	ybr	a													
751	794998	848471	A	40	18	dbr	a		t1	90	120	40	50	0.8	so	90		1	12 Gf	Fluvisol
			B	100	30	ybr/r	a													
752	798090	849976	A	25	5	pgbr/br	sg							0.5		35		1	Tailings	
			B	100	8	pybr	sg	w2/w3												
753	794636	857644	A	25	10	dybr	a		r1/g2	20	40			0.8	hp	20			4 Dr/Gc	Ferralsol
			B	40	12	y/r	hp													
754	791982	857107	A	30	8	dybr	a		r1/g3	40	60			1.2	hp	30			4-8 Dr/Gc	Ferralsol
			B	80	15	r	hp													
755	790323	856008	A	20	8	dbr	a		r2/g2	20	40			1	hp	25			2-6 Dr/Gc	Ferralsol
			B	60	15	r	hp													
756	790021	856636	A	20	8	dbr/ybr	sg		r2/g1	20	40			1.2	hp	20			2-4 Dr/Gc	Ferralsol
			B	40	15	r/br	hp													
757	789988	856657	A	20	10	dbr/br	a		r2/g3	20	40			1.2	hp	25			2-4 Dr/Gc	Ferralsol
			B	40	15	r	hp													
758	789877	856697	A	35	6	dbr	sg		r2/g3	30	50			1.5	hp	30			4-6 Dr/Gc	Ferralsol
			B	60	15	r/br	hp													
759	789817	856720	A	35	12	dbr	a		r2/g7/b1	40	60	20	40	1.8	sp/hp	45			6-8 Gc	
			B	80	35	ybr/rbr	hp													
760	789077	857278	A	20	12	pgbr/br	mb		g2	20				1.8	gc				2-4 Rg	Gleysol
			B	40	25	mgybr	gc	w3												
761	789082	857269	A	20	15	pgbr/br	mb		g1	20				1.5	gc				2-4 Rg	Gleysol
			B	40	25	mgybr	gc	w3												
762	792135	855035	A	35	10	ybr	a		t1/g1	80	120	35	40	0.8	so	80			8-12 Gf	Fluvisol
			B	80	18	ybr/r	a													
763	791831	855296	A	40	6	ybr	a		g1/t1	90	120	40	45	1.1	so	80			12-15 Gf/Cv	Fluvisol
			B	100	15	ybr/r	a													
764	791316	859100	A	35	10	dybr	a			60	100			1.2	so	75			6-10 Cv	Fluvisol
			B	80	18	ybr	wc													
765	791316	859100	A	35	10	dybr	sg			80	120			1.8	so	85			8-12 Cv	Fluvisol
			B	80	12	ybr	a													
766	791167	859342	A	40	6	dybr	sg			60	100			1.2	so	80			6-12 Cv	Fluvisol
			B	80	12	ybr/r	a													
767	787922	860607	A	20	8	dybr/rbr	sg		r2/g3	20	40			1	hp				2-4 Dr	Ferralsol
			B	40	15	br/rbr	a													
825	798880	846291	A	40	12	dybr	a		t1	60	80	40	50	0.8	so	85			10 Cv	Fluvisol
			B	100	20	ybr	wc													

Obs No	X	Y	Horizon	Depth cm	Clay	Colour	Str	Wet	Cult Fact	ERD	Amel ERD	Comp-Min	Comp-Max	C-Cont	Lith	TAM	Surf Feat	Rough	Tax	
826	798943	846151	A	45	12	ybr/dybr	a		t1	100	120	45	50	1	so	90			10-15 Cv	Fluvisol
			B	125	18	ybr	a													
827	799073	845963	A	40	10	dybr	a		r1/g2	80	110			1	so/hp	110			12 Cv/Gc	Fluvisol
			B	120	18	ybr/yr	a													
828	799507	845622	A	35	12	dybr	a		t1	80	100	35	40	0.8	so	85			10Cv	Fluvisol
			B	100	20	ybr	wc													
829	799774	845473	A	35	10	dybr	a		t1	90	100	35	40	0.8	so	85			10 Cv	Fluvisol
			B	100	18	ybr	wc													
830	798102	846069	A	40	8	rbr	sg		g2/t1	60		35	40	1.2	sp/hp	60			6-8 Gc/Av	
			B	60	15	mpybr/r	a	w1												
831	798446	846074	A	35	8	dbr/rbr	sg		r1/g3	40	60			1.2	hp	45			6 Gc	Ferralsol
			B	60	15	rbr	a													
832	798311	846325	A	25	12	ybr	a		t1	80	100	25	40	0.8	so	80			8-10 Cv	Fluvisol
			B	80	25	br/ybr	wc													
834	798464	845529	A	30	12	ybr/pybr	a		r1/g1	60				0.8	sp/hp	65			6-8 Gc/Av	
			B	60	15	mybr/rbr	a	w1												
835	795433	847723	A	25	10	pybr	a		g2	30				0.8	sp				4Gc/We	
			B	40	22	mybr/rbr	wc													
836	795702	847640	A	35	8	ybr	sg			80	100			0.8	so	100			12 Cv	Fluvisol
			B	100	20	ybr/rbr	a													
837	795159	847846	A	40	6	dybr	a			80	100			1	so	100			12 Cv	Fluvisol
			B	100	18	ybr/r	a													
838	794929	847783	A	40	10	dbr	a		t1	80	100	40	45	1.2	so/hp	80			8-10 Gc/Cv	
			B	80	18	rbr	a													
839	794496	847946	A	35	12	dbr	a		t1	60	80	35	40	1.2	so/hp	80			6-10 Gc/Cv	
			B	60	25	rbr	wc													
842	795451	849496	A	30	10	dbr/rbr	a		r1/g2	80	100			1.8	hp	75			8-10 Gc	
			B	80	18	rbr	wc													
843	795142	849599	A	35	6	ybr	sg		t1	100	120	35	40	1.2	so	110			10-15 Oa/Cv	Fluvisol
			B	100	15	mybr	a													
844	794836	849913	A	35	8	dbr	sg		r1/g2	60				1.5	hp	75			8 Gc	
			B	80	12	rbr	a													
845	794638	850330	A	45	15	ybr	a		t1	100	120	45	50	1	so	110			10-15 Oa/Cv	Fluvisol
			B	120	22	mybr	wc													
846	794455	850024	A	35	12	br/rbr	a		g2/t1	80		35	40	1	so/hp	85			8-10 Gc/Cv	
			B	100	20	ybr	wc													
847	794221	850139	A	40	10	ybr	a		t1	100	120	40	45	1.5	so	100			10-12 Oa/Cv	Fluvisol
			B	120	22	mybr	wc													
848	793999	849722	A	45	10	ybr	a		t1	80	120	45	50	1	so	100			10-12 Oa/Cv	Fluvisol
			B	100	22	mybr	wc													
849	792939	849413	A	40	8	dybr	sg			80	120	40	45	1.2	so	85			8-10 Cv	Fluvisol
			B	100	15	ybr/br	wc													
850	792748	849861	A	35	8	dybr	sg		t1	100		35	40	1	so	90			12 Cv	Fluvisol
			B	100	15	ybr/rbr	a													
851	793098	849953	A	35	6	dybr	sg		t1	100		35	40	1	so	90			12 Cv	Fluvisol
			B	100	18	ybr/rbr	a													
852	793177	850389	A	40	12	dbr	a		g2/t1	80	100	40	45	1.1	so/hp	85			8-12 Gc/Cv	
			B	100	25	rbr/br	wc													
853	793193	851040	A	35	12	dbr/ybr	a		g2	60	100			1.2	so/hp	80			6-10 Gc/Cv	
			B	60	25	rbr	wc													
854	793050	850738	A	35	8	dbr/rbr	sg		r1/g2	60				1.8	hp	60			8 Gc	
			B	80	15	r	a													
855	792661	851231	A	40	8	br/dbr	sg		r1/g2	40	60			1.2	so/hp				4-8 Gc/Cv	
			B	80	15	rbr	a													
856	790877	856682	A	35	10	br/dbr	a		g2	40	60			1.5	so/hp				4-8 Gc/Cv	
			B	60	18	rbr	wc													
857	790581	856561	A	20	6	br/rbr	sg		r2/g3	40				1.2	hp				2-6 Dr/Gc	Ferralsol
			B	40	15	rbr	a													

Obs No	X	Y	Horizon	Depth cm	Clay	Colour	Str	Wet	Cult Fact	ERD	Amel ERD	Comp-Min	Comp-Max	C-Cont	Lith	TAM	Surf Feat	Rough	Tax	
858	789339	857921	A	25	12	pg	a			20				2	gc				4-6 Ka/Rg	Gleysol
			B	40	30	mgyr/r	mb	w3												
859	789657	857783	A	35	8	pgbr/ybr	sg		r1/g2	60				1.8	sp/hp	40			6-8 Gc/Av	
			B	60	15	mpybr/rbr	a	w1												
860	789477	857619	A	40	12	pg/mgybr	mb	w3		20				2	gc				4 Rg	Gleysol
861	789689	857354	A	30	8	dbr	sg		r2/g2	40	60			1.5	hp	40			6 Gc	Ferralsol
			B	60	15	rbr	a													
862	789985	857079	A	30	8	dbr/rbr	sg		r2/g3	40	60			1.2	hp	40			6 Gc	Ferralsol
			B	60	15	rbr	a													
863	790265	856804	A	35	8	dbr/ybr	sg		r2/g2	40	60			1.5	hp	25			4-6 Dr/Gc	Ferralsol
			B	60	12	rbr	a													
864	788456	857910	A	20	15	mg/ybr/r	mb	w3						2	gc				2 Rg	Gleysol
865	788334	858079	A	20	15	mg/ybr/r	mb	w3						2	gc				2 Rg	Gleysol

APPENDIX 3

Soil Analysis (Chemical and Physical) and Laboratory Certification

										MEHLICH III																	
Lab No	Sample no	pH(H2O 1:1)	Density	TEC	Org Mat	Avail N	Bray II	K	Na	Ca	Mg	P	Fe	Mn	Cu	Zn	S	B	Ca	Mg	K	Na	H	Other	Clay	Silt	Sand
		-	g/ml	ME/100g	%	kg/ha	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	Base Saturation						%	%	%
	Norms	5.2 - 6.5		5-15	>0.75			> 40	> 2.0	> 200	> 60	> 20													15-25		
12909	SRL270a	5.20	1.09	1.02	6.00	117.58	1	17	9	76	10	4	53.79	1.31	0.63	0.55	10.85	0.00	37.43	8.36	4.37	3.84	39.00	7.00	4	20	76
12910	SRL270b	5.45	1.17	0.43	0.89	40.00	1	8	7	34	6	3	26.20	1.05	0.65	0.57	6.12	0.00	38.62	11.78	4.93	6.67	31.50	6.50	8	21	71
12911	SRL271a	5.22	1.09	2.53	0.67	29.91	1	19	9	204	33	6	56.42	1.65	0.70	0.76	7.36	0.00	40.40	10.62	1.95	1.63	38.43	6.96	6	15	79
12912	SRL271b	4.98	1.27	1.22	0.96	43.15	1	6	5	94	9	10	38.73	0.63	0.57	0.45	5.14	0.00	38.42	5.88	1.26	1.64	45.36	7.44	8	18	74
12913	SRL278a	5.01	0.99	1.29	0.69	30.96	1	32	8	69	19	6	47.06	1.18	0.73	0.52	22.63	0.00	26.68	12.25	6.30	2.68	44.70	7.38	14	20	66
12914	SRL278b	5.35	0.96	0.98	1.28	50.98	2	12	13	73	16	3	50.91	0.73	1.00	0.61	14.03	0.00	37.06	12.93	3.08	5.76	34.47	6.70	18	19	63
12915	SRL733a	5.22	1.05	2.08	0.85	37.90	1	24	10	153	33	5	74.36	1.73	0.80	0.61	10.03	0.00	36.80	12.88	2.95	2.00	38.40	6.96	4	7	90
12916	SRL733b	5.03	1.30	0.37	1.20	49.26	1	7	3	20	6	2	28.01	0.37	0.51	0.41	17.89	0.00	27.13	12.69	4.91	3.90	44.04	7.34	10	20	70
12917	SRL735a	4.96	1.04	0.92	0.72	32.22	1	20	6	51	12	4	62.14	0.88	0.67	0.53	6.58	0.00	27.67	10.43	5.67	2.95	45.80	7.48	4	17	79
12918	SRL735b	5.17	1.31	0.63	0.78	34.89	1	14	6	41	8	3	36.95	0.67	0.60	0.43	9.22	0.00	32.30	10.85	5.84	4.18	39.78	7.05	4	19	77
12919	SRL736a	5.29	1.15	1.46	0.99	44.34	2	20	8	112	22	6	74.91	1.65	0.69	0.58	5.90	0.00	38.52	12.52	3.43	2.40	36.30	6.82	2	13	85
12920	SRL736b	5.31	1.06	0.90	0.75	33.41	1	11	9	70	12	5	47.57	1.33	0.80	0.71	11.69	0.00	38.93	11.05	3.27	4.27	35.70	6.78	16	17	67
12921	SRL739a	5.08	1.11	0.68	0.90	40.42	1	12	5	45	7	2	49.33	1.36	0.64	0.47	19.34	0.00	33.13	8.79	4.69	3.49	42.66	7.24	4	20	76
12922	SRL739b	5.01	1.09	0.53	0.60	26.90	1	10	4	31	7	2	20.96	1.19	0.62	0.44	31.59	0.00	29.05	10.44	4.97	3.46	44.70	7.38	8	21	71
12923	SRL744a	5.17	1.18	1.34	1.18	48.74	1	16	8	92	21	2	82.64	0.99	0.80	0.45	9.32	0.00	34.53	12.72	3.03	2.75	39.90	7.06	18	15	67
12924	SRL744b	5.45	1.30	0.66	1.88	64.47	1	12	5	45	15	2	111.46	2.35	0.66	0.42	7.10	0.00	34.38	19.34	4.82	3.30	31.65	6.51	22	15	63
12925	SRL745a	5.19	1.22	0.85	2.08	69.05	2	17	10	61	8	3	83.85	0.77	0.71	0.44	6.40	0.00	36.00	7.81	4.98	4.89	39.30	7.02	10	19	71
12926	SRL745b	5.22	1.30	0.47	1.02	45.27	2	9	4	31	7	2	63.04	0.52	0.56	0.40	4.00	0.00	33.27	12.46	4.85	4.12	38.34	6.96	8	20	72
12927	SRL747a	4.99	0.93	2.68	0.67	30.12	2	89	10	140	36	8	91.63	1.62	1.04	0.74	32.35	0.00	26.17	11.03	8.51	1.67	45.20	7.42	6	20	74
12928	SRL747b	5.18	1.01	0.98	1.69	60.16	1	18	8	57	19	4	75.08	1.23	0.78	0.53	10.26	0.00	29.26	16.00	4.73	3.40	39.57	7.04	20	15	65
12929	SRL748a	5.29	1.17	1.75	1.25	50.32	1	19	9	146	22	5	58.95	2.60	0.73	0.55	6.48	0.00	41.57	10.39	2.71	2.21	36.30	6.82	4	15	81
12930	SRL748b	5.37	1.22	0.73	0.73	32.71	1	8	6	60	11	2	70.69	1.13	0.59	0.43	4.94	0.00	40.95	12.26	2.95	3.28	33.90	6.66	4	16	80
12931	SRL751a	5.34	0.96	1.39	0.50	22.49	2	24	8	107	22	5	58.09	3.28	0.79	1.06	14.17	0.00	38.44	13.18	4.39	2.40	34.86	6.72	16	15	69
12932	SRL751b	5.22	1.01	0.71	1.20	49.23	1	8	6	48	12	1	23.67	1.36	0.63	0.47	6.61	0.00	34.27	13.71	3.01	3.55	38.49	6.97	22	14	64
12933	SRL750a	5.10	0.97	0.87	0.83	37.41	1	11	7	56	13	1	39.45	0.85	0.74	0.55	13.18	0.00	32.11	11.74	3.29	3.66	42.00	7.20	18	15	67
12934	SRL750b	5.29	1.01	0.62	0.95	42.59	1	10	10	40	10	3	20.98	0.59	0.65	0.55	9.27	0.00	32.23	13.53	4.01	7.24	36.18	6.81	14	22	64
12935	SRL752 1	5.76	1.30	0.49	0.84	37.76	1	3	7	49	8	2	9.14	0.49	0.52	0.41	13.57	0.00	50.67	13.15	1.58	6.51	22.20	5.88	1	4	95
12936	SRL759a	4.99	1.12	1.52	2.48	78.06	2	22	11	99	15	3	79.05	1.16	0.71	0.55	7.52	0.00	32.47	8.16	3.71	3.10	45.14	7.41	2	37	61
12937	SRL759b	5.15	1.05	0.72	1.81	63.03	1	9	6	54	7	0	42.36	1.01	0.41	0.46	17.45	0.00	37.79	7.73	3.35	3.53	40.50	7.10	34	29	37
12938	SRL760	5.67	1.06	44.11	Empty	Empty	1	329	4010	662	1075	5	332.47	3.46	0.61	1.44	850.17	4.09	7.50	19.98	1.91	39.52	25.02	6.07	8	49	43
12939	SRL763a	5.31	1.05	1.10	1.03	45.55	2	6	13	97	9	3	156.00	0.72	1.02	0.52	33.26	0.00	44.36	6.66	1.45	5.04	35.70	6.78	4	19	77
12940	SRL763b	5.45	1.12	1.12	1.10	47.02	1	7	12	112	8	4	113.48	0.77	0.90	0.55	34.98	0.00	50.02	5.74	1.56	4.68	31.50	6.50	6	20	74
12941	SRL765a	5.21	1.09	2.85	1.63	58.86	3	51	8	215	37	6	47.96	4.08	1.02	1.08	11.01	0.00	37.75	10.67	4.54	1.20	38.85	6.99	6	19	75
12942	SRL765b	5.13	1.19	1.50	1.15	48.21	1	12	5	100	27	2	46.90	1.52	1.04	0.45	9.65	0.00	33.40	14.66	2.11	1.53	41.16	7.14	4	31	65
12943	SRL766a	5.13	1.01	1.56	1.01	44.96	2	15	8	131	9	4	52.08	1.58	0.86	0.52	6.61	0.00	42.04	4.86	2.54	2.32	41.10	7.14	4	16	80
12944	SRL766b	5.30	1.13	0.87	0.88	39.30	1	7	6	79	7	2	44.18	1.01	0.79	0.44	6.14	0.00	45.52	6.44	2.18	2.94	36.12	6.81	8	18	74

NviroTek Labs

Geldig / Valid: 1/7/2016 - 31/12/2016

Grond Pryslys / Soil Price list

Office Code	Toetse	Tests	R per monster/sample	
			BTW uit/Vat Excl	BTW in/Vat incl
	Standaard Grond	**Standard Soil**		
150	pH (water/KCl), P (Bray I/II), Ca, Mg, K, Na, S (AmAc), Uitruilbare suur, Digtheid.(Berekende katioon %, - verhoudings en S -en T-waardes *op versoek)*	pH (water/KCl), P (Bray I/II), Ca, Mg, K, Na, S (AmAc), Exchangeable acidity, Density. (Calculated cation % -ratio's, S- and T-values *on request)*	R 188.60	R 215.00
	Mehlich III Pakket	**Mehlich III Package**		
279	pH KCl (1:2.5) of pH H_2O (1:1), P (Bray I/II), Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B, S, P	pH KCl (1:2.5) of pH H_2O (1:1), P (Bray I / II), Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B, S, P	R 201.75	R 230.00
	Mehlich III Volledige Pakket	**Mehlich III Complete Package**		
635	pH KCl (1:2.5) of pH H_2O (1:1), P (Bray I/II), Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B, S, P Koolstof, Berekende TUK, H & ander basisse	pH KCl (1:2.5) of pH H_2O (1:1), P (Bray I/II), Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B, S, P Carbon, Calculated TEC, H & other bases	R 241.23	R 275.00
	Unieke pakkette kan saamgestel word	***Customised packages are available***		
	Addisionele Ontledings	**Additional Analysis**		
910	Voorbereiding vir enkel bepalings	Preparation for single analytes	R 28.07	R 32.00
167	Addisionele P (Olsen/Truog/Bray I of II) of pH (water/KCl)	Additional P (Olsen/Truog/Bray I of II) or pH (water/KCl)	R 57.02	R 65.00
155	Beskikbare Boor (Warm water ekstrak)	Available Boron (Hot water extract)	R 70.18	R 80.00
161	Chloried (Cl)	Chloride (Cl)	R 60.53	R 69.00
637	Eksteen uitruilbare suur	Eksteen exchangeable acidity	R 42.11	R 48.00
158	Klei	Clay	R 65.79	R 75.00
166	Kleur & Vingertoets	Colour & Finger Test	R 17.54	R 20.00
248	Klipfraksie	Stone Fraction	R 12.28	R 14.00
160	Koolstof (C) Walkley Black	Carbon (C) Walkley Black	R 89.47	R 102.00
911	Kalkbehoefte	Lime Requirement	R 188.60	R 215.00
636	KUV (Katioon Uitruilbare Vermoë)	CEC (Cation Exchange Capacity)	R 133.33	R 152.00
152/153	Mikro's (HCl/DTPA) (Zn, Cu, Mn, Fe)	Micro's (HCl/DTPA) (Zn, Cu, Mn, Fe)	R 74.56	R 85.00
278	Mikro's (Mehlich III) (Zn, Cu, Mn, Fe, S, B)	Micro's (Mehlich III) (Zn, Cu, Mn, Fe, S, B)	R 100.88	R 115.00
162	Molibdeen (Mo)	Molybdenum (Mo)	R 107.89	R 123.00
157	S (Ca PO_4)	S (Ca PO_4)	R 70.18	R 80.00
254	Sandfraksies	Sand fractions	R 45.61	R 52.00
163	Stikstof (NH_4 + NO_3)	Nitrogen (NH_4 + NO_3)	R 122.81	R 140.00
159	Tekstuur (Klei, Slik, Sand)	Texture (Clay, Silt, Sand)	R 92.98	R 106.00
171	Uitruilbare Aluminium	Exchangealbe Aluminium	R 39.47	R 45.00
165	Weerstand (Versadigde Pasta Ekstrak)	Resistance (Saturated Paste extract)	R 42.98	R 49.00
154	Zn	Zn	R 29.82	R 34.00
	1:2 Water ekstrak	**1:2 Water extract**		
168	Standaard: PO_4,Ca, Mg, K, Na, Cu, Zn, Mn, Fe, SO_4, B	Standard: PO_4, Ca, Mg, K, Na, Cu, Zn, Mn, Fe, SO_4, B	R 197.37	R 225.00
813	Ander:pH, NH_4 - N, NO_3 - N, Cl, HCO_3, CO_3,EG **(elk)**	Other:pH, NH_4 - N, NO_3 - N, Cl, HCO_3, CO_3,EC **(each)**	R 26.32	R 30.00
	Versadigde Pasta ekstrak	**Saturated Paste extract**		
914	Standaard: Ca, Mg, K, Na, Cu, Zn, Mn, Fe, S, B,P	Standard: Ca, Mg, K, Na, Cu, Zn, Mn, Fe, S, B,P	R 241.23	R 275.00
915	Ander: NH_4 - N, NO_3 - N, Cl, HCO_3, CO_3,EG **(elk)**	Other: NH_4 - N, NO_3 - N, Cl, HCO_3, CO_3,EC **(each)**	R 33.33	R 38.00
	Grond gesondheid	**Soil health**		
873	Aggregaat stabiliteit	Aggregate stability	R 153.51	R 175.00
658	Potensiëel Mineraliseerbare N (PMN)	Potential Mineralisable N (PMN)	R 236.84	R 270.00
917	Aktiewe Koolstof	Active Carbon	R 114.04	R 130.00
934	Gesondheidsindeks;en Haney - ekstrak	Soil Health Index;and Haney extract	op aanvraag	on request
	Solvita CO_2 -grondmikrobe	Solvita CO_2 -soil microbiology	R 192.98	R 220.00