Land Capability Classification System for Forest Ecosystems in the Oil Sands, 3rd Edition

Volume 1: Field Manual for Land Capability Determination

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Alberta Environment

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GLOSSARY

Aggregates: The arrangement of individual soil particles into compound particles which are separated from adjoining compound particles (aggregates) by planes of weakness through processes of soil development.

Athabasca oil sands region: Generic description of a subsection of the Boreal Central Mixedwood region of northeastern Alberta, centered roughly on the zone of surface oil sand mining, north of Ft. McMurray and on both sides of the Athabasca River.

AWHC or Available water holding capacity: The difference in soil water content, typically measured volumetrically, between "field capacity" (typically -10 or -33 kPa of matric potential, depending on soil texture) and "permanent wilting point" (-1500 kPa of matric potential).

Capping depth: The thickness of soil material or "cap" placed on a given substrate as part of reclamation activities.

Capping: A reclamation activity where a reclaimed structure or area with a given substrate is reclaimed by placing a "cap" of soil material at the surface.

Commercial forest: A forest ecosystem producing trees of sufficient size/quality to enable commercial recovery of their stems for pulp or sawlogs.

Control section: The vertical section upon which soil classification is based. The control section usually extends to a depth of 100 cm in mineral materials and to 160 cm in organic materials.

Cretaceous Clearwater material: Saline-sodic clay shale of the Cretaceous period (~100 million year before the common era).

Cretaceous McMurray material: Bitumenous sands (a.k.a. oil sand, tar sand). The sand having been deposited during the Cretaceous period (~100 million years before the common era).

Ecosystem productivity: The ability of an ecosystem to produce, grow, or yield biomass (total living matter).

Edaphic: Of or pertaining to the soil.

Edatope: Soil moisture/nutrient grid that displays the potential ranges of combinations of moisture (very dry to wet or xeric to hydric moisture regimes) and nutrient (very poor to very rich) conditions (adapted from Beckingham and Archibald, 1996).

Edatope position: A location on the edatope, as defined above, delineating a specific combination of soil moisture and nutrient conditions.

Equivalent land capability: The ability of the land to support various land uses after conservation and reclamation similar to the ability that existed prior to an activity being conducted on the land. The individual land uses will not necessarily be identical (Province of Alberta, 2003).

Footprint: The area of land occupied by an industrial disturbance**.**

Fragments: Pieces of non-soil (*e.g.*, geologic) material that has fractured along planes of weakness.

Horizon: A layer of mineral or organic soil material approximately parallel to the land surface that has characteristics altered by processes of soil formation (Soil Classification Working Group, 1998).

Impermeable: A substance that cannot be permeated by water.

Land capability rating: The product, on a scale of 0 to 100 points, of the integration of numeric values assigned to soil and landscape characteristics as described in this LCCS. The land capability rating replaces the soil and landscape ratings from previous editions of this document.

Material salvage: The process of physically removing soil from the pre-disturbance landscape for use in reclamation activities.

Mineral horizon/material: Material having 17% or less total organic carbon by weight.

Natural soils: Those soils not severely disturbed by industrial activities such as surface mining, aggregate mining, or oil/gas extraction. Soils may still be described as pre-disturbance/natural soils after experiencing less severe disturbances resulting from industrial activities such as forest harvest.

Organic horizon/material: Material having more than 17% organic carbon by weight.

Parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils developed by pedogenic processes (Brady and Weil, 1996).

Peat:mineral mix: A combination of organic and mineral soil that is typically achieved by over-stripping organic deposits during material salvage or by mechanical incorporation post-placement**.**

Pedon: A real unit of soil; the smallest homogenous, three-dimensional unit that can be considered a soil.

Polygon: From mapping conventions - refers to a unit of land identified for land capability assessment and is typically large enough to be mapped at the desired/required scale. Ideally polygons are stratified prior to assessment based on known characteristics to reduce variability.

Principal horizons: The LCCS principal horizons include the topsoil (0-20 cm), the upper subsoil (20-50 cm) and the lower subsoil (50-100 cm). Properties of horizons or strata existing in each of these principal horizons are weighted differently.

Reclaimed: Reconstructed soils resulting from some form of soil salvage and replacement, where the "soil" materials themselves (*e.g.* tailings sand) or their horizonation has been anthropogenically altered.

Sodium adsorption ratio: the comparative concentrations of sodium, calcium, and magnesium in the soil solution, where $[Na^+]$, $[Ca^{2+}]$, and $[Mg^{2+}]$ are the concentrations in mmol of charge per litre of solution. The SAR of a soil extract takes into consideration that the adverse effect of sodium is moderated by the presence of calcium and magnesium ions. SAR values of 7 and higher cause dispersion of soils.

$$SAR = \frac{[Na^+]}{(0.5[Ca^{2+}] + 0.5[Mg^{2+}])^{1/2}}$$

Soil conservation: The planning, management and implementation of an activity with the objective of protecting the essential physical, chemical and biological characteristics of the soil against degradation (Province of Alberta, 2003).

Soil moisture regime index: Each soil moisture regime class is assigned a numerical index for use in this LCCS to determine the land capability rating. The integration of numerical values

assigned to individual soil and landscape characteristics as described in this document determines the soil moisture regime index for a given site.

Soil moisture regime properties: For the purposes of land capability determination, these include depth to water table, slope percent, slope type, aspect, percent volume coarse fragments, horizonation, horizon thickness, soil texture, and mottles.

Soil moisture regime: The available moisture supply for plant growth on a relative scale ranging from very dry (xeric) to very wet (hydric) classes (adapted from Beckingham and Archibald, 1996). In this LCCS, it is assessed through an integration of soil and landscape characteristics.

Soil nutrient regime index: Each nutrient regime class is assigned a numerical index for use in this LCCS to determine the land capability. The integration of numerical values assigned to individual soil characteristics as described in this document determines the soil nutrient regime index for a given site.

Soil nutrient regime properties: For the purpose of land capability determination, these include percent total organic carbon, total nitrogen, soil texture and bulk density.

Soil nutrient regime: Amount of essential nutrients that are available for plant growth on a relative scale ranging form very poor to very rich (adapted from Beckingham and Archibald, 1996). In this LCCS, it is assessed through an integration of soil characteristics.

Strata: A layer of mineral or organic material that is either not soil (such as rock or water or unconsolidated material unaffected by soil forming processes) or a layer of material used in reclamation.

Substrate: The material that underlies the reclamation material cap. Typical substrates include cretaceous Clearwater formation, cretaceous McMurray formation (oil sand), and tailings sand.

Tailings sand: The coarse mineral by-product of the oil extraction process.

PURPOSE OF MANUAL AND STATEMENT OF LIMITATIONS

The goal of reclamation in Alberta is to achieve land capability equivalent to that which existed prior to disturbance. The *Land Capability Classification System for Forest Ecosystems* manual (LCCS) is a working document intended to facilitate evaluation of land capabilities for forest ecosystems on natural and reclaimed lands in the Athabasca oil sands region, as required by Alberta's Environmental Protection and Enhancement Act (EPEA) approvals, and by current Alberta Environment terms of reference for Environmental Impact Assessments. The LCCS is based on an integration of numeric values assigned to soil and landscape characteristics that are known to be fundamental to ecosystem productivity. Parameters considered include soil moisture regime, soil nutrient regime and soil physical and chemical properties that are potentially limiting to plant growth.

The first edition of the LCCS was developed in 1996 by the Tailings Sand Reclamation Practices Working Group, and was revised in 1998 based on results from field testing. The Soil and Vegetation Subgroup (SVSG) of the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA) is currently responsible for the continued refinement of the LCCS, and has developed this 3rd (2006) Edition.

Commencing in 2000, a network of long-term monitoring plots (hereafter referred to as the “Soil and Vegetation Plots”) was established to refine understanding of natural ecosystems and evolution of reclaimed ecosystems. The 2006 Edition represents improvements in knowledge, particularly in soil moisture and nutrient regime determination, gained from initial characterization and analysis of plot data. This characterization and analysis has also resulted in the identification of several key areas requiring additional research and monitoring. The SVSG is managing a comprehensive work program, including ongoing assessment of the plot network, to address remaining uncertainties associated with the LCCS (note that some components of this work program are being addressed by non-SVSG industry research initiatives). Details of this program, and remaining unaddressed issues, are presented in Appendix A. As understanding of reclaimed ecosystems improves, the LCCS will be correspondingly improved (pursuant to C&R/IL/98-7 [Alberta Environment, 1998] and individual project approval conditions).

As described above, the goal of the LCCS is to provide a rating of land capability for forest ecosystems. In order to both validate and calibrate the LCCS manual's integration of numerically valued soil/landscape properties, it is intended that the LCCS ratings be indexed to measured tree growth performance. The first round of monitoring of the long-term plots has not resulted in establishment of a clear correlation between LCCS-predicted forest site productivity and measured forest site productivity, particularly on reclaimed sites. Further, reclaimed forest stands are young, and, due to the dynamic nature of stand nutrient demand, early performance may not be a reliable indicator of later growth and nutrient status. This is because regenerating stands place increasing nutrient demand on soils with increasing foliar biomass, until peak foliar biomass is attained approximately at crown closure (Ballard, 1984; Miller, 1984). Continued measurement of the long-term plot network will provide a solid basis to further determine the correlation between forest productivity and land capability classification, and provide data for reclaimed stands as they reach maturity. Because long-term performance of reclaimed sites is not fully documented or understood, there are uncertainties about the ability of minimum capping depths to successfully achieve equivalent capability for productive forests on reclaimed sites. The SVSG of CEMA is undertaking further monitoring in an attempt to resolve these uncertainties. There is no foreseeable short-term solution for this issue, and caution should be taken in relying on minimum capping depths until such time as the uncertainty is reduced.

Because the link between LCCS rating and forest productivity is currently undemonstrated, the LCCS should be considered as one in a suite of tools for site evaluation and reclamation planning, rather than a comprehensive system that alone will ensure replacement and documentation of equivalent land capabilities. Reclamation certification (*e.g.*, for a commercial forest use site) will ultimately be evaluated based on above-ground measures of site productivity as well as on the LCCS rating, and on other landscape characteristics (see Alberta Land Conservation and Reclamation Council, 1991).

This document (LCCS Vol. 1) is a field manual intended to enable determination of land capability. A complementary software tool designed to ensure correct and consistent calculation of LCCS ratings will be available shortly. In addition, a corresponding background and rationale document (LCCS Vol. 2) is under development, and will be released in the near future.

1.0 MANUAL APPROACH

This manual outlines the procedure for determining land capability rating for natural and reclaimed soils in forest ecosystems in the Athabasca Oil Sands Region of Alberta. Guidance is also provided for sampling methods and intensities.

The products of land capability determination are the land capability rating, class and subclasses, and the soil moisture and nutrient regime indices (combining to establish edatope position) for an assessed soil polygon. These can be used in conjunction with the companion document *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Oil Sands Vegetation Reclamation Committee [OSVRC], 1998) for developing revegetation treatments on reclaimed landscapes.

1.1 Assumptions and Boundaries

- This LCCS has been calibrated for and is intended for use in the Athabasca Oil Sands Region only. Use outside of this region is not supported by the issuers of this document.
- Application of this manual requires knowledge and experience in the areas of soil survey and classification. It is the responsibility of the project manager to ensure that field personnel are competent in these areas. It is strongly recommended that projects be managed by suitably qualified members of recognized professional associations.
- This LCCS is intended to evaluate equivalent land capability by comparing pre- and post-disturbance capability.
- The use of the LCCS as a tool to calculate minimum soil requirements (*i.e.*, thicknesses) necessary for the achievement of particular capability classes in the design of reclaimed soils is not recommended. Reclamation treatments should be based on knowledge of site-specific materials and objectives.
- This LCCS is used for evaluating the land capability to support upland commercial forests. This assumes that all classes are capable of providing a range of other values and end land uses.

- Lands in each class can be similar in degree, but not necessarily in kind, for limitations for forest production (*i.e.*, similarly classed lands may be produced by different limitations on different sites).
- Land capability assessment applies to the upper one metre of soil. It is the responsibility of the respective permit holders to be aware of underlying material quality.
- The climatic regime present during development of natural forest stands is assumed to be similar to that which is affecting and will affect reclaimed sites. Thus, neither climatic factors nor climate change, whether naturally or anthropogenically induced, are incorporated in the LCCS.
- This LCCS assumes that soils meet operating approval requirements and do not have characteristics that pose significant environmental risks to humans or the environment, for example potentially toxic constituents.
- The LCCS manual is a "living document" that will be refined through testing and evaluation in the field. As more experience is gained, and different natural soil and reclaimed landscapes are evaluated, the LCCS will be modified through discussions with stakeholders (C&R/IL/98-7; Alberta Environment, 1998).

2.0 LAND CAPABILITY CLASSIFICATION SYSTEM

The LCCS is an integrated soil and landscape rating calculated from key parameters including soil moisture regime (SMR) properties, soil nutrient regime (SNR) properties, and potentially limiting soil physical and chemical properties, in the three principal soil horizons (see below). SMR properties are integrated into the SMR index (ranging from 10 to 80 points) and the SNR properties are integrated into the SNR index (ranging from 0 to 20 points). The LCCS Base Rating is the sum of the SMR and SNR indices. Potential limiting factors, including soil structure and consistence, pH, electrical conductivity (EC [dS m^{-1}]) and sodium adsorption ratio (SAR), are calculated as a function of the Base Rating for each of the LCCS principal horizons and deducted from the Base Rating to give the LCCS land rating (Equation 1). The Final Land Rating determines the land capability class.

Equation 1. LCCS general equation.

Final Land Rating = Base Rating – Limiting Factor Deductions

2.1 LCCS Principal Horizons

The LCCS rating is largely based on soil properties of the one-metre soil profile. Three principal horizons are defined: topsoil (TS) 0-20 cm; upper subsoil (US) 20-50 cm; and lower subsoil (LS) 50-100 cm in the LCCS model to arrive at the land capability rating.

In the LCCS, ratings for limiting factor deductions are weighted by soil horizon: the properties of the TS horizon are weighted most heavily and incur full (100%) deductions for any applicable limiting factors; the US incurs 67 % deductions; and the LS incurs 33 % deductions.

The LCCS principal horizons are imposed on natural mineral, natural organic and reclaimed soils. The LCCS principal horizon boundaries at 20, 50 and 100 cm will not necessarily match up with the natural horizonation or the reclamation material boundaries as illustrated in Figure 1; these measurements are intended as guidelines.

Soil description and sampling for the application of the LCCS is done on the basis of soil horizon or strata. The boundary condition of 17 % total organic carbon (TOC) on a dry weight basis (Soil Classification Working Group, 1998) is adopted in the LCCS to separate mineral soil horizons from organic soil horizons (or strata).

This section presents how the LCCS principal horizons are applied to natural mineral, natural organic, and reclaimed soils. Further details for the application of the principal horizons to soils are provided in Section 3.3, Sampling Methods, and Section 3.5, Landscape and Soil Features.

2.1.1 NATURAL MINERAL SOILS

For natural mineral soils, defined as those having less than 40 cm of organic material at the soil surface, the LCCS principal horizons begin at the mineral soil surface and normally include three soil master horizons: topsoil horizons (*e.g.*, Ae, Ahe, Ah), subsoil horizons (various B horizons) and parent materials (C horizons). In general, the TS is typically comprised of natural A, AB and possible B horizons; the US is comprised of natural B, BC and possible C horizons; and the LS is comprised of natural C horizons.

Surface organic materials (*i.e.*, L, F, H, or O horizons less than 40 cm thick) are sampled separately from the mineral horizons. These organic horizons do contribute to the soil nutrient regime index determination but do not contribute to the profile available water holding capacity (AWHC) determination.

2.1.2 NATURAL ORGANIC SOILS

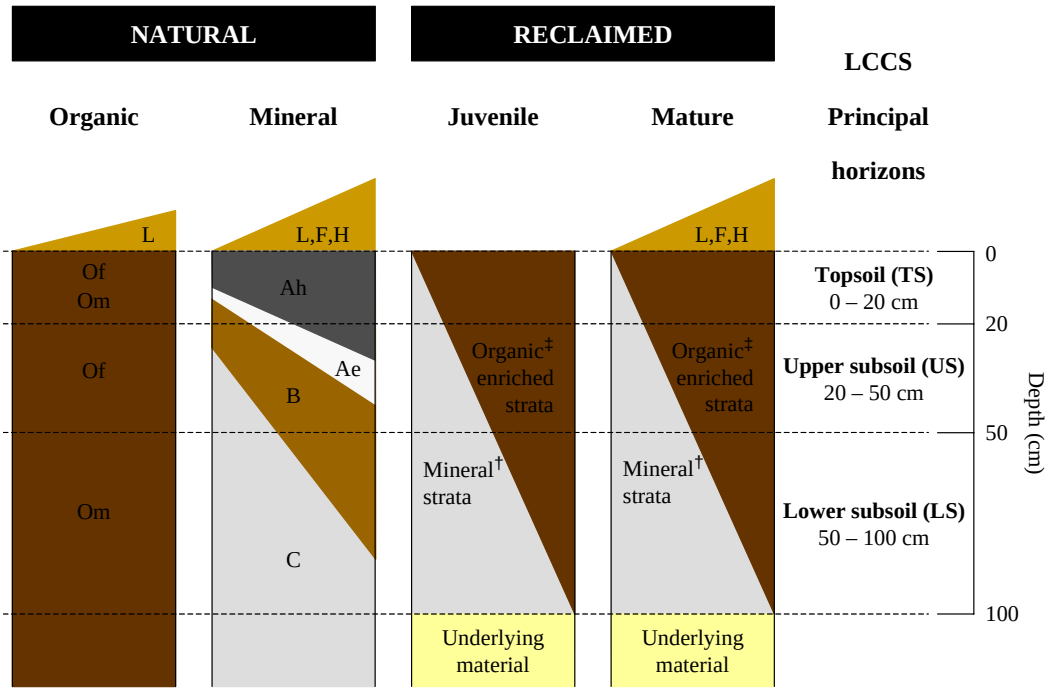
For natural organic soils, defined as those having 40 cm or more of organic material at the soil surface, the LCCS principal horizons include the surface tier (0-40 cm) and the upper 75 % of the middle tier (40-120 cm). This may include many different combinations of organic horizons (Of, Om Oh, and Oco), mineral C horizons and water (W). Soil classification of organic soils requires the investigation of all three tiers (Soil Classification Working Group, 1998).

Where L, F and/or H horizons overlay organic soil horizons (*e.g.*, O horizons), they are sampled separately. The former materials, in addition to the upper 20 cm of the underlying organic horizons, contribute to the soil nutrient regime index determination. For organic soils, soil moisture regime is determined by indicators including surface organic thickness, depth to water table, and mottles/gleying, not by the profile AWHC.

2.1.3 RECLAIMED SOILS

For reclaimed soils, the LCCS principal horizons normally include the reconstructed soil strata and may also include underlying mine waste materials. Reconstructed soil strata are materials salvaged from the natural landscape and can be categorized very broadly as mineral or organic-enriched.

Because it is often difficult to determine in the field whether a stratum is mineral or organic, the TS is assumed to begin at the surface of material placement (as opposed to the mineral/organic interface as in natural mineral soils).



† Mineral horizons are defined as those having less than 17% total organic carbon (TOC) determined as outlined in Table 5).

‡ Organic-enriched strata are mineral horizons containing organic matter (*i.e.*, peat/mineral mixes and shallow soil salvage). In the cases where the surface strata of a reclaimed soil or natural mineral soil with an O layer contains 17% or more TOC it is not considered to contribute to the moisture regime of the soil (see Section 4.2.1.1.1).

§ These profiles are generalizations. Each soil type presented is characterized by wide ranges of variability in horizon thickness and development.

Figure 1. Schematic diagram of principal horizons applied to idealized[§] natural and reclaimed soil profiles.

2.2 Land Capability Classes

There are five classes of land recognized in the LCCS, rated according to potential and limitations for productive forest use. Classes are based on adjusted Canada Land Inventory categories, with Classes 1, 2, and 3 being capable of supporting commercial/productive forests, and Classes 4 and 5 being non-commercial/lower-productivity forest lands. The classes are an approximate assessment of the degree or intensity of limitation. For example, Class 3 land has limitations that are more severe than Class 2. The subclasses describe the kind of limitations responsible for class designation.

The classes represent an idealized generic trend of forest productivity representing 20 % difference in productivity between classes. Different tree species are not all equally adaptable to the range of moisture and nutrient regimes, and will respond differently to different soil-based limitations.

Class 1 High Capability (Final land rating 81 to 100): Land having no significant limitations to supporting productive forestry, or only minor limitations that can be overcome with normal management practices.

Class 2 Moderate Capability (Final land rating 61 to 80): Land having limitations which, combined, are moderately limiting for forest production. The limitations will result in reduced productivity or benefits, or require increased inputs to the extent that the overall advantage to be gained from the use will still be attractive, but appreciably inferior to that expected on Class 1 land.

Class 3 Low Capability (Final land rating 41 to 60): Land having limitations which, combined, are moderately severe for forest production. The limitations will result in reduced productivity or benefits, or require increased inputs to the extent that the overall advantage to be gained from the use will be low.

Class 4 Conditionally Productive (Final land rating 21 to 40): Land having severe limitations, some of which may be surmountable through management, but which cannot be feasibly corrected with existing practice.

Class 5 Non-Productive (Final land rating 0 to 20): Land having limitations that appear so severe as to preclude any possibility of successful forest production.

2.3 Land Capability Subclasses

A subclass, denoted by the letter(s) in brackets, indicates the kind of limitation, as follows:

Horizon-independent factors:

- Soil moisture regime (SMR): Very dry (X), Wet (W)
- Organic surface (O), Stoniness (P), Impermeable layer (Z)
- Soil nutrient regime (SNR): Fertility (F)

Horizon-dependent factors:

- Soil structure and consistence (D)
- Soil reaction (V)
- Soil salinity (N)

- Soil sodicity (Y)

Combination of three or more factors: (S)

2.3.1 SUBCLASS NOTATION

Two approaches to subclass notation, general and detailed, have been developed, depending on user needs. The general notations are recommended for overview purposes such as environmental impact assessments and mapping. Detailed notations are recommended for reclamation planning, management and monitoring. The general and detailed notations are not necessarily exclusive; for a single project, it may be necessary to determine both types of subclasses to meet data presentation needs.

Class 1 soils do not have subclasses. Horizon-independent subclasses ”X” or ”W” are applied for SMR as directed by Table 9, (subclasses O, P, and Z are applied as directed in Sections 4.2.1.1.1, 4.2.1.1.2, and 4.2.1.1.3), and ”F” for ”Poor” overall SNR, as calculated in Section 4.3. Horizon-dependent subclasses for limiting factor deductions are applied differently based on the approach: general versus detailed. A comparison of the general versus the detailed approach with examples is presented in Table 1.

2.3.1.1 General Notation

The general approach limits the subclass notation to two limiting factors. Where three or more limiting factors exist, the combination subclass notation (S) is applied. Notations are applied for limiting factors where they incur a total 20-point deduction for the entire profile (*i.e.*, the sum of the TS, US, and LS point deductions [b, d, and e]). For example, subclass notations can be applied for deductions incurred in a single horizon (as in Table 1, Profile 2) or for more than one horizon (as in Table 1, Profiles 1 and 3). Where the total profile deduction is less than 20 points, subclass notations are not applied (as in Table 1, Profile 4).

The advantages of the general approach are simplicity and ease in data management. The disadvantage is that the quality and location (principal horizon) of the limitation is not readily understood.

2.3.1.2 Detailed Notation

The detailed approach does not limit the subclass notation to two limiting factors, and the combination subclass notation (S) is not used. Up to six subclasses can be included with a single soil rating and the principal horizons are identified for horizon-dependent factors using numerical subscripts (see examples presented in Table 1). Notations are applied where they incur a 20-percent deduction for a principal horizon. For example, Profiles 1 and 2 (Table 1) have subclasses because the deductions were 20 % in the respective soil horizons. Profile 4 (Table 1) has subsoil point deductions (3 and 1 points respectively for the US and LS) but subclasses are not applied because these deductions were only 10 % in the respective horizons.

The primary advantage of the detailed approach is the higher resolution of limitation notations. The disadvantage is the greater complexity and corresponding increased data management requirements.

Table 1. General Subclass Approach Examples.

Rating Component (subclasses)[†]		**Profile 1**		**Profile 2**		**Profile 3**		**Profile 4**	
SMR index		52		80		38	(X)	38	(X)
SNR index		10		20		20		0	(F)
Base rating (SMR+SNR)	a	62		100		58		38	
TS deduction	b	12	(V)	20	(V)	12	(V)	0	
Interim soil rating	c	50		80		46		38	