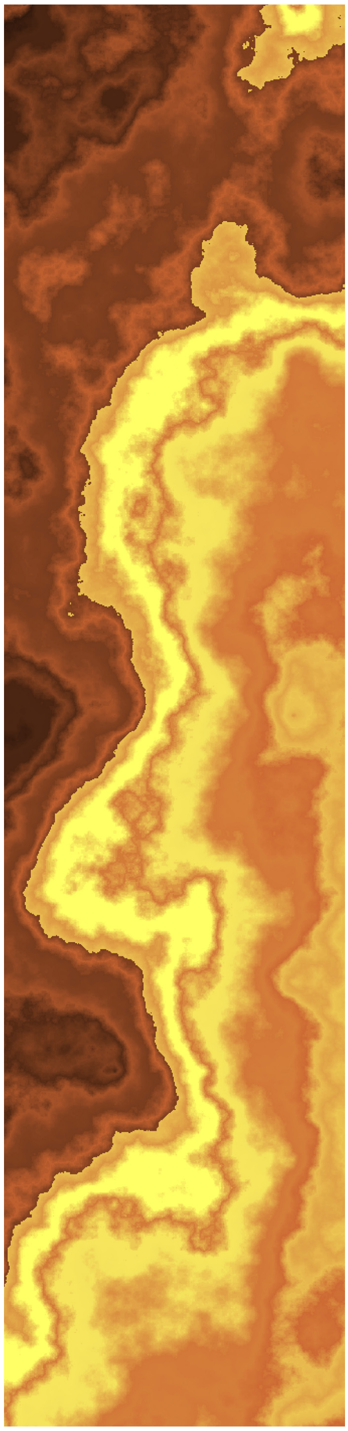
Australian Collaborative Land Evaluation Program ACLEP

ASRIS

Australian Soil Resource Information System



Technical specifications

Version 1.5
October 2005

Prepared by NJ McKenzie, DW Jacquier, DJ Maschmedt, EA Griffin and DM Brough on behalf of the National Committee on Soil and Terrain Information

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Prepared by NJ McKenzie[1], DW Jacquier[1], DJ Maschmedt[2], EA Griffin[3] and DM Brough[4] on behalf of the National Committee on Soil and Terrain Information

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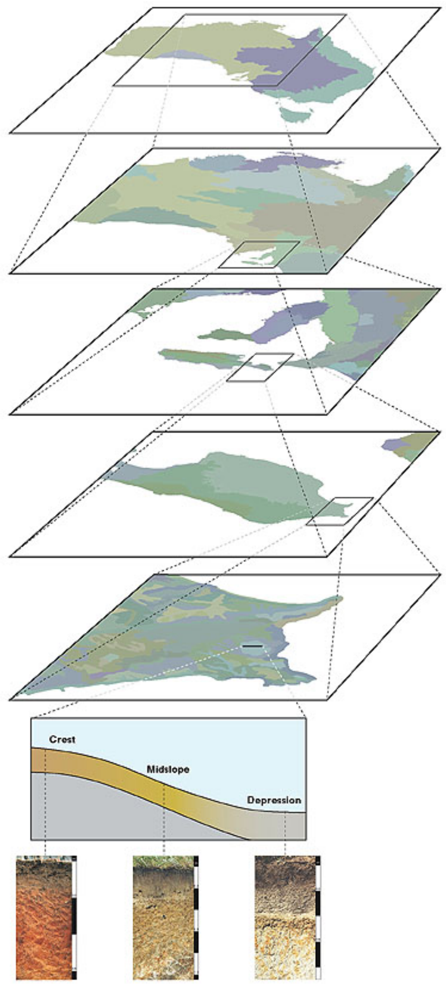
1. Summary

This document specifies the variables, codes and estimation procedures for the Australian Soil Resource Information System (ASRIS). ASRIS has been developed to provide primary data on soil and land to meet the demands of a broad range of users including natural resource managers, educational institutions, planners, researchers, and community groups. The online system provides access to the best available soil and land resource information in a consistent format across the country – the level of detail depends on the survey coverage in each region. More specifically, ASRIS provides the following.

- A spatial hierarchy of land-unit tracts with seven main levels of generalization (Figure 1). The upper three levels (L1–L3) provide descriptions of soils and landscapes across the complete continent while the lower levels (L4–L6) provide more detailed information, particularly on soil properties, for areas where mapping has been completed. The lowest level (L7) relates to an individual site in the field. The system can also be used to provide summaries of soil and landscape properties for a range of higher level stratifications of the country (e.g. Interim Biogeographic Regions of Australia (v5.1), Groundwater Flow Systems, and catchment management boundaries).
- A consistent set of land qualities. These are described for land-unit tracts. Descriptions from the lowest level are used to generate summaries for higher-level units. The land qualities relate to the intrinsic capability of land to support various land uses – the land qualities relate to soil depth, water storage, permeability, fertility, and erodibility.
- A soil profile database. These fully characterized sites are representative of significant areas and environments. The data provide catchment managers with primary information for improving land literacy in their region, and natural resource specialists with a fundamental data set for assessing and predicting resource condition.
- Estimates of uncertainty. These are provided with most data held within ASRIS. A distinction is made between attribute uncertainty (due to the measurement or estimation procedure for a given soil material) and spatial uncertainty (due to the natural variation across a landscape). The estimates are provided to encourage formal analysis of the uncertainty of predictions generated using ASRIS data (e.g. crop yield, runoff, land suitability for a range of purposes).

ASRIS is being released in stages. At the end of 2006 the upper levels of the hierarchy will be completed for the complete country. There will be a restricted coverage at lower levels. Data will also be available for approximately 10 000 profiles. ASRIS can be accessed online at www.asris.csiro.au.

Figure 1: The ASRIS land-unit hierarchy (see also Table 3) – ILUZ refers to the intensive land-use zone.



Level illustration	Level and tract name	Mapping window	Main attributes used for mapping	Typical uses for the soil information	Area of Australia to be covered (Dec. 2006)
	Level 1 Division	30 km	Broad landform (slope and relief) and geology	Broad geographic context	ILUZ: 100% Rangelands: 100%
	Level 2 Province	10 km	Landform, water balance, dominant soil-order and substrate	National natural resource policy	ILUZ: 100% Rangelands: 100%
	Level 3 Zone	3 km	Landform, regolith materials, age of land surface, water balance, dominant soil suborder	Regional natural resource policy	ILUZ: 100% Rangelands: 100%
	Level 4 District	1 km	Groupings of geomorphically related systems	Catchment planning, location of new industries	ILUZ: 60% Rangelands: 70%
	Level 5 System	300 m	Local climate, relief, modal slope, lithology, drainage network, related soil profile class	Catchment management, hydrological modelling, land conservation strategies, infrastructure planning	ILUZ: 60% Rangelands: <5%
	Level 6 Facet	30 m	Slope, aspect, land curvature, soil profile class	Farm management, land-use planning, on-ground works	ILUZ: 60% Rangelands: <5%
	Level 7 Site	10 m	Soil properties, surface condition, microrelief	Precision agriculture, site development	

2. User needs for soil and land resource information

The general proposition that our natural environment should be mapped and monitored is widely supported by agencies responsible for managing natural resources, industry groups and community organizations. This information provides a basis for devising, implementing and monitoring land management. It also provides a basis for diagnosing the general condition of landscapes. Information on soil and land resources is fundamental and this is where ASRIS plays a central role.

The emergence of a range of large-scale environmental problems in Australia has added to the general demand for better information on spatial variation and trends in the condition of soils and landscapes. Satisfying this demand requires a clear view of how information on natural resources is used to good effect. The first way is through reducing risks in decision-making, and the second involves improving our understanding of biophysical processes.

2.1 Reducing risks in decision making

Reducing risk in decision-making requires the provision of information to be closely linked to, and preferably driven, by the decision-making process, whether at the scale of the paddock, enterprise, small catchment, region or nation. For example, farmers need information at the scale of the paddock, while a federal funding agency will usually require information at the regional and continental scale. Decision makers in Australia require timely access to information at relevant scales. ASRIS is a significant component in the delivery system. It has been developed with a view to satisfying a diverse range of needs at various levels of resolution. The following demands from government, industry, and community groups are of primary interest.

Government

The provision of reliable natural resource information to support policy decisions by federal, state, territory and regional agencies is necessary to address serious environmental problems, including global warming, dryland salinity and soil acidification. Improved natural resource information is required to:

- design, implement and assess the effectiveness of major natural resource management programs (e.g. schemes for widespread planting of perennials to control recharge)
- implement trading schemes (e.g. for salt, water and carbon) to achieve better natural resource management outcomes
- establish baselines (e.g. for contaminants)

- set targets and monitor trends.

Industry

Agricultural industries require better soil and land resource information to:

- optimize the matching of land use and management with land suitability (some sectors, most notably viticulture and industrial-scale farm forestry, have increased investment in user-specific land resource assessment during recent years)
- gain market advantage by demonstrating the benign nature of production systems (e.g. green labeling)
- implement environmental management systems to comply with duty of care regulations and industry codes
- identify opportunities for new industries and regional development
- optimize the use of inputs (e.g. soil nutrient testing to guide fertilizer rates).

Regional Communities

Regional communities require better soil and land resource information to:

- assess and improve the efficacy of natural resource management
- target community action (e.g. remedial tree planting, fencing, weed control)
- improve land literacy.

2.2 Improving process understanding

The reasons for using soil and land information outlined in the previous section focus on reducing risk in decision making. Another distinct application for soil information is to improve the understanding of landscape processes. This is largely the domain of educational, research and development organizations. Studies providing an improved understanding of landscape processes vary greatly in scope. For example, geomorphic studies of landscape evolution may involve intensive characterization and dating of stratigraphic sequences. Pedologic investigations of soil formation can require detailed surveys of key areas to determine the influence of different soil forming factors. Long-term monitoring studies usually involve some form of field experiment at the scale of the plot (e.g. agricultural tillage trials), through to the small catchment (e.g. paired-catchment studies in ecohydrology).

ASRIS provides a frame of reference for studies of landscape processes – it gives context by providing a geomorphic stratification of the landscape into zones where baselines can be established, trends monitored, and results extrapolated. It also provides the basis for creating improved models for explanation and prediction (e.g. better statistical models for spatial prediction and improved simulation models to assess the environmental impact of land uses). Knowledge from these activities enables improved systems of land use and management, and provides a scientific basis for improved policies on natural resources.

2.3 Mapping, monitoring, modelling, and environmental history

Land resource survey provides the spatial framework for managing natural resources. ASRIS integrates outputs from survey programs across Australia and these must be considered with the mutually beneficial activities of monitoring and modelling, and all three should then be set within the context of environmental history – the latter provides an understanding of rates of soil and landscape change on much longer time scales (decades, centuries and millennia).

In isolation, each activity fails to provide appropriate information for land management and planning. In combination, they provide a powerful and synergistic means for transforming the quality of land management in Australia (Figure 2, Table 1).

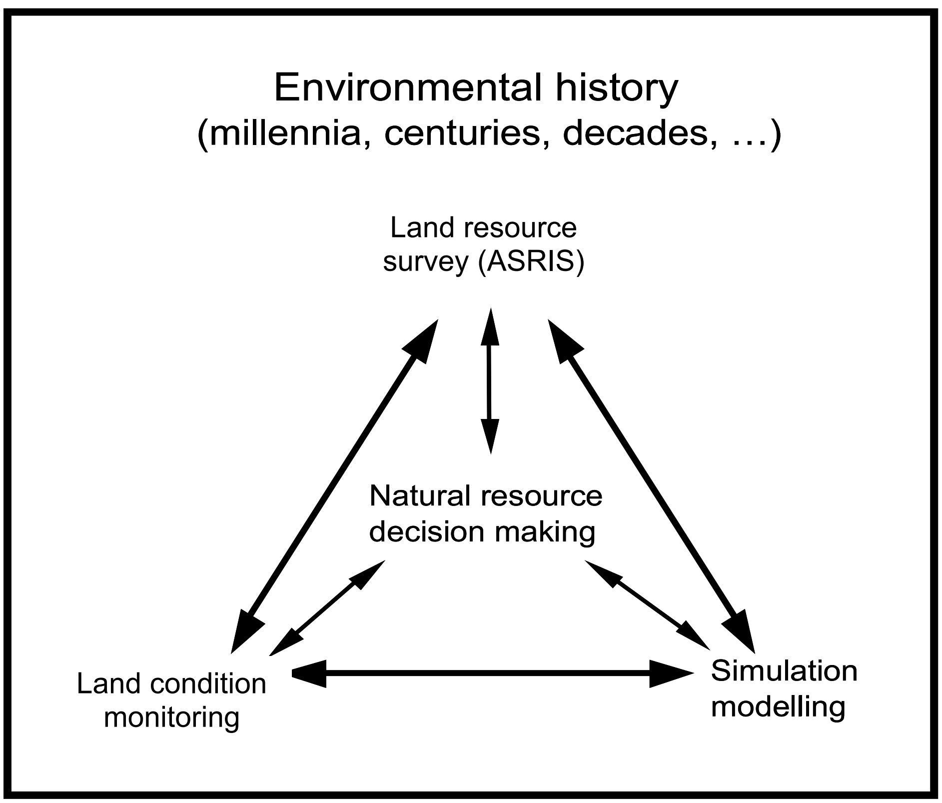


Figure 2: Mapping, monitoring and modelling are complementary activities for natural resource management and they must be set against the context of the environmental history of events and processes for a given landscape. ASRIS provides the national framework for soil and land resource information.

Table 1: Complementary benefits of mapping (contained within ASRIS), monitoring and modelling

Complementary Relationship	Benefits
ASRIS mapping → Monitoring	• Spatial framework for selecting representative sites • System for spatial extrapolation of monitoring results • Broad assessment of resource condition
ASRIS mapping → Modelling	• Provides input data for modelling • Provides spatial association of input variables
Monitoring → ASRIS mapping	• Quantifies and defines important resource variables for mapping • Provides temporal dimension to land suitability assessment (including risk assessments for recommended land management practices)
Modelling → ASRIS mapping	• Allows spatial and temporal prediction of landscape processes
Modelling → Monitoring	• Determines whether trends in specific land attributes can be successfully detected with monitoring • Identifies key components of system behaviour that can be measured in a monitoring program
Monitoring → Modelling	• Provides validation of model results • Provides input data for modelling

2.4 Land condition

Surveys provide general information on land condition but in most cases they do not reveal much about trends over time for several reasons.

- In most parts of Australia, field work for a survey spans several seasons. Land cover and management vary over this time so establishing a consistent baseline is challenging.

- To maximize objectivity and consistency, observations on land condition (e.g. scald erosion, wind erosion, sheet and rill erosion, gully erosion, mass movement, human-induced saline seepage, surface scalding) are made using the evidence present in the field at the time of sampling. The rates of most land degradation processes are difficult to estimate unless permanent monitoring sites are used (see McKenzie et al. 2002). For example, in cropping areas, evidence for severe rill erosion can be obliterated by subsequent trafficking and cultivation. Similarly, the degree of expression and extent of saline seepage areas can vary dramatically with season.

- The field observations and interpretations in the state and territory land resource databases span many decades – it is simply not possible to use these to generate a useful assessment of land condition.

Fortunately, ASRIS can be used to support the assessment of land condition in other ways and it requires a broad view of the biophysical information base necessary for natural resource management (Figure 1).

ASRIS provides the basis for assessing land-degradation *hazard*. This can be achieved in various ways. For example, the Universal Soil Loss Equation can be parameterized using attributes from ASRIS to provide estimates of soil erosion by water. Models for predicting the hazard of wind erosion are also available. NLWRA (2001) provides other examples of how broad-scale soil information can be used to predict land condition and threatening processes (e.g. soil acidification).

ASRIS also provides a basis for locating monitoring sites for land condition and a framework for the extrapolation of results (Table 1).

2.5 Striking a balance between general-purpose and problem-specified information

There is a long history of land resource survey failing to satisfy the needs of decision makers. It is very difficult to provide the right soil information at an appropriate scale in a timely manner. Dalal-Clayton and Dent (2001) provide a sobering assessment. A difficult challenge here is anticipating the demand for soil information well ahead of time. Surveys are rarely commissioned and completed in time to solve a particular problem, instead, general-purpose surveys are undertaken and a suite of likely problems is anticipated. It is easy to miss collecting key soil properties or to do the survey at an inappropriate scale.

Despite these difficulties, our experience has been that a core set of soil properties is needed for most applications. These are listed in Table 2.

2.6 The task of interpretation

ASRIS aims to provide access to consistent soil information at the finest resolution available across Australia. It is a source of *primary data* for natural resource management and research. Wherever possible, these data have been presented in a form that can be readily interpreted; for example, estimates of functional landscape attributes such as plant available water capacity are given rather than more obscure variables that may be used to estimate the attribute. Of course, this is far short of the information required by many decision makers. For example, the profile available water capacity will only be one of many variables needed to estimate the potential productivity of different farming systems. More complex analyses of environmental risk or optimal mixes of land-use require much higher levels of integration (e.g. incorporating social, economic and political considerations).

At this point in time, ASRIS does not provide a system for making interpretations of soils and landscapes. However, a logical pathway for development would see the addition of an interface for performing rule-based analysis (e.g. land suitability for a range of uses). There is a limit to the level of complexity and it will often be more logical to download data from ASRIS for use within a purpose-built simulation modelling environment or decision support system.

Table 2: The main soil properties included in ASRIS and their significance

Attribute	Significance
Texture	Affects most chemical and physical properties. Indicates some processes of soil formation
Clay content	As for texture
Coarse fragments	Affects water storage and nutrient supply
Bulk density	Suitability for root growth. Guide to permeability. Necessary for converting gravimetric estimates to volumetric
pH	Controls nutrient availability and many chemical reactions. Indicates the degree of weathering
Organic carbon	Guide to nutrient levels. Indicator of soil physical fertility
Depths to A1, B2, impeding layers, thickness of solum and regolith	Used to calculate volumes of water and nutrient (e.g. plant available water capacity, storage capacity for nutrients and contaminants),
$\theta_{-10\ kPa}$	Used to calculate water availability to plants and water movement
$\theta_{-1.5MPa}$	Used to calculate water availability to plants and water movement
Plant available water capacity	Primary control on biological productivity and soil hydrology
Ksat	Indicates likelihood of surface runoff and erosion. Indicator of the potential for water logging. Measure of drainage.
Electrical conductivity	Presence of potentially harmful salt. Indicates the degree of leaching.
Aggregate stability	Guide to soil physical fertility. Potential for clay dispersion and adverse impacts on water quality.
Sum of exchangeable bases	Guide to nutrient levels. Indicates the degree of weathering
CEC	Guide to nutrient levels. Indicates the degree of weathering. Guide to clay mineralogy (when used with clay content)
ESP	Indicator of dispersive clays and poor soil physical properties.
ASC (Great Group)	Shorthand for communication across Australia
WRB	Shorthand for communication internationally
Substrate type	Control on soil formation, landscape hydrology, groundwater movement, nutrients and solutes
Substrate permeability	Affects landscape hydrology and groundwater movement.

3. Development of ASRIS

ASRIS was initiated through the National Land and Water Resources Audit (NLWRA) in 1999 (see NLWRA 2002, Henderson et al. 2002). The initial release (ASRIS 2001) provided primary inputs for a broad range of simulation modelling studies supported by the NLWRA. These studies provided continental perspectives on erosion, sediment delivery to streams, nutrient cycling, acidification, net primary productivity, and water quality (NLWRA 2001, 2002).

The ASRIS 2001 team achieved a great deal given the short time available and daunting nature of the task (see Johnston et al. 2003). During the project, the core team and the National Committee on Soil and Terrain Information (which acted as the Steering Committee) identified a series of deficiencies in the land resource information base for Australia. They also identified a logical pathway for overcoming these problems to ensure a greatly improved system for providing information to support natural resource management in Australia. The task was recognized to be long-term, and requiring a permanent project team (NLWRA 2002).

With this background, the Australian Collaborative Land Evaluation Program (ACLEP) was commissioned by the Department of Agriculture, Forestry and Fisheries (DAFF) to provide land managers, regional organizations, industry partners, policy specialists and technical experts in natural resource management, with online access to soil and land resource information, and assessments of land suitability.[1] The information is to be available at a range of scales, and in a consistent and easy-to-use format across Australia. The activity must also provide a scientific framework for assessing and monitoring the extent and condition of Australia's soil and land resources.

This document presents specifications for the official release of ASRIS in 2005. This release provides the following:

- A hierarchy of land units for the Australian Soil Resource Information System to allow comprehensive reporting on land suitability and soil resources from the National down to the Subregional scale. Upper levels of the hierarchy are generated using digital terrain analysis and refinements of existing geomorphic maps. Other information sources include results from continent-wide calculations of the water balance and geologic mapping. Lower levels are derived from the component state, territory and federal land databases. There is also the facility to represent information on soil and lands using other high-level stratifications including the Interim Biogeographic Regions of Australia (v5.1), Groundwater Flow Systems, and catchment management boundaries.

[1] The term *land capability* was used in the original brief – this term is usually associated with the United States Department of Agriculture eight-class system for classifying land. The term *land suitability* is preferred here (see Dent and Young 1981, McKenzie 1991).

- Consistent land qualities are presented for units at the lowest levels in the hierarchy and these are used to generate summaries for higher-level units. The land qualities relate to the intrinsic capability of land to support various land uses – they relate to soil depth, water storage, permeability, fertility, and erodibility.
- ASRIS will be released progressively so check the website (www.asris.csiro.au) for the latest information. ASRIS uses SQL Server, the Arc Spatial Data Engine (ArcSDE), and Arc Internet Map Server (ArcIMS).
- ASRIS is compliant with standards agreed by the Open GIS Consortium. It includes a Web Map Server that enables integration with online viewers such as Google Earth and NASA World Wind.
- ASRIS includes a soil profile database with fully characterized sites that are known to be representative of significant areas and environments. The profile database will be expanded to approximately 10 000 profiles by the end of 2006.
- ASRIS will continue to include the original ASRIS 2001 soil information layers for the country in cases where improved coverages have not been generated.

4. Hierarchy of land units and terminology

4.1 Concepts and terms

A wide range of survey methods has been used in Australia (Beckett and Bie 1978, Gibbons 1983, McKenzie 1991) but most have been based on some form of integrated or soil-landscape survey (Christian and Stewart 1968, Mabbutt 1968, Northcote 1984) at medium to reconnaissance scales (1:50,000–1:250,000). Speight (1988) notes that the wide variation in mapping practice among different Australian survey organizations is largely a matter of level of classification or precision, rather than a difference in the conceptual units that surveyors recognize and describe.

Only small areas have been mapped using strict soil mapping units (e.g. soil series, type, variant, phase, association). Most of these studies have used free survey (Steur 1961, Beckett 1968) as the survey method and the majority of surveys have been detailed (i.e. 1:10,000–1:25,000) and for irrigation developments.

Quantitative surveys based on grid-based methods across small areas (usually <1000 ha), are becoming more common with the growth of precision agriculture. Quantitative surveys are also being applied at more general scales using methods of environmental correlation (e.g. McKenzie and Ryan 1999, Henderson et al. 2002, McKenzie et al. 2006). The key feature of these survey methods is the generation of predictions of individual soil properties rather than soil types.

This document is primarily concerned with capturing information from traditional integrated and soil-landscape surveys because these constitute more than 90% of land resource survey information for Australia. There are many aspects of land resource assessment that must be changed to take advantage of digital methods and ensure a more technically defensible approach to natural resource management in Australia. The new guidelines for land resource survey outline directions for change (McKenzie et al. 2006).

The terminology used to define spatial units in Australia has been confused despite the pre-eminence of Australian workers in land resource survey and the existence of a well-defined literature (e.g. Stewart 1968, Austin and Basinski 1978, Dent and Young 1981, Gunn et al. 1988). Different groups have applied terms such as land unit, land system, and unique mapping area, in various ways. Speight (1988) brings order to the situation and his recommendations on terminology are adopted here because they are consistent with most aspects of current practice.

Individuals in agencies with a well-accepted local terminology may balk at the recommended terminology. This will be a problem for any set of proposed terms and flexibility is required if a consistent national standard is to be achieved. It is worth noting that the definitions of Speight (1988) are broadly consistent with international terminology (e.g. Dent and Young 1981). They are also part of the guidelines for survey practice in Australia (Gunn et al. 1988, McKenzie et al. 2006).

Speight (1988) uses *land unit* as a generic term and in a different sense to Christian and Stewart (1968). *Land unit* does not imply a particular scale and it can be used to refer to:

- conceptual units (e.g. land facets or systems as *conceptual* constructs)
- mapping units (e.g. a *tract* of land or an individual polygon)
- taxonomic units (e.g. a *type* of land such as the Oxford Land System).

For these reasons, we will refer generally to the *hierarchy of land units* in ASRIS.

Speight (1988) also defines a *land-unit individual* – this is a particular area of land having the same size as the land unit *characteristic dimension* of the land unit. Users of the Field Handbook (McDonald et al. 1990) will be familiar with this notion through the site concept. For example, attributes for a landform element are observed over a circle (the site) of about 40 m diameter – the site in this instance defines the land-unit individual and its characteristic dimension. In contrast, landform pattern attributes are observed over a circle of about 600 m diameter.

Speight's (1988, 1990) observations on the characteristic dimensions of landform elements and patterns were intended to provide a guide rather than a fixed value. The concept is far more valuable than this and we use it here in conjunction with sets of defining attributes to construct the *hierarchy of land-unit tracts*.

Table 3 shows the hierarchy of land-unit tracts. Each level in the hierarchy has a specified characteristic dimension along with a set of defining attributes measured at the accompanying scale. The characteristic dimension can be viewed as the window size over which the defining attributes can be sensibly measured – different landscapes will have contrasting characteristic dimensions. For example, hillslope lengths may be very short (e.g. only a few metres in a strongly gullied landscape) or long (greater than a kilometer in strongly weathered landscapes of low relief), so land facets of very different size result. In some landscapes, nested patterns of landform may be evident and sublevels within the hierarchy can be sensibly delineated using the same set of defining attributes at more than one characteristic dimension (e.g. land systems within a land system). The ASRIS hierarchy and database structure allows sublevels to be defined for a given attribute set (e.g. Level 6.1).

The characteristic dimensions in Table 3 have been changed from Speight's (1988) original proposition to emphasize its role as a variable that defines both the appropriate of measurement and the nature of the landscape. The suggested values also better match the styles of survey undertaken across large areas during the last 15 years.

In Table 3, *tracts* are mapping units as opposed to taxonomic units. Note that *polygon* is often used synonymously with *land-unit tract*. Most land resource assessment in Australia is concerned with the mapping and description of land-unit tracts at the *land facet* and *land system* level. Speight (1988) defines these as follows:

Land facet (Level 6): This is a land unit with attributes that include slope, aspect, toposequence position, microclimate, moisture regime, soil profile class, land surface features, vegetation formation and vegetation community. Speight (1988) considers its characteristic dimension to be about 40 m but it can vary from 100 to just a few metres. Note that the terms *land component* and *land element* have often been equated with this definition of land facet.

Land system (Level 5): This is a land unit with attributes that include relief, modal slope, stream pattern, toposequences, local climate, lithology, soil association, vegetation type or sequence, and proportional occurrence and arrangement of land facets. Speight (1988) considers its characteristic dimension to be about 600 m, and he recommends this diameter for a land-system site.

Note that these are definitions of *conceptual* land units. Explicit reference can be made to land-unit individuals, types or tracts (e.g. land-facet individual, land-facet tract, land-facet type) but the context will usually convey the appropriate meaning. Particular mention should also be made of *unique mapping areas* – these are usually instances of land-system tracts that are later grouped into land-system types.

To reiterate, the concept of scale in the hierarchy of land-unit tracts is based not on the cartographic scale of mapping, but rather on:

- the characteristic dimension
- a set of defining attributes.

If land facets and land systems are defined in terms of landform attributes alone, they are identical with the landform elements and landform patterns defined by McDonald et al. (1990).

Mapping *land districts (Level 4)* is usually achieved by grouping land systems. Mapping land units at higher levels can be achieved by grouping land districts but in reality, most mapping at the division (Level 1), province (Level 2), and zone (Level 3) level is undertaken using a divisive rather than an agglomerative approach. Furthermore, different criteria for mapping emerge at these more generalized levels and many of the criteria used at lower levels lose significance (and vice versa).

In ASRIS, tracts at levels 1–3 delineate regions comprised of contiguous land units rather than multiple instances of the same land-unit type. This is necessary for cartographic efficiency at broad scales.

Table 3: The spatial hierarchy of land-unit tracts (after Speight 1988). Note that the database design for ASRIS allows intermediate Levels to be characterized (e.g. a System with a characteristic dimension significantly less that 100 m would be designated as Level 5.1 or 5.2 in the hierarchy)

Level	Order of land-unit tract	Speight	Characteristic dimension	Descriptive or defining attributes	Appropriate map scale
1.0	Division	300km	30 km	Broad physiography (slope and relief) and geology	1:10 million
2.0	Province	100 km	10 km	Physiography, water balance, dominant soil order and substrate	1: 2.5 million
3.0	Zone	30 km	3 km	Physiography, regolith materials, age of land surface, water balance dominant soil suborder	1:1 million
ASRIS Mapping Hiatus Levels above are based on subdivisions of the continent Levels below are aggregated from surveys.					
4.0	District	5 km	1 km	Groupings of geomorphically related systems	1:250 000
5.0	System	600 m	300 m	Local climate, relief, modal slope, single lithology or single complex of lithologies, similar drainage net throughout, related soil profile classes (soil-landscape*)	1:100 000
5.1			100 m	As for Level 5	1:25 000
6.0	Facet	40 m	30 m	Slope, aspect, soil profile class	1:10000
6.1			10 m		1:2500
6.2			3 m		1:1000
7.0	Site	20 m	10 m	Soil properties, surface condition, microrelief	rarely mapped in conventional survey

* Sensu Thompson and Moore (1984)

4.2 Upper levels of the hierarchy

The upper levels of the land-unit hierarchy are described in Sections 6–8. There are many other maps of Australia's natural resources at scales equivalent to the land zone, land province or land division. Some examples relevant to soils and landscapes include:

- Northcote et al. (1960–1968) – Atlas of Australian soils
- Löffler and Ruxton (1969) – Relief and landform map of Australia

- Laut et al. (1980) – Provisional environmental regions of Australia
- CSIRO (1983) – Soil landscape regions
- Grant et al. (1984) – Geotechnical landscape map of Australia
- Chan et al. (1986) – Regolith terrain map of Australia
- Jennings and Mabbutt (1986) – Physiographic regions of Australia
- Environment Australia (2000) – Interim biogeographic regions Version 5.1
- Coram et al. (2001) – Groundwater flow systems
- Williams et al. (2002) – Agro-ecological regions of Australia

ASRIS has the facility to substitute such stratifications above the level of the mapping hiatus. IBRA regions, groundwater flow systems, and catchment management boundaries are available and others will be added if required. The ability to substitute other stratifications allows summaries of soil and landscape properties to be generated in various formats. This promotes both integration of natural resource information and more widespread use of soil and land data by non soil-science based groups.

The linework and principles of Jennings and Mabbutt (1986) have been used to develop methods for Levels 1–3 in ASRIS. In particular:

- land-unit tracts at these levels are discrete entities and outliers are permitted only in exceptional cases (e.g. offshore islands, major plateau adjacent to extensive tablelands)
- tracts are hierarchical and have a single parent-tract
- the conventions for geographic naming outlined by Jennings and Mabbutt (1986) are followed except where their existing terms fail to have a local resonance (e.g. Werriwa Tablelands for the northern section of the Southern Tablelands in New South Wales) – this judgement will be made by state and territory agency staff with reference local naming conventions.

4.2.1 Data presentation

Apart from the online maps, data summaries (e.g. for soil properties such as pH, exchangeable cations, hydraulic conductivity) in the ASRIS land-unit hierarchy are of two basic types:

- area-weighted means (only for attributes where this is appropriate)
- histograms of attributes based on percentage area.

These two options, when combined with estimates of uncertainty, should form a sufficient basis for most queries of the system. The provision of histograms is to ensure compatibility with modelling systems such as those used in hydrology that use distributional information rather than simple measures of central tendency (e.g. mean, median). It is also an essential step towards providing better measures of uncertainty for all users of soil and land information.

4.3 Relationships between the land-unit hierarchy and continental grids

A theoretical ideal would be to have estimates for all relevant soil and land attributes at all locations with an acceptable level of uncertainty for all forms of decision-making. A grid-based representation of these attributes would be convenient and ASRIS 2001 generated such coverages for selected soil properties using environmental correlation (i.e. point data from field measurements are correlated with environmental variables that are measured everywhere to produce predictions of soil attributes for all locations – see McKenzie and Ryan 1999, Bui et al. 2004, McKenzie et al. 2006). The land-unit hierarchy provides another method for providing predictions at locations. Estimates are based on field observations or interpretations of soil variation within land-unit tracts. While the mental models used to delineate and describe the land-unit tracts are rarely explicit and sampling is purposive, the resulting maps have been useful for many purposes and they contain considerable information.

The land-unit hierarchy has been prepared with this context and it is recognized that the predictions of individual attributes will often have a large uncertainty – we cannot estimate this uncertainty in an objective manner unless there is an independent statistical sample.

The land-unit hierarchy has another very important role. It can be used to stratify landscapes to allow:

- more precise interpretations relating to landscape processes
- development of robust models for environmental correlation that predict individual soil attributes using a grid-based approach.

The hierarchy of land units and grid-based methods for predicting soil and landscape attributes are complementary both for the analysis and interpretation of data.

Database development within ASRIS will therefore include not only the construction of the soil profile database for fully characterized profiles (i.e. with comprehensive analytical data), but also the development of a much larger soil profile database for all locations characterized during agency survey programs. This comprehensive database will include other sources of data if quality control and privacy considerations can be resolved (e.g. soil-testing data). However, the initial priority is on development of the land-unit hierarchy, interpretations of soil and land qualities, and the database of fully characterized representative profiles. The grid-based estimates from ASRIS 2001 (Johnston et al. 2003) are included for completeness.

4.4 Description of land-facet and land-system tracts

This document concentrates on tracts at the level of land facet and land system. Land facets are usually described but not mapped in most Australian surveys. However, precision of mapping varies considerably. For example, the Atlas of Australian Soils uses very general soil-landscapes (equivalent here to land systems) with un-mapped land facets. In contrast, the soil-landscape mapping undertaken in New South Wales is more precise although it still maps soil-landscapes and describes unmapped land facets.

The land-unit hierarchy in ASRIS requires description of individual land-system tracts and their component land facets. In some cases, individual land system tracts (i.e. unique mapping areas) may be described according to a land-system type (i.e. according to Christian and Stewart's (1968) original definition of a land system where individual land system tracts belong to the same land system type and the tracts have the same descriptive attributes). It would be preferable to have access to descriptions of each land system tract prior to grouping into a land-system type but in many cases these data were never recorded (e.g. in the earlier CSIRO l surveys).

5. Accuracy, precision and a basis for stating uncertainty

5.1 Rationale

Estimates of uncertainty for each attribute in ASRIS are needed to encourage more appropriate use of data on soil and land resources. Uncertainty estimates are essential for tracking propagation of errors in various forms of analysis, particularly simulation modelling (e.g. Heuvelink 1998, Moss and Schneider 2000, Minasny and Bishop 2004). In many instances, the information on uncertainty generated by a model is as important as the prediction itself.

As far as possible, we have followed guidelines from the National Institute of Standards and Technology for evaluating and expressing uncertainty (Taylor and Kuyatt 1994, http://physics.nist.gov.cuu/Uncertainty).

Type A evaluations of standard uncertainty are based on any valid statistical method for treating data. These are not common in Australian soil and land resource survey. An example would be estimation of uncertainties in carbon or pH based on stratified random sampling of a land-unit tract.

Type B evaluations of standard uncertainty are based on scientific judgement using all the relevant information available, which may include:

- previous measurements on related soils
- experience with, or general knowledge of, the behaviour and properties of the relevant soils and measurement methods (e.g. accuracy of laboratory determinations and field description methods, reliability of pedotransfer functions)
- uncertainties published in reviews of spatial variation in soils (e.g. Beckett and Webster 1971, Wilding and Drees 1983, McBratney and Pringle 1999)

5.2 Estimating uncertainty

Most estimates of uncertainty in ASRIS rely on Type B evaluations. The estimate depends on the measurement scale, assumed probability distribution, and likely variation for each attribute.

Continuous variables with an assumed Normal probability distribution have their uncertainty represented by an estimated *standard deviation*. This is denoted by u_i and u_j for Type A and B evaluations respectively. In most cases, an attribute's uncertainty will arise from several sources and the combined standard uncertainty (u_c) is reported. There are many issues to resolve in calculating u_c. We assume the component variances are additive (i.e. $u_c = \sqrt{(u_1^2 + u_2^2 + u_3^2 \ldots)}$ where u_1, u_2 and u_3 are uncertainties attributable to different sources (e.g. arising from operator error in the field, a pedotransfer function, and spatial variability, respectively). Only two components of uncertainty are recorded in ASRIS (see below) – Table 4 provides default values.

It is difficult to nominate the most appropriate error distribution for some variables. For example, some must be positive (e.g. CEC, layer thicknesses) so a Gamma distribution may be most appropriate but in practice it will be simpler to use a log-normal distribution. Other variables are bounded (e.g. clay content varies from 0–100%) and the assumptions of the Normal and Gamma distributions are violated so another approach is needed. We have adopted the following conventions.

- Continuous variables that are not normally distributed are transformed to an approximately normal distribution and uncertainties are then estimated. Hydraulic conductivity and electrical conductivity are assumed to be distributed log-normally, unless there is evidence to the contrary. The mean is recorded in untransformed units to improve the ease of interpretation but the standard deviation is recorded as a transformed value. For example, the hydraulic conductivity may be estimated to be 100 mm/hr with a standard deviation of 0.5 log(mm/hr). The range of ± 1 standard deviation (i.e. 68% of the population) around the mean of 100 mm/hr would therefore be 32–320 mm/hr. The advantage of recording the transformed standard deviation is that that only one value is needed to represent dispersion of the asymmetric distribution.

- Variables with fixed ranges (e.g. percentage coarse fragments) or coarse stepped scales are modeled with triangular probability distributions unless there is evidence to the contrary. The triangular probability distribution is assumed to be symmetric. The mean is estimated and dispersion is defined as (95% quantile – 5% quantile)/2. The distribution between the minimum value and the 5% quantile, and between the 95% quantile and the maximum, is assumed to be flat. The distribution is shown in Figure 3.

- Uncertainties for nominal variables are represented by the probability that a class is correct (e.g. the uncertainty that a landform element type is a beach ridge is 0.8). Combined uncertainties are calculated by multiplying component probabilities.

Every soil attribute has an estimated uncertainty with two components.

- The first component (u1) is associated with the measurement error for the given attribute at the profile or site – it will be significantly reduced if replicated sampling or bulking has been undertaken. If the attribute (e.g. water retention at –10 kPa) is being estimated using a pedotransfer function, then the uncertainty includes both the measurement error of the explanatory variables (e.g. texture, structure, and bulk density) and error due to model underlying the pedotransfer function.

- The second component (u2) of uncertainty is due to spatial variability within the land-unit tract at the lowest level in the hierarchy for which data are available.

In most parts of Australia, there is limited information on both of these sources of uncertainty and it will require good judgment to provide estimates. However, the alternative of providing estimates of mean values without information on variability is potentially misleading.

In the absence of better information, we will use default values of uncertainty drawn from the published literature on spatial variation and our general knowledge (Table 4). The default values are conservative (i.e. most likely on the high side) and intended to encourage more attention to the estimation of uncertainty. The component of uncertainty due to measurement (u_1) can be determined using the estimation method for each variable as a guide (e.g. Table 26 for bulk density). The component of uncertainty due to spatial variability (u_2) can be determined using several lines of evidence including:

- cartographic scale of the survey and intensity of sampling (this is expressed via the Order of Survey (Table 10, Soil Survey Staff 1993))
- qualitative assessment of landscape complexity.

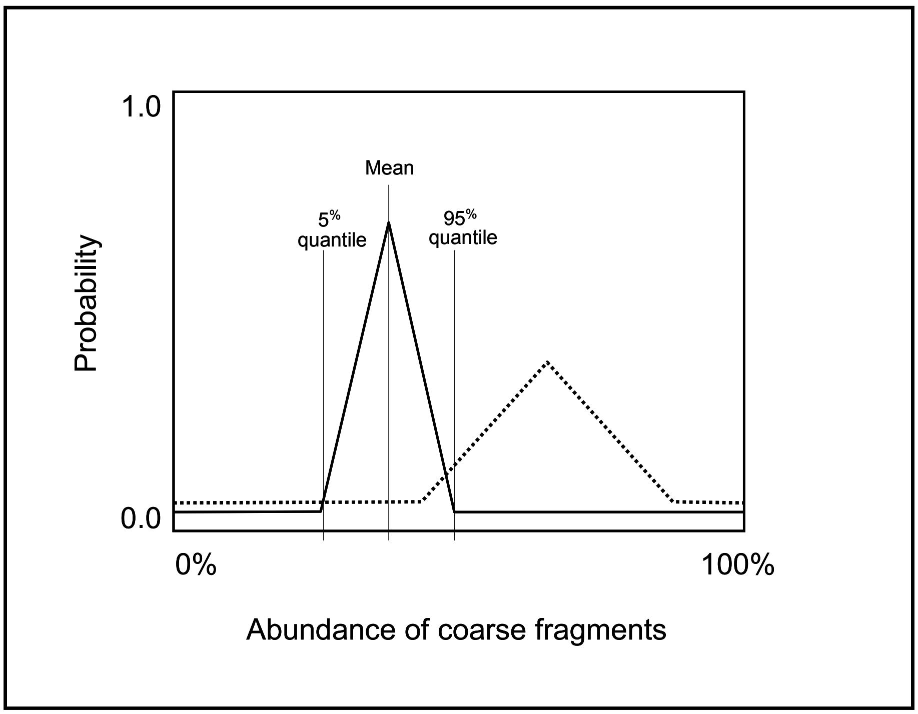


Figure 3: Examples of triangular probability distribution functions for coarse fragments. The mean, 5% and 95% quantiles are shown for the material with less variation (solid line).

Table 4: Default estimates of uncertainty for attributes of land-unit tracts in ASRIS – defaults for landform and land surface (relief, modal slope, element, pattern, microrelief, rock outcrop and surface coarse fragments) are yet to be determined.

Attribute	Units (un-transformed)	Scale of measurement and probability distribution*	Attribute uncertainty due to measurement (u_1)	Indicative Spatial Uncertainty (simple– complex landscape)** (u_2)		
				Order 3 Survey	Order 4 Survey	Order 5 Survey
Landform pattern		Nominal				
Rock outcrop (Level 5)	%					
Surface coarse fragments	%					
Morphologic type		Nominal				
Landform element		Nominal				
Slope class		Nominal				
Site drainage		Nominal				
Rock outcrop (element)	%					
Surface coarse fragments	%					
Microrelief type		Nominal				
Gilgai component		Nominal				
Microrelief biotic agent		Nominal				
Biotic component		Nominal				
Texture		Nominal	0.8 – S, LS, CS, MC, MHC, HC. 0.7 – other classes	0.7–0.4	0.6–0.3	0.5–0.2
Clay content	%	Triangular	10%	10–20%	20–30%	30–40%
Coarse fragment abundance	%	Triangular	20%	20–30%	30–40%	40–50%
Coarse fragment porosity	m^3/m^3	Triangular	0.1	0.1–0.2	0.1–0.2	0.2–0.3
Bulk density	Mg/m^3	Normal	0.1	0.1–0.2	0.2–0.3	0.3–0.4
pH		Normal	0.2	0.2–0.5	0.5–1.0	1.0–2.0
Organic carbon	%	Normal	0.2	0.4–0.8	0.8–1.2	1.2–2.0
Depth A1	m	Triangular	0.05	0.1–0.2	0.2–0.3	0.3–0.4
Depth to B2	m	Normal	0.1	0.1–0.2	0.2–0.3	0.3–0.4
Depth of solum	m	Normal	0.2	0.2–0.4	0.4–0.6	0.6–1.0
Depth to impeding layer	m	Normal	0.2	0.2–0.4	0.4–0.6	0.6–1.0
Depth of regolith	m	Normal	0.3	0.3–1.0	1.0–2.0	2.0–3.0
Layer thicknesses 1-4	m	Normal	0.1	0.1–0.2	0.2–0.3	0.3–0.4
Layer thickness 5	m	Normal	0.2	0.3–1.0	1.0–2.0	2.0–3.0
$\theta_{-10\ kPa}$	%	Normal	2	2–4	4–6	6–8
$\theta_{-1.5MPa}$	%	Normal	1	1–3	3–5	5–7
Ksat	mm/hr	Log_{10}-normal	0.5	1–2	1.5–3	2–4
Electrical conductivity	dS/m	Log_{10}-normal	-1	-0.7–-0.4	-0.4–-0.2	-0.2–-0.1
Aggregate stability		Nominal	0.9	0.8–0.7	0.7–0.6	0.6–0.4
Water repellence		Nominal	0.8	0.6–0.4	0.5–0.3	0.4–0.2
Sum of exchangeable bases	cmol(+)/kg	Normal	0.5	0.5–1	1–4	4–8
CEC	cmol(+)/kg	Normal	0.5	0.5–1	1–4	4–8
ESP	%	Normal	1	1–2	2–4	4–8
Australian Soil Classification (Great Group)		Nominal	0.9	0.8–0.7	0.7–0.5	0.5–0.4
World Reference Base		Nominal	0.8	0.7–0.6	0.6–0.4	0.4–0.1
Substrate type		Nominal	0.8	0.7–0.6	0.6–0.5	0.5–0.4
Substrate permeability	mm/hr	Log_{10}-normal	0.5	1–2	1.5–3	2–4

* Uncertainty for Normally distributed attributes is estimated using the standard deviation (sd) – note 68% of observations are within ±1sd and 95% are within ±2sd.

** Spatial uncertainty includes the component due to measurement or estimation (i.e. u_1) along with uncertainty arising from spatial variation within a land-unit tract. Spatial uncertainty increases with decreasing survey effort (e.g. less intensive field sampling and broader scale mapping) and with increasing landscape complexity. Survey effort has been classified according to the Survey Order while the range in uncertainty due to landscape complexity has been estimated.

6. Level-1 descriptors (land division)

Level 1 distinguishes major physiographic divisions across the country. These tracts are defined primarily by slope and relief although the principles of mapping are essentially the same as those used for integrated survey (Gunn et al. 1988). Various strands of evidence are used to delineate boundaries of these large tracts: for example, existing geology and landform maps at the same scale, Landsat imagery, and various terrain attributes (see the ASRIS website).

Three terrain attributes in particular are useful at the continental level to both help delineate and describe land-unit tracts. The Multi-resolution Valley Bottom Flatness (MrVBF) index (Gallant and Dowling 2003) identifies areas that are both relatively flat and low in the landscape at different scales – these are interpreted as valley bottom areas (Figure 4). MrVBF is interpreted as an index of deposition, based on the assumption that flat valley bottoms are flat because they are filled with sediment. The index separates upland terrain dominated by erosional processes from lowland depositional terrain, and further divides the depositional areas into different classes based on slope and areal extent. Values less than 0.5 are considered to be erosional, while values greater than 0.5 are considered to be depositional. The second terrain variable is relief (Figure 5). It is defined using departure of an individual cell from the average elevation in a 2 km diameter window centred on the cell. Investigations are underway to refine this relief measure (using sectoral relief or upslope/downslope relief, both within a multiscale scheme similar to MrVBF). Finally, the shaded relief image derived from the SRTM digital elevation data provides an unprecedented perspective on landscapes of low relief.

In the absence of a better stratification[2], Jennings and Mabbutt's physiographic regions provide a first approximation in ASRIS. A level of generalization between their Division and Province is used for Level 1 in ASRIS. As a guide, the hierarchy of land-unit tracts divides by a factor of approximately seven between each level (i.e. Level 1 has ~7 tracts, Level 2 has ~49, Level 3 has ~ 343 and so forth). Adjustments to the Jennings and Mabbutt linework are made manually using the terrain variables and other sources of information (particularly the SRTM digital elevation model and Landsat imagery) – the goal is to create units that minimize within-unit variation and maximize between-unit variation in the two terrain attributes. The possibility for a more explicit and repeatable method is being investigated.

Level 1 can be used to make interpretations about landscape processes at the broadest scale. These relate primarily to distinctions between erosional and depositional landscapes, and the potential energy of landscapes (e.g. zones of high energy have steep slopes and large relief so they will have correspondingly large rates of sediment

[2] Note that some states already have good upper level stratifications (e.g. Vic, WA, Tas) and these, rather than Jennings and Mabbutt, form the starting point.

movement). Each land-unit tract will have a geographical name, statistical summaries of slope and relief (including histograms) and a generalized description of geology (Table 5).

Table 5: Summary of descriptors for tracts at Level 1 (land division)

Descriptor	Example	Comment
Name	Eastern Uplands	Follows Jennings and Mabbutt unless better descriptors are available
Landscape	–	Text description of the major geologic, and geomorphic features
Slope	6% (2–9%)	Modal slope with the 5th and 95th percentile. ASRIS will also display a histogram of slope for each tract at Level 1.
Relief	150 m (30–370 m)	Modal relief with the 5th and 95th percentile. ASRIS will also display a histogram of relief for each tract at Level 1.

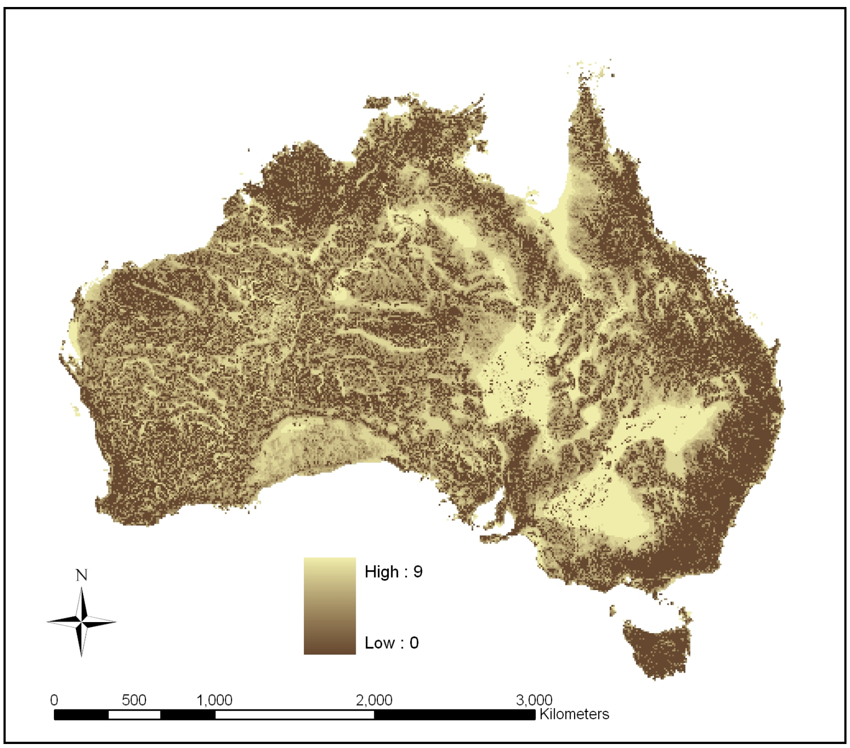


Figure 4: The Multi-resolution Valley Bottom Flatness index identifies erosional and depositional areas from continental to local scales.

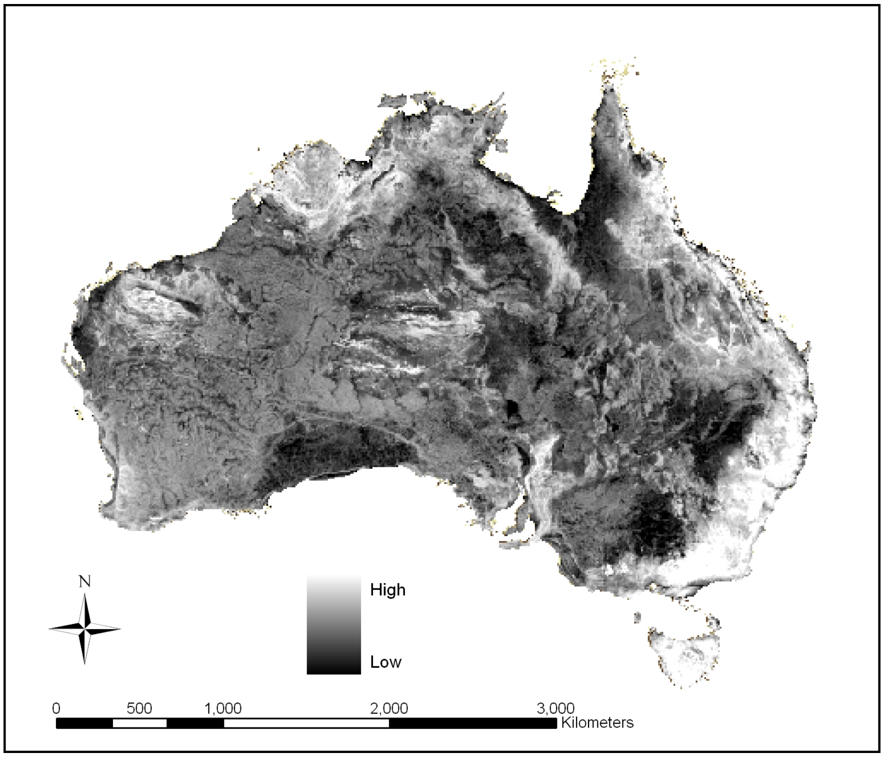


Figure 5: Relative relief

7. Level-2 descriptors (land province)

Level 2 subdivides Level-1 units using physiographic distinctions at a finer level of detail. Again, relief and modal slope are used as the primary discriminants and in the absence of a better stratification[3], Jennings and Mabbutt's physiographic regions are used as a first approximation. Level 2 is between the Province and Section in that scheme. Adjustments to the linework are made manually using the terrain variables – the goal is to create units that minimize within-unit variation and maximize between-unit variation in the two terrain attributes.

Primary descriptors at Level 2 are relief, modal slope, regolith materials, dominant soil order, and an estimate of water-balance. As with Level 1, each tract has a geographic name and simple text description.

Regolith materials will be described using the first level of classification in Table 50 (unweathered bedrock (BU), evaporites (EVA), sediments (SDE), unconsolidated materials (UO) and weathered in-situ residuals (WIR)). Some of these categories may be split if necessary (e.g. to discriminate alluvial, colluvial and aeolian sediments). The relative area of up to three classes will be shown using the descriptors dominant (>50%), subdominant (20–50%) and minor (<20%). The same system is used to describe the soil order.

Water-balance is estimated using outputs from the BIOS model (Raupach et al. 2001) calculated using a 5 km grid across the country. The model partitions precipitation into transpiration and evaporation with the remainder being allocated to drainage and runoff. This drainage and runoff ('excess water') provides an estimate of potential leaching. This acts as a guide to accumulations of soluble salts, organic matter dynamics, pH, and intensity of weathering (Figure 6).

There are limits to the degree to which contemporary climate can be used to infer current or past soil processes. However, spatial representation in ASRIS of Pleistocene and earlier Tertiary climates is not feasible at this stage.

[3] Note that some states already have good upper level stratifications (e.g. Vic, WA, Tas) and these, rather than Jennings and Mabbutt, will form the starting point.

Table 6: Summary of descriptors for tracts at Level 2 (land province)

Descriptor	Example	Comment
Name	Tasmanian Uplands	Follows Jennings and Mabbutt unless better descriptors are available
Landscape	–	Text description of the major geologic, and geomorphic features
Slope	11% (3–18%)	Modal slope with the 5th and 95th percentile. ASRIS will also display a histogram of slope for each tract at Level 2
Relief	190 m (50–395 m)	Modal relief with the 5th and 95th percentile. ASRIS will also display a histogram of relief for each tract at Level 2.
Excess water	350 mm (90–850mm)	Median value for excess water (runoff + deep drainage) with the 5th and 95th percentile. ASRIS will also display a histogram of excess water for each tract at Level 2.
Regolith materials	Dominant: unweathered bedrock Subdominant: unconsolidated materials Minor: weathered in-situ residuals	
Soil Order	Dominant: Rudosols Subdominant: Organosols Minor: Podosols	

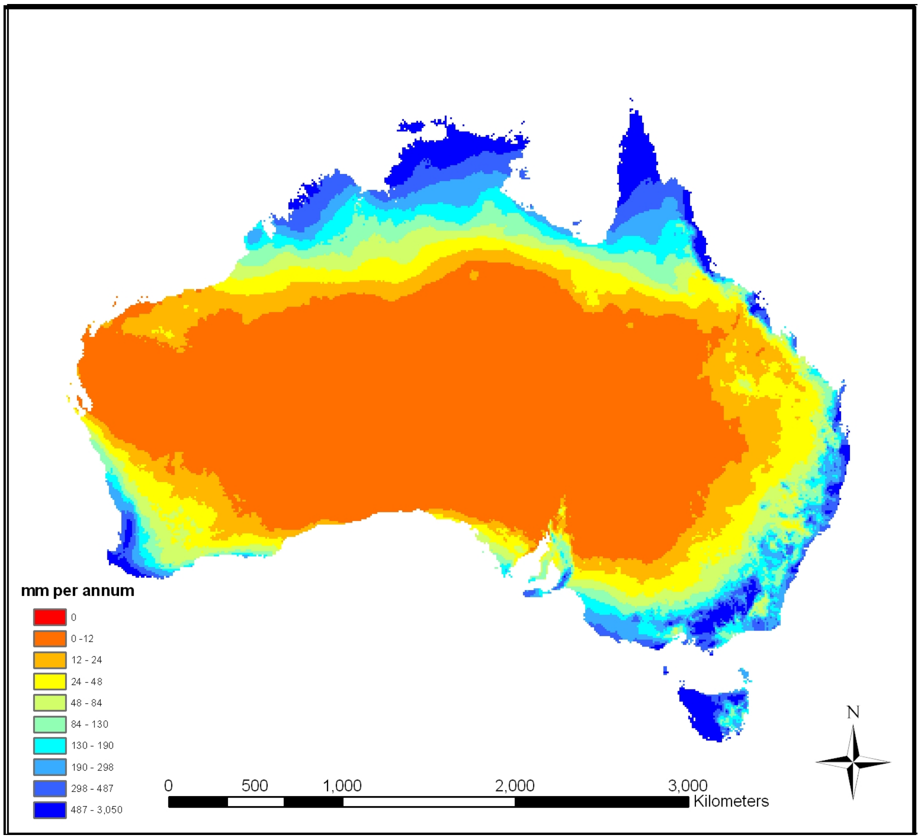


Figure 6: Average annual excess water (mm deep drainage and runoff per annum) (Raupach et al. 2001)

8. Level-3 descriptors (land zone)

Level 3 subdivides Level-2 units with finer distinctions based on physiography. The number and detail of descriptors are also increased. Between 200–300 land-unit tracts will be delineated and described as follows.

- regolith materials are defined using Table 50 and an estimate of areal proportion (dominant, subdominant, minor). At this stage, the line work will most likely come from high level groups from land resource surveys or geologic and geomorphic mapping
- relative age of the land surface at a very general level (i.e. Holocene, Pleistocene, Neogene and Palaeogene, and pre- Palaeogene)
- climate summaries are given for excess water (see Level 2), mean annual temperature and mean annual precipitation
- up to three soil sub-orders are listed with an estimate of relative area (dominant, subdominant and minor)
- a geographic name and text description.

Table 7: Summary of descriptors for tracts at Level 3 (land zone)

Descriptor	Example	Comment
Name	Mallee dunefield	Follows Jennings and Mabbutt unless better descriptors are available
Landscape	–	Text description of geologic, geomorphic and pedologic features
Slope	3% (1–8%)	Modal slope with the 5th and 95th percentile. ASRIS will also display a histogram of slope for each tract at Level 3
Relief	16 m (2–25 m)	Modal relief with the 5th and 95th percentile. ASRIS will also display a histogram of relief for each tract at Level 3.
Excess water	10 mm (1–70mm)	Median value for excess water (runoff + deep drainage) with the 5th and 95th percentile. ASRIS will also display a histogram of excess water for each tract at Level 3.
Regolith materials	Dominant: aeolian sand Subdominant: aeolian sediments Minor: lacustrine sediments	
Relative age of the land surface	Pleistocene	Only five broad categories at present (Holocene, Pleistocene, Neogene, Palaeogene, Pre-Palaeogene)
Soil Suborder	Dominant: Brown-Orthic Tenosol Subdominant: Lithocalcic Calcarosol Minor: Red Sodosol	

9. Level-4 descriptors (land district)

The land units at Level 4 are normally groupings of geomorphically related systems. These units differ from Level 3 in both detail and concept. Level-4 tracts are not geographically contiguous and conformable boundaries with Level 3 are not mandatory. Level-4 tracts are normally aggregated from surveys and are below the ASRIS Mapping Hiatus whereas Levels 1–3 are based on subdivisions of the continent. Most descriptors for Level 4 are generated as weighted averages and histograms from Level-5 tracts. Additional descriptions provide:

- Estimates of the resistance to weathering of the substrate
- A text description of the tract

In many cases, the number of Level-4 tracts per Level-3 parent will be greater than seven.

10. Level-5 descriptors (land system)

10.1 Identifiers

Most field-based land resource surveys in Australia collect information at Levels 5 and 6. In this section and the next, descriptors are specified for land-unit tracts at the system and facet level. State and territory agencies will most commonly provide data at Level 5 (land system) with unmapped tracts at Level 6 (land facets). In some instances, land systems or land facets may be provided at two or more levels of detail (e.g. nested land systems with unmapped facets, or a land system with 2 levels of land facet). In some circumstances, the lowest level may only consist of land systems.

Most source data for ASRIS have been collected during particular projects that cover a specified area and defined period. Project and agency codes are provided with all data. In the case of soil profile data collected independently of survey projects, a miscellaneous code (MISC) is used along with the Agency Code. States and territories need to provide unique Level-5 identifiers for each land-system tract. An extra identifier (*proportion*) is needed when the land-unit tract is described but not mapped. The identifiers are summarized in Table 8.

Table 8: Level-5 land-unit tract identifiers

Variable	Definition	Example	Comments
Agency code	SITES agency code	505	
Project code	Agency code for the source survey	ALP58 (Alpine survey, 1958)	See ASRIS Website for a full listing of codes
Feature identification	Agency defined and unique number for the tract	mtk00245	
Hierarchy level	Level in the ASRIS land-unit hierarchy	5.0	
Component identification	Unique code for the unmapped component if present	0001	
Feature name	Plain text description of the land unit	Mt Kosciuszko land system	Text can also include a broad description of the tract (<240 characters)
Proportion	Area occupied by the tract within the parent land unit	60%	Only applicable when the land-unit tract is described but not mapped

10.2 Mapping intensity and scale

Observations

The nature of observations within each land-unit tract at Level 5 and 6 is recorded according to Table 9. Note that a field observation involves, as a minimum, completion of a full site and profile description according to McDonald et al. (1990).

Table 9: Nature of observations for the land-unit tract

Class	Description
1	Multiple field observations recorded and extensive traverses
2	Single field observation and restricted traverses
3	Characterization relies on field observations made in similar units in the parent District (if tract is Level 5) or parent System (if tract is Level 6)
4	Characterization relies on remotely sensed information only
5	Unknown

Order of survey

The order of survey used to generate the interpretations for each land-unit tract is recorded according to Table 10 (for further details see Soil Survey Staff (1993, p48–49)).

Table 10: Orders of survey (modified from Soil Survey Staff (1993, p48–49))

Order level	Intensity	Minimum size delineation (ha)	Cartographic scale for publication
1	Very intensive	<0.3	More detailed than 1:10 000
2	Intensive	0.3 – 1	1:10 000 – 1:20 000
3	Extensive	1 – 5	1:20 000 – 1:50 000
4	Extensive	5 – 150	1:50 000 – 1:250 000
5	Very Extensive	150 – 4 000	1:250 000 – 1: million or less detailed

Year of survey

This is the year in which the information was collected (the year of publication will usually be sufficient).

10.3 Landform

Relief/modal slope

Relief and modal slope will be calculated for land-unit tracts above and including the level of land system. *Relief and modal slope classes* will also be generated according to Table 5 of Speight (1990). The ASRIS team will undertake these tasks using the continental digital elevation model. It is acknowledged that slopes will be underestimated in some landscapes as a result. Codes are provided in Table 11.

Table 11: Relief and modal slope classes

Code	Code description
B	Badlands <9 m >32%
B1	Badlands 9–30 m >56%
B2	Badlands 30–90 m >100%
GP	Gently undulating plains <9 m 1–3%
GR	Gently undulating rises 9-30 m 1–3%
LP	Level plain <9 m <1%
PH	Precipitous hills 90-300 m >100%
PM	Precipitous mountains >300 m >100%
RH	Rolling hills 90–300 m 10–32%
RL	Rolling low hills 30–90 m 10–32%
RM	Rolling mountains >300 m 10–32%
RP	Rolling plains <9 m 10–32%
RR	Rolling rises 9–30 m 10–32%
SH	Steep hills 90–300 m 32–56%
SL	Steep low hills 30–90 m 32–56%
SM	Steep mountains >300 m 32–56%
SR	Steep rises 9–30 m 32–56%
UH	Undulating hills 90–300 m 3–10%
UL	Undulating low hills 30–90 m 3–10%
UP	Undulating plains <9 m 3–10%
UR	Undulating rises 9–30 m 3–10%
VH	Very steep hills 90–300 m 56-100%
VL	Very steep low hills 30–90 m 56–100%
VM	Very steep mountains >300 m 56–100%

Landform pattern

Landform pattern is recorded using the glossary provided by Speight (1990, p48–57, Table 12).

Rock outcrop

Rock outcrop is the percentage of the land-unit tract occupied by rock outcrop. This attribute is usually recorded using the classes on page 101 of McDonald et al. (1990) – use the mid-point of the class range if more accurate information is not available. Rock outcrop is only recorded at Level 5 if data are not available for Level 6. Care is needed to avoid double counting with *surface coarse fragments*.

Surface coarse fragments

The *areal percentage of surface coarse fragments* is recorded as a percentage for the land-unit tract but again only when Level-6 tracts are not described. These variables are recorded for five size-classes: gravelly (2–60mm) (i.e. grouping of the fine, medium and coarse gravelly categories in McDonald et al. (1990)), cobbles (60–200 mm), stones (200–600 mm), boulders (600 mm–2m) and large boulders (>2 m).

Table 12: Codes for landform pattern

Code	Landform pattern	Code	Landform pattern
ALF	Alluvial fan	MAD	Made land
ALP	Alluvial plain	MAR	Marine plain
ANA	Anastomatic plain	MEA	Meander plain
BAD	Badlands	MET	Meteor crater
BAR	Bar plain	MOU	Mountains
BEA	Beach ridge plain	PAR	Parabolic dunefield
CAL	Caldera	PED	Pediment
CHE	Chenier plain	PEP	Pediplain
COR	Coral reef	PLA	Plain
COV	Covered plain	PLT	Plateau
DEL	Delta	PLY	Playa plain
DUN	Dunefield	PNP	Peneplain
ESC	Escarpment	RIS	Rises
FLO	Flood plain	SAN	Sand plain
HIL	Hills	SHF	Sheet-flood fan
KAR	Karst	STA	Stagnant alluvial plain
LAC	Lacustrine plain	TEL	Terraced land (alluvial)
LAV	Lava plain	TER	Terrace (alluvial)
LON	Longitudinal dunefield	TID	Tidal flat
LOW	Low hills	VOL	Volcano

11. Level-6 descriptors (land facets)

11.1 Identifiers

In the previous section it was noted that in most Australian surveys, land facets at level are described but not mapped. The areal percentage of each unmapped tract within its parent tract must be recorded to allow the calculation of area-weighted statistics within ASRIS. The identifiers for Level-6 land facets are presented in Table 13 for completeness – they are the same as those for Level-5 tracts.

Table 13: Identifiers for tracts at level-6

Variable	Definition	Example and explanation	Comments
Agency code	SITES agency code	505	See ASRIS Website for a full listing of valid codes
Project code	Agency code for the source survey	ALP58 (Alpine soil survey, 1958 – Bloggs et al. (1964))	See ASRIS Website for a full listing of codes
Feature identification	Agency defined and unique code for the tract	mtk00245003	
Component identification	Unique code for the unmapped component if present	0001	
Hierarchy level	Level in the ASRIS land-unit hierarchy	6.0	
Feature name	Plain text description of the land unit	Feldmark on exposed slopes of Mt Kosciuszko	Text can also include a broad description of the tract (<240 characters)
Proportion	Areal percentage occupied by the tract within the parent land unit	30%	Only applicable when the land-unit tract is described but not mapped

11.2 Landform

The method code for observations (Table 9) is recorded and it forms the basis for assessing the uncertainty of estimates for morphologic type, landform element type, slope class, site drainage, rock outcrop, surface coarse fragments and microrelief.

Morphological type

The land facet is described using one of the ten morphologic types defined by Speight (1990, p13) and listed in Table 14.

Table 14: Landform morphological type

Code	Code desciption
C	Crest
D	Closed depression
F	Flat
H	Hillock
L	Lower-slope
M	Mid-slope
R	Ridge
S	Simple-slope
U	Upper-slope
V	Open depression (vale)

Landform element type

Landform element is recorded using the terms in the glossary provided by Speight (1990, p24–34) and listed in Table 16.

Slope class

The average slope of the land facet is recorded in percent.

Site drainage

Site drainage is recording using the six classes defined by McDonald and Isbell (1990, p151) and shown in Table 15.

Table 15: Drainage classes

Code	Code description
1	Very poorly drained
2	Poorly drained
3	Imperfectly drained
4	Moderately well drained
5	Well drained
6	Rapidly drained

Table 16: Landform elements (after Speight 1990)

Code	Landform element	Code	Landform element
ALC	Alcove	LAK	Lake
BAN	Bank	LDS	Landslide
BAR	Bar	LEV	Levee
BEA	Beach	LUN	Lunette
BEN	Bench	MAA	Maar
BER	Berm	MOU	Mound
BKP	Backplain	OXB	Ox-bow
BOU	Blow out	PED	Pediment
BRI	Beach ridge	PIT	Pit
BRK	Breakaway	PLA	Plain
CBE	Channel bench	PLY	Playa
CFS	Cliff-foot slope	PST	Prior stream
CIR	Cirque	REF	Reef flat
CLI	Cliff	RFL	Rock flat
CON	Cone	RPL	Rock platform
COS	Cut-over surface	SCA	Scarp
CRA	Crater	SCD	Scald
CUT	Cutface	SCR	Scroll
DAM	Dam	SFS	Scarp-foot slope
DDE	Drainage depression	SRP	Scroll plain
DOL	Doline	STB	Stream bed
DUC	Dunecrest	STC	Stream channel
DUN	Dune	STF	Supratidal flat
DUS	Duneslope	SUS	Summit surface
EMB	Embankment	SWL	Swale
EST	Estuary	SWP	Swamp
FAN	Fan	TAL	Talus
FIL	Fill-top	TDC	Tidal creek
FLD	Flood-out	TDF	Tidal flat
FOO	Footslope	TEF	Terrace flat
FOR	Foredune	TEP	Terrace plain
GUL	Gully	TOR	Tor
HCR	Hillcrest	TRE	Trench
HSL	Hillslope	TUM	Tumulus
ITF	Intertidal flat	VLF	Valley flat
LAG	Lagoon		

11.3 Land Surface

Descriptions of the land surface are defined by: *microrelief type*, the described *gilgai component* (if present), *biotic agent*, and *biotic component*. The descriptors follow the definitions of McDonald et al. (1990) and the codes are presented in Table 17, Table 18, Table 19, and Table 20 respectively.

Rock outcrop

Rock outcrop is the percentage of the land-unit tract (usually a land facet) occupied by rock outcrop. Care is needed to avoid double counting with *surface coarse fragments*.

Surface coarse fragments

The *areal percentage of surface coarse fragments* is recorded as a percentage for the land facet (Table 16) or land system if it is the lowest level recorded. These variables are recorded for five size classes: gravelly (2–60mm), cobbles (60–200 mm), stones (200–600 mm), boulders (600 mm–2m) and large boulders (>2 m).

Table 17: Microrelief type

Code	Code description
Z	No microrelief
NR	Microrelief not recorded
A	Lattice Gilgai
C	Crabhole Gilgai
D	Debil-debil
G	Contour Gilgai
H	Spring hollow
I	Sinkhole
K	Karst microrelief
L	Linear Gilgai
M	Melonhole Gilgai
N	Normal Gilgai
O	Other
P	Spring mound
R	Terracettes
S	Mass movement microrelief
T	Contour trench
U	Mound/depression microrelief
W	Swamp hummock

Table 18: Described gilgai component (if present)

Code	Code description
D	Depression
M	Mound
S	Shelf

Table 19: Biotic agent for microrelief (if present)

Code	Code description
A	Ant
B	Bird
M	Human
N	Animal
O	Other
T	Termite
V	Vegetation

Table 20: Biotic component of microrelief (if present)

Code	Code desciption
D	Depression
H	Hole
M	Mound
O	Other
T	Terrace

11.4 Soil

Soil in the land-unit tract at the finest level of resolution (usually Level 6) is described using the descriptors outlined in the following sections (unless the land unit is composed entirely of bare rock). If a land-unit tract (e.g. Level-6 land facet) has several component soils, then the land unit description remains the same, with separate soil descriptions for each component.

The description of a soil profile for a land unit refers to an idealized soil. Estimates for attributes are derived from various sources including field descriptions, detailed representative profiles, and general field knowledge – all estimates have an accompanying measure of uncertainty (page 25). Soil data relating to actual soils are presented in the representative soil profile data base (page 75).

11.4.1 Control sections

Soil profiles vary greatly in the morphology, composition, dimensions, and arrangement of soil horizons and stratigraphic layers. Generalization and simplification are essential for land evaluation and spatial analysis. As a consequence, a simple but sufficient model is needed to describe idealized soils in the land-unit hierarchy.

Each idealized soil profile is represented by five contiguous soil layers (see Figure 7 for examples). The layers are intended to discriminate materials in terms of their function in relation to water and gas movement, nutrient supply, plant growth, and physical behaviour more generally. Numbers are used to denote the layers and attributes (e.g. *Layer-1 texture*, *Layer-3 organic carbon*), and they will often correspond with particular types of soil horizons. In general, Layers 1 and 2 refer to the A horizon (often an A1 and A2 horizon respectively), Layers 3 and 4 refer to the subsoil (often a B21 and B22 horizon respectively), and Layer 5 refers to the profile base (often a C horizon at around 1.5-2.0 m). Judgement is needed to define the layers in complex profiles (e.g. buried soils with pans) where the simple A-B-C sequence of master horizons is not evident.

The first step in preparing soil estimates is to define the position of the five soil layers and record their thicknesses. It is important to ensure the five layers are contiguous and that layer thicknesses sum to equal the total profile thickness – this is necessary for calculation of integral properties such as the profile and plant available water capacities.

The rules for defining the layers and estimating attributes are reasonably straightforward. In most cases, attribute values are averages for a specified layer (e.g. available water capacity, texture). In some instances, attribute values refer to a particular part of the layer. For example, *Layer-1 hydraulic conductivity* refers to the upper few centimetres of the layer, while *Layer-3 bulk density* refers to the densest part of the layer. The following sections provide guidance on defining and describing the five generalized layers. It is difficult to anticipate all possible cases and judgement will be needed when soils have many contrasting layers.

If the A horizon of the idealized soil is thin and the profile has only a few layers (i.e. two or three), then Layer 2 may be recorded as missing. If the A horizon is thin, but multiple and contrasting layers occur deeper in the profile, Layer 2 can refer to layers below the A horizon (e.g. B1, IIA, IIB).

As noted earlier, Layers 3 and 4 in most profiles refer to the upper and lower B horizon respectively. In stratigraphically complex profiles, Layers 3 and 4 are defined according to how the profile functions in relation to plant growth and water movement (e.g. Figure 7c).

The soil data include a cross-reference to the ASRIS Soil Profile Database. The cross-reference is a link to a representative soil profile for the land-unit tract along with a measure of its similarity (Table 21) – this measure will be possibly augmented with a multivariate statistical metric at a later date. Ideally, land-unit tracts should have representative soil profiles nominated with a similarity of 1–3: relying on profiles with a similarity of 4 or 5 will be problematic in most instances.

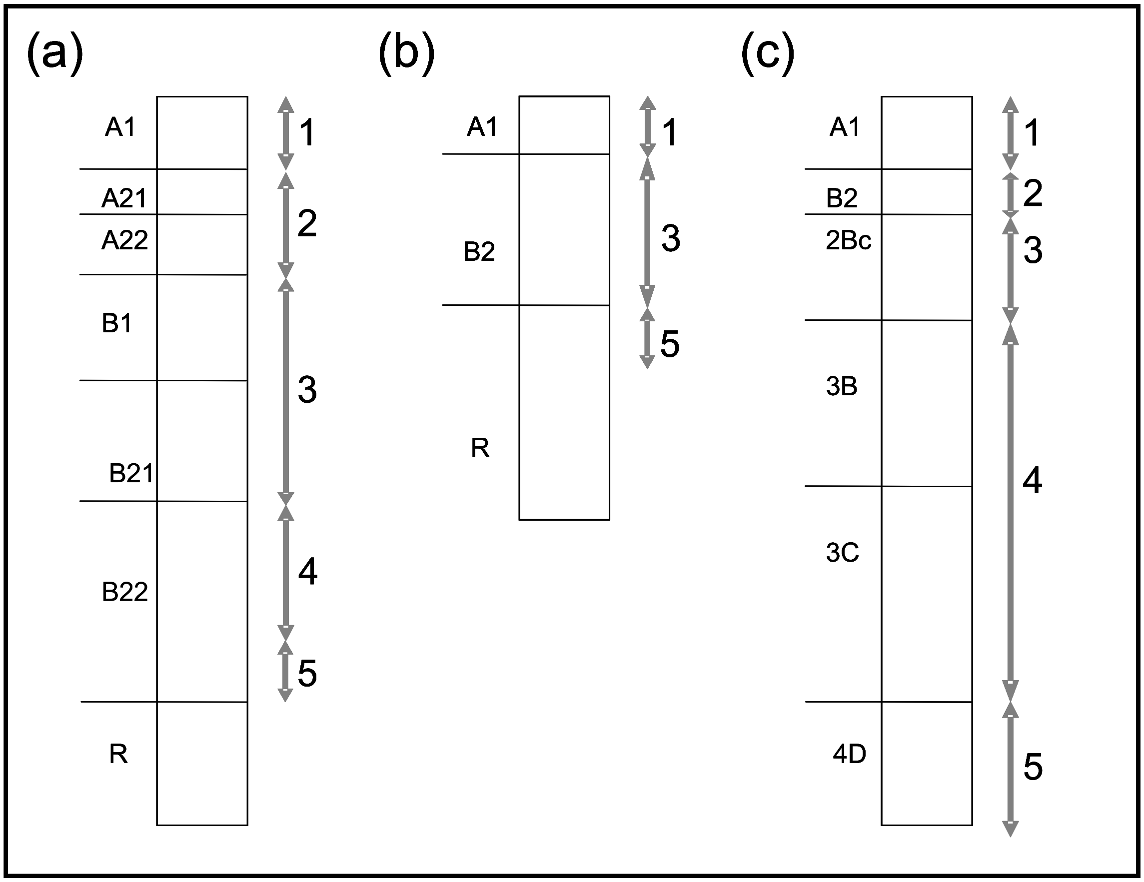


Figure 7: Examples of horizon sequences and allocation to the five-layer model used to describe idealized soil profiles in the land-unit hierarchy. Example (a) is a common sequence. In example (b), Layers 2 and 4 are recorded as missing because the profile is shallow and has only a few horizons. Example (c) is a complex profile and Layers are specified according to their influence on plant growth and water movement.

Table 21: Representativeness of the most similar soil profile in the ASRIS Soil Profile Database

Similarity	Description
1	Representative profile sampled within the land-unit tract
2	Representative profile sampled from the same land unit type
3	Representative profile for the soil profile class[4], and sampled within the region
4	Representative profile from another district but allocated to the same taxon within the Australian Soil Classification at the Great Group level or more detailed
5	Most similar profile from the ASRIS soil profile database based on expert judgement.

[4] See the definition by Isbell (1988). Some agencies use a different nomenclature: for example, Soil Groups (Western Australia) are examples of soil profile classes defined at a general level.

Texture

Texture class and clay content (%) are estimated for the five layers. In Australia, field texture is not synonymous with the particle size distribution. The former integrates particle size information with extra aspects relating to soil mechanical behaviour – the latter is affected by mineralogy, sodicity, organic matter content and cation composition. Estimates of clay content based on field texturing should therefore take these factors into account. For example, a Red Ferrosol with 80% clay that is very strongly aggregated can have a clay-loam texture, while another soil with a clay content of only 35%, but strong sodicity and abundant fine sand, may have a heavy-clay texture.

Estimation methods for texture and clay content are recorded (Table 22 and Table 23). Field-texture follows the definitions in McDonald and Isbell (1990) – the codes are shown in Table 24. Use of the modifiers and qualifiers is optional.

Table 22: Estimation method for field texture

Estimation Method	Description
1	Estimate based on measurements of field texture for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of field texture in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions).

Table 23: Estimation method for clay content

Estimation Method	Description
1	Estimate based on replicated laboratory measurements of particle size from representative soil profiles in the land-unit tract
2	Estimate based on laboratory measurement of particle size from a representative soil profile in the land-unit tract
3	Estimate based on particle size analysis on similar soils in the same land unit type (e.g. modal profiles)
4	Estimate is based on field textures from representative soil profiles in the land-unit tract
5	Estimate based on particle size analysis of similar soils in the region or project area
6	Estimate is based on field textures from soil profiles in the land-unit tract
7	Estimate is based on field textures from similar soils in the project area
8	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions).

Layer-1 Texture and clay content

The control section and convention for recording *Layer-1 Texture* and *Layer-1 Clay content* are as follows.

- If there is a single A1 horizon without subdivisions (e.g. A11, A12), then *Layer-1 Texture* and *Layer-1 Clay content* are the texture and clay content of the A1 horizon.
- If there are subdivisions within the A1 horizon, the *Layer-1 Texture* and *Layer-1 Clay content* are taken from the thickest A1 horizon layer within the top 0.20 m of the soil profile (the upper layer is used if thicknesses are equal).
- If the surface layer is an O horizon, the texture of the underlying A1 horizon is used in accord with the above criteria.
- If the surface layer is an O horizon and there is no underlying A1 horizon, the *Layer-1 Texture* and *Layer-1 Clay content* are taken from the thickest layer in the 0.20 m directly beneath the O horizon.
- If the surface layer is a peat, *Layer-1 Texture* and *Layer-1 Clay content* are recorded using the 7 classes of organic materials defined by McDonald and Isbell (1990) and shown in Table 24.

Layer-2 Texture and clay content

The *Layer-2 Texture* and *Layer-2 Clay content* usually refer to the average texture and clay content of the lower portion of the A horizon. The A horizon at this depth may be an A1, A2, A3, AB, A/B or subdivision thereof. Layer 2, if present, is always below Layer 1.

- If the surface layer is not an A1 horizon (e.g. O horizon) and there is no underlying A horizon, the attribute is recorded as missing (NA for texture, –9999 for clay content – see page 76)
- If the A horizon is thin and the profile only has a few layers, *Layer-2 Texture* and *Layer-2 Clay content* may be recorded as missing.
- If the A horizon is thin and multiple contrasting layers occur deeper in the profile, *Layer-2 Texture* and *Layer-2 Clay content* can refer to layers below the A (e.g. B1, 2A, 2B, 2D).

Layer-3 Texture and clay content

The B-horizon definition below follows the Field Handbook with the modification suggested by Isbell (1996) (the criteria in part being "…an illuvial concentration of silicate clay, iron, aluminium, humus, carbonates, gypsum, or silica, alone or in combination"). The *Layer-3 Texture* and *Layer-3 Clay content* are defined in most cases as follows.

- If a B horizon is present, the *Layer-3 Texture* and *Layer-3 Clay content* are the texture encountered in the upper B (usually B1 and B21).

- If no B horizon is present and the sequence consists of an AC profile, the *Layer-3 Texture* and *Layer-3 Clay content* generally refers to the materials directly below the A horizon (usually the upper 0.20 m).
- In more complex profiles, *Layer-3 Texture* and *Layer-3 Clay content* refer to the third functional layer in the profile.

Layer-4 Texture and clay content

In most profiles, *Layer-4 Texture* and *Layer-4 Clay content* refer to the lower part of the B horizon – this is usually a B22 or B3 and it often starts at around 0.80 m. If the profile and B horizon are thin (<1.0 m and <0.20 m respectively) and overlie an R horizon, Layer 4 may be recorded as missing. This definition is deliberately vague because of variations across the country.[5]

Layer-5 Texture and clay content

The *Layer-5 Texture* and *Layer-5 Clay content* are normally estimated at a depth between 1.5–2.0 m. The intention is to characterize the material in the lower portion or base of the potential root zone. If an R horizon or hard materials (including a continuous calcrete pan, partially weathered rock or saprolite, or other hard materials) occurs at a shallower depth, and this is still below the control section used for the *Layer-4* estimate, then the *Layer-5 Texture* and *Layer-5 Clay content* applies to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing (NA for texture, –9999 for clay content – see page 76).

Table 24: Field-texture grades, modifiers and qualifiers

Code	Grade	Code	Modifiers and qualifiers
S	Sand	FS	Fine sand
		MS	Medium sand
		KS	Coarse sand
		SA	Sapric sand
		SI	Fibric sand
LS	Loamy sand	LFS	Loamy fine sand
		LMS	Loamy medium sand
		LKS	Loamy coarse sand
		LSA	Sapric loamy sand
		LSI	Fibric loamy sand
CS	Clayey sand	CFS	Clayey fine sand
		CMS	Clayey medium sand
		CKS	Clayey coarse sand
		CSA	Sapric clayey sand
		CSI	Fibric clayey sand
SL	Sandy loam	FSL	Fine sandy loam

[5] In Queensland, this layer is interpreted to be the dominant B horizon (including 2B or 3B) below Layer 3 with an upper depth of <1.5 m. In South Australia, Layer 4 is often used for deeper horizons that are below calcrete (Layer 3) but still accessible to plant roots.

		MSL	Medium sandy loam
		KSL	Coarse sandy loam
		SLA	Sapric sandy loam
		SLI	Fibric sandy loam
L	Loam	LA	Sapric loam
		LI	Fibric loam
ZL	Silty loam	ZLA	Sapric silty loam
		ZLI	Fibric silty loam
SCL	Sandy clay loam	SCLFS	Sandy clay loam, fine sand
		SCLA	Sapric sandy clay loam
		SCLI	Fibric sandy clay loam
CL	Clay loam	FSCL	Fine sandy clay loam
		MSCL	Medium sandy clay loam
		KSCL	Coarse sandy clay loam
		CLA	Sapric clay loam
		CLI	Fibric clay loam
CLS	Clay loam, sandy	CLFS	Clay loam, fine sandy
		CLMS	Clay loam, medium sandy
		CLKS	Clay loam, coarse sandy
		CLSA	Sapric clay loam, sandy
		CLSI	Fibric clay loam, sandy
ZCL	Silty clay loam	ZCLA	Sapric silty clay loam
		ZCLI	Fibric silty clay loam
LC	Light clay	SLC	Sandy light clay
		FSLC	Fine sandy light clay
		MSLC	Medium sandy light clay
		KSLC	Coarse sandy light clay
		ZLC	Silty light clay
		LCA	Sapric light clay
		LCI	Fibric light clay
LMC	Light medium clay	ZLMC	Silty light medium clay
		SLMC	Sandy light medium clay
		FSLMC	Fine sandy light medium clay
		MSLMC	Medium sandy light medium clay
		KSLMC	Coarse sandy light medium clay
		LMCA	Sapric light medium clay
		LMCI	Fibric light medium clay
MC	Medium clay	ZMC	Silty medium clay
		SMC	Sandy medium clay
		FSMC	Fine sandy medium clay
		MSMC	Medium sandy medium clay
		KSMC	Coarse sandy medium clay
		MCA	Sapric medium clay
		MCI	Fibric medium clay
MHC	Medium heavy clay	ZMHC	Silty medium heavy clay

		SMHC	Sandy medium heavy clay
		FSMHC	Fine sandy medium heavy clay
		MSMHC	Medium sandy medium heavy clay
		KSMHC	Coarse sandy medium heavy clay
		MHCA	Sapric medium heavy clay
		MHCI	Fibric medium heavy clay
HC	Heavy clay	SHC	Sandy heavy clay
		FSHC	Fine sandy heavy clay
		MSHC	Medium sandy heavy clay
		KSHC	Coarse sandy heavy clay
		ZHC	Silty heavy clay
		HCA	Sapric heavy clay
		HCI	Fibric heavy clay
AP	Sapric peat		
SP	Sandy peat		
LP	Loamy peat		
CP	Clayey peat		
GP	Granular peat		
HP	Hemic peat		
IP	Fibric peat		

Coarse fragments

Coarse fragments are estimated using the conventions in McDonald et al. (1990). The main purpose for the variable is to allow calculation of available water capacity. In ASRIS, hard segregations are included in the estimate of coarse fragments. If porous segregations (i.e. capable of storing water or providing surfaces for ion-exchange) are present, then the *porosity* of coarse fragments needs to be estimated. In most regions, porosity of coarse fragments will be 0.00 m^3/m^3 (see page 58). Use Table 25 for the estimation method.

Abundance is estimated as an average percentage for each of the five layers (if source data rely on the classes listed by McDonald et al. (1990, p97), then use midpoints of each class). The control sections for coarse fragments are the same as those for texture.

Table 25: Estimation method for coarse fragments

Estimation Method	Description
1	Estimate based on replicated measurements of coarse fragments in an exposure or soil pits within the land-unit tract
2	Estimate based on a single measurement of coarse fragments in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils

Bulk density

The bulk density estimation method is recorded (Table 26) along with the bulk density for each layer. Apart from Layer-3, the bulk density is the average for each layer. The guidelines on control sections used for Texture apply generally for bulk density.

The *Layer-3 Bulk Density* is estimated as follows.

- In soils with a B2 horizon, the estimate is for the densest portion of the upper 0.20 m of the B2 horizon (or for the major part of the B2 horizon if it is less than 0.20 m thick).
- If no B horizon is present and the sequence consists of an AC profile, the *Layer-3 Bulk Density* is taken from the densest layer in the 0.20 m directly below the A horizon.

The *Layer-5 bulk density* is normally estimated at a depth between 1.5–2.0 m. The intention is to characterize the material in the lower portion or base of the potential root zone. If an R horizon or hard materials (including a continuous calcrete pan, partially weathered rock or saprolite, or other hard materials) occurs at a shallower depth, and this is still below the control section used for the *Layer-4* estimate, then the *Layer-5 Bulk density* applies to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing (NA for texture, –9999 for clay content – see Section 13.1).

Table 26: Estimation method for bulk density

Estimation Method	Description
1	Estimate based on measurements of bulk density for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of bulk density in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions).

pH profile

The pH in a 1:5 $CaCl_2$ solution is estimated for the five layers in the soil profile. If measurements were on a 1:5 soil-to-water, then use the conversion table in Appendix 1 taken from Henderson and Bui (2003). The estimation method is shown in Table 27.

Layer-1 pH

The *Layer-1 pH* is recorded as follows.

- In most instances, the estimate applies to the *upper 50 mm* of the A1 horizon.
- If the surface layer is an O horizon, the estimate applies to the *upper 50 mm* of the underlying A horizon.
- If the surface layer is an O horizon and there is no underlying A horizon, the *Layer-1 pH* refers to the 50 mm thick layer directly beneath the O horizon.
- If the surface layer is a peat, the estimate applies to the *upper 50 mm* of the surface horizon.
- If the A1 horizon is thinner than 50 mm, then the estimate is for the horizon.

Table 27: Estimation method for pH

Estimation Method	Description
1	Estimate based on measurements of pH for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of pH in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions).

pH in Layers 2–5

The pH for these layers is an average rather than an estimate for the upper portion. The guidelines on the definition of layers used for texture apply to Layers 2–5. If no B horizon is present and the sequence consists of an AC profile, the *Layer-3 pH* is taken from the layer 0.20 m directly below the A horizon. Again, the *Layer*-5 estimate refers to a depth between 1.5–2.0 m. If an R horizon or hard materials (including a calcrete pan, partially weathered rock or saprolite, or other hard materials) occurs at a shallower depth, and this is still below *Layer 4*, then the *Layer-5 pH* applies to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing.

Organic carbon

Organic carbon is estimated for the five layers using the same guidelines presented for pH. The estimation methods are shown in Table 28.

Table 28: Estimation method for organic carbon.

Estimation Method	Description
1	Estimate based on measurements of organic carbon for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of organic carbon in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions).

Diagnostic Depths

Several diagnostic depths are recorded (m) apart from the thickness of each of the five layers to allow flexible analysis including the calculation of plant available water capacity (page 57). The estimation method is also recorded (Table 29).

Table 29: Estimation method for depths and layer thicknesses

Estimation Method	Description
1	Estimate based on measurements of depth for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of depth supplemented by opportunistic sampling (e.g. road cuttings)
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils and landscapes from other regions.

Depth of A1

The depth of A1 horizon is recorded in meters. If an A1 is not present (e.g. OB profile), then the attribute is recorded as missing.

Total thickness of A horizon

The total thickness of A horizon is recorded in meters. If an A is not present (e.g. OB profile), then the attribute is recorded as missing.

Depth to B2 horizon

The depth from the landsurface to the top of the B2 is recorded in meters. If there is no B horizon (e.g. AC profile), then the attribute is recorded as missing.

Depth to impeding layer

The depth to impeding layer will in many cases be difficult to estimate. An impeding layer prevents root growth beyond the layer. If sufficient information is available, the depth to impeding layer is estimated for:

- Annual crops and pastures – ACP (e.g. wheat, barley, canola)
- Perennial pastures – PP (e.g. lucerne), and
- Perennial native vegetation – PNV (e.g. trees and shrubs).

Impeding layer type

Impeding layer type is recorded for each vegetation type (Table 30, Table 31). Peverill et al. (1999) provide a basic reference on chemical toxicities and deficiencies. There is provision to record the specific toxicity or deficiency if it is known. This list will be expanded if there is sufficient demand.

Depth to base of regolith

Regolith refers to the “mantle of earth and rock, including weathered rocks and sediments, altered or formed by land surface processes” (Speight and Isbell 1990). Depth to the base of regolith is estimated in meters. It will be difficult to estimate in many instances, particularly in deeply weathered landscapes where depths greater than 100 m are not uncommon.

Table 30: Type of impeding layer

Code	Type of impeding layer
CT1	chemical toxicity – unspecified
CT2	chemical toxicity – pH/aluminium
CT3	chemical toxicity – boron
CD1	chemical deficiency – unspecified
CD2	chemical deficiency – phosphorus
CD3	chemical deficiency – micronutrients
PI	direct physical impedance (e.g. moist soil strength > 4 MPa or R horizon)
HY	hydrologic (e.g. permanent water table)

Table 31: Estimation method for the type of impeding layer

Code	Estimation method
1	Direct field observation of root patterns for the plant type (ACP, PP, PNV) with supporting soil analytical data within the land-unit tract
2	Interpretation of analytical data (relying on published limits for plants in question)
3	Direct field observation of root patterns for the plant type (ACP, PP, PNV) with supporting soil analytical data for similar soils in the region
4	Interpretation of analytical data (relying on published limits for plants in question) for similar soils in the region
5	General experience with morphologically similar soils

Water retention and available water capacity

An estimate is made of the volumetric water content at –10 kPa (notional field capacity) and –1.5 MPa (notional wilting point) of the fine earth fraction for the five layers (the procedure for discounting the effect of coarse fragments is presented below). The units are mm^3/mm^3. An accompanying method code is also recorded (Table 32). The estimates of volumetric water content are averages for each layer and they are used with the layer thicknesses to calculate an approximate profile available water capacity. Note that water contents at –10 kPa and –1.5 MPa can be estimated using Williams et al. (1992) on the basis of field texture, bulk density and structure grade (if necessary, calculate the estimates with the spreadsheet from www.asris.csiro.au).

The control sections for estimating volumetric water contents at –10 kPa and –1.5 MPa are the same as those used for texture, coarse fragments and bulk density. However, Layer-5 thickness will often be problematic. In landscapes with deep regolith, an arbitrary maximum corresponding to the likely maximum depth of rooting by perennial native plants may be sufficient. Note that the estimates of water retention (θ_{-10kPa} and $\theta_{-1.5MPa}$) for Layer 5 usually relate to a depth of 1.0–1.5 m, and that application of the discounting method for water extraction (see below) means that the contribution of materials at depth is heavily discounted in the calculation of *plant* available water capacity.

Plant available water capacity can be estimated for the three generalized types of vegetation noted above (viz. annual crops and pastures, perennial pastures, and native trees and shrubs) by discounting the available water capacity for each layer. This discounting can be based on generalized models of root distribution and likely water extraction patterns (e.g. McKenzie et al. 2003) or through estimation of the non-limiting water range for each layer (e.g. using information on bulk density and nutrient availability).

If the surface layer is a peat, *Layer-1* $\theta_{-10\ kPa}$ *and* $\theta_{-1.5MPa}$ are recorded only if direct measurements are available. Reliable pedotransfer functions for Australian conditions are not yet available and very few such soils have been characterized.

Table 32: Method for the estimation of water retention parameters

Method	Description
1	Estimate derived from direct measurements of water retention in the land-unit tract
2	Water retention data estimated from direct measurements (e.g. Cresswell and Paydar (1996))
3	Water retention data estimated using pedotransfer functions such as Williams et al. (1992) and with predictor variables derived from measurements in the land-unit type
4	Estimate based on direct measurements of similar soils
5	Estimate based on experience with similar soils

Discounting estimates of available water capacity

The estimates of water retention listed above refer to the fine-earth fraction (e.g. AWC_{fe}). They need to be adjusted to take account of coarse fragments, both their volumetric percentage and porosity, to estimate available water capacity of the whole soil (AWC_{ws}).

$$AWC_{ws} = AWC_{fe} \times \left(\frac{100 - CF}{100} \right) + AWC_{cf} \times \left(\frac{CF}{100} \right)$$

In most cases, coarse fragments will be non-porous and the right-hand term will be zero (i.e. $AWC_{cf} = 0$). Estimation of water retention properties for porous coarse fragments (e.g. AWC_{cf}) is difficult because reliable data are rarely available. Cresswell and Hamilton (2002) outline how to calculate total porosity in the presence of porous coarse fragments. However, information is needed on the water retention properties of the coarse fragments before a reliable estimate can be made on a whole-soil basis. If coarse fragments have the same water retention properties as the fine earth, then the AWC_{ws} and AWC_{fe} will be equivalent. It is feasible for AWC of the coarse fragments to be greater than AWC_{fe} (i.e. AWC_{ws} and coarse fragment content will be positively correlated). The procedure for estimation will vary depending on the availability of information.

The estimate of coarse fragment percentage for the layers (see page 52) are averages and care is needed when bands of coarse fragments are present. Porous coarse fragments are common in some parts of Australia (e.g. southwest Western Australia).

Calculating Profile and Plant Available Water Capacity

Five variables are used to calculate profile available water capacity ($\theta_{-10\ kPa}$, $\theta_{-1.5MPa}$, layer thickness, and the percentage and porosity of coarse fragments) and a sixth is needed for plant available water capacity to express the degree to which plants can extract the water. The water retention and layer thickness variables are described above. A simple estimate of Plant Available Water Capacity can be generated by summing the available water capacities over the depth of the root zone – the depth to impeding layer along with a maximum rooting depth for the vegetation type in question can be used. An improved approximation can be made by applying a scaling term that discounts the available water capacity according to the capacity for roots to extract water. One such method is described by McKenzie et al. (2003) and shown in

Figure 8 and

Figure 9. While largely untested, their method uses a single parameter to summarize the effectiveness of water extraction – it can be estimated using soil attributes within ASRIS (e.g. bulk density, ESP, taxonomic class) along with the vegetation type.

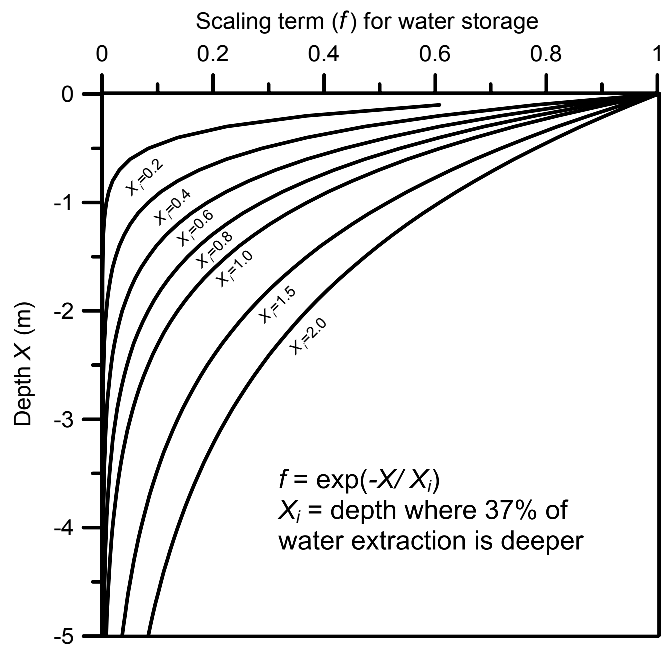


Figure 8: Scaling term for water storage. The curves range from those likely for a soil with severe root constraints (e.g. Sodosols, X_i=0.2–0.4 m) to a deep soil without constraints (e.g. Red Ferrosol, X_i=2.0 m).

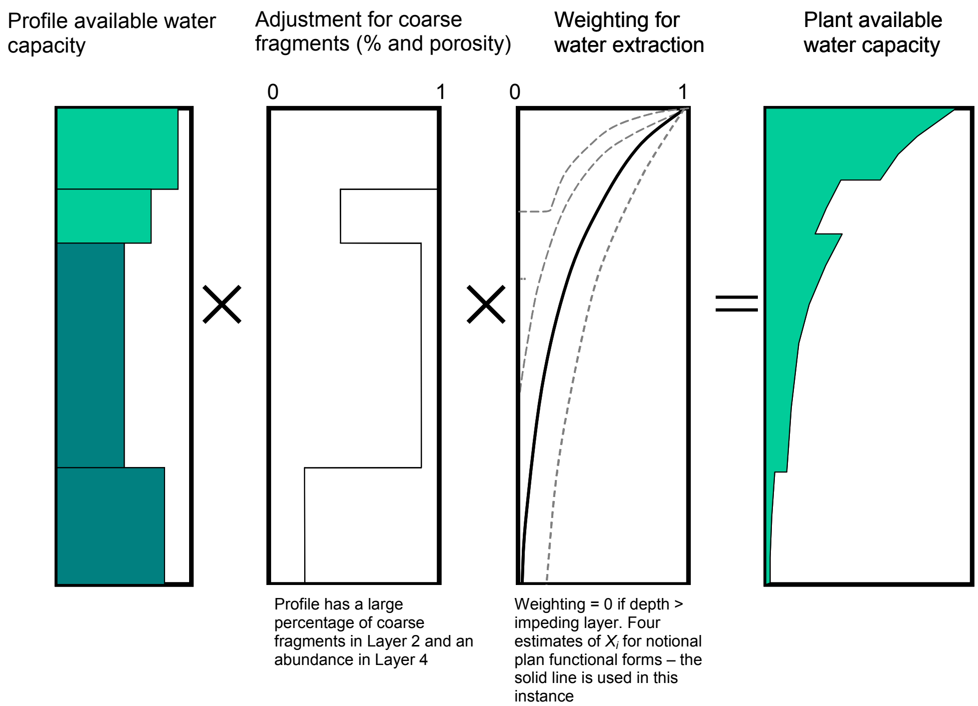


Figure 9: Calculation procedure for plant available water capacity

Permeability

The permeability of each layer is recorded using estimates of saturated hydraulic conductivity. A coarse-stepped scale is presented in Table 33, the median values for each class are equidistant on a logarithmic scale because K_s data are generally log-normally distributed. The descriptive names are approximately the same as McDonald and Isbell (1990). The method codes are presented in Table 34.

Layer-1 K_s

The *Layer-1* K_s is for the soil surface.

- If the soil has a surface crust or surface flake (McDonald et al. 1990), the estimate is for the upper 10 mm of the surface horizon.
- If there is no surface crust or flake, the estimate applies to the upper 0.20 m of the A1 horizon if present. If the *Layer-3* K_s control section upper boundary is within 0.20 m of the surface, *Layer-1* K_s applies to the layer above the upper boundary of the *Layer-3* K_s control section.
- If the surface layer is an O horizon, the estimate applies to the upper 50 mm of the underlying A horizon.
- If the surface layer is an O horizon and there is no underlying A horizon, the *Layer-1* K_s refers to the 50-mm thick layer directly beneath the O horizon.
- If the surface layer is a peat, the estimate applies to the upper 50 mm of the surface horizon.
- If the A1 horizon is thinner than 50 mm, then the estimate is for the horizon.

***Layer-2* K_s**

- The *Layer-2* K_s is usually the average saturated hydraulic conductivity of the lower 100 mm of the A horizon. The A horizon at this depth may be an A1, A2, A3, AB, A/B or subdivision thereof.
- If the surface layer is not an A horizon (e.g. O horizon) and there is no underlying A horizon, the attribute is usually recorded as missing.
- If the A horizon is thin and multiple contrasting layers occur deeper in the profile, *Layer-2* K_s can refer to layers below the A (e.g. B1, 2A, 2B, 2D).

***Layer-3* K_s**

- In soils with a B2 horizon, the estimate is usually for the least permeable portion of the upper 0.20 m of the B2 horizon (or for the major part of the B2 horizon if it is less than 0.20 m thick).
- If no B horizon is present and the sequence consists of an AC profile, the *Layer-3* K_s is taken from the least permeable layer in the 0.20 m directly below the A horizon.

***Layer-4* K_s**

- In soils with a thick B horizon, the estimate is usually for the least permeable portion of the lower B2 or B3 horizon.
- If no B horizon is present or the sequence consists of multiple contrasting layers, the *Layer-4* K_s is usually taken from the least permeable layer from 0.8–1.5 m.

***Layer-5* K_s**

The *Layer-5* K_s is for the least permeable layer between 1.5–3.0 m. If an R horizon or hard materials (including a calcrete pan, partially weathered rock or saprolite, or other hard materials) occur at a shallower depth, and this is still below the control section used for the *Layer 4* estimate, then the *Layer-5* K_s applies to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing.

Table 33: Permeability classes

Class	Median Ks (mm/hr)	Class boundaries (mm/hr)
		0
Impermeable	0.01	
		0.03
Very slowly permeable	0.1	
		0.3
Slowly permeable	1	
		3
Moderately permeable	10	
		30
Highly permeable	100	
		300
Extremely permeable	1000	
		>>1000

Table 34: Estimation method for saturated hydraulic conductivity

Estimation Method	Description
1	Estimate based on direct laboratory measurements of saturated hydraulic conductivity using undisturbed soil cores within the land-unit type
2	Estimate based on direct field measurements of saturated hydraulic conductivity using permeameters within the land-unit type
3	Estimate based on pedotransfer functions using predictor variables from the land-unit tract
4	Estimate based on direct measurements on similar soils
5	Estimate based on experience with similar soils

Electrical conductivity

The electrical conductivity (EC) is estimated for the five layers. The estimation method is recorded according to Table 35. The electrical conductivity refers to a 1:5 soil:water extract and the units are dS/m.

Layer-1 EC

- If there is a single A1 horizon without subdivisions (e.g. A11, A12), then estimate the *Layer-1 EC* using the A1 horizon.
- If there are subdivisions within the A1 horizon, the *Layer-1 EC* is generally taken from the thickest A1 horizon layer within the top 0.20 m of the soil profile (the upper layer is used if thicknesses are equal).
- If the surface layer is an O horizon, the underlying A horizon is used in accord with the above criteria.
- If the surface layer is an O horizon and there is no underlying A horizon, the *Layer-1 EC* is taken from the 0.20 m directly below below the O horizon.
- If the surface layer is a peat, the estimate applies to the upper 0.20 m of the surface horizon.

Layer-2 EC

- The *Layer-2 EC* is generally the average electrical conductivity of the lower 100 mm of the A horizon. The A horizon at this depth may be an A1, A2, A3, AB, A/B or subdivision thereof.
- If the surface layer is not an A horizon (e.g. O horizon) and there is no underlying A horizon, the attribute is recorded as missing.
- If the A horizon is thin and the profile only has a few layers, *Layer-2 EC* may be recorded as missing.

- If the A horizon is thin and multiple contrasting layers occur deeper in the profile, *Layer-2 EC* can refer to layers below the A (e.g. B1, 2A, 2B, 2D).

Layer-3 EC

- In soils with a B2 horizon, the estimate is for the upper 0.20 m of the B2 horizon (or for the major part of the B2 horizon if it is less than 0.20 m thick).
- In more complex profiles, *Layer-3 EC* refers to the third functional layer in the profile.

Layer-4 EC

In most profiles, *Layer-4* EC refers to the lower part of the B horizon – this is usually a B22 or B3 and it often starts at around 0.80 m. If the profile and B horizon are thin (<1.0 m and <0.20 m respectively) and overlie an R horizon, Layer 4 may be recorded as missing.

Layer-5 EC

The *Layer-5 EC* is estimated at a depth of approximately 1.5–2.0 m. If an R horizon or hard materials (including a calcrete pan, partially weathered rock or saprolite, or other hard materials) occur at a shallower depth, and this is still below the control section for the *Layer-4* estimate, then the *Layer-5 EC* applies to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing.

Table 35: Estimation method for electrical conductivity

Method	Description
1	Estimate based on measurements of electrical conductivity for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of electrical conductivity in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions)

Aggregate stability

Aggregate stability is estimated using a three-class system based on Emerson (2002) (

Table 36) using the same control sections as for electrical conductivity. The method code is also recorded (Table 37).

Table 36: Aggregate stability classes based on Emerson (2002)

Code	Class	Description
S	Stable	Aggregates are stable in distilled water (e.g. Emerson Classes 5–7)
M	Moderately stable	Dispersion occurs after re-moulding when wet (e.g. Emerson Classes 3a and 3b)
U	Unstable	Aggregates disperse spontaneously in distilled water (e.g. Emerson Classes 1–2)

Water repellence

Water Repellence of dry soil at the land surface is classified into one of three levels according to Table 38. The estimation method is also recorded (Table 39). The Molarity of Ethanol Drop (MED) test has been used by some survey agencies during recent years (see Carter 2002). The attribute is not mandatory but is recorded in regions where water repellence is significant for hydrology and plant growth.

Table 37: Estimation method for aggregate stability

Estimation Method	Description
1	Estimate based on measurements of aggregate stability for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of aggregate stability in the land-unit tract
3	As for 2 but rapid measurement, often in the field (e.g. 1-hour dispersion)
4	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
5	Estimate based on direct measurements of similar soils in the region or project area
6	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions)

Table 38: Water repellence (after Moore 1998).

Code	Severity	Description
N	None	Not significant (MED <1)
M	Moderate	Observed in most years and a strong manifestation 1 year in 3 (MED 1-2)
S	Severe	Strong manifestation in most years (MED >2)

Table 39: Method for estimating water repellence of the land surface

Estimation Method	Description
1	Estimate based on measurements of water repellence for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of water repellence in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type and under a similar land management system
4	Estimate based on direct measurements of similar soils and land-use systems in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions)

Exchangeable bases, CEC, and ESP

Estimates of exchangeable bases (i.e. Σ(Ca+Mg+Na+K) in cmol/kg), CEC (cmol/kg), and Exchangeable Sodium Percentage (ESP) are made for the five layers using the same guidelines for pH. Estimates for Layers 2–5 are averages for the complete layer. Method codes describe both the estimation procedure (Table 40) and laboratory procedure – the latter is needed to distinguish between buffered and un-buffered methods (Table 41).

Table 40: Estimation method for exchangeable bases, CEC and ESP

Estimation Method	Description
1	Estimate based on measurements of exchangeable bases, CEC and ESP for replicated soil profiles in the land-unit tract
2	Estimate based on a single measurement of exchangeable bases, CEC and ESP in the land-unit tract
3	Estimate based on direct measurements of similar soils in the same land unit type (e.g. modal profiles)
4	Estimate based on direct measurements of similar soils in the region or project area
5	Estimate based on experience with similar soils (e.g. same taxa in the Australian Soil Classification but from other regions)

Layer-1 Exchangeable bases, CEC, and ESP

- In most instances, the estimate applies to the *upper 50 mm* of the A1 horizon.

- If the surface layer is an O horizon, the estimate applies to the *upper 50 mm* of the underlying A horizon.
- If the surface layer is an O horizon and there is no underlying A horizon, the estimates refer to the 50 mm thick layer directly beneath the O horizon.
- If the surface layer is a peat, the estimate applies to its *upper 50 mm*.
- If the A1 horizon is thinner than 50 mm, then the estimate is for the horizon.

Exchangeable Bases, CEC, and ESP in Layers 2–5

The *Exchangeable Bases, CEC,* and *ESP* for these layers are averages. The guidelines on the definition of layers used for texture apply to Layers 2–5. If no B horizon is present and the sequence consists of an AC profile, the Layer-3 estimates are taken from the layer 0.20 m directly below the A horizon. Again, the *Layer*-5 estimate refers to a depth between 1.5–2.0 m. If an R horizon or hard materials (including a calcrete pan, partially weathered rock or saprolite, or other hard materials) occurs at a shallower depth, and this is still below *Layer 4*, then the *Layer-5* estimates apply to the lowest 100 mm in the profile. Otherwise the variable is recorded as missing.

Table 41: Method codes for Exchangeable Bases, CEC, and ESP (These are currently under review by the National Committee on Soil and Terrain Information)

Code	Code description
15A1_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, no pretreatment for soluble salts
15A2_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, pretreatment for soluble salts
15A3_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, adjusted for soluble sodium
15B1_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, no pretreatment for soluble salts
15B2_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, pretreatment for soluble salts
15B3_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium chloride at pH 7.0, adjusted for soluble sodium
15C1_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) - alcoholic 1M ammonium chloride at pH 8.5, pretreatment for soluble salts
15D1_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium acetate at pH 7.0, pretreatment for soluble salts; manual leach
15D2_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium acetate at pH 7.0, pretreatment for soluble salts; automatic extractor
15D3_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) – 1M ammonium acetate at pH 7.0, rapid method with no pretreatment for soluble salts
15E1_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) by compulsive exchange, no pretreatment for soluble salts
15E2_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) by compulsive exchange, pretreatment for soluble salts
15E3_BASES	Exchangeable bases (Ca^{2+},Mg^{2+},Na^{+},K^{+}) by compulsive exchange, adjusted for soluble sodium
15F1_BASES	Exchangeable bases by 0.01M silver-thiourea $(AgTU)^{+}$, no pretreatment for soluble salts
Cation Exchange Capacity	
15B1_CEC	CEC – 1M ammonium chloride at pH 7.0, no pretreatment for soluble salts
15B2_CEC	CEC – 1M ammonium chloride at pH 7.0, pretreatment for soluble salts

15B3_CEC	CEC – 1M ammonium chloride at pH 7.0, adjusted for soluble sodium
15C1_CEC	CEC - alcoholic 1M ammonium chloride at pH 8.5, pretreatment for soluble salts
15D1_CEC	CEC – 1M ammonium acetate at pH 7.0, pretreatment for soluble salts; manual leach
15D2_CEC	CEC – 1M ammonium acetate at pH 7.0, pretreatment for soluble salts; automatic extractor
15E1_CEC	CEC by compulsive exchange, no pretreatment for soluble salts
15E2_CEC	CEC by compulsive exchange, pretreatment for soluble salts
15E3_CEC	CEC by compulsive exchange, adjusted for soluble sodium
15F3_CEC	CEC by 0.01M silver-thiourea $(AgTU)^+$
15I1_CEC	CEC measurement - distillation of ammonium ions
15I2_CEC	CEC measurement - automated determination of ammonium ions
15I3_CEC	CEC measurement - automated determination of ammonium and chloride ions
15I4_CEC	CEC measurement - titration of ammonium and chloride ions
15JG_CEC	Effective CEC using 15G1 for exchangeable acidity
15JH_CEC	Effective CEC using 15H1 for exchangeable acidity
15K1_CEC	CEC – pH 8.2

Australian Soil Classification

The Australian Soil Classification (Isbell 1996) is recorded at the Soil Order level as a minimum. Recording at the Sub-Order or Great Group level along with the Family level is preferred but in some regions will not be feasible. The confidence levels, version and method for allocation are also recorded (Table 42, Table 43, and Table 45)

Table 42: Confidence level for the allocation to the Australian Soil Classification

Code	Code description
–	No confidence level recorded.
1	All necessary analytical data are available.
2	Analytical data are incomplete but reasonable confidence.
3	No analytical data are available but confidence is fair.
4	No analytical data and little or no knowledge of this soil.

Table 43: Version of the Australian Soil Classification used for allocation

Code	Code description
2	A Classification System for Australian Soils 2nd approximation
3	A Classification System for Australian Soils 3rd approximation
4	Australian Soil Classification 1st Edition
5	Australian Soil Classification Revised Edition

Table 44: Codes for Soil Orders in the Australian Soil Classification

Code	Soil Order	Code	Soil Order
AN	Anthroposol	KU	Kurosol
CA	Calcarosol	OR	Organosol
CH	Chromosol	PO	Podosol
DE	Dermosol	RU	Rudosol

FE	Ferrosol	SO	Sodosol
HY	Hydrosol	TE	Tenosol
KA	Kandosol	VE	Vertosol

Table 45: Codes for Suborders, Great Groups and Subgroups

Code	Code description				
AA	Red	BR	Epihypersodic	DL	Melanic–Bleached
AB	Brown	BS	Epic–Pedal	DM	Melanic-Mottled
AC	Yellow	BT	Extratidal	DN	Melanic-Vertic
AD	Grey	BU	Ferric	DO	Mellic
AE	Black	BV	Arenaceous	DP	Mesonatric
AF	Dystrophic	BW	Fibric	DQ	Mottled
AG	Mesotrophic	BX	Fluvic	DR	Subhumose
AH	Eutrophic	BY	Fragic	DS	Orthic
AI	Acidic	BZ	Gypsic	DT	Oxyaquic
AJ	Acidic–Mottled	CB	Calcarosolic	DU	Paralithic
AK	Andic	CC	Halic	DV	Parapanic
AL	Aeric	CD	Haplic	DW	Peaty
AM	Aquic	CE	Hemic	DX	Peaty–Parapanic
AN	Anthroposols	CF	Histic	DY	Pedal
AO	Arenic	CG	Humic	DZ	Petrocalcic
AP	Argic	CH	Chromosol	EA	Petroferric
AQ	Argillaceous	CI	Humic/Humosesquic	EB	Pipey
AR	Basic	CJ	Humic/Sesquic	EC	Placic
AS	Bauxitic	CK	Humose	ED	Redoxic
AT	Bleached	CL	Humose–Magnesic	EE	Rendic
AU	Bleached–Acidic	CM	Humose–Mottled	EF	Reticulate
AV	Bleached–Ferric	CN	Humose–Parapanic	EG	Salic
AW	Bleached–Leptic	CO	Humosesquic	EH	Sapric
AX	Bleached–Magnesic	CP	Hypervescent	EI	Self–Mulching
AY	Bleached–Manganic	CQ	Hypercalcic	EJ	Semiaquic
AZ	Bleached–Mottled	CR	Hypernatric	EK	Sesquic
BA	Bleached–Sodic	CS	Hypersalic	EL	Shelly
BB	Bleached–Vertic	CU	Epihypersodic–Epiacidic	EM	Silpanic
BC	Calcareous	CV	Hypocalcic	EN	Snuffy
BD	Calcic	CW	Intertidal	EO	Sodic
BE	Chernic	CX	Kurosolic	EP	Episodic–Epiacidic
BF	Chernic–Leptic	CY	Leptic	EQ	Sodosolic
BG	Chromosolic	CZ	Lithic	ER	Stratic
BH	Crusty	DA	Lithocalcic	ES	Subnatric
BI	Densic	DB	Magnesic	ET	Subplastic
BJ	Duric	DC	Manganic	EU	Sulfidic
BK	Pedaric	DD	Marly	EV	Sulfuric
BL	Endoacidic	DF	Massive	EW	Supratidal
BM	Endic	DG	Melacic	EX	Vertic
BN	Episodic	DH	Melacic–Magnesic	EY	Humose–Bleached
BO	Endic–Pedal	DI	Melacic–Mottled	EZ	Melacic–Bleached
BP	Endohypersodic	DJ	Melacic–Parapanic	FA	Siliceous

BQ	Epic	DK	Melanic	FB	Supracalcic
FC	Melanic–Calcareous	GU	Humose–Calcareous	IO	Brown–Orthic
FD	Natric	GV	Lutic	IP	Yellow–Orthic
FF	Submelacic	GX	Manganic–Acidic	IQ	Grey–Orthic
FG	Submelanic	GY	Humose–Acidic	IR	Black–Orthic
FH	Palic	GZ	Bleached–Orthic	IS	Ferric–Reticulate
FI	Ochric	HA	Melanic–Sodic	XX	Available Class Inappropriate
FJ	Hypergypsic	HB	Mottled–Sodic	YY	Class Undetermined
FK	Ferric–Duric	HC	Ferric–Sodic	ZZ	No Available Class
FL	Gypsic–Subplastic	HD	Rudaceous		
FM	Epicalcareous–Epihypersodic	HE	Endocalcareous–Mottled		
FN	Mottled–Subnatric	HF	Tephric		
FO	Mottled–Mesonatric	HG	Carbic		
FP	Mottled–Hypernatric	HH	Clastic		
FQ	Dermosolic	HI	Colluvic		
FR	Kandosolic	HJ	Lithosolic		
FS	Terric	HK	Supravescent		
FT	Humose–Basic	HL	Episulfidic		
FU	Melacic–Basic	HM	Episulfidic–Petrocalcic		
FV	Melanic–Acidic	HN	Densic–Placic		
FW	Faunic	HO	Acidic–Sodic		
FX	Lutaceous	HP	Palic–Acidic		
FY	Epicalcareous	HQ	Ochric–Acidic		
FZ	Endocalcareous	HR	Cumulic		
GA	Epiacidic	HS	Hortic		
GB	Epicalcareous–Endohypersodic	HT	Garbic		
GC	Melacic–Reticulate	HU	Urbic		
GD	Peaty–Placic	HV	Dredgic		
GE	Ferric–Petroferric	HW	Spolic		
GF	Regolithic	HX	Scalpic		
GG	Episodic–Endoacidic	HZ	Ashy		
GH	Episodic–Epicalcareous	IA	Inceptic		
GI	Episodic–Endocalcareous	IB	Epibasic		
GJ	Epicalcareous–Endoacidic	IC	Ceteric		
GK	Epiacidic–Mottled	ID	Subpeaty		
GL	Endoacidic–Mottled	IE	Effervescent		
GM	Endocalcareous–Endohypersodic	IF	Folic		
GN	Epihypersodic–Endoacidic	IG	Humosesquic/Sesquic		
GO	Epihypersodic–Endocalcareous	IH	Humic/Alsilic		
GP	Magnesic–Natric	IJ	Modic		
GQ	Episodic–Gypsic	IK	Histic–Sulfidic		
GR	Rudosolic	IL	Sequi–Nodular		
GS	Epipedal	IM	Calcenic		
GT	Tenosolic	IN	Red–Orthic		

Table 46: Codes for Family criteria in the Australian Soil Classification

Code	Code description		
–	Not recorded	M	Clay-loamy
A	Thin	N	Silty
B	Medium	O	Clayey
C	Thick	P	Granular
D	Very thick	Q	Fine
E	Non-gravelly	R	Medium fine
F	Slightly gravely	S	Very fine
G	Gravelly	T	Very shallow
H	Moderately gravelly	U	Shallow
I	Very gravely	V	Moderately deep
J	Peaty	W	Deep
K	Sandy	X	Very deep
L	Loamy	Y	Giant

Table 47: Method for allocating profile to the classification system (either ASC or WRB)

Method	Description based on:
1	Morphology and analytical data from the land-unit tract
2	Morphology data from the land-unit tract
3	Morphology and analytical data from similar soils in the same land unit type
4	Morphology data for similar soils in the region or project area
5	Experience with morphologically similar soils in other regions

World Reference Base

Allocation to the World Reference Base to the level of the Reference Group with one or two qualifiers is preferred but conversion of historic data sets may not be possible in the short term. This attribute is required to ensure compatibility with SOTER.

Experience with the World Reference Base in Australia is limited and few allocations have been recorded in agency databases. The time needed to allocate soils within ASRIS is not available. As an interim measure, dominant soils will be identified at approximately Level 3 within ASRIS – the most common three will be allocated to the World Reference Base.

Table 48: Reference Soil Group codes for the World Reference Base

Code	Code description		
AB	Albeluvisol	HS	Histosol
AC	Acrisol	KS	Kastanozem
AL	Alisol	LP	Leptosol
AN	Andosol	LV	Luvisol
AR	Arenosol	LX	Lixisol
AT	Anthrosol	NT	Nitisol
CH	Chernozem	PH	Phaeozem
CL	Calcisol	PL	Planosol
CM	Cambisol	PT	Plinthosol
CR	Cryosol	PZ	Podzol
DU	Durisol	RG	Regosol
FL	Fluvisol	SC	Solonchak
FR	Ferralsol	SN	Solonetz
GL	Gleysol	UM	Umbrisol
GY	Gypsisol	VR	Vertisol

Table 49: Qualifiers for Reference Soil Groups in the World Reference Base

Code	Qualifier	Code	Qualifier	Code	Qualifier
AB	Albic	FI	Fibric	LEN	Endoleptic
ABG	Glossalbic	FL	Ferralic	LEP	Epileptic
ABH	Hyperalbic	FLH	Hyperferralic	LI	Lithic
AC	Acric	FLW	Hypoferralic	LIP	Paralithic
AD	Aridic	FO	Folic	ME	Melanic
AE	Aceric	FR	Ferric	MG	Magnesic
AH	Anthropic	FRH	Hyperferric	MO	Mollic
AI	Aric	FU	Fulvic	MS	Mesotrophic
AL	Alic	FV	Fluvic	MZ	Mazic
AM	Anthric	GA	Garbic	NA	Natric
AN	Andic	GC	Glacic	NI	Nitic
ANA	Aluandic	GE	Gelic	OA	Oxyaquic
ANS	Silandic	GI	Gibbsic	OH	Ochric
AO	Acroxic	GL	Gleyic	OHH	Hyperochric
AP	Abruptic	GLN	Endogleyic	OM	Ombric
AQ	Anthraquic	GLP	Epigleyic	OR	Orthic
AR	Arenic	GM	Grumic	PA	Plaggic
AU	Alumic	GP	Gypsiric	PC	Petrocalcic
AX	Alcalic	GR	Geric	PD	Petroduric
AZ	Arzic	GS	Glossic	PE	Pellic
CA	Calcaric	GSM	Molliglossic	PF	Profondic
CB	Carbic	GSU	Umbriglossic	PG	Petrogypsic
CC	Calcic	GT	Gelistagnic	PH	Pachic
CCH	Hypercalcic	GY	Gypsic	PI	Placic
CCO	Orthicalcic	GYH	Hypergypsic	PL	Plinthic
CCW	Hypocalcic	GYW	Hypogypsic	PLH	Hyperplinthic
CH	Chernic	GZ	Greyic	PLO	Orthiplinthic

CL	Chloridic	HA	Haplic	PLP	Epiplinthic
CN	Carbonatic	HG	Hydragric	PLR	Paraplinthic
CR	Chromic	HI	Histic	PN	Planic
CT	Cutanic	HIB	Thaptohistic	PO	Posic
CY	Cryic	HIF	Fibrihistic	PP	Petroplinthic
DN	Densic	HIS	Saprihistic	PR	Protic
DU	Duric	HK	Hyperskeletic	PS	Petrosalic
DY	Dystric	HT	Hortic	PT	Petric
DYE	Epidystric	HU	Humic	PTP	Epipetric
DYH	Hyperdystric	HUM	Mollihumic	RD	Reductic
DYO	Orthidystric	HUU	Umbrihumic	RG	Regic
ES	Eutrisilic	HY	Hydric	RH	Rheic
ET	Entic	II	Lamellic	RO	Rhodic
EU	Eutric	IR	Irragric	RP	Ruptic
EUH	Hypereutric	IV	Luvic	RS	Rustic
EUN	Endoeutric	IVW	Hypoluvic	RU	Rubic
EUO	Orthieutric	IX	Lixic	RZ	Rendzic
FG	Fragic	LE	Leptic	SA	Sapric
SD	Spodic	SU	Sulphatic	TY	Takyric
SI	Silic	SZ	Salic	UB	Urbic
SK	Skeletic	SZN	Endosalic	UM	Umbric
SKN	Endoskeletic	SZP	Episalic	VI	Vitric
SKP	Episkeletic	SZW	Hyposalic	VM	Vermic
SL	Siltic	TF	Tephric	VR	Vertic
SO	Sodic	TI	Thionic	VT	Vetic
SON	Endosodic	TIO	Orthithionic	XA	Xanthic
SOW	Hyposodic	TIT	Protothionic	YE	Yermic
SP	Spolic	TR	Terric	YES	Nudiyermic
ST	Stagnic	TU	Turbic		
STN	Endostagnic	TX	Toxic		

Local taxonomic class

If available, the local taxonomic class, established by soil and land resource survey, is recorded. The local class will most commonly be a Soil Profile Class (Isbell 1988).

11.5 Substrate

Substrate type

The substrate (as defined by Speight and Isbell 1990) is characterized using the codes and descriptions for regolith published in the ‘RTMAP database field guide and users guide’ (Pain et al. in press) and shown in Table 50 and Table 51.

Table 50: Regolith material descriptions used for the characterization of substrate (after Pain et al. 2004)

Code	Regolith	Code	Regolith
BU00	unweathered bedrock	SDS00	coastal sediments
EVA00	evaporite	SDS01	beach sediments
EVA01	halite	SDS02	estuarine sediments
EVA02	gypsum	SDS03	coral
EVA03	calcrete	SDT00	terrestrial sediments
SDA00	alluvial sediments	UOC00	clay (unknown origin)
SDA10	channel deposits	UOM00	weathered material (unknown origin)
SDA20	overbank deposits	UOS00	sand (unknown origin)
SDC00	colluvial sediments	VOL00	volcanic sediments
SDC01	scree	VOL01	lava flow
SDC02	landslide deposit	VOL02	tephra
SDC03	mudflow deposit	WIR10	saprolith
SDC04	creep deposit	WIR11	saprock
SDC05	sheet flow deposit	WIR12	moderately weathered bedrock
SDC06	fanglomerate	WIR13	highly weathered bedrock
SDE00	aeolian sediments	WIR14	very highly weathered bedrock
SDE01	aeolian sand	WIR15	completely weathered bedrock
SDE02	loess	WIR15.1	mottled zone
SDE03	parna	WIR15.2	pallid zone
SDF00	fill	WIR16	saprolite
SDG00	glacial sediments	WIR20	residual material
SDL00	lacustrine sediments	WIR21	lag
SDM00	marine sediments	WIR22	residual sand
SDP00	swamp (paludal) sediments	WIR23	residual clay
SDP01	peat	WIR24	soil on bedrock

Table 51: Estimation method for substrate type

Estimation Method	Description
1	Estimate based on direct observation of substrate at the observation site(s) used for soil description
2	Estimate based on direct observations of substrate in the land-unit tract
3	Estimate based on direct observations of substrate in the same land-unit type within the region or project area
4	Estimate based on broad-scale regolith mapping for the area
5	Estimate based on geological mapping for the area

Substrate permeability

The permeability of the substrate is estimated using the classes in Table 33. The estimate refers to the least permeable layer. Note that the substrate permeability may be the same as the *Layer-5 Ks*. Estimates are restricted to the upper 10 m.

Table 52: Estimation method for substrate permeability

Method	Description
1	Estimate based on direct measurement of saturated hydraulic conductivity within the land-unit type
2	Estimate based on pedotransfer functions using predictor variables from the land-unit tract
3	Estimate based on direct measurements on similar substrate materials
4	Estimate based on general knowledge of groundwater movement
5	Estimate based on experience with similar substrate materials

12. Soil Profile Database

As noted earlier, ASRIS contains the database of descriptors for land units (described in the previous sections) along with separate soil profile database that contains primary data on the site, soil morphology, soil chemistry and soil physical properties from fully characterized sites. These are known to be representative of significant areas and environments. The minimum data set is listed in Table 53. Data transfer for the Representative Soil Profile Database within ASRIS should follow the SITES protocol (Kidston and McDonald 1995). Further details on the ASRIS soil profile database will be included in the next version of this document.

Table 53: Recommended minimum data set for the ASRIS soil profile database

Attribute	Method	Attribute	Method
Site		**Soil chemical properties (major horizons)**	
Location		pH(*1:5 $CaCl_2$*)	
Type of observation		$EC_{1:5}$	
Landform element		Organic carbon	
Land use		Exch. Ca	
Microrelief type		Exch. Mg	
Surface coarse fragments		Exch. K	
Rock outcrop		Exch. Na	
Surface condition		CEC	
		Total P	
Morphology (horizon/depth basis)		Available P	
Horizon type		Total N	
Depth		Total K	
Boundary shape			
Boundary distinctness		**Soil Physical Properties (major horizons)**	
Colour hue, value, chroma		Bulk density	
Mottle abundance		Particle size	
Coarse fragment abundance		–10 kPa θ_v	
Field pH		–1.5 MPa θ_v	
Texture		Soil shrinkage	
Structure grade		Dispersion class	
Structure size		Saturated K	
Structure type		Unsaturated K (–50mm)	
Segregation abundance			
Segregation type		**Taxonomy**	
Carbonate effervescence		ASC (to Family level)	
		World Reference Base	

13. Data conventions, transfer procedures and database design

13.1 Missing data, explicit zeros and explanatory notes

Blank entries are ambiguous because they can be interpreted to be a real zero (e.g. 0%), absence of a nominal variable (e.g. no redoximorphic mottles), missing data (e.g. through an oversight or deliberate decision), or a logical impossibility (e.g. mottle colour when mottle abundance is 0%). To avoid ambiguity, the following conventions are used throughout ASRIS – absences or zeros must be explicit.

- Real zeros and absences: Use 0 for numeric fields. For alphanumeric fields, use Z to denote the attribute is absent unless the code table already has an assigned code.
- Not known: Use –1234 for numeric fields. For alphanumeric fields, use NR unless the code table has an assigned code.
- Logically impossible: Use –9999 for numeric fields. For alphanumeric fields, use NA unless the code table has an assigned code.

Finally, a free text field can be used to note any difficulties encountered with the data model and definitions. For example, it may be difficult to reliably represent a soil profile using the five-layer model adopted by ASRIS. The note should outline the problem and method used for estimating soil attributes.

13.2 Database design

The database design for ASRIS is presented in Figure 10. Definitions and formats for the variables in each component database table are listed in the following tables. The full list of method codes, including those for the profile data, is available from the ASRIS team. When providing data to ASRIS, it is necessary to supply the necessary decode data and tables (e.g. the codes used for identifying officers responsible for soil descriptions). Identify instances where codes from McDonald et al. (1990) have not been used.

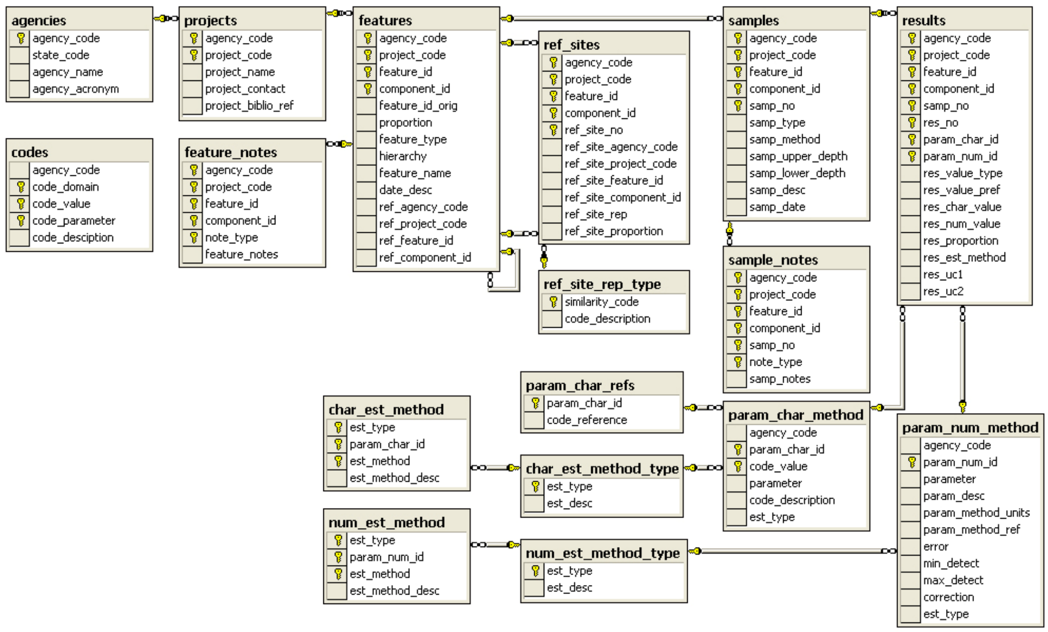


Figure 10: Database design for ASRIS. Definitions of variables are provided in the Tables below.

The method to be used by state and territory agencies for transferring data to ASRIS depends heavily on the information systems and support staff available in each contributing organization. The most technically demanding but best approach is to generate ASRIS data through a series of formal queries to the agency information system. This requires a very well organized agency database and significant investment in computer coding. Another approach is to use the ASRIS Data Entry Spreadsheet available from the ASRIS website. This EXCEL spreadsheet allows for manual or semi-automated data-entry (e.g. cutting and pasting from agency spreadsheets).

While it would be advantageous for agencies to provide data using the ASRIS database design, it is recognized that many field operators have difficulty with the principles guiding relational database design and that most prefer the flat file format provided by the spreadsheet. The key requirement is for each agency to select a procedure that encourages efficient updating when new information becomes available.

Referential integrity is necessary within the ASRIS database so ensure that unique identifiers are used for land-unit tracts. Avoid using upper or lower case letters as a means of creating unique keys. Also avoid including the letters *o* or *i* in unique keys wherever possible.

ASRIS is provided via the Internet using SQL Server, the ARC Spatial Data Engine, and ARC Internet Map Server. As a result, the spatial data should be supplied to ASRIS with a defined topology and in a format that can be imported to ARC Info. These data need a nominated projection and datum along with metadata conforming at least to ANZLIC standards. All spatial data in ASRIS are based on the Geodetic Datum of Australia (GDA94). It would be advantageous for the polygon coverages to conform to the vector baseline GEODATA COAST 100K 2004. This dataset contains boundaries for the coastline, states and territories. It is available as a free download from the Geoscience Australia website.

Table 54: The *agencies* table.

Column Name	Data Type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
state_code	nvarchar	3	no	State code i.e. NSW=1, VIC=2, QLD=3, SA=4, WA=5, TAS=6, NT=7, ACT=8
agency_name	nvarchar	240	no	Name of agency
agency_acronym	nvarchar	10	yes	Acronym of agency (e.g. CSIRO)

Table 55: The *projects* table

Column Name	Data Type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
project_name	nvarchar	240	no	Project name
project_contact	nvarchar	4	no	Project contact officer
project_biblio_ref	nvarchar	240	yes	Bibliographic reference

Table 56: The *features* table.

Column Name	Data Type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
feature_id_orig	nvarchar	30	yes	Feature identifier of orginating agency if different to feature_id
proportion	int	5	no	Feature proportion if component_id=0 otherwise component proportion
feature_type	nvarchar	2	no	Feature type, e.g. point, polygon
hierarchy	nvarchar	3	no	Level of ASRIS hierarchy
feature_name	nvarchar	30	yes	Name of the feature
date_desc	datetime	8	yes	Date feature was described
ref_agency_code	nvarchar	3	yes	Parent feature's agency code
ref_project_code	nvarchar	10	yes	Parent feature's project code
ref_feature_id	nvarchar	20	yes	Parent feature's feature code
ref_component_id	nvarchar	30	no	Parent feature's component identifier

Table 57: The *feature notes* table

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
note_type	nvarchar	30	no	Type of note e.g. horizon note
feature_notes	nvarchar	240	yes	Feature notes if component_id = 0 otherwise notes refers to the component

Table 58: The *ref_sites* table

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
ref_site_no	int	5	no	Reference site number
ref_site_agency_code	nvarchar	3	yes	Reference site agency code
ref_site_project_code	nvarchar	10	yes	Reference site project code
ref_site_feature_id	nvarchar	20	yes	Reference site feature code
ref_Site_component_id	nvarchar	30	yes	Reference site component identifier
ref_site_rep	int	4	yes	Reference site representativeness
ref_site_proportion	decimal	5	yes	Reference site proportion

Table 59: The *samples* table

Column Name	Data Type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
samp_no	int	4	no	Sample number
samp_type	nvarchar	15	yes	Type of sample (e.g. fine earth, whole soil)
samp_method	nvarchar	15	yes	Sampling method
samp_upper_depth	numeric	5	yes	Sample upper depth (m)
samp_lower_depth	numeric	5	yes	Sample lower depth (m)
samp_desc	nvarchar	240	yes	Sample description
samp_date	datetime	8	yes	Date of sampling

Table 60: The *sample notes* table

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
samp_no	int	4	no	Sample number
note_type	nvarchar	30	no	Note type (e.g. sampling procedure)
samp_notes	nvarchar	240	yes	Sample notes

Table 61: The *results* table

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
project_code	nvarchar	10	no	Project identifier
feature_id	nvarchar	20	no	Feature identifier
component_id	nvarchar	30	no	Unmapped component identifier
samp_no	int	4	no	Sample number
res_no	int	4	no	Result number
param_char_id	nvarchar	20	no	Parameter method identifier (categorical data)
param_num_id	nvarchar	20	no	Parameter method identifier (continuous data)
res_value_type	nvarchar	1	yes	Value type (e.g. maximum, minimum, average)
res_value_pref	nvarchar	1	yes	Value prefix (e.g. -, <, >)
res_char_value	nvarchar	25	yes	Character value
res_num_value	numeric	5	no	Numerical value
res_proportion	int	4	yes	Percentage of area the value represents
res_est_method	nvarchar	2	yes	Result estimation method
res_uc1	numeric	5	yes	Result uncertainty1
res_uc2	numeric	5	yes	Result uncertainty2

Table 62: The *param_num_method* table.

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
param_num_id	nvarchar	20	no	Parameter method identifier
parameter	nvarchar	20	no	Parameter measured (e.g. pH, organic carbon)
parameter_desc	nvarchar	240	yes	Method description
param_method_units	nvarchar	10	yes	Units of measurement
param_method_ref	nvarchar	20	yes	Technical reference for the method
error	numeric	5	yes	Error of measurement
min_detect	numeric	5	yes	Minimum detection limit
max_detect	numeric	5	yes	Maximum detection limit
correction	numeric	5	yes	Required Corrections
est_type	nvarchar	20	yes	Type of parameter estimated (e.g. bulk density)

Table 63: The *num_est_method_type* table

Column name	Data type	Length	Nullable	Description
est_type	nvarchar	20	no	Type of parameter estimated (e.g. bulk density)
est_desc	nvarchar	50	yes	Description of the estimated parameter

Table 64: The *num_est_method* table

Column Name	Data type	Length	Nullable	Description
est_type	nvarchar	20	no	Type of parameter estimated (e.g. aggregate stability)
param_num_id	nvarchar	20	no	Parameter method identifier (e.g. bulk density, pH, CEC)
est_method	int	4	no	Estimation method value (e.g. 1, 2, 3, 4)
est_method_desc	nvarchar	16	yes	Estimation method description

Table 65: The *param_char_method* table

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
param_char_id	nvarchar	20	no	Parameter method identifier e.g. texture, mottle abundance, segregation form
code_value	nvarchar	25	no	Code value (e.g. LC, 2, N)
parameter	nvarchar	20	no	Parameter measured (e.g. pH, texture, depth, mottles)
code_desciption	nvarchar	128	yes	Code description (e.g. light clay, few 2–10%, nodules)
est_type	nvarchar	20	yes	Type of parameter estimated (e.g. texture)

Table 66: The char_est_method_type table

Column Name	Data type	Length	Nullable	Description
est_type	nvarchar	20	no	Type of parameter estimated (e.g. aggregate stability)
est_desc	nvarchar	50	yes	Description of the estimated parameter

Table 67: The *char_est_method* table

Column Name	Data type	Length	Nullable	Description
est_type	nvarchar	20	no	Type of parameter estimated (e.g. aggregate stability)
param_char_id	nvarchar	20	no	Parameter method identifier (e.g. texture, mottle abundance, segregation form)
est_method	int	4	no	Estimation method value (e.g. 1,2,3,4)
est_method_desc	nvarchar	16	yes	Estimation method description

Table 68: The *param_ char_refs* table

Column Name	Data type	Length	Nullable	Description
param_char_id	nvarchar	20	no	Parameter method identifier (e.g. texture, mottle abundance, segregation form)
code_reference	nvarchar	50	yes	Page of reference from McDonald et al. (1990) unless otherwise stated

Table 69: The *codes* table.

Column Name	Data type	Length	Nullable	Description
agency_code	nvarchar	3	no	Agency identifier
code_domain	nvarchar	20	no	Code domain
code_value	nvarchar	20	no	Code value
code_parameter	nvarchar	20	no	Parameter type (e.g. officers, feature type)
code_desciption	nvarchar	128	yes	Code description

14. Relationship to SOTER

ASRIS has been designed to facilitate the Australian contribution to SOTER – this is the new global soil and land resource information system. Details on the conversion protocols will be provided in the next version of this document.[6]

[6] See http://lime.isric.nl/index.cfm?contentid=236 for information on SOTER

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Appendix 1: Conversion for pH in water to pH in $CaCl_2$

The conversion table for pH in water (1:5 soil to water) to pH in $CaCl_2$ (1:5 soil to 0.01M $CaCl_2$) is from Henderson and Bui (2002). It is based on 70,465 observations collated to support ASRIS 2001. The values in italics are to be regarded as more doubtful extrapolations of the statistical curve because they are supported by a smaller number of observations.

Table 70: Conversion for pH in water to pH in $CaCl_2$.

Observed pH water	Predicted pH $CaCl_2$	Observed pH water	Predicted pH $CaCl_2$	Observed pH water	Predicted pH $CaCl_2$
3.0	2.8	5.4	4.6	7.8	7.2
3.1	2.9	5.5	4.7	7.9	7.3
3.2	3.0	5.6	4.8	8.0	7.4
3.3	3.0	5.7	4.9	8.1	7.5
3.4	3.1	5.8	5.0	8.2	7.5
3.5	3.2	5.9	5.1	8.3	7.6
3.6	3.2	6.0	5.2	8.4	7.7
3.7	3.3	6.1	5.3	8.5	7.8
3.8	3.4	6.2	5.4	8.6	7.8
3.9	3.5	6.3	5.5	8.7	7.9
4.0	3.5	6.4	5.7	8.8	8.0
4.1	3.6	6.5	5.8	8.9	8.0
4.2	3.7	6.6	5.9	9.0	8.1
4.3	3.7	6.7	6.0	*9.1*	*8.2*
4.4	3.8	6.8	6.2	*9.2*	*8.2*
4.5	3.9	6.9	6.3	*9.3*	*8.3*
4.6	3.9	7.0	6.4	*9.4*	*8.4*
4.7	4.0	7.1	6.5	*9.5*	*8.4*
4.8	4.1	7.2	6.6	*9.6*	*8.5*
4.9	4.2	7.3	6.7	*9.7*	*8.6*
5.0	4.2	7.4	6.8	*9.8*	*8.7*
5.1	4.3	7.5	6.9	*9.9*	*8.7*
5.2	4.4	7.6	7.0	*10.0*	*8.8*
5.3	4.5	7.7	7.1	*10.1*	*8.9*

Appendix 2: Updates to the Technical Specifications

Version 1.4 March 2005

- Substantial change to the definition and variables used to characterize Levels 1 to 3. Climate variables are now used as descriptors of land-unit tracts rather than defining variables for boundary placement (primarily Table 3 Section 4.2, and Sections 6–8). Regolith characterization as been refined and summaries of soil taxonomic units added.
- Removal of reference to a correction factor for coarse fragments and plant available water capacity. Replacement with a method relying on the percentage of coarse fragments and their porosity (page 58). Addition of *porosity of coarse fragments* as a variable (Table 4, page 52).
- Change in formatted length of the variable *feature_id*
- Coverages of spatial data are recommended to conform to the vector baseline GEODATA COAST 100K 2004 rather than the earlier 1992 version.

Version 1.5 October 2005

- Corrections to the spatial uncertainties listed for texture in Table 4
- Listing of tables of attributes for Levels 1–3
- Clarification of control sections when O horizons are present
- Clarification of control section intent for Layer-4 texture
- New database schema and related changes to table descriptions.

Future consideration

- Addition of two fields to Table 50 – SDL10 for fluvio-lacustrine and estuarine, and INF00 for ferricrete.

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