The Australian Soil Resource Information System

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Abstract

The Australian Soil Resource Information System (ASRIS) provides online 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. ASRIS provides a spatial hierarchy of land-unit tracts with seven main levels of generalization. The upper three levels provide descriptions of soils and landscapes across the continent while the lower levels provide more detailed information for areas where mapping has been completed. The lowest level relates to an individual site in the field. A consistent set of land qualities is described for land-unit tracts. Descriptions from the lowest-level units are used to generate summaries for higher-level units. The land qualities relate to soil depth, water storage, permeability, fertility and erodibility. ASRIS includes a soil profile database with fully characterized sites that are known to be representative of significant areas and environments. Estimates of uncertainty are provided with most data held within ASRIS. 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. ASRIS 2004 will contain some 5,000 soil profiles along with the upper levels of the hierarchy for most of the country and restricted coverage for lower levels. ASRIS 2006 will complete the coverage at the lower levels and contain an expanded soil profile database.

Key Words

Soil survey, internet GIS, soil information systems

Introduction

The Australian Soil Resource Information System (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 county – the level of detail depends on the survey coverage in each region. This paper outlines development of the system and describes the hierarchy of land-unit tracts and their descriptors. Procedures for estimating uncertainties are also introduced.

Development of ASRIS

ASRIS was initiated through the National Land and Water Resources Audit (NLWRA) in 1999 (see NLWRA 2001; Henderson *et al.* 2002). The initial release (ASRIS 2001) provided primary inputs for a broad range of simulation modeling 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).

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 Working Group on Land Resource Assessment (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.

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. The project brief required information to be available at a range of scales, and in a consistent and easy-to-use format across Australia. Another requirement was provision of a scientific framework for assessing and monitoring the extent and condition of Australia’s soil and land resources. The current

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version of ASRIS is a collaborative effort involving all state, territory and commonwealth agencies with a role in land resource assessment. Direct funding is from the CSIRO, Natural Heritage Trust and National Land and Water Resources Audit. Collaborating agencies are also providing substantial resources.

Hierarchy of land units and terminology

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 etc). 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.

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 in ASRIS because they are consistent with most aspects of current practice.

The hierarchy of land-unit tracts

Table 1 describes the hierarchy of land-unit tracts. The hierarchy has seven levels of generalization. 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.

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. In some landscapes, nested patterns of landform may be evident and sublevels within the hierarchy can be 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 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 and set of defining attributes. Mapping land districts (L4) 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 (L1), province (L2), and zone (L3) 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).

Upper levels of the hierarchy

ASRIS has the facility to substitute other stratifications of the continent above the level of the mapping hiatus. Maps of biogeographic 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.

Table 1: The spatial hierarchy of land-unit tracts (after Speight 1988). Intermediate levels can be included (e.g. a System with a characteristic dimension <100 m would be designated as Level 5.1 or 5.2 in the hierarchy)

Level	Order of land unit tract	Speight	Characteristic dimension	Defining attributes	Appropriate map scale
1.0	Division	300km	30 km	Simple physiography (modal slope and relief)	1:10 million
2.0	Province	100 km	10 km	Physiography and water balance (excess water to drive chemical reactions)	1: 2.5 million
3.0	Zone	30 km	3 km	Physiography, water balance and substrate lithology	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	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	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	10 m	Soil properties, surface condition, microrelief	rarely mapped in conventional survey

* Sensu Thompson and Moore (1984)

Attributes

Land-unit tracts are described using a consistent set of soil and land attributes. The main soil properties are summarised in Table 2. Land attributes include slope, landform element, surface condition, rock outcrop, micro-topography (e.g. presence of gilgai), site drainage and substrate materials.

Descriptions from the lowest-level units are used to generate summaries for higher-level units. These summaries are presented in several forms including area-weighted means (only for attributes where this is appropriate) and 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 users of soil and land information.

Accuracy, precision and a basis for stating uncertainty

Rationale

Estimates of uncertainty for each attribute in ASRIS are included to encourage more appropriate use of soil and land resource data. Uncertainty estimates are essential for the tracking of error propagation in various forms of analysis, particularly simulation modeling (e.g. Heuvelink 1998; Moss and Schneider 2000; Minasny and Bishop 2005). 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).

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),
$\theta_{-10\ \mathrm{kPa}}$	Used to calculate water availability to plants and water movement
$\theta_{-1.5\mathrm{MPa}}$	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 dispersal 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)

Two forms of evaluation are recognized. *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. *Type B* evaluations of standard uncertainty are based on scientific judgement using all the relevant information available, which may include:

- Previous measurement data 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 soil spatial variability (e.g. Beckett and Webster 1971; Wilding and Drees 1983; McBratney and Pringle 1999).

Estimating uncertainty

Most estimates of uncertainty in ASRIS rely on Type B evaluations. The form of the estimate depends on the measurement scale and assumed probability distribution for each attribute. Continuous variables with an assumed Normal probability distribution have their uncertainty represented by an estimated standard deviation. 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. 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 modelled 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. 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.

Table 3: 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
Texture		Nominal	0.8 – S, LS, CS, MC, MHC, HC. 0.7 – other classes	0.4–0.7	0.2–0.8	0.1–0.9
Clay content	%	Triangular	10%	10–20%	20–30%	30–40%
Coarse fragments	%	Triangular	20%	20–30%	30–40%	40–50%
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
ASC (Great Group)	–	Nominal	0.9	0.8–0.7	0.7–0.5	0.5–0.4
WRB	–	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 a range in uncertainty due to landscape complexity has been estimated

Every soil attribute has an estimated uncertainty with two components. The first component (u_1) 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 (u_2) 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 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, and it will often be appropriate to simply assume the component variances additive. 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, default values of uncertainty are being used. These are drawn from the published literature on spatial variability and our general knowledge (Table 3). 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 knowledge of the estimation method for each variable (e.g. direct measurement, pedotransfer function). The component of uncertainty due to spatial variability (u_2) can be determined using several lines of evidence including: the cartographic scale of the survey and intensity of sampling (this is expressed via the Order of Survey (Table 3; Soil Survey Staff 1993)); and qualitative assessment of landscape complexity.

Other components and access

ASRIS contains a variety of data sets that provide geographic and environmental context for the soil information. These include grid-based data (e.g. terrain attributes, satellite images, climate surfaces), vector data (e.g. roads, streams, place names, topographic maps). Select soil data are also presented as grids (e.g. results from ASRIS 2001) and electronic files (e.g. documents with images, text and tabular summaries of individual soil profiles).

The formal releases of ASRIS will be in two stages. ASRIS 2004 will contain upper levels of the hierarchy for the whole country, along with lower levels for three States. ASRIS 2006 will contain the complete coverage. Both releases are provided via the Internet using SQL Server, the Arc Spatial Data Engine (ArcSDE), and Arc Internet Map Server (ArcIMS). The prototype version of the system can be accessed at www.asris.csiro.au and the required password is available from the authors.

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