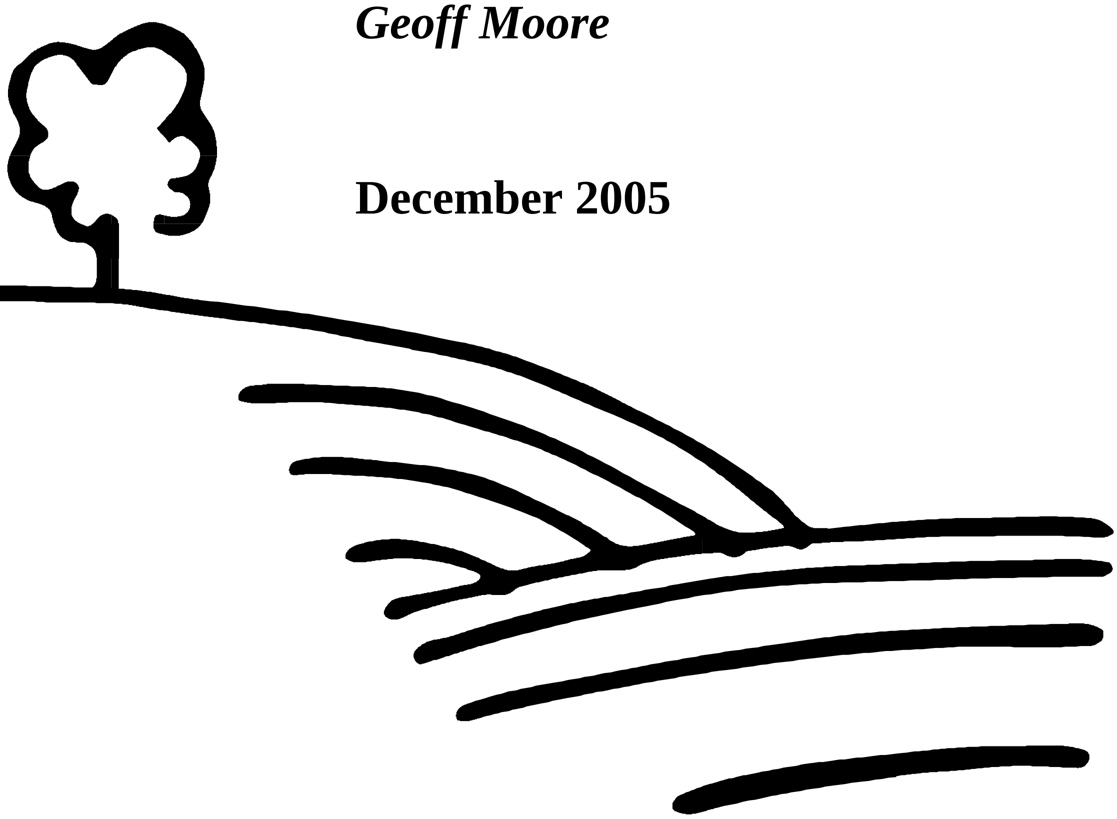
LAND EVALUATION STANDARDS FOR LAND RESOURCE MAPPING

Third edition

Dennis van Gool, Peter Tille and Geoff Moore

December 2005



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Resource Management Technical Report 298

Land evaluation standards for land resource mapping

ASSESSING LAND QUALITIES
AND DETERMINING LAND CAPABILITY IN
SOUTH-WESTERN AUSTRALIA

Third edition, replaces Resource Management Technical Report 181

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WHY THIS REPORT HAS BEEN UPDATED

This report has been updated to include developments in the Department of Agriculture's map unit database. Apart from minor edits the main inclusions are:

1) A description of zone land units used in the agricultural region of WA
2) A greater range of land quality code values for existing land qualities
3) New land qualities for trafficability and soil absorption ability
4) Inclusion of land characteristics that are measurable, or can be derived (Appendix 1)
5) Updated capability ratings tables and description of two methods for displaying proportional mapping in the section about land capability
6) Inclusion of soil group selections for pines (*Pinus pinaster*).

This form of information was first published in 1998. The map unit database is constantly undergoing changes due to new information and improved methods for assessment (e.g. access to more remotely-sensed information such as digital elevation models, faster computers and improved assessment techniques). There is also a gradual introduction of more quantitative measures. It is not possible to complete a final definitive report. This is now a third, revised edition of the original publication. It is a detailed description of zone land units, land characteristics, land qualities and land capability in the Department of Agriculture's map unit database at the date of publication.

Flexibility in the compilation and use of digital data is an advantage to researchers and those simply seeking information. However it can be a disadvantage when the degree of flexibility and uncertainty, typical of natural resource information, is not understood by legalistic planning processes. This report tries to document the underlying assumptions so that the scope for the mapping can be better assessed by those using the information.

Although technological advances are improving the accuracy of the information presented, scale limitations associated with the original surveys mean that uncertainty remains in any derived maps or tables. The cost of reducing this uncertainty to a negligible amount is prohibitive because soils vary often over only a few metres or less. **Feedback** from those using the information can ensure that the best information is presented for a given situation. It also means that the underlying information continues to be improved. There are many instances when an incorrect looking map can be 'fixed up' or simply presented differently to still give useful information.

Any feedback, questions or suggestions can be forwarded to Dennis van Gool (dvangool@agric.wa.gov.au) or Peter Tille (ptille@agric.wa.gov.au). Alternatively contact the Department of Agriculture in South Perth on telephone (08) 9368 3333.

1. INTRODUCTION

This report describes the standard method for attributing and evaluating conventional[1] land resource survey maps in the south-west agriculture region of Western Australia so that strategic decisions about the management, development and conservation of land resources can be based on the best information available.

Initially attribution was done manually by agency soil survey staff using the rules described in this report. In 2003, these land evaluation rules, which are sometimes referred to as pedotransfer[2] functions, were incorporated into visual basic code in an Access database. Now land qualities, land characteristics and land capability can be auto-generated for all survey map units that have been populated with the consistently structured soil and landscape information described below. (See also Schoknecht *et al*. 2004.)

The standards described are similar to the land suitability assessment (stage one of the two stage) methods described by the Food and Agriculture Organisation (FAO 1976, 1983). The first Western Australian adaptation of these methods by Wells and King (1989) used the term land capability assessment (a name derived from Klingbiel and Montgomery 1961). As a result most catchment, farm and land use planning reports in south-western Australia refer to land capability. The term land suitability has recently become the national standard (van Gool, Maschmedt and McKenzie, in press). Because of the prevailing use of the term, land capability, in WA, we continue to use it in this report.

This edition updates and replaces the first and second editions by van Gool and Moore, 1998 and 1999.

The aim has been to:

- describe land attributes (zone land units, land characteristics and land qualities) which have been applied to conventional soil-landscape land resource surveys available in WA;
- account for variability in scales (i.e. from 1:20,000 to 1:250,000);
- combine the best information available for published and unpublished survey information, including both descriptive information about map unit variability buried in land resource reports and laboratory information associated with soil samples collated in the Department of Agriculture's soil profile database;
- describe a large portion of the information held in the Department of Agriculture's map unit database.

All conventional land resource surveys available or in preparation in 2005 are listed in Appendix 3.

> This report is ***not a field assessment guide***. It is designed for estimating land qualities using limited information commonly available in reports or data tables. Estimates should be checked or improved using measured data or field observations whenever possible.

[1] Where areas of land are depicted by discrete mapping units.

[2] "Transferring data we have into what we need" Bouma 1989.

1.1 Background

The land resource mapping program in WA is largely complete. As computer mapping tools are now widely available, there is an opportunity - and an obligation - to greatly improve how land resource surveys are used to meet very diverse information requirements.

In 1985, the national mapping program focused on land degradation problems through the National Soil Conservation Program. The Decade of Landcare plan (SLCC 1992) gave a more positive focus on the sustainable use or development of natural resources. There are different views on the definition of sustainability. A national overview is:

> "The development and implementation of systems of land use and management which will sustain individual and community benefits now and in the future."
> SCARM (1995)

Conventional land resource surveys can serve many purposes, including business planning and research. However the major traditional uses, which are still important today, are to help plan[3] new developments (e.g. agriculture, forestry, urban, recreation) and to identify management, conservation or degradation issues.

Surveys usually provide three outputs:

1. A survey report which may include technical soil information and discussions about the distribution of soil resources in a given region, plus any relationships with landscape, geology and vegetation. These discussions usually consider the implications for land use and land management.
2. Soil profile observations, which include intermittent analysis of soil physical and chemical properties, and sometimes current vegetation and land use information. Since 1993 most soil profiles, including much historical information, have been entered into a profile database under national guidelines.
3. A published map that groups similar land areas into one or more similar map units, which (usually qualitatively) relate to the survey report and soil profile observations.

A fourth more recent output is a digital map, which is distinct from the published map because it can integrate information from the other three survey outputs.

Until recently the main use of digital land resource maps has been for efficient desktop publishing. Other uses require some type of attribution to be attached to the map units. Examples include semi-automated map preparation using computer-aided mapping software to prepare map themes for catchment and land use plans. Another use is spatial analysis using a Geographic Information System (GIS). This could simply be the rapid calculation of land areas or a number of more advanced techniques that involve overlays with other themes such as satellite images or digital elevation models, or for use in predictive modelling. An example is yield mapping and impacts of seasonal and long-term climatic change (van Gool *et al*. 2004).

Three problems with land resource surveys have hampered GIS uses in Australia:

1. Most survey reports contain much technical information. This means environmental or soils professionals are required to decipher it. Few community groups and (particularly) rural shires have the resources or time to seek this expertise, hence land resource information, though valuable, is often only used in a very rudimentary manner.

[3] Plan is used in preference to locate, because in Australia many 'surveys were made after it had been decided how to use the land' (Hallsworth 1978). So although surveys are used to locate new developments, a major role has been to assist in developing management strategies for existing land uses.

2. Documentation of surveys varies dramatically (e.g. Beckett and Bie 1976, Hallsworth 1978, Shields *et al*. 1996). This can mean considerable time and difficulty in comparing adjacent survey areas.
3. Differences in survey scale (i.e. 1:20,000 to 1:250,000).

Because of time constraints, GIS projects have tended to focus on developing data structures **only** for a specific study area with little regard for adjacent areas. For example one project may collate soil depth and soil moisture characteristics suitable for catchment water use modelling, and another collates information relevant to wind erosion, such as topsoil texture and surface condition. As a result survey information can rarely be used directly for other projects or other areas without significant manual editing by experts. Adjacent and overlapping study areas therefore commonly collate new data and result in a lot of duplicated effort. This is a major reason why the ability of GIS to rapidly provide resource summaries has been lower than expected. Until recently there had been few assessments of broad regional land resources based on the most detailed information available in the survey reports even though this should arguably be routine.

In the past, regional resources were, by necessity, prepared using mapped information of an appropriate scale. A state overview could be gleaned from the *Atlas of Australian Soils* prepared at 1:3,000,000 scale; regional plans might use systems mapping at 1:250,000 scale such as the Darling landforms and soils (Churchward and McArthur 1978, *in* CALM 1983); local plans would use 1:100,000 or 1:50,000 scale surveys if they were available for catchment plans and local rural planning strategies. Land resource survey information has been compiled into a comprehensive and consistent database and broad summaries can readily be compiled using the best information available. For example information from 1:50,000 scale surveys can be summarised to prepare a state overview.

The land evaluation standards described in this report are applied throughout the south-west agricultural region. The methods can be applied to any conventional surveys when the base information has been similarly compiled. Runge and van Gool (1999) is an early example of a resource summary covering many surveys. This information is now routinely used for reporting land resources. Recent examples include the AGMAPS CDs, and catchment appraisal reports. Nine AGMAPS CDs are presently available, the most recent for the Mortlock Catchment (DoA 2005a). Fifteen catchment appraisal reports available as Resource Management Technical Reports, the most recent for the Grass Patch-Salmon Gums area (DoA 2005b).

National context

In most States land resource survey information has only been compiled on a project basis, as discussed above. To significantly improve the summaries[4] prepared for the *Australian Natural Resources Atlas* (audit.ea.gov.au/anra), all available land resource surveys must be re-interpreted and correlated under the guidance of the Australian Soil Resource Information System or ASRIS (www.asris.csiro.au). WA and South Australian work has provided major templates for the national data model developed for ASRIS. It will take many years for data consistency to be achieved throughout Australia.

ASRIS offers opportunities for improving the direct use of land resource information, and for researching and (initially) developing new techniques in WA and SA, for example techniques that utilise digital elevation models (DEMs), remotely sensed data, climate information or crop yield information. A comprehensive review of many new survey techniques can be found in McKenzie *et al*. (in prep).

[4] To make it relevant to detailed local and regional planning. Currently it is only relevant to broad policies and some themes are suitable for "big picture" strategic plans.

1.2 Accuracy and scale of land resource mapping

As well as requiring some type of consistent land attributes, the potential uses of land resource mapping are limited by several other factors largely related to scale, but also influenced by the survey method, mapping date (an indicator of the spatial reliability of the information) and land complexity. The difficulty is that a low quality map at 1:50,000 may be less reliable than a high quality 1:100,000 scale map[5]. The published survey report can be used to provide some indication of map reliability. However it also needs to be recognised that many maps and the associated data have been updated since the publication of the original reports. Appendix 2 is a list of all digital land resource maps, their bibliographic reference and some details such as the mapping scale and survey date.

Table 1.2.2 gives a general guide for the appropriate use of land resource survey maps. The approximate resolution is given as a general guide. For example, even at high survey intensity (1:10,000-1:50,000), the resolution could be as broad as 25 hectares. Detailed planning decisions about land uses of only 1 or 2 ha could be inaccurate, and should be field checked or cross-referenced with other information sources (e.g. typically high resolution aerial photographs and/or a digital elevation model and occasionally a field check, which may simply be a drive past the property). Figure 1 is a subjective guide to survey reliability in south-west Western Australia.

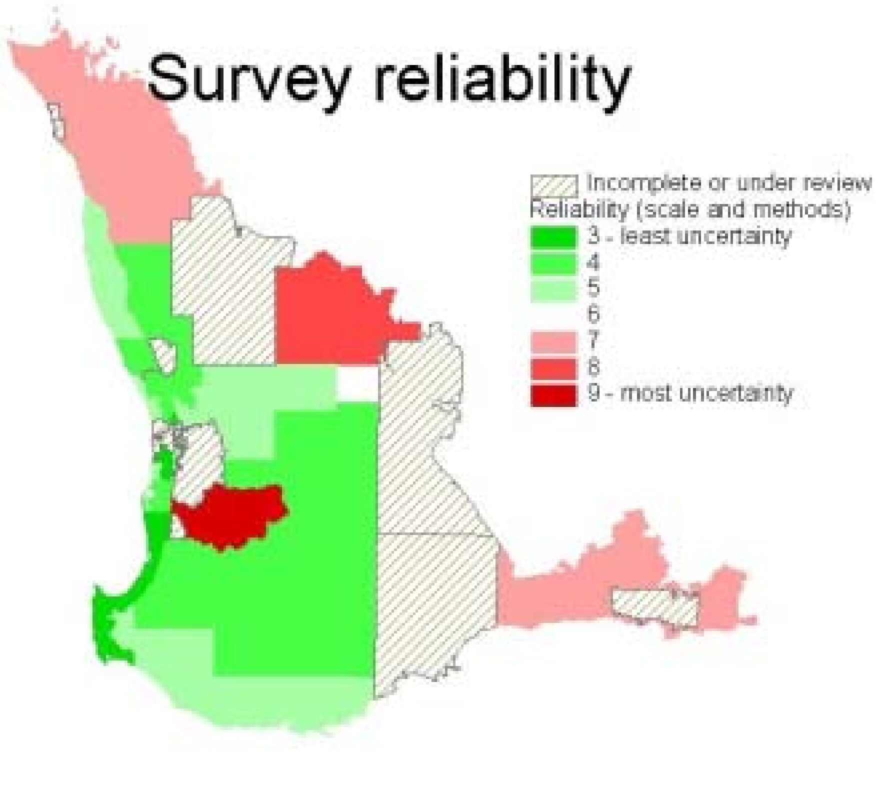

Figure 1. A guide to survey reliability in south-west Western Australia

5 Hence the large overlap in approximate scale in Table 1.2.2.

Table 1.2.2. How map scale affects use of land resource mapping (adapted from Gunn *et al*. 1988, McKenzie 1991)

Approximate scale (survey intensity) approximate resolution*	Examples of recommended uses
<1:10,000 (very high intensity) *<1 ha*	• Detailed suitability for specific forms of land use • Intensive land use development (e.g. urban, horticulture, engineering uses) • Local urban structure planning • Detailed farm planning • Property development planning
1:10,000-1:50,000 (high intensity) *1-25 ha*	• General suitability for various forms of land use • Strategic planning for intensive land use developments including urban and horticulture • Shire planning for the development of rural land in shires experiencing high land use pressure (i.e. shires near the metropolitan region or major urban centres) • Management plans for small catchments • Farm planning for low intensity agricultural uses • Forestry production areas
1:25,000-1:100,000 (medium intensity) *6-100 ha*	• General suitability for various forms of land use • Planning for low intensity land uses such as dry land agriculture • Strategic planning for more intensive land uses such as urban and horticulture • Shire planning for development of rural land experiencing moderate land use pressure (i.e. shires with larger rural towns that are experiencing some development pressure or have major development opportunities) • Regional planning in areas with high development pressure • Management of medium catchments • General planning of forests
1:50,000-1:150,000 (medium to low intensity) *25-225 ha*	• Broad suitability for major kinds of land use • Best suited for planning low intensity land uses such as dry land agriculture • Generally locating more intensive land uses such as urban and horticulture • Regional and local planning for predominantly rural shires • Management of large catchment areas
1:100,000-1:250,000 (low intensity) *100-625 ha*	• Broad suitability for major kinds of land use • Strategic planning for broad dryland agricultural uses or generally locating other major kinds of land use with limitations on the amount of detail that can be considered • Regional plans, planning for rural shires (particularly smaller wheatbelt and pastoral shires) • Overview of management issues for very large catchments • General planning for pastoral shires
>1:250,000 (reconnaissance) *>625 ha*	• Overview of land resources and their status • A general prediction of land resources in a given location • General planning for pastoral shire.
>1:500,000 (overview) *>2,500 ha*	• Overview of land resources and their status • General summaries of regional resources • National/regional resource inventory

[1] Resolution based on 1 cm^2 on the map. This figure is an indicator of the size of land use developments that can be planned for. The minimum resolution is assumed to be 0.5 cm^2 in the Australian Land Survey Guidelines (Gunn *et al*. 1988) however the average resolution of map units in practice is usually much larger.

The soil-landscape map unit hierarchy

A hierarchy of soil-landscape mapping units for land resource surveys in the agricultural south-west has been adopted by the Department of Agriculture in order to maintain a consistent approach with the different mapping scales and varying levels of complexity in both landscape and soil patterns. Details of the mapping hierarchy are given in Schoknecht *et al*. (2004). At higher levels of the hierarchy the soil-landscape mapping units cover large areas and have a high degree of internal complexity. At the lower end, mapping units cover small areas with usually only minor soil variation. These are suitable for detailed maps of small areas such as individual farms.

An example from the Wellington-Blackwood land resource survey is shown below:

Region

A broad morphogenetic unit based on continental-scale tectonic geology and climate described by CSIRO (1983).

Example: The Western Region (2) comprises the Yilgarn and Pilbara Blocks and the intervening Hamersley Basin. The Carnarvon and Perth Basins are included because they are too small to form their own Regions. The area has been continuously exposed to weathering and denudation since the Precambrian period.

Province

A broad-scale unit based on geology (lithology and stratigraphy) and regolith, described by CSIRO (1983).

Example: The Avon Province (25) comprises Precambrian granites and gneisses with past lateritic weathering.

Zone

A regional unit based on geomorphological and geological criteria.

Example: The Western Darling Range Zone (255) is an extensive undulating lateritic plateau (Darling Plateau) which is largely intact. The plateau has some deeply incised valleys where it has been dissected by the major river systems of the inland zones.

System

A regional unit based on landform pattern, soil parent material and soil associations.

Example: The Coalfields System (255Cf) overlies Permian sedimentary basins containing coal, and is dominated by broad lateritic divides with gravels and sands, swampy terrain, shallow minor swampy floors and shallow valleys with well drained flats.

Subsystem

A local unit based on landform element and morphological type, and soil associations.

Example: The Stockton Subsystem (255CfSK) consists of shallow minor valleys with gentle side slopes and swampy floors, with sandy gravels and deeps sands.

Phase

A local unit based on one or more of: drainage, salinity, slope, erosion, soil.

Example: The Stockton upstream valleys phase (255CfSKu) are valleys 5-15 m deep with 2-5 per cent gradients on the side slopes. The valley floor is usually narrower than downstream.

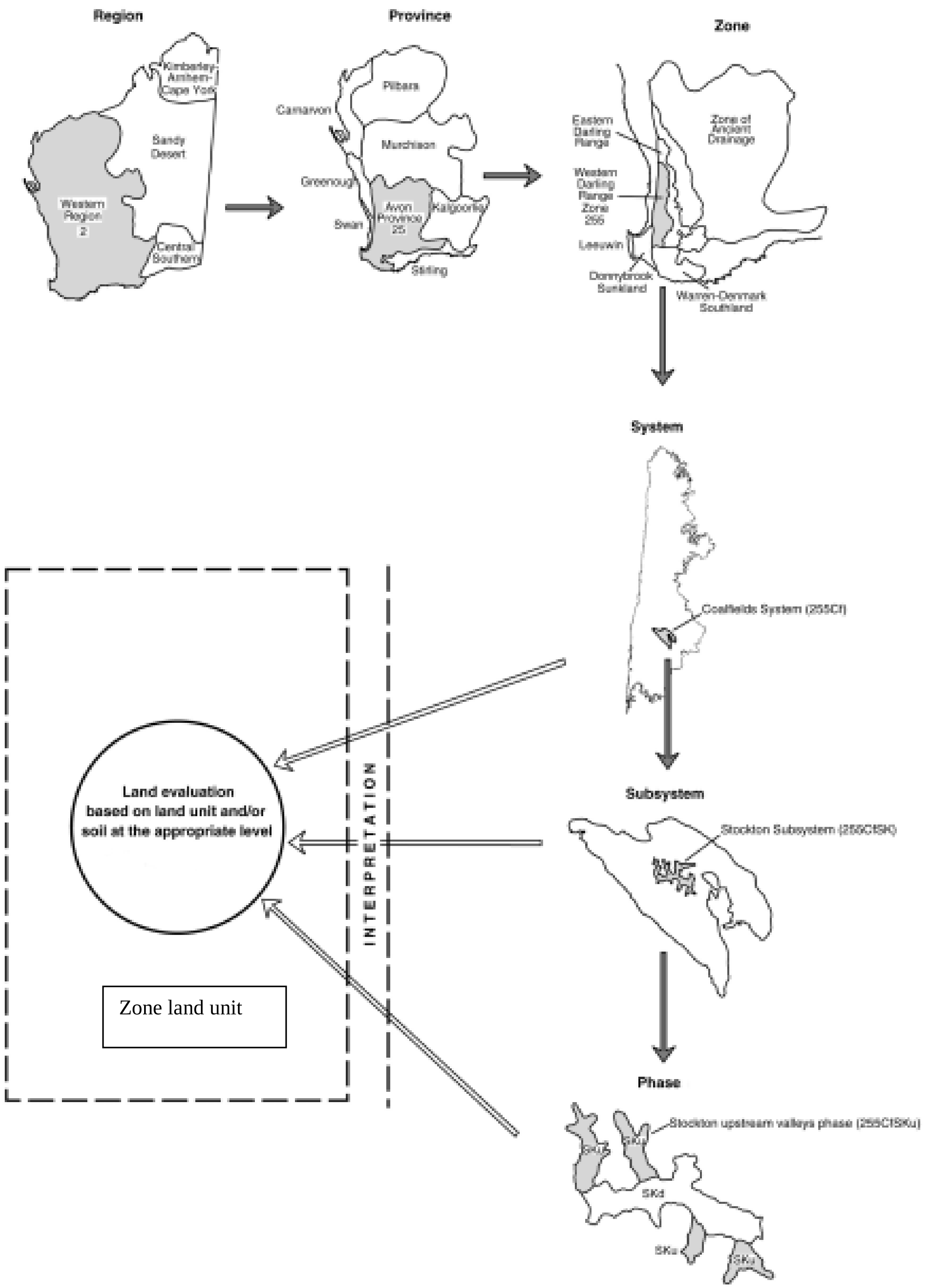

Figure 2. The map unit hierarchy and its relationship to zone land units (see Section 1.5)

How scale affects map unit composition

Probably the most important information for conventional surveys[6] which use map units[7] to depict areas of land is the cartographic scale for which it is prepared, along with the means by which the soil-landscapes are summarised. When you look at the simplified cross-sectional diagram (Figure 3), a typical range of scales for conventional land resource surveys is shown (1:25,000 to 1:250,000).

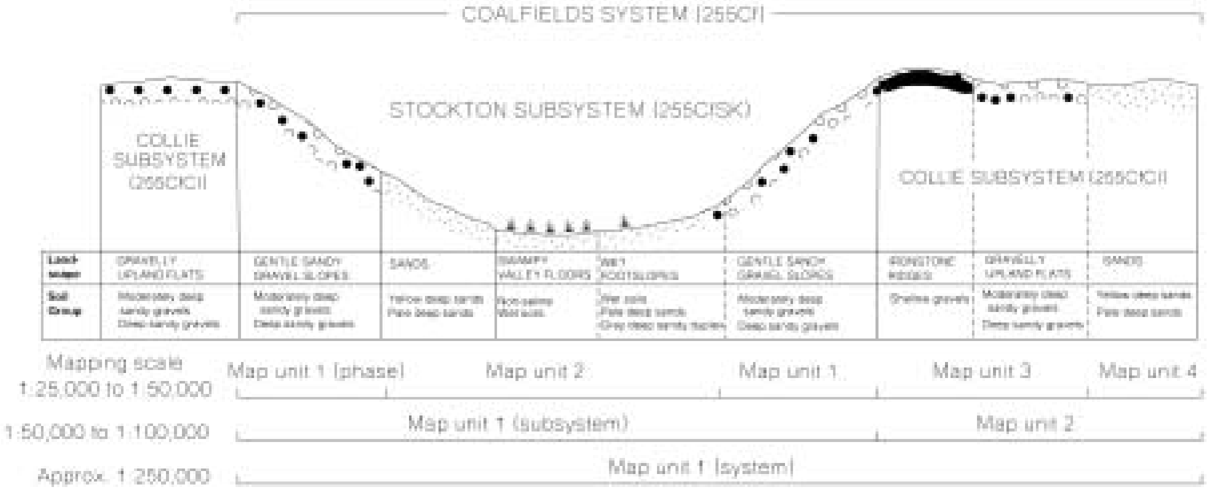

Figure 3. Map units drawn at different scales for a simplified soil-landform cross-section diagram

At 1:25,000 to 1:50,000 scale, four map units give a good grouping of landforms and soils. For example map unit 1 (a phase) – Gentle sandy gravel slopes have moderately deep and deep sandy gravels. At 1:50,000 to 1:100,000 scale the whole Stockton valley is mapped, including the gentle sandy gravel slopes, wet foot slopes and the swampy valley floors. Seven soils are described for the Stockton valley. At 1:250,000 scale a single mapping unit covers eight land units and at least 10 soil types.

Figure 3 highlights that a single rating applied to 1:250,000 or even 1:100,000 mapping unit can be very misleading. Efforts are being made to improve map accuracy using other information, such as DEMs. Land normally changes gradually and the expected variation within mapping units is described within the survey report. With better relational databases it is now common practice to display this variation, as a percentage or proportion within a mapping unit (discussed under Section 1.4 proportional mapping).

[6] On digital maps these are called shapes or polygons.

[7] The digital maps are referred to as vector mapping to differentiate them from raster maps where the information is attached to small squares in a grid.

1.3 Terminology

Terminology used in survey reports and land evaluation is often confusing and used inconsistently (e.g. van de Graaf 1988, Shields *et al*. 1996). Some common terms used when using land resource surveys in WA are considered in Appendix 4. Even though the context and definition of specific terms may be slightly different, this rarely matters for general land evaluation purposes, as long as the context in which it is used is understood.

Conventional land resource survey systematically describes attributes associated with land. In the south-west of WA these attributes are primarily soil and landform-related information. Land resource survey maps use *mapping units* depicted by a distinct boundary and identified by a map unit label. Mapping units for conventional land resource survey are often referred to as *land unit tracts*. Map units have similar properties that can be attributed in various ways. One way is via land units, which can be applied to land resource maps irrespective of whether they are based on soil or landform information, including maps that depict soil associations, soil series, soil-landscapes, soil landforms or land systems.[8]

Land units described in this report are an area of common landform and similar soils that occur repeatedly at similar points in the landscape. For a soil-landscape zone they usually have similar vegetation, geology and climate which affects their properties, hence the term *zone land units*. Zone land units are components of map units. At relatively detailed scales (e.g. 1:25,000) the zone land unit may be synonymous with the map unit, though this can vary according to the complexity of the soils and landforms. More commonly, zone land units are described as a *proportion* or percentage of a map unit. A detailed description of zone land units, and their associated properties is given in Sections 1.5 and 1.6.

1.4 Proportional mapping

Proportional mapping has unmapped components (e.g. land units and/or soil type) which are described as a percentage of the map unit. The use of proportionally mapped information allows the closest match between mapping and reported information. It shows the variability associated with map units and helps identify high or low values which are significant to land use or land management. A difficulty in the past has been that most conventional survey maps only show the average condition, hence these high or low values are not evident. An example is water erosion hazard associated with stream lines or drainage depressions. Since this may only be 5% of a map unit it is hidden by a map which only describes the average condition. However, the use of proportional mapping could be used to identify any areas, no matter how small, where streamlines, or drainage lines normally occur. This may be important for a specific land management issue, such as nutrient pollution (eutrophication), which is greatly influenced by land adjacent to stream lines. You get a similar problem with groundwater recharge estimates derived from conventional survey maps, where a small amount of deep sand within a map unit often greatly increases predicted recharge because it is a preferred flow path for water. For example, the deep sand may represent 10% of the land area, but be responsible for 90% of the recharge[9]

For displaying proportional mapping see Section 3.7.

8 Although the strict definition and hence the emphasis on what is mapped and how it is recorded is different, in reality the differences are usually fairly subtle. The main difference is the accuracy of the map and the associated information.

9 To establish whether recharge estimates are realistic knowledge of water transmission through deeper substrates and the hydrology of the area is needed.

1.5 Zone land units

A set of zone land units has been generated for the agricultural district of WA. Each land unit is unique but may be shared by different map units and in different survey areas. Each zone land unit consists of four components:

1. The soil-landscape zone in which the land unit is found (see Table 1.5a and Figure 4).
2. The soil group which typifies the land unit (see Table 1.5b, Schoknecht 2002).
3. The soil group qualifier which defines the soil properties of the soil group in more detail (see Tables 1.5c & d).
4. The landform which characterises the land unit (see Table 1.5e).

Table 1.5a. Soil-landscape zones in Western Australia

Code	Zone name	Code	Zone name
211	Coastal Dune Zone	**243**	Jerramungup Plain Zone
212	Bassendean Zone	**244**	Ravensthorpe Zone
213	Pinjarra Zone	**245**	Esperance Sandplain Zone
214	Donnybrook Sunkland Zone	**246**	Salmon Gums-Mallee Zone
215	Scott Coastal Zone	**248**	Stirling Range Zone
216	Leeuwin Zone	**250**	South-eastern Zone of Ancient Drainage
221	Coastal Zone	**253**	Eastern Darling Range Zone
222	Dandaragan Plateau Zone	**254**	Warren-Denmark Southland Zone
223	Victoria Plateau Zone	**255**	Western Darling Range Zone
224	Arrowsmith Zone	**256**	Northern Zone of Rejuvenated Drainage
225	Chapman Zone	**257**	Southern Zone of Rejuvenated Drainage
226	Lockier Zone	**258**	Northern Zone of Ancient Drainage
231	Geraldton Coastal Zone	**259**	South-western Zone of Ancient Drainage
232	Kalbarri Sandplain Zone	**261**	Southern Cross Zone
233	Inland Zone	**271**	Irwin River Zone
241	Pallinup Zone	**272**	Greenough River Zone
242	Albany Sandplain Zone	**111**	Default Zone

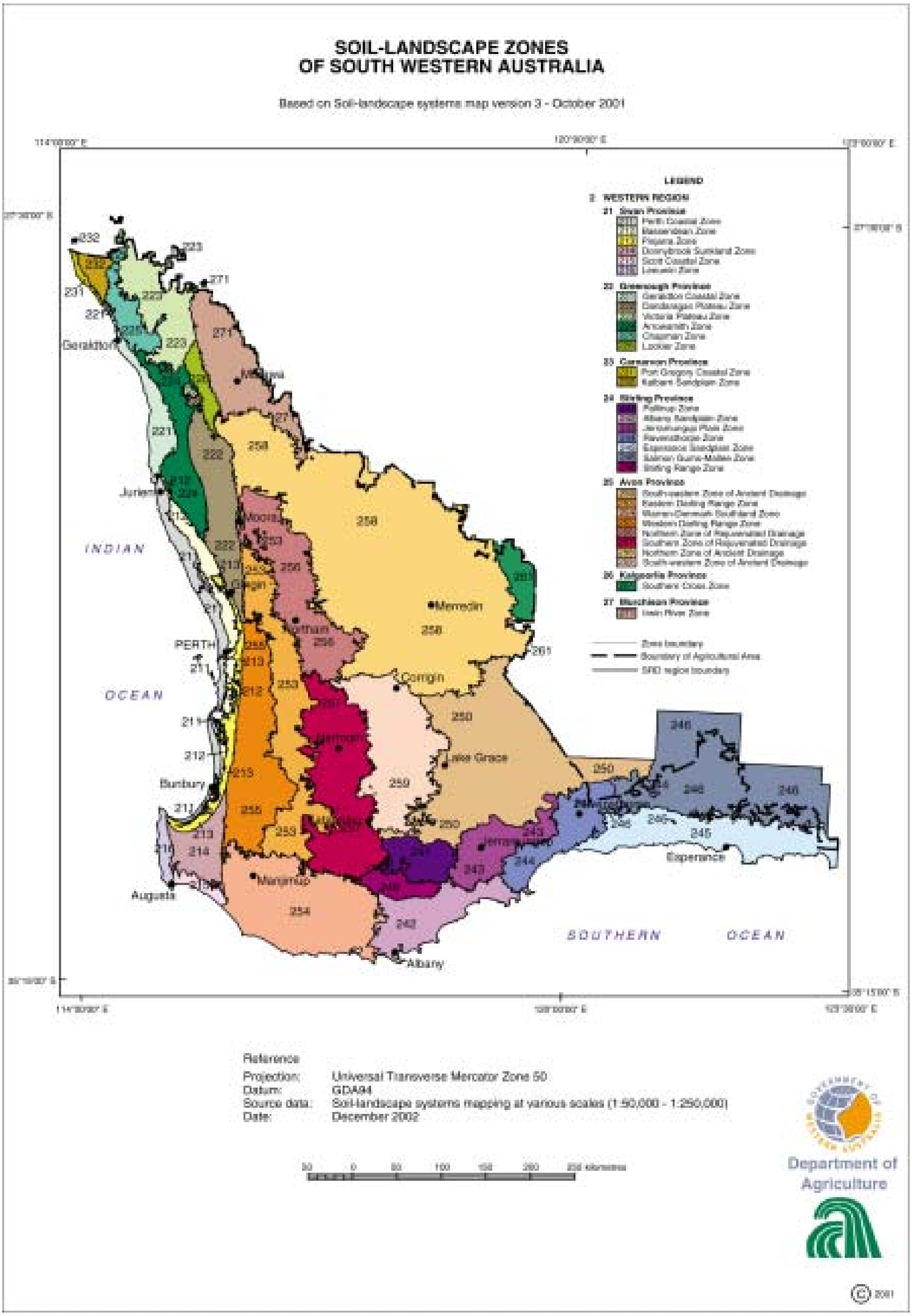

Figure 4. Soil-landscape zones in Western Australia

Table 1.5b. Soil groups in Western Australia

Code	Soil group name	Code	Soil group name
100	Wet or waterlogged soils supergroup	**460**	Sandy earths supergroup
101	Saline wet soil	**461**	Acid yellow sandy earth
102	Salt lake soil	**462**	Brown sandy earth
103	Semi-wet soil	**463**	Red sandy earth
104	Tidal soil	**464**	Yellow sandy earth
105	Wet soil	**465**	Pale sandy earth
200	Rocky or stony soils supergroup	**500**	Loamy duplexes supergroup
201	Bare rock	**501**	Acid shallow duplex
202	Calcareous stony soil	**502**	Alkaline grey shallow loamy duplex
203	Stony soil	**503**	Alkaline red shallow loamy duplex
300	Ironstone gravely soils supergroup	**504**	Grey shallow loamy duplex
301	Deep sandy gravel	**505**	Brown deep loamy duplex
302	Duplex sandy gravel	**506**	Red deep loamy duplex
303	Loamy gravel	**507**	Red shallow loamy duplex
304	Shallow gravel	**508**	Yellow/brown shallow loamy duplex
400	Sandy duplexes supergroup	**520**	Shallow loams supergroup
401	Alkaline grey deep sandy duplex	**521**	Calcareous shallow loam
402	Alkaline grey shallow sandy duplex	**522**	Red shallow loam
403	Grey deep sandy duplex	**523**	Red-brown hardpan shallow loam
404	Grey shallow sandy duplex	**540**	Loamy earths supergroup
405	Red deep sandy duplex	**541**	Brown loamy earth
406	Red shallow sandy duplex	**542**	Calcareous loamy earth
407	Yellow/brown deep sandy duplex	**543**	Friable red/brown loamy earth
408	Yellow/brown shallow sandy duplex	**544**	Red loamy earth
409	Reticulite deep sandy duplex	**545**	Yellow loamy earth
420	Shallow sands supergroup	**600**	Cracking clays supergroup
421	Calcareous shallow sand	**601**	Hard cracking clay
422	Pale shallow sand	**602**	Self-mulching cracking clay
423	Red shallow sand	**620**	Non-cracking clays supergroup
424	Yellow/brown shallow sand	**621**	Grey non-cracking clay
440	Deep sands supergroup	**622**	Red/brown non-cracking clay
441	Brown deep sand	**700**	Miscellaneous soils supergroup
442	Calcareous deep sand	**701**	Disturbed land
443	Gravelly pale deep sand	**702**	Water
444	Pale deep sand	**703**	No suitable group
445	Red deep sand	**704**	Undifferentiated soils
446	Yellow deep sand		

Table 1.5c. Soil group qualifiers

Code	Qualifier name and summary description
ACD	Good acid subsoil: Acid pH, well structured or permeable non-sodic subsoil
ALK	Good alkaline subsoil: Alkaline pH, well structured or permeable non-sodic subsoil
CAC	Acid subsoil
CLK	Alkaline subsoil
CLM	Clayey matrix: Clay loam to clay topsoil
CLY	Clay topsoil: Clay loam to clay topsoil
CNE	Neutral subsoil
DNR	Differentiation not required.
DSA	Deep sand: Sand to 80 cm
DSD	Deep sandy duplex: Sandy duplex 30-80 cm
DSK	Calcareous or alkaline sands: calcareous or alkaline sands
EDX	Effective duplex: Effective duplex. (Drainage barrier at 80-150 cm)
FSE	Fair sand, effective duplex: Fine sand throughout OR increasing to clayey or loamy sand below 30 cm, clay loam or clay 80-150 cm
FSR	Fair sand, rock substrate: Fine sand throughout OR increasing to clayey or loamy sand below 30 cm AND pan or rock <150 cm
FSV	Fair sand, very deep: Fine sand throughout OR increasing to clayey or loamy sand below 30 cm AND no pan or rock <150 cm
GRG	Gravelly subsurface, good subsoil: Gravelly below 15 cm with well structured, non-sodic clay subsoil
GRI	Coarse gritty sand: Coarse, gritty sand OVER rock 30-80 cm
GRP	Gravelly subsurface, poor subsoil: Gravelly below 15 cm AND poorly structured (often sodic) clay subsoil
GRV	Gravelly: Ironstone gravelly IN top 15 cm
GSA	Good sand topsoil, good acid subsoil: Clayey, loamy OR fine sand OVER acid pH, well structured or permeable non-sodic clay subsoil
GSE	Good sand, effective duplex: Clayey, loamy or fine sand OVER clay loam to clay at 80-150 cm
GSN	Good sand topsoil, good neutral subsoil: Clayey, loamy OR fine sand OVER neutral pH well structured or permeable non-sodic clay subsoil
GSP	Good sand topsoil, poor subsoil: Clayey, loamy OR fine sand OVER poorly structured, often sodic clay
GSR	Good sand, deep rock substrate: Fine OR clayey OR loamy sand (may contain some gravels) OVER rock or pan
GSV	Good sand, very deep: Clayey or loamy or fine sand BY 30 cm AND no pan or rock <150 cm
GSX	Good sand, permeable substrate: Clayey OR loamy sand OVER reticulite or permeable clay at 80-150 cm
GTR	Gritty sand, rock substrate: Gritty or coarse deep bleached sand OVER rock at 80-150 cm
GVR	Good sand, very shallow rock substrate: Dark sand OVER rock or cemented layer at <30 cm
GWK	Good sand, good alkaline subsoil: Clayey, loamy OR fine sand OVER alkaline pH well structured or permeable non-sodic clay subsoil at 30-80 cm
LCA	Loamy-calcareous: Loamy and calcareous
LDP	Loamy duplex: Loam OVER clay at 30-80 cm
LMM	Loamy matrix: Loamy matrix predominates

Code	Qualifier name and summary description
LMR	Loam, rock substrate: Loam OVER hardpan at 30-80 cm
LMY	Loam topsoil: Loamy surfaced soils (i.e. loamy earths)
LVR	Loam, very shallow rock substrate: Over rock or cemented layer @ <30 cm
NEU	Good neutral subsoil: Neutral pH AND well structured or permeable non-sodic subsoil
NSA	Non-saline: Non-saline
PEA	Peaty: Organic matter dominates (often sandy)
POE	Poor sand, effective duplex: Sand (texture lighter than clayey sand) for top 80 cm, OVER clay loam to clay @ 80-150 cm
PPS	Poor sand, poor subsoil: Coarse and medium sand OVER poorly structured (often sodic) subsoil
PSE	Poor sand, effective duplex: Coarse or medium sand dominant AND clay loam or clay <150 cm
PSR	Poor sand, deep rock substrate: Coarse or medium sand dominant AND pan or rock at depth
PSS	Poor subsoil: Poorly structured (often sodic) subsoil
PSV	Poor sand, very deep: Coarse or medium sand dominant AND no pan or rock <150 cm
PSX	Poor sand, permeable substrate: Sand (texture lighter than CS) for top 80 cm, OVER reticulite or permeable clay @ 80-150 cm
PVR	Poor sand, very shallow rock substrate: Pale sand OVER rock or cemented layer @ <30 cm
PWA	Poor sand, good acid subsoil: Coarse and medium sand OVER acid pH, well structured non-sodic subsoil
PWK	Poor sand, good alkaline subsoil: Coarse and medium sand OVER alkaline pH, well structured or permeable non-sodic subsoil @ 30-80 cm
PWN	Poor sand, good neutral subsoil: Coarse and medium sand OVER neutral pH, well structured or permeable non-sodic subsoil @ 30-80 cm
RET	Reticulite: Reticulite substrate @ 30-80 cm
RKD	Deep rock substrate: Over rock @ 80-150 cm
RKM	Rock substrate: Rock, hardpan or cemented layer @ 30-80 cm
RST	Rocky or stony: Rocky or stony throughout
SAC	Acid sand: Strongly acid within top 30 cm
SAL	Saline: Saline (ECe >400 mS/m)
SAM	Sandy matrix: Sandy matrix
SEA	Sandy earth: Sandy earth
SHL	Shallow loam: Loam OR clay OVER rock or cemented layer @ 30-80 cm
SHS	Shallow sand: Sand OVER rock or cemented layer @ 30-80 cm
SSD	Shallow sandy duplex: Sandy duplex <30 cm
SSS	Saline subsoil: Saline (ECe >400 mS/m) subsoil
TYP	Typical qualifier for zone: Typical qualifier for zone
UDF	Undifferentiated: Not yet differentiated
VDE	Very deep: No rock, clay or reticulite IN top 150 cm
VGR	Very gravelly: Majority with >60% gravel @ <80 cm
VSH	Very shallow rock substrate: Over rock or cemented layer @ <30 cm
WSS	Good subsoil: Structured, non-sodic, permeable subsoil

Only a subset of qualifiers applies to any given soil group. For Yellow deep sand (soil group 446) 12 qualifiers apply (see Table 1.5d). The qualifiers are ordered from most to least restrictive for plant growth. The UDF is only an interim step and the TYP is a typical value for the soil within the zone which provides a quick summary and fills gaps where surveys are still incomplete. In the longer term the typical value will be obsolete.

Table 1.5d. Soil group qualifiers for Yellow deep sand (soil group 446)

Qualifier	Order	Qualifier Description
TYP	-1	Typical qualifier for this soil group in this zone
UDF	0	Soil has not yet been differentiated
SAC	1	Sand is strongly acid (pH_w <5.6) at <30 cm
PSR	2	Sand is coarse or medium grained AND hardpan, cemented layer or solid rock at 80-150 cm
PSE	3	Coarse or medium sand is dominant AND clay loam to clay layer or soft coffee rock (but no solid rock or hardpan) at 80-150 cm
PSV	4	Sand is coarse or medium grained AND no hardpan, solid rock or clay layer above 150 cm
FSR	5	Fine sand to 80 cm OR sand increasing to clayey or loamy sand at >30 cm AND solid rock or hardpan at 80-150 cm
FSE	6	Fine sand to 80 cm OR sand increasing to clayey or loamy sand at >30 cm AND (clay loam to) clay layer (but no solid rock or hardpan) at 80-150 cm
FSV	7	Fine sand throughout OR sand increasing to clayey or loamy sand at >30 cm AND no hardpan, solid rock or clay layer above 150 cm
GSR	8	Clayey or loamy sand AND occurs at <30 cm AND hardpan, cemented layer or solid rock at 80-150 cm
GSE	9	Clayey or loamy sand AND occurs at <30 cm AND clay loam or clay layer (but no solid rock or hardpan) at 80-150 cm
GSV	10	Clayey or loamy sand AND occurs at <30 cm AND no hardpan, clay layer or solid rock above 150 cm

The model has been designed so that the definition of a qualifier can be varied in specific soil-landscape zones. The objective is to get a more succinct definition for a soil within a zone. This is briefly discussed under soil group layers (pp 22-25).

Table 1.5e. Landforms for zone land units ordered in a landscape catena, from the highest to lowest position in the landscape

Ord	Code	Name	Landform description
1	**SPL**	**Upland plain**	Extensive upland plain, commonly sandplain or gravelly upland flat.
2	**LRI**	**Low rise <2 m**	Discrete smooth convex rises (less than 2-3 m high) rising from the surrounding flats with generally <3% slope. Includes sandy rises on clayey substrates on valley floors.
3	**RIS**	**Rise >2 m**	Discrete smooth convex rises (in excess of 2-3 m high) rising from the surrounding flats with generally with very gentle slopes (gradients up to 3%). Includes sandy rises on clayey substrates on valley floors.
4	**RCR**	**Ridge crest**	Abrupt or peaked crests and divides, often including the upper slopes. Note: Broad, gentle divides and crests belong to the SL_1 category.
5	**SL_C**	**Crests and upper slopes <3%**	Crests and upper, and sometimes mid slopes <3%, that receive minimal run-off or seepage from upslope. Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
6	**CLI**	**Breakaway/cliff**	Short steep free scarp face including the summit, rock face and a short debris footslope. Covers lateritic breakaways as well as cliffs of granite, sandstone, limestone, etc.
7	**LSP**	**Landslip**	Area where mass movement has occurred – landslips, slumps, land slides etc. Includes both source area of soil loss and sink area of accumulated debris (***high land instability hazard***).
8	**ROC**	**Rock outcrop**	Areas with common rock outcrops, but bare rock is generally >3 m apart.
9	**SL30**	**Slopes >30%**	Upper, mid or lower slopes with steep gradients (>30%). Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
10	**SL15**	**Slopes 15-30%**	Upper, mid or lower slopes with moderate gradients (15-30%). Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
11	**SL10**	**Slopes 10-15%**	Upper, mid or lower slopes with moderate (10-15%). Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
12	**SL_5**	**Slopes 5-10%**	Upper, mid or lower slopes with gentle gradients (5-10%). Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
13	**SL_3**	**Slopes 3-5%**	3-5% slopes. Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium.
14	**SL_1**	**Slopes 1-3%**	Very gently sloping (1-3% gradients) slopes (<200 m long). Includes sand dune slopes as well as slopes formed on fresh rock, deeply weathered material and colluvium. **Note:** Longer slopes that will generate more run-off themselves belong to the SL_L category.
15	**SL_L**	**Long slopes 1-3%**	Long 1-3% slopes, >200 m long capable of generating their own run-off. Excludes sand dunes.
16	**HSC**	**Hillside scald**	Salt scald (bare surface with ***extreme surface salinity***) situated on a hillslope (gradient >3%)
17	**HSP**	**Hillside seep**	Areas on hillslopes (any gradient) where seepage is currently occurring (***moderate to very high waterlogging risk and nil to low salinity hazard***)
18	**HSPs**	**Hillside seep, salt risk**	As above, with ***moderate to high salinity hazard***.
19	**FOS**	**Footslopes <3%**	Lower slope with gradient of 1-3% subjected to seepage or run-on emanating from upslope. ***Nil to low salinity hazard****. Moderate to very high waterlogging risk.*
20	**FOSs**	**Footslopes <3%, salt risk**	As above, with ***moderate to high salinity hazard***.
21	**GID**	**Gilgai depression**	Gilgai depressions with different land qualities to the surrounding clay flat or floodplain.

Ord	Code	Name	Landform description
22	**GIDs**	**Gilgai depression, salt risk**	As above, with ***moderate to high salinity hazard***.
23	**FOW**	**Footslopes <3%**	Lower slope with gradient of 1-3% subjected to run-on emanating from upslope, but not subject to seepage. *Nil to low salinity hazard. Moderately well to rapidly drained.*
24	**FOWs**	**Footslopes <3%, salt risk**	As above, with ***moderate to high salinity hazard***.
25	**FPD**	**Poorly drained flat**	Plains and flats (lowland or upland with <2% gradients) with ***moderate to high waterlogging risk***. Often includes broad poorly defined drainage depressions (open or closed) not subject to flooding. ***Nil to low salinity hazard and nil flood hazard***.
26	**FPDs**	**Poorly drained flat, salt risk**	As above, with ***moderate to high salinity hazard***.
27	**FPP**	**Poorly drained floodplain**	Flat prone to inundation, waterlogging (***moderate to high waterlogging risk***) and irregular flooding (***low to high flood hazard***). Nil to low salinity hazard.
28	**FPPs**	**FPP, salt risk**	As above, with ***moderate to high salinity hazard***.
29	**FPW**	**Well drained floodplain**	Well drained (***nil to low waterlogging risk***) flats prone to irregular flooding (***low to high flood hazard***), typically the upper terrace of a river system.
30	**FPWs**	**FPW, salt risk**	As above, with ***moderate salinity hazard***.
31	**FWD**	**Well drained flat**	Plains and flats (lowland or upland with <2% gradient). ***Nil to low waterlogging risk***.
32	**FWDs**	**Well drained flat, salt risk**	As above, with ***moderate salinity hazard***.
33	**CDE**	**Well drained closed depression**	Moderately well to rapidly drained (***nil to low waterlogging risk***) closed depressions and dune swales. Typically concave, with gentle side slopes.
34	**DDW**	**Well drained drainage depression**	Long open depressions, subject to regular flooding (***moderate to high flood hazard***) but rarely inundated or waterlogged (***nil to low waterlogging risk***). Generally flat to smoothly concave cross-section rising to gently or very gently inclined side slopes. Also includes well drained low level terraces which flank major streams and rivers.
35	**DDWs**	**Well drained drainage depression, salt risk**	As above, with ***moderate salinity hazard***.
36	**DDP**	**Poorly drained drainage depression**	Long open depressions, subject to regular flooding (***moderate to high flood hazard***), inundation and waterlogging (***moderate to high waterlogging risk***). Typically poorly defined seasonal stream channels, generally flat to smoothly concave cross-section rising to gently or very gently inclined side slopes. Also includes poorly drained low level terraces which flank major streams and rivers. ***Nil to low salinity hazard***.
37	**DDPs**	**DDP, salt risk**	As above, with ***moderate to high salinity hazard***.
38	**STC**	**Stream channel**	Incised stream channel beds and narrow stream banks with yearly flooding (***high flood hazard***).
39	**STCs**	**STC, salt risk**	As above, with ***moderate to high salinity hazard***.
40	**SWM**	**Swamp**	Poorly drained closed depressions (***high to very high waterlogging risk***). Seasonal or permanent swamps, subject to long periods of inundation, often with peat accumulation. Nil to low salinity hazard.
41	**SWMs**	**Swamp, salt risk**	As above, with ***moderate to high salinity hazard***.
42	**SAS**	**Salt scald**	Flat, very gentle slope or depression with bare surface and ***extreme surface salinity.***
43	**SAL**	**Salt lake**	Salt lake.

Ord	Code	Name	Landform description
44	**SWL**	**Swale**	Narrow valley or dune swale. Concave, with moderate slopes and generally well drained. (Unless swales are small would usually be described as a combination of slopes.)
45	**SWLs**	**Swale, salt risk**	As above, with ***moderate salinity hazard***.
46	**BLO**	**Blowout**	Area of bare, mobile sand in a dune field, subject to wind erosion (***high land instability hazard***).
47	**FDH**	**High foredune**	Moderate to steep slopes (generally in excess of 10-15%) directly exposed to wind and salt spray of the ocean (***susceptible to salt spray***). Typically the seaward slopes of the first line of high sand dunes but can also include rocky headlands and slopes with sandy, loamy or clayey soils formed on bedrock.
48	**FDL**	**Low foredune**	Gentle to moderate slopes (generally less than 10-15%) directly exposed to wind and salt spray of the ocean (***susceptible to salt spray***). Typically the seaward slopes of the foredunes and small ridges and plains built up from wind blown sand, but can also include rocky headlands and slopes with sandy, loamy or clayey soils formed on bedrock.
49	**BCH**	**Beach**	Beach, situated to the seaward side of foredunes and subject to wave action (***high land instability hazard***).
50	**WAT**	**Water**	Open water – lakes, reservoirs, inlets, etc.
51	**DST**	**Disturbed land**	Any unnatural land surface suffering major disturbances due to human activity. Includes mine dumps, quarries, areas of landfill or extensive scraping and remoulding. **Note:** Not intended to include lesser disturbed areas such as cultivated or laser levelled paddocks or landslips and other types of mass movement.
52	**UDF**	**Undifferentiated**	Not differentiated.
53	**TYP**	**Typical**	Typical landscape position for WA Soil Group in zone (only for use with systems).

An example of a zone land unit from Tables 1.5a, b, c, e is 257.403.PSS.FPD. This land unit is found in the Zone of Rejuvenated Drainage (257). The soil is a Grey deep sandy duplex (403) with poorly structured, often sodic subsoil (PSS) on well drained flats (FPD). This land unit will share many characteristics and qualities with 257.403.PSS.SL10, the differences being due to the landform. As the latter land unit is the same soil on slopes with 10-15 per cent gradient (SL10) the risk of waterlogging will be greatly reduced, salinity risk would normally be negligible (hillside seeps are considered separately). However the water erosion hazard and phosphorus erosion hazard will be increased.

As an indication of the amount of land quality information in the current soil-landscape map unit database, there are approximately 110,000 polygons, with about 5,000 unique map units and also about 50 to 1,000 unique zone land units within 32 soil-landscape zones in the south west agriculture region. Within any given map unit there are between one and 20 or more of these unique zone land units used, but these land units may be shared between many map units within the zone. The model is very flexible as hundreds of thousands of unique combinations of land unit are possible, yet it is still possible to get attributes that do not fit a land unit neatly. An example is a few minor areas of naturally water repellent loamy soils, as normally only sandy soils become water repellent. In this case the unique map unit can be included in place of the soil-landscape zone code to create a map unit specific land unit.

1.6 Zone land unit attribution - land characteristics and land qualities

Because zone land units have landform and soil information (i.e. soil group and soil group qualifier), they can be attributed with land characteristics and land qualities. A land *characteristic* is an attribute of the land which can be measured or estimated and which can be employed as a means of describing land qualities (FAO 1983). A characteristic may influence several different qualities. For example the characteristic 'slope' influences the qualities 'waterlogging' and 'water erosion hazard'. As slope increases the degree of waterlogging is likely to decrease while water erosion hazard increases. *Land qualities* are 'those attributes of land that influence its capability for a specified use' (Wells and King 1989). Land qualities are used to determine capability. Because we have used a generic definition of land qualities, a characteristic can be synonymous with a land quality (Table 1.6a).

Each land characteristic and quality has a range of possible values. For example the range of values for the land quality water repellence is high, moderate, low and nil. Land qualities can be used alone to prepare degradation hazard maps such as phosphorus export hazard or wind erosion. They can also be combined to prepare *land capability* maps such as capability for horticulture or grazing. Land capability ratings tables for important agricultural land uses are described in Section 4.

Section 2 identifies 22 land qualities that are broadly applicable to land use and can be derived from existing survey information. Land qualities can apply to soil, soil and landform or landform only (see Table 1.6a). Appendix 1 identifies 16 land characteristics (see Table 1.6b).

Table 1.6a. Soil, soil and landform, and landform-related land qualities

	Land qualities	Soil-related	Soil and landform-related	Landform-related
19	Ease of excavation		✓	
20	Flood hazard			✓
18	Land instability		✓	
17	Microbial purification		✓	
12	pH at 20-25 cm and 50-80 cm[1]	✓		
7	Phosphorus export		✓	
10	Rooting depth		✓	
9	Salinity hazard		✓	
16	Salt spray exposure[1]			✓
13	Site drainage potential		✓	
22	Soil absorption ability		✓	
2	Surface soil structure decline	✓		
11	Soil water storage[1]		✓	
15	Soil workability		✓	
4	Subsurface acidification	✓		
3	Subsurface compaction	✓		
8	Surface salinity[1]	✓		
21	Trafficability		✓	
6	Water erosion hazard		✓	
1	Water repellence[1]	✓		
14	Waterlogging/inundation		✓	
5	Wind erosion hazard		✓	

Note: Most land qualities include some elements of soil and some of landscape. There is no clear cut division of land qualities which are purely soil-related and those which are influenced by landform. For example, soil water storage and microbial purification are ideally assessed as soil and landform qualities, but can be estimated as a soil only property where landform information is absent.

[1] Can also be considered to be land characteristics.

Table 1.6b. Soil, soil and landform, and landform-related land characteristics

	Land qualities	Soil-related	Soil and landform-related	Landform-related
1	Coarse fragments in profile	✓		
2	Depth of profile	✓		
3	Permeability	✓		
4	Rock outcrop			✓
5	Slope			✓
6	Stones and boulders in profile	✓		
7	Surface condition	✓		
8	Surface texture	✓		
10	Watertable depth		✓	
11	Organic carbon			
12	Phosphorus adsorption	✓		
13	Soil dispersion	✓		
14	Soil slaking	✓		
15a	Available water capacity	✓		
15b	Field capacity	✓		
15c	Wilting point	✓		
16	Bulk density	✓		

Climate

The relatively simple zone climate regions (Table 1.6c and Figure 5) described only use the Bureau of Meteorology 30-year mean (from 1961 to 1990) of average annual rainfall to estimate properties such as waterlogging risk and water erosion hazard. More detailed climate information can be used to improve the derived land qualities, though may be of limited value because of the scale of mapping available. Initially a simple relationship between zone and average annual rainfall is used, which is appropriate to the scale of the survey information. High (H) is >600 mm, Moderate (M) is 350-600 mm and Low (L) <350 mm. In the future better use of climate information is required to deal with issues such as seasonal variability and climate change and to undertake climate and soil-driven yield predictions of crops. An example of yield maps that are derived from conventional survey and climate information using a rainfall driven yield equation (e.g. French and Schultz 1984[10]) is summarised in Crop Updates 2004 (van Gool *et al.* 2004).

[10] This equation was developed for wheat but has been widely adopted for many other crops with fairly good results, even though these results have not always been quantified.

Table 1.6c. Average rainfall within soil-landscape zones

Zone	Mu_name	Rainfall
111	**Default zone**	**M**
211	Perth Coastal Zone	H
212	Bassendean Zone	H
213	Pinjarra Zone	H
214	Donnybrook Sunkland Zone	H
215	Scott Coastal Zone	H
216	Leeuwin Zone	H
221	Geraldton Coastal Zone	M
222	Dandaragan Plateau Zone	M
223	Victoria Plateau Zone	L
224	Arrowsmith Zone	M
225	Chapman Zone	M
226	Lockier Zone	M
231	Port Gregory Coastal Zone	M
232	Kalbarri Sandplain Zone	M
241	Pallinup Zone	M
242	Albany Sandplain Zone	M
243	Jerramungup Zone	M
244	Ravensthorpe Zone	M
245	Esperance Sandplain Zone	M
246	Salmon Gums-Mallee Zone	L
248	Stirling Range Zone	M
250	South-eastern Zone of Ancient Drainage	L
253	Eastern Darling Range Zone	M
254	Warren-Denmark Southland Zone	H
255	Western Darling Range Zone	H
256	Northern Zone of Rejuvenated Drainage	M
257	Southern Zone of Rejuvenated Drainage	M
258	Northern Zone of Ancient Drainage	L
259	South-western Zone of Ancient Drainage	M
261	Southern Cross Zone	L
271	Irwin River Zone	L
381	Ord temporary	H
999	Default value	M

Figure 5

Landform

Slope is critical to many of the assessments. Most existing surveys have been checked against slope maps generated using ERmapper™ software, based on the best available DEM to ensure that the mean slopes reported within a collection of mapping units are accurate (see the Land Monitor project on the internet at www.landmonitor.wa.gov.au/). Because mapping units share attribution there will be some variation of slopes within them. This could be overcome if detailed analyses make use of DEMs to evaluate slopes for each map unit. This is not needed for general assessments, but could be important when considering water movement, or issues related to water movement, such as water erosion or waterlogging.

Soil

Some level of quantification is slowly being introduced to improve soil type information, via the soil group and the soil group qualifier. Similar to the use of DEMs the relative proportions of soil groups can be checked to varying degrees against available soil profile site observations. Most survey samples have been collected using free survey techniques, which focus samples on areas where the surveyors initial guesses based on stereoscopic examination are incorrect. This means that samples are highly biased as they greatly over-represent small variations in the soils. Hence meaningful statistical analyses of the soil profile information in relation to the mapping are difficult. This means that the use of this information requires careful consideration so that incorrect conclusions are avoided.

New methods for increasing map accuracy

There is an increasing demand to use survey information well beyond the original intended purpose and published scale. The main problem is that, although a reasonable proportional allocation of soils within a mapping unit is possible, it is difficult to locate these soils accurately within a mapping unit. There have been a number of attempts to use models to locate or predict where soils will occur using a DEM (terrain analysis), Gamma ray spectrometry and other remotely-sensed information, environmental correlation and so forth. Most have had limited success over large areas because the best techniques vary in different regions. The rules for locating the soils vary spatially because of differences in geology, climate, vegetation, topography and land use history. (For explanation of the many techniques available see McKenzie *et al*. in prep.) This has caused problems for modellers who commonly attempt to use land resource survey information in a raster environment. Here they need to know which soil occurs in any given grid cell, but how do they do this when there may be many grid cells within a single map unit with a proportional allocation of soil and landform (as land units)? They can use the dominant soil – but in some cases this may only be 20 per cent of a map unit. They may use an average value, which becomes pretty meaningless when you have map units that contain everything from deep sands to heavy clay soils. For example you may have one map unit that covers an entire farm. This farm has a large amount of rocky and stony soils where nothing grows, and the remaining soil is the most productive in the district. However an average value for the map unit means that this farm appears to have lower productivity per hectare than is really the case, because the rocky areas are not used.

Our ability to predict soils in different parts of the landscape is improving, but the surveyors' observations plus local knowledge by people with soil-related training are usually still the best readily available estimate for many soil-landform properties. Hence subjective judgements are still used to improve the attribution associated with the zone land units described. As mentioned varying degrees of quantification are occurring so that there is a slow but gradual progression to better quantification of individual components (e.g. land characteristics or qualities). Some examples are the Land Monitor areas of low productivity land, which are used to predict areas of surface salinity, or DEMs which can be used for many purposes, including identification of slope classes. See www.landmonitor.wa.gov.au/. However it is unlikely that all the information in conventional surveys will be replaced in the foreseeable future.

Soil group layers

The soil properties for each zone, soil group and qualifier (the zone land unit) are summarised into four functional layers, to a depth of 2 metres for each soil group.

Table 1.6d. Soil layer properties

Layer No.	Zone land unit (soil-landscape zone, soil group, soil group qualifier)	Attribution of layers
1	Surface water repellence	At the surface
1	Surface condition	At the surface
1,2,3,4	Layer texture	Average value
1,2,3,4	Layer lower depth (cm)	Average value
1,2,3,4	Layer arrangement	Average value
1,2,3	Layer coarse fragments (%)	Average value
1,2,3	Layer stones (%)	Average value
1,2,3	Layer total organic carbon (%)	Average value
1,2,3	Layer pH (1:5 water)	pH ≥8 highest value pH ≤6 lowest value pH 6-8 use average value
1,2,3	Layer slaking code	Average value
1,2,3	Layer dispersion code	Average value
1,2,3	Layer Electrical Conductivity (mS/m)	Highest mean value within the layer
1,2,3	Layer exchangeable sodium (%)	Average value
1,2,3	Layer phosphorus retention index	Average value
1,2,3,4	Layer soil wetness code	Average value
?	Blank for further properties (e.g. aluminium)	

There is a set of default properties for each soil group and qualifier (Table 1.6d). However, the properties of similar soil groups can vary considerably between regions. For example, Grey sandy duplex soils usually have a loose surface near Esperance. In the central wheatbelt it is more common to find soft or even firm surfaces for Grey sandy duplex soils. This clearly has implications for the assessment of properties such as wind erosion hazard. Slowly, regional differentiation of soil information is being incorporated into the database. Ideally this is based on research work or measured properties. However observations by people with local knowledge are also included after review by a trained soil resource officer. The database entries include brief notes describing the source of the information. Because of the degree of uncertainty in spatially extrapolating soil-landscape properties (e.g. using 1:100,000 and 1:250,000 scale mapping) the default values are used unless there is quite a large[11] difference with recorded values for a soil-landscape zone.

[11] Large is a value judgement by an experienced person.

Relationship of functional layers to soil horizons

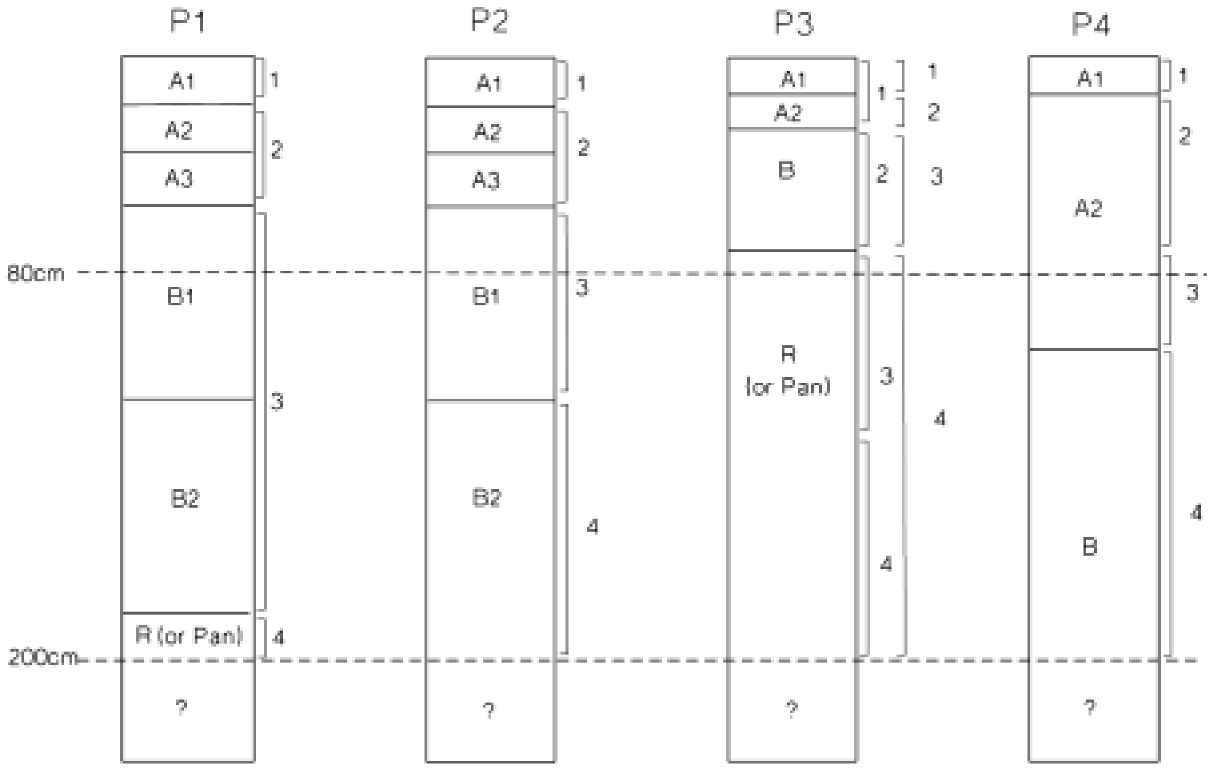

Figure 6. Relationship between functional soil layers and some hypothetical pedogenic[12] soil horizons

The 80 cm layer (see Figure 6) is a critical value used in Soil Group classification, because this is where the majority of crop roots occur. The depth of the soil group layers are selected to reflect the main changes in soil properties that affect crop roots, and can therefore impact on crop performance. Hence they can vary from the pedogenic soil horizons. A description of the layers is provided below.

Layer 1. The surface horizon is usually an A1 horizon. When the surface layer is only a few centimetres thick, the layer may be a combined A1 and A2/3 layer. Very shallow surface layers are common on sandy earths, e.g. see profile P3, which has two options for layer designation. The option selected will depend on the information available and the depth of the soil. For example 20 cm of soil over rock may have little agricultural significance due to restricted rooting depth, whereas 70 cm of soil has plenty of room for plant root development, hence the second option for layer designation may be selected.

Layer 2. The topsoil below the surface layer. It is usually an A2 or A3 horizon, though it can occasionally be a B horizon (again see profile P3). The lower depth of layer 2 is always less than 80 cm.

Layer 3. The subsoil is commonly a B (and usually a B2) horizon. However, this layer typifies the upper subsoil below the main texture change within the top 80 cm of the profile (hence the 80 cm line marked on Figure 6). If there is no texture change within 80 cm, as

[12] Layers that are relevant to how the soils formed.

often occurs in pale deep sand, layer 3 could be an A3 horizon, e.g. profile P4. It could also be a B1 horizon, as in profile P2, which could be a coloured sandy soil.

The size of layer 3 can vary considerably. See profiles P1 and P2. Because in P1 rock occurs at less than 2 m, it is assigned to layer 4. Hence the B1 and B2 horizons are grouped into layer 3.

Layer 4. The substrate occurs between 80 and 200 cm and is often a B3, C or D horizon, which could be sand, clay or rock.

Attribution of the layers

We currently have insufficient information to assign information to the soil layers below 2 m with any confidence. Some generic models for regolith depth are being explored.

Characteristics are estimated from available measured information (see Table 1.6d). Manual estimates are used because, although there are over 60,000 soil profile observations the number of detailed physical and chemical measurements are limited to only a few thousand records. Measurements are also unevenly distributed spatially. Two[13] major difficulties associated with soil profile data that make spatial extrapolation onto maps difficult are:

1. We know soil properties vary spatially, but some extensive regions have no measured laboratory data at all.

2. Most surveys are compiled using free survey techniques. Free survey focuses on where land is different and soils on typical or common land are assumed to be known, hence typical areas are sampled less frequently.

Clearly an average value from soil profile data can be misleading and manual adjustments by experienced soil survey staff are generally desirable when compiling soil layer data. Increasingly, remotely sensed information, such as satellite images, digital elevation models or radiometric data are also used to improve the information for some soil or landscape properties. However the relationship with soil layer data may still be difficult to ascertain and manual adjustments are still likely to be desirable for many uses.

[13] There are many other difficulties such as incomplete records, different analysis techniques, poor and missing geo-location, etc.