



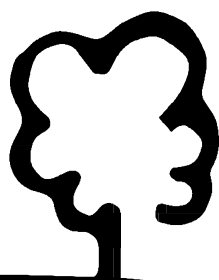
Department of Agriculture  
Government of Western Australia



# LAND EVALUATION STANDARDS FOR LAND RESOURCE MAPPING

Third edition

*Dennis van Gool, Peter Tille and  
Geoff Moore*



December 2005



## RESOURCE MANAGEMENT TECHNICAL REPORT 298

**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

**Dennis van Gool, Peter Tille and Geoff Moore**

December 2005

© State of Western Australia, 2005

## **DISCLAIMER**

The Chief Executive Officer of the Department of Agriculture and the State of Western Australia accept no liability whatsoever by reason of negligence or otherwise arising from use or release of this information or any part of it.



## CONTENTS

	Page
<b>WHY THIS REPORT HAS BEEN UPDATED .....</b>	<b>iv</b>
<b>1. INTRODUCTION .....</b>	<b>1</b>
1.1 Background .....	2
1.2 Accuracy and scale of land resource mapping .....	4
1.3 Terminology .....	9
1.4 Proportional mapping .....	9
1.5 Zone land units .....	10
1.6 Zone land unit attribution - land characteristics and land qualities .....	19
<b>2. ASSESSMENT OF LAND QUALITIES .....</b>	<b>26</b>
2.1 Ease of excavation .....	28
2.2 Flood hazard .....	29
2.3 Land instability hazard .....	30
2.4 Microbial purification .....	32
2.5 pH .....	33
2.6 Phosphorus export hazard .....	34
2.7 Physical crop rooting depth .....	36
2.8 Salinity hazard .....	38
2.9 Salt spray exposure .....	39
2.10 Site drainage potential .....	40
2.11 Soil absorption ability .....	43
2.12 Soil water storage .....	44
2.13 Soil workability .....	47
2.14 Subsurface acidification susceptibility .....	48
2.15 Subsurface compaction susceptibility .....	50
2.16 Surface salinity .....	51
2.17 Surface soil structure decline susceptibility .....	53
2.18 Trafficability .....	55
2.19 Water erosion hazard .....	56
2.20 Water repellence susceptibility .....	59
2.21 Waterlogging/inundation risk .....	61
2.22 Wind erosion hazard .....	66
<b>3. LAND CAPABILITY ASSESSMENT .....</b>	<b>70</b>
3.1 Land capability ratings tables .....	71
3.2 Land capability for annual horticulture .....	72

	<b>Page</b>
3.3 Land capability for perennial horticulture .....	75
3.4 Land capability for grazing .....	78
3.5 Land capability for dryland cropping .....	81
3.6 Land capability for septic tanks for rural residential development .....	85
3.7 Displaying capability ratings on maps .....	87
REFERENCES .....	90
ACKNOWLEDGEMENTS .....	95
Appendix 1. LAND CHARACTERISTICS .....	97
A1.1 Coarse fragments in profile .....	98
A1.2 Depth of profile .....	98
A1.3 Permeability .....	99
A1.4 Rock outcrop .....	101
A1.5 Slope .....	101
A1.6 Stones and boulders in profile .....	102
A1.7 Surface condition .....	102
A1.8 Soil texture .....	103
A1.9 Soil arrangement .....	104
A1.10 Watertable depth (to highest seasonal watertable) .....	105
A1.11 Organic carbon .....	106
A1.12 Phosphorus retention index .....	106
A1.13 Soil dispersion .....	106
A1.14 Soil slaking .....	107
A1.15 Available water capacity, lower and upper storage limits .....	107
A1.16 Bulk density .....	111
APPENDIX 2. SUITABLE SOILS FOR COMMERCIAL PINE PLANTATIONS ( <i>PINUS PINASTER</i> ) .....	112
APPENDIX 3. AVAILABILITY OF DIGITAL LAND RESOURCE SURVEYS (MAY 2005) .....	115
APPENDIX 4. LAND EVALUATION TERMINOLOGY .....	131

## 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](mailto:dvangool@agric.wa.gov.au)) or Peter Tille ([ptille@agric.wa.gov.au](mailto: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<sup>1</sup> 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<sup>2</sup> 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.

<sup>1</sup> Where areas of land are depicted by discrete mapping units.

<sup>2</sup> "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<sup>3</sup> 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.

---

<sup>3</sup> 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<sup>4</sup> prepared for the *Australian Natural Resources Atlas* ([audit.ea.gov.au/anra](http://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](http://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).

---

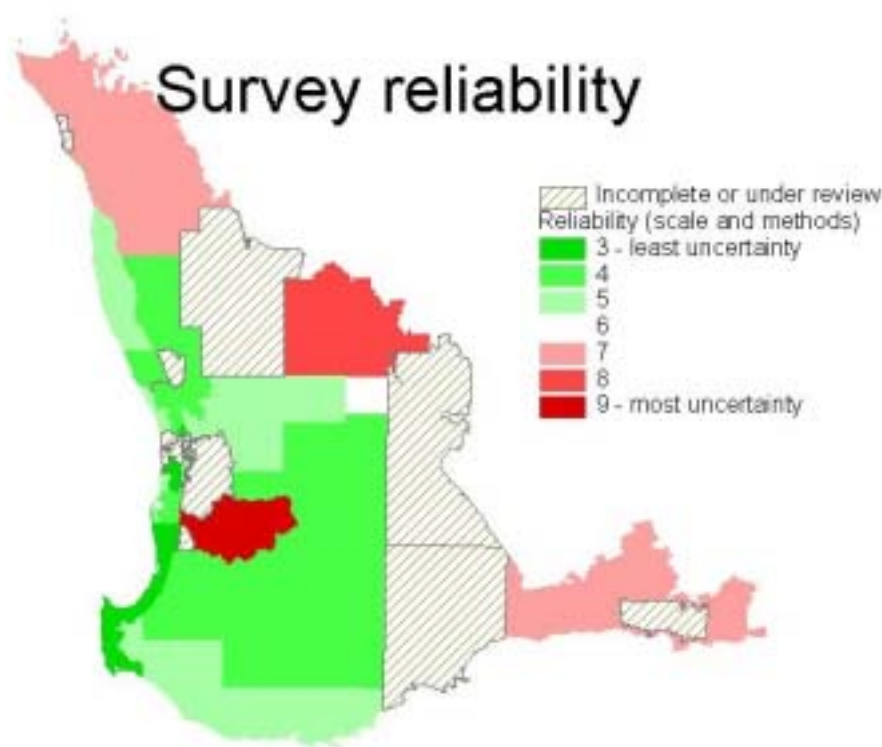
<sup>4</sup> To make it relevant to detailed local and regional planning. Currently it is only relevant to broad policies and some themes are suitable for "big picture" strategic plans.



## 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<sup>5</sup>. 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**

<sup>5</sup> 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	<ul style="list-style-type: none"> <li>• Detailed suitability for specific forms of land use</li> <li>• Intensive land use development (e.g. urban, horticulture, engineering uses)</li> <li>• Local urban structure planning</li> <li>• Detailed farm planning</li> <li>• Property development planning</li> </ul>
1:10,000-1:50,000 (high intensity) 1-25 ha	<ul style="list-style-type: none"> <li>• General suitability for various forms of land use</li> <li>• Strategic planning for intensive land use developments including urban and horticulture</li> <li>• 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)</li> <li>• Management plans for small catchments</li> <li>• Farm planning for low intensity agricultural uses</li> <li>• Forestry production areas</li> </ul>
1:25,000-1:100,000 (medium intensity) 6-100 ha	<ul style="list-style-type: none"> <li>• General suitability for various forms of land use</li> <li>• Planning for low intensity land uses such as dry land agriculture</li> <li>• Strategic planning for more intensive land uses such as urban and horticulture</li> <li>• 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)</li> <li>• Regional planning in areas with high development pressure</li> <li>• Management of medium catchments</li> <li>• General planning of forests</li> </ul>
1:50,000-1:150,000 (medium to low intensity) 25-225 ha	<ul style="list-style-type: none"> <li>• Broad suitability for major kinds of land use</li> <li>• Best suited for planning low intensity land uses such as dry land agriculture</li> <li>• Generally locating more intensive land uses such as urban and horticulture</li> <li>• Regional and local planning for predominantly rural shires</li> <li>• Management of large catchment areas</li> </ul>
1:100,000-1:250,000 (low intensity) 100-625 ha	<ul style="list-style-type: none"> <li>• Broad suitability for major kinds of land use</li> <li>• 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</li> <li>• Regional plans, planning for rural shires (particularly smaller wheatbelt and pastoral shires)</li> <li>• Overview of management issues for very large catchments</li> <li>• General planning for pastoral shires</li> </ul>
>1:250,000 (reconnaissance) >625 ha	<ul style="list-style-type: none"> <li>• Overview of land resources and their status</li> <li>• A general prediction of land resources in a given location</li> <li>• General planning for pastoral shire.</li> </ul>
>1:500,000 (overview) >2,500 ha	<ul style="list-style-type: none"> <li>• Overview of land resources and their status</li> <li>• General summaries of regional resources</li> <li>• National/regional resource inventory</li> </ul>

<sup>1</sup> Resolution based on 1 cm<sup>2</sup> 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<sup>2</sup> 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 deep 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.*

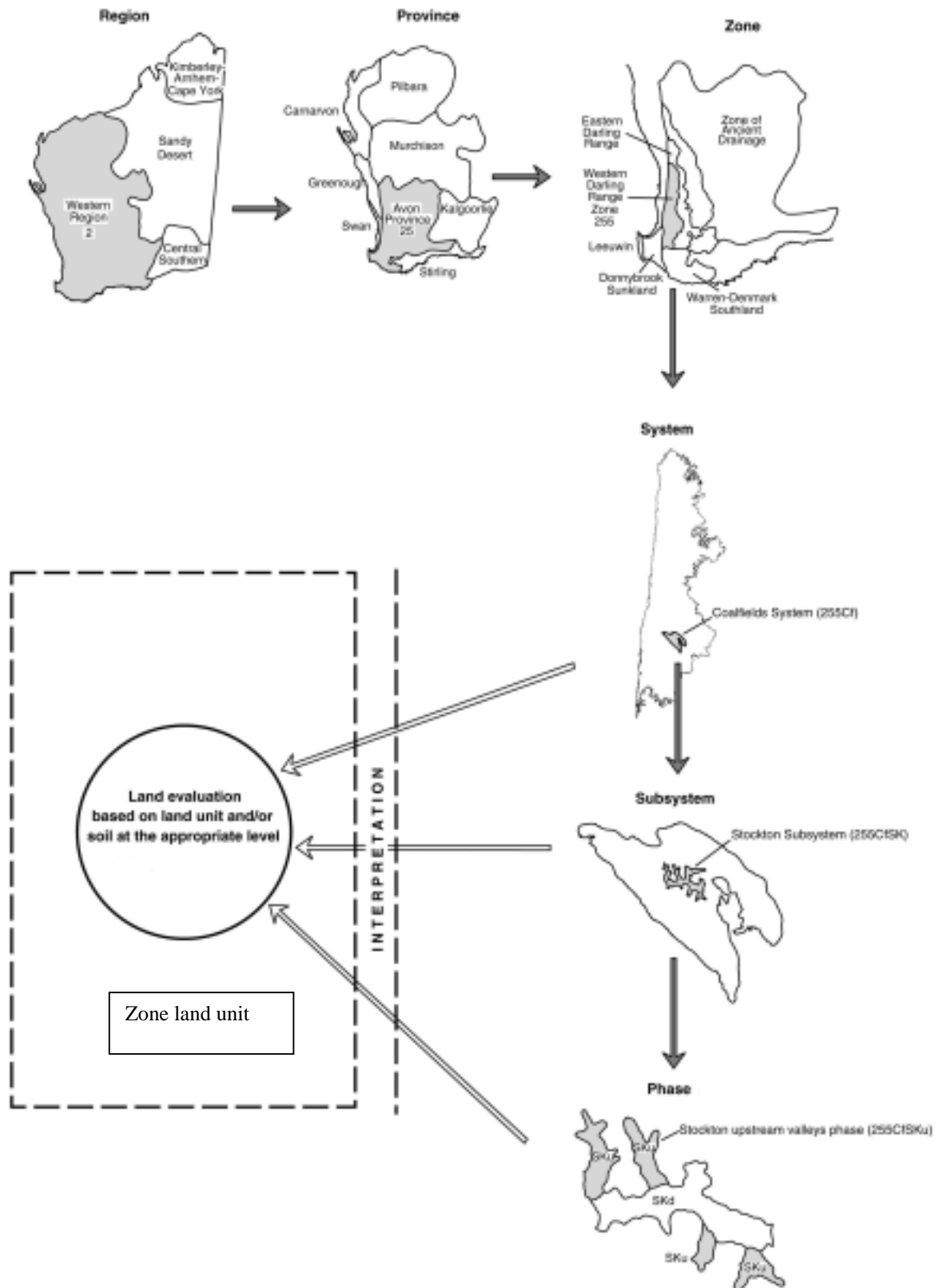
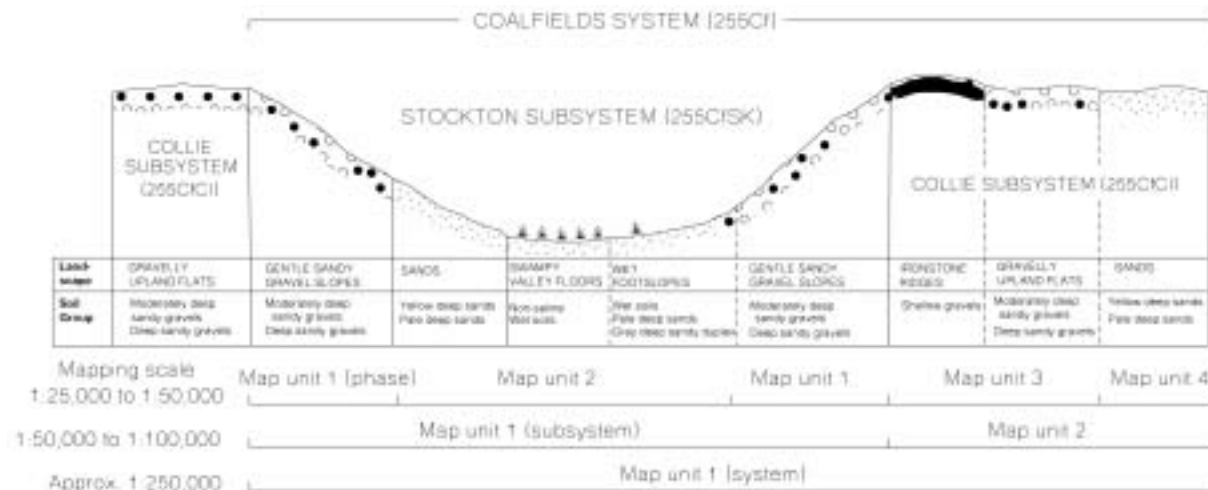


Figure 2. The map unit hierarchy and its relationship to zone land units (see Section 1.5)

### How scale affects map unit composition

Probably the most important information for conventional surveys<sup>6</sup> which use map units<sup>7</sup> 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).

<sup>6</sup> On digital maps these are called shapes or polygons.

<sup>7</sup> 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.<sup>8</sup>

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<sup>9</sup>

For displaying proportional mapping see Section 3.7.

<sup>8</sup> 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.

<sup>9</sup> 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

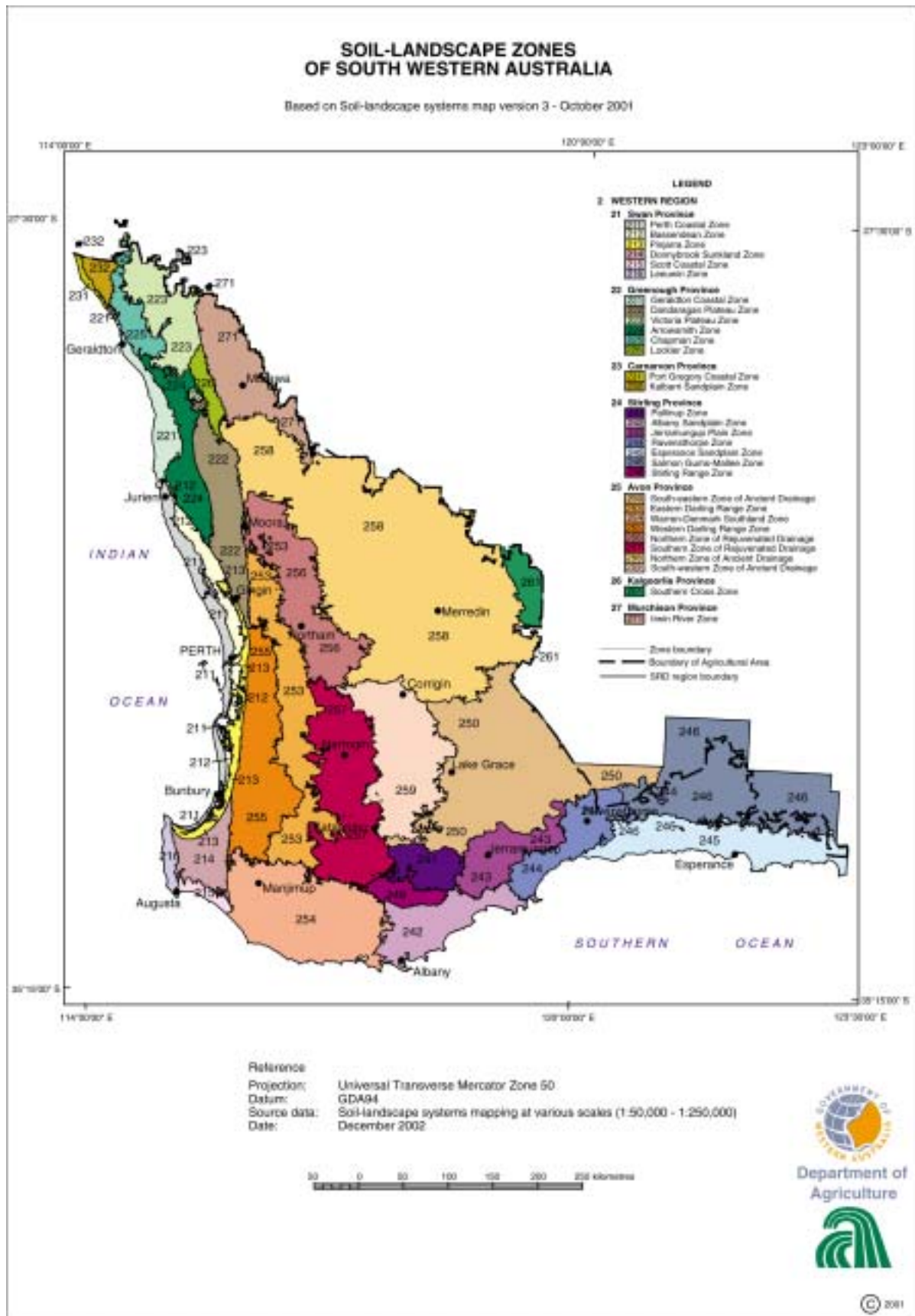


Figure 4. Soil-landscape zones in Western Australia



**Table 1.5b. Soil groups in Western Australia**

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

**Table 1.5c. Soil group qualifiers**

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

Code	Qualifier name and summary description
<b>LMR</b>	Loam, rock substrate: Loam OVER hardpan at 30-80 cm
<b>LMY</b>	Loam topsoil: Loamy surfaced soils (i.e. loamy earths)
<b>LVR</b>	Loam, very shallow rock substrate: Over rock or cemented layer @ <30 cm
<b>NEU</b>	Good neutral subsoil: Neutral pH AND well structured or permeable non-sodic subsoil
<b>NSA</b>	Non-saline: Non-saline
<b>PEA</b>	Peaty: Organic matter dominates (often sandy)
<b>POE</b>	Poor sand, effective duplex: Sand (texture lighter than clayey sand) for top 80 cm, OVER clay loam to clay @ 80-150 cm
<b>PPS</b>	Poor sand, poor subsoil: Coarse and medium sand OVER poorly structured (often sodic) subsoil
<b>PSE</b>	Poor sand, effective duplex: Coarse or medium sand dominant AND clay loam or clay <150 cm
<b>PSR</b>	Poor sand, deep rock substrate: Coarse or medium sand dominant AND pan or rock at depth
<b>PSS</b>	Poor subsoil: Poorly structured (often sodic) subsoil
<b>PSV</b>	Poor sand, very deep: Coarse or medium sand dominant AND no pan or rock <150 cm
<b>PSX</b>	Poor sand, permeable substrate: Sand (texture lighter than CS) for top 80 cm, OVER reticulite or permeable clay @ 80-150 cm
<b>PVR</b>	Poor sand, very shallow rock substrate: Pale sand OVER rock or cemented layer @ <30 cm
<b>PWA</b>	Poor sand, good acid subsoil: Coarse and medium sand OVER acid pH, well structured non-sodic subsoil
<b>PWK</b>	Poor sand, good alkaline subsoil: Coarse and medium sand OVER alkaline pH, well structured or permeable non-sodic subsoil @ 30-80 cm
<b>PWN</b>	Poor sand, good neutral subsoil: Coarse and medium sand OVER neutral pH, well structured or permeable non-sodic subsoil @ 30-80 cm
<b>RET</b>	Reticulite: Reticulite substrate @ 30-80 cm
<b>RKD</b>	Deep rock substrate: Over rock @ 80-150 cm
<b>RKM</b>	Rock substrate: Rock, hardpan or cemented layer @ 30-80 cm
<b>RST</b>	Rocky or stony: Rocky or stony throughout
<b>SAC</b>	Acid sand: Strongly acid within top 30 cm
<b>SAL</b>	Saline: Saline (ECe >400 mS/m)
<b>SAM</b>	Sandy matrix: Sandy matrix
<b>SEA</b>	Sandy earth: Sandy earth
<b>SHL</b>	Shallow loam: Loam OR clay OVER rock or cemented layer @ 30-80 cm
<b>SHS</b>	Shallow sand: Sand OVER rock or cemented layer @ 30-80 cm
<b>SSD</b>	Shallow sandy duplex: Sandy duplex <30 cm
<b>SSS</b>	Saline subsoil: Saline (ECe >400 mS/m) subsoil
<b>TYP</b>	Typical qualifier for zone: Typical qualifier for zone
<b>UDF</b>	Undifferentiated: Not yet differentiated
<b>VDE</b>	Very deep: No rock, clay or reticulite IN top 150 cm
<b>VGR</b>	Very gravelly: Majority with >60% gravel @ <80 cm
<b>VSH</b>	Very shallow rock substrate: Over rock or cemented layer @ <30 cm
<b>WSS</b>	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 ( $\text{pH}_w < 5.6$ ) 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 ( <b>high land instability hazard</b> ).
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. <b>Note:</b> 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 <b>extreme surface salinity</b> ) situated on a hillslope (gradient >3%)
17	HSP	Hillside seep	Areas on hillslopes (any gradient) where seepage is currently occurring ( <b>moderate to very high waterlogging risk and nil to low salinity hazard</b> )
18	HSPs	Hillside seep, salt risk	As above, with <b>moderate to high salinity hazard</b> .
19	FOS	Footslopes <3%	Lower slope with gradient of 1-3% subjected to seepage or run-on emanating from upslope. <b>Nil to low salinity hazard. Moderate to very high waterlogging risk.</b>
20	FOSs	Footslopes <3%, salt risk	As above, with <b>moderate to high salinity hazard</b> .
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 <b><i>moderate to high salinity hazard</i></b> .
23	FOW	Footslopes <3%	Lower slope with gradient of 1-3% subjected to run-on emanating from upslope, but not subject to seepage. <i>Nil to low salinity hazard. Moderately well to rapidly drained.</i>
24	FOWs	Footslopes <3%, salt risk	As above, with <b><i>moderate to high salinity hazard</i></b> .
25	FPD	Poorly drained flat	Plains and flats (lowland or upland with <2% gradients) with <b><i>moderate to high waterlogging risk</i></b> . Often includes broad poorly defined drainage depressions (open or closed) not subject to flooding. <b><i>Nil to low salinity hazard and nil flood hazard</i></b> .
26	FPDs	Poorly drained flat, salt risk	As above, with <b><i>moderate to high salinity hazard</i></b> .
27	FPP	Poorly drained floodplain	Flat prone to inundation, waterlogging ( <b><i>moderate to high waterlogging risk</i></b> ) and irregular flooding ( <b><i>low to high flood hazard</i></b> ). Nil to low salinity hazard.
28	FPPs	FPP, salt risk	As above, with <b><i>moderate to high salinity hazard</i></b> .
29	FPW	Well drained floodplain	Well drained ( <b><i>nil to low waterlogging risk</i></b> ) flats prone to irregular flooding ( <b><i>low to high flood hazard</i></b> ), typically the upper terrace of a river system.
30	FPWs	FPW, salt risk	As above, with <b><i>moderate salinity hazard</i></b> .
31	FWD	Well drained flat	Plains and flats (lowland or upland with <2% gradient). <b><i>Nil to low waterlogging risk</i></b> .
32	FWDs	Well drained flat, salt risk	As above, with <b><i>moderate salinity hazard</i></b> .
33	CDE	Well drained closed depression	Moderately well to rapidly drained ( <b><i>nil to low waterlogging risk</i></b> ) closed depressions and dune swales. Typically concave, with gentle side slopes.
34	DDW	Well drained drainage depression	Long open depressions, subject to regular flooding ( <b><i>moderate to high flood hazard</i></b> ) but rarely inundated or waterlogged ( <b><i>nil to low waterlogging risk</i></b> ). 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 <b><i>moderate salinity hazard</i></b> .
36	DDP	Poorly drained drainage depression	Long open depressions, subject to regular flooding ( <b><i>moderate to high flood hazard</i></b> ), inundation and waterlogging ( <b><i>moderate to high waterlogging risk</i></b> ). 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. <b><i>Nil to low salinity hazard</i></b> .
37	DDPs	DDP, salt risk	As above, with <b><i>moderate to high salinity hazard</i></b> .
38	STC	Stream channel	Incised stream channel beds and narrow stream banks with yearly flooding ( <b><i>high flood hazard</i></b> ).
39	STCs	STC, salt risk	As above, with <b><i>moderate to high salinity hazard</i></b> .
40	SWM	Swamp	Poorly drained closed depressions ( <b><i>high to very high waterlogging risk</i></b> ). 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 <b><i>moderate to high salinity hazard</i></b> .
42	SAS	Salt scald	Flat, very gentle slope or depression with bare surface and <b><i>extreme surface salinity</i></b> .
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 <b><i>moderate salinity hazard</i></b> .
46	BLO	Blowout	Area of bare, mobile sand in a dune field, subject to wind erosion ( <b><i>high land instability hazard</i></b> ).
47	FDH	High foredune	Moderate to steep slopes (generally in excess of 10-15%) directly exposed to wind and salt spray of the ocean ( <b><i>susceptible to salt spray</i></b> ). 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 ( <b><i>susceptible to salt spray</i></b> ). 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 ( <b><i>high land instability hazard</i></b> ).
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. <b>Note:</b> 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 <sup>1</sup>	✓		
7	Phosphorus export		✓	
10	Rooting depth		✓	
9	Salinity hazard		✓	
16	Salt spray exposure <sup>1</sup>			✓
13	Site drainage potential		✓	
22	Soil absorption ability		✓	
2	Surface soil structure decline	✓		
11	Soil water storage <sup>1</sup>		✓	
15	Soil workability		✓	
4	Subsurface acidification	✓		
3	Subsurface compaction	✓		
8	Surface salinity <sup>1</sup>	✓		
21	Trafficability		✓	
6	Water erosion hazard		✓	
1	Water repellence <sup>1</sup>	✓		
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.

<sup>1</sup> 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<sup>10</sup>) is summarised in Crop Updates 2004 (van Gool *et al.* 2004).

<sup>10</sup> 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/](http://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/](http://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 $\geq 8$ highest value pH $\leq 6$ 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<sup>11</sup> difference with recorded values for a soil-landscape zone.

<sup>11</sup> Large is a value judgement by an experienced person.

## Relationship of functional layers to soil horizons

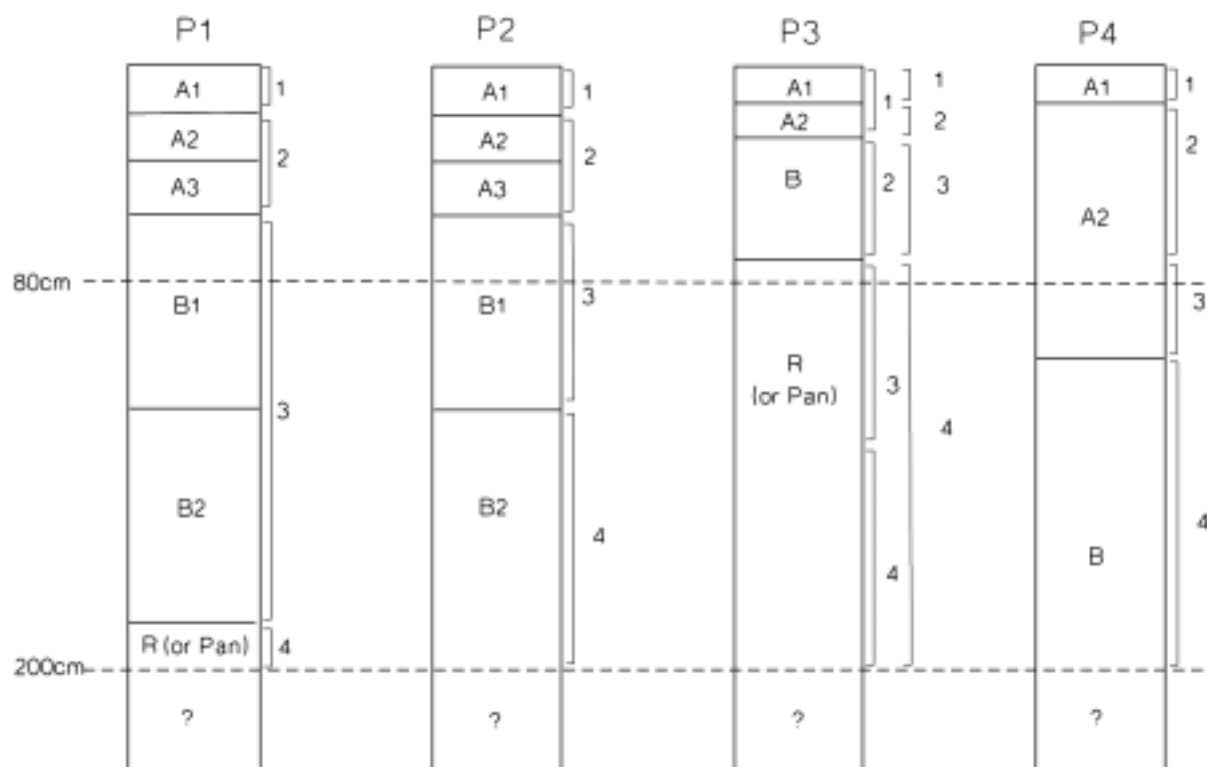


Figure 6. Relationship between functional soil layers and some hypothetical pedogenic<sup>12</sup> soil horizons

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

<sup>12</sup> 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<sup>13</sup> 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.

---

<sup>13</sup> There are many other difficulties such as incomplete records, different analysis techniques, poor and missing geo-location, etc.

## 2. ASSESSMENT OF LAND QUALITIES

This section describes how to assess 22 land qualities. It is difficult to develop a generic system for assessing land qualities which considers all variations in primary data. However, the scale of maps and the detail of associated field observations mean that more complex rules are difficult to justify. The assessment is expressly for establishing the best evaluation based on all available information.

As a general guide:

- Where a property is estimated e.g. soil water storage from texture and arrangement (see Appendix 1), soil depth and evidence of seasonal watertables, results should always be compared with any available measured values.
- Any derived map should be checked against field observations or other sources of complementary information such as DEMs, Landsat images or aerial photographs.

For example, if a map unit is rated as having low wind erosion hazard, but local knowledge strongly suggests that this is a common problem, the landscape position of the land unit might be incorrect or the underlying soil layer information might need adjustment, unless, of course, the higher than expected incidence was due to particularly poor management and not because the soils were inherently more susceptible.

**Table 2. Land quality code values**

Section	Description and code value	Sub-script	Acceptable codes (ratings)*
2.1	Ease of excavation (EXCAVA)	<b>x</b>	<b>H</b> (high), <b>M</b> (moderate), <b>L</b> (low), <b>VL</b> (very low)
2.2	Flood hazard (FLOODR)	<b>f</b>	<b>N</b> (nil), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.3	Land instability (INSTAB)	<b>c</b>	<b>N</b> (nil), <b>VL</b> (very low), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.4	Microbial purification (MI_PURE)	<b>p</b>	<b>VL</b> (very low), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.5a 2.5b	pH at 0-10 (PH0_10), 20 (PH20) and 50-80 (PH5080) cm depth	<b>zf</b> <b>zg</b>	<b>Vsac</b> (very strongly acid), <b>Sac</b> (strongly acid), <b>Mac</b> (moderately acid), <b>Slac</b> (slightly acid), <b>N</b> (neutral), <b>Malk</b> (moderately alkaline), <b>Salk</b> (strongly alkaline)
2.6	Phosphorus export hazard (PHOS_L)	<b>n</b>	<b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high), <b>VH</b> (very high) <b>E</b> (Extreme)
2.7	Rooting depth (URD)	<b>r</b>	<b>VS</b> (<15), <b>S</b> (<30), <b>MS</b> (30-50), <b>M</b> (50-80), <b>D</b> (>80), <b>VD</b> (>150) cm
2.8	Salinity hazard (SA_RIS)	<b>y</b>	<b>NR</b> (no hazard), <b>PR</b> (partial or low hazard), <b>MR</b> (moderate hazard), <b>HR</b> (high hazard), <b>PS</b> (saline land)
2.9	Salt spray exposure (SALTEX)	<b>zi</b>	<b>S</b> (susceptible), <b>N</b> (not susceptible)
2.10	Site drainage potential (SI_DRA)	<b>zh</b>	<b>R</b> (rapid), <b>W</b> (well), <b>MW</b> (moderately well), <b>M</b> (moderate), <b>P</b> (poor), <b>VP</b> (very poor)
2.11	Soil absorption (S_ABSOR)	<b>zj</b>	<b>H</b> (high), <b>M</b> (moderate), <b>L</b> (low), <b>VL</b> (very low)
2.12	Soil water storage (WA_STO)	<b>m</b>	<b>VL</b> (<35), <b>L</b> (35-70), <b>ML</b> (70-100), <b>M</b> (100-140), <b>H</b> (>140 mm/m for 0-100 cm <b>or</b> the rooting depth)
2.13	Soil workability (WORKAB)	<b>k</b>	<b>G</b> (good), <b>F</b> (fair), <b>P</b> (poor), <b>VP</b> (very poor)
2.14	Subsurface acidification susceptibility (SU_ACI)	<b>zd</b>	<b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high), <b>P</b> (presently acid)
2.15	Subsurface compaction susceptibility (SU_COM)	<b>zc</b>	<b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.16	Surface salinity (SALIN)	<b>ze</b>	<b>N</b> (nil), <b>S</b> , (slight), <b>M</b> (moderate), <b>H</b> (high), <b>E</b> (extreme)
2.17	Surface soil structure decline susceptibility (ST_DEG)	<b>zb</b>	<b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.18	Trafficability (TRAFIC)	<b>zk</b>	<b>G</b> (good), <b>F</b> (fair), <b>P</b> (poor), <b>VP</b> (very poor)
2.19	Water erosion hazard (WA_ERO)	<b>e</b>	<b>VL</b> (Very low), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high), <b>VH</b> (very high), <b>E</b> (extreme)
2.20	Water repellence susceptibility (WA_REP)	<b>za</b>	<b>N</b> (Nil), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
2.21	Waterlogging/inundation risk (WA_LOG)	<b>i</b>	<b>N</b> (nil), <b>VL</b> (very low), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high), <b>VH</b> (very high)
2.22	Wind erosion hazard (WI_ERO)	<b>w</b>	<b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high), <b>VH</b> (very high), <b>E</b> (extreme)

\* XX is the default NOT APPLICABLE value.

- Grey boxes indicate new land quality ratings in this edition.



## 2.1 Ease of excavation

This refers to the ease of excavating soil for building construction or earthworks, commonly from 30-150 cm deep. These earthworks relate to activities such as:

- levelling of building sites;
- installation of septic tanks and leach drains;
- shallow excavations for building foundations;
- deep ripping as preparation for tree crops, where soil preparation is deeper than normal cultivation depths (0-30 cm). For example, deep ripping may be used to break up subsoil pans or subsurface compaction layers (see land quality 3).

**Table 2.1. Ease of excavation (adapted from Wells and King 1989)**

Characteristic	Ease of excavation rating <sup>1</sup>			
	High (H)	Moderate (M)	Low (L)	Very low (VL)
<b>Depth to rock (cm)</b> <sup>2</sup>	Very deep (> 150 cm)	Deep (80-150 cm)	Moderately shallow to Moderate (30-80 cm)	Very shallow to Shallow (<30 cm)
<b>Slope (%)</b> <sup>3</sup> All soils except very deep sands	Flat to Moderate 1 (<15%)	Moderate 2 (15-30%)	Mixed (MX)	Steep (> 30%)
Very deep sands (>150 cm deep)	Flat to Gentle 2 (<10%)		Moderate 1 (10-15%)	Moderate 2 to Steep (>15%) and Mixed (MX)
<b>Stone within profile (% volume)</b> <sup>4</sup> (include cemented gravels)	Few to Common (<20%)	Many (20-50%)	Abundant (>50%)	-
<b>Rock outcrop (% surface area)</b> <sup>5</sup>	None (<2%)	Slight (2-10%)	Rocky to Very rocky (10-50%)	Rockland (>50%)
<b>Waterlogging risk</b> <sup>6</sup>	Nil to moderate	High	Very high	Very high <sup>7</sup>
<b>Surface condition and soil texture</b>	All coarse sand to clay loams, Non-hardsetting clays	Hardsetting clay or heavy clay	-	-
<b>Soil texture and arrangement within top 100 cm</b>	All coarse sand to clay loams, Moderate to well structured clays, Shrink-swell clays	Poorly structured clay or heavy clay layer present within top 100 cm	-	-

<sup>1</sup> Rating determined by the most limiting characteristic.

<sup>2</sup> See Appendix A1.2.

<sup>3</sup> See Appendix A1.5. Very deep sands on slopes are treated separately because of the risk of pit/batter collapse.

<sup>4</sup> See Appendix A1.6. 50 per cent by volume can be as much as 80 per cent by weight.

<sup>5</sup> See Appendix A1.4

<sup>6</sup> See Section 2.21

<sup>7</sup> Swampy areas with watertables at <30 cm for most of the year.

## 2.2 Flood hazard

Flooding is the temporary covering of land by moving flood waters derived from overflowing streams and/or run-off from adjacent slopes.

Flooding should ideally be assessed using specific purpose flood studies, however in the absence of this information soil-landscapes within zones give a reasonable estimate. The table only assesses flood frequency, and not the intensity, which varies depending on catchment size, surface hydrology and rainfall.

**Table 2.2. Assessment of flood hazard**

	Flood hazard rating			
	Nil (N)	Low (L)	Moderate (M)	High (H)
<b>Flood frequency return interval in years<sup>1</sup></b>	Nil	>10 (usually <100)	2-10	1
<b>Geomorphologic description/landform</b>	Flats above the flood limits and all other elevated areas.	Floodplains consisting of the high terraces of major rivers. Ill-defined drainage pathways associated with minor creeks and streams in low rainfall areas.	Well drained drainage depressions. Lower terraces of major rivers.	Stream channels, poorly drained drainage depressions and the immediate margins of major rivers.
<b>Most likely landform<sup>2</sup> units</b>				
High rainfall	FWD, FPD, etc.	FPW(s), SAL, SAS, SWM(s)	DDW	BCH, DDP(s), FPP(s), STC(s), WAT
Moderate rainfall	FWD, FPD, etc.	DDW, FPW(s), SAL, SAS, SWM(s)	DDP(s), FPP(s)	BCH, STC(s), WAT
Low rainfall	FWD, FPD, etc.	DDW, FPW(s), SAL, SAS, SWM(s), FPP(s)	DDP(s), STC(s)	WAT

<sup>1</sup> Refer to Water Authority flood studies (where available) which delineate land susceptibility to flooding and estimated flood frequency.

<sup>2</sup> See Table 1.5e.

## 2.3 Land instability hazard

Land instability assesses the potential for rapid movement of a large volume of soil. This includes mass soil movement through slope failure, shifting sand dunes, wave erosion and subsidence in karst topography (land underlain by caves).

Three factors are essential for landslips to occur (from Pilgrim and Conacher 1974):

- a threshold slope of 27 per cent;
- the presence of through-flow;
- a range of soil factors (that affect through-flow and shear strength).

Other factors that may need to be considered include:

- geological factors such as attitude of bedding planes relative to slope, rock fracture and shear zones, the nature of any clay minerals present in the weathered rock (and soil);
- topographic features such as proximity to cliff or scarp faces and the angle of repose of loose materials;
- climatic features such as the susceptibility to groundwater saturation of the regolith.

Table 2.3a is derived from slope instability hazard (Wells and King 1989) and land instability hazard (Tille and Lantzke 1990). It also considers karst topography, such as occurs on the limestone ridge of the Leeuwin-Naturaliste Coast where there are problems with subsidence and cave collapse (Tille and Lantzke 1990).

**Table 2.3a. Assessment of land instability hazard**

	Land instability rating				
	Nil (N)	Very low (VL)	Low (L)	Moderate (M)	High (H)
<b>Site description</b>	Gentle slopes <10%	Moderate slopes (10-27%) that shed water readily or where it is unlikely that significant seepage or through-flow will occur.	Moderate slopes (10-27%) where soil cover is relatively thin (<100 cm) and basement rock outcrop is common. Seepage or through-flow may occur. Steep (>27%) sand dunes where significant seepage or through-flow is unlikely.	Steep slopes (>27%), sloping valley headwaters and side slopes where significant seepage or through-flow is likely and/or colluvial material is deep. Areas underlain by caves.	Areas already subject to landslip or earth flows. Areas susceptible to wave erosion. Areas susceptible to sand dune movement (potential or actual). Areas known to be underlain by caves.

Alternatively, Tables 2.3b and 2.3c may be used to determine the land instability hazard of a land unit.

1. Using Table 2.3b, assign each land unit a score between 0 and 10 for each of the following factors: slope, soil depth, waterlogging risk and landform.
2. Add the scores together.
3. Determine the land instability hazard from the total instability score using Table 2.3c.

**Table 2.3b. Determining land instability scores**

	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>6</b>	<b>10</b>
<b>Slope<sup>1</sup></b>	Flat to gentle (<10%)	-	Moderate 1 (10-15%)	Moderate 2 (15-27%)	Steep (>27%)	-
<b>Soil depth<sup>2</sup></b>	Very deep (>150 cm)	Deep (150-100 cm)	Very shallow to Moderate (<100 cm)	-	-	-
<b>Waterlogging<sup>3</sup></b>	Nil (N)	Very low to Low (VL-L)	Moderate (M)	High to Very high (H-VH)	-	-
<b>Landform<sup>4</sup></b>	All other landforms	-	-	-	-	BCH, BLO, FDH, LSP, STC

<sup>1</sup> See Appendix A1.5.

<sup>2</sup> See Appendix A1.2.

<sup>3</sup> See Section 2.21.

<sup>4</sup> See Table 1.5e.

**Table 2.3c. Assessing land instability land instability score derived from Table 2.3b**

	<b>Land instability rating</b>				
	<b>Nil (N)</b>	<b>Very low (VL)</b>	<b>Low (L)</b>	<b>Moderate (M)</b>	<b>High (H)</b>
<b>Total score</b>	<3	3-4	5-6	7-9	>9

## 2.4 Microbial purification

Microbial purification relates to the ability of soil used for septic effluent disposal to remove micro-organisms which may be detrimental to public health. It is essentially a measure of the permeability and aeration within a soil profile, which influences its ability to:

- remove undesirable micro-organisms from septic effluent;
- provide suitable conditions for the oxidation of some organic and inorganic compounds added to the soil as effluent.

This attribute will be influenced by the time of travel through the soil profile which in turn is related to the size and distribution of pore spaces and the depth to watertable or an impermeable layer. Important soil characteristics include permeability, depth, particle size and the clay and/or organic matter content.

**Table 2.4. Microbial purification conditions (adapted from Wells 1987)**

Permeability of most limiting layer (Saturated hydraulic conductivity) <sup>1</sup>	Microbial purification rating			
	Very low (VL)	Low (L)	Moderate (M)	High (H)
<b>A. Very slow to Slow</b> (<5 mm/h. Drainage time weeks to months) Includes shallow gravels, sands and loams and other soils overlying bedrock or impermeable pans, many clays and sandy and loamy duplexes with poorly structured subsoils <sup>3</sup>	<0.5 m to impermeable layer or watertable <sup>3</sup> or slope >30% <sup>2</sup>	>0.5 m to impermeable layer or watertable <sup>3</sup> or slope 15-30% <sup>2</sup>	-	-
<b>B. Moderately slow to Moderately rapid</b> (5-130 mm/h. Drainage time days) Includes most many Loamy earths, Sandy earths, Sandy and Loamy duplexes with well structured subsoils.	<0.5 m to impermeable layer or watertable <sup>3</sup>	0.5-1.5 m to impermeable layer or watertable <sup>3</sup> or slope >30% <sup>2</sup>	1.5-2 m to impermeable layer or watertable <sup>3</sup> or slope 15-30% <sup>2</sup>	>2 m to impermeable layer or watertable <sup>3</sup>
<b>C1. Rapid to Very rapid</b> (>130 mm/h. Drainage time hours) for all soils except Calcareous deep sands, Pale deep sands and Gravelly pale deep sands. Includes very deep Brown, Red and Yellow deep sands.	<0.8 m to impermeable layer or watertable <sup>3</sup>	0.8-2 m to impermeable layer or watertable <sup>3</sup>	>2 m to impermeable layer or watertable <sup>3</sup>	-
<b>C2. Rapid to Very rapid</b> for Calcareous deep and shallow sands, Pale deep and shallow sands and Gravelly pale deep and shallow sands and Poor or gritty brown deep and shallow sands and poor or gritty yellow deep and shallow sands.	<5 m to impermeable layer or watertable <sup>3</sup>	>5 m to impermeable layer or watertable <sup>3</sup>	-	-

<sup>1</sup> See Appendix A1.3.

<sup>2</sup> When these soils occur on steep slopes lateral seepage may intercept the surface and result in ineffective purification.

<sup>3</sup> Depth to rock, poorly structured/massive clay or seasonal watertable if known (see A1.2 and A1.10).

## 2.5 pH

The pH of a soil measures its acidity or alkalinity. In acid soils pH is a useful surrogate for aluminum toxicity, while in alkaline soils high pH can indicate the presence of calcium carbonate, high sodicity or the presence of toxic compounds like sodium carbonate (for more information see Moore *et al.* 1998a, Scholz and Moore 1998).

The standard method for measuring pH in WA is 1:5 0.01M CaCl<sub>2</sub> (pH<sub>Ca</sub>). However, in most land resource surveys it has been measured in a 1:5 soil:water suspension (pH<sub>w</sub>). It is preferable to record actual data rather than derived data, therefore pH should be recorded according to the method used. The pH measured using different methods should not be compared directly for site investigations. For general land interpretation purposes, the relationship between pH<sub>w</sub> and pH<sub>Ca</sub> can be estimated by the equation:

$$\text{pH}_{\text{Ca}} = 1.04 \text{ pH}_{\text{w}} - 1.28 \text{ (Brennan et al. 1997).}$$

The most widely available pH measurement is for the surface layer. However, the pH of the topsoil varies dramatically, and based on a comparison of map unit and soil profile data, estimated mean values for topsoil pH is commonly underestimated. Hence it is suggested that only an estimate of subsoil pH should be attempted. Even for subsoil the value can only be used as an indicator because pH varies dramatically with land use and minor soil variations.

### Soil depth

The pH should be recorded for each soil group layer (see Section 1.6 and Figure 6). It is then reported at the following predefined depths:

- 0-10 cm (the surface layer);
- 20 cm (used for assessing subsoil acidity);
- 50-80 cm. If there is a layer boundary within this depth use the higher value (used for assessing subsoil alkalinity).

**Table 2.5. General pH ratings for land interpretation**

	Soil pH rating						
	Very strongly acid (Vsac)	Strongly acid (Sac)	Moderately acid (Mac)	Slightly acid (Slac)	Neutral (N)	Moderately alkaline (Malk)	Strongly alkaline (Salk)
pH <sub>w</sub>	< 5.3	5.3-5.6	5.6-6.0	6.0-6.5	6.5-8.0	8.0-9.0	> 9.0
pH <sub>Ca</sub>	< 4.2	4.2-4.5	4.5-5.0	5.0-5.5	5.5-7.0	7.0-8.0	> 8.0

## 2.6 Phosphorus export hazard

Eutrophication and corresponding algal blooms are a worldwide problem for waterways and bodies of water such as wetlands, lakes and estuaries. Nitrogen (N) and phosphorus (P) are both essential for plant growth. However, as N is more difficult to control and because some algae (e.g. nodularia) can utilise atmospheric N, P is commonly targeted as the limiting nutrient for algal growth.

Phosphorus export hazard refers to the likelihood that P (usually applied as fertiliser), moves from a given land unit to where it can contribute to eutrophication of surface water. The phosphorus can move either dissolved in water or attached to soil particles. This quality does not consider movement into deep groundwater, which is more commonly associated with nitrogen.

Phosphorus movement through the landscape is influenced by many factors. In addition to the soil and landform, many other factors such as catchment size, drainage density and/or proximity to drains, rainfall/run-off, climate and the presence or absence of vegetation affect movement and should be considered. (A large, but not exhaustive list is provided in Weaver and Summers 1998.)

Dominant factors in most situations include total water flow, time of travel and catchment size, hence water movement factors influence P export because when water moves rapidly contact time between soil particles and P is insufficient for sorption (Summers *et al.* in prep.).

Soil characteristics such as Phosphorus Retention Index (PRI) are of secondary importance because even at low PRI values P is rapidly bound (i.e. adsorbed and/or fixed) in the topsoil for most soil types. Where P is bound to the topsoil, water erosion becomes the main mechanism of export. P is also lost through wind erosion, but this is usually associated with declining soil fertility rather than with eutrophication.

PRI assumes greater importance in uniform sands, because if water moves rapidly, contact time between soil particles and P may be insufficient for sorption to occur. Hence uniform sands are assessed separately. Bleached or pale sandy soils are extensive in many coastal areas in WA.

Table 2.6 estimates the inherent susceptibility of a land unit to export phosphorus. The rating is decided by the most limiting factor. For land use planning or management, the issue is not really where P is lost but what and where detrimental impacts occur. It is not possible to determine this from land quality information alone.

**Table 2.6. Assessing susceptibility of land units to phosphorus export from the most limiting factor**

Soil property	Phosphorus export hazard rating				
	Low (L)	Moderate (M)	High (H)	Very high (VH)	Extreme (E)
<b>Assess for all soils</b> Water erosion hazard <sup>1</sup>	Low	Moderate	High	Very high	Extreme
Flood hazard <sup>2</sup>	Low	Moderate	Moderate (for highly erodible soils)	High	High (for highly erodible soils)
Landform <sup>3</sup>	All other areas	FOS(s), FPD(s), HSC, HSP(s) <sup>4</sup>	DDW, SWM(s) <sup>4</sup>	DDP(s), FPP(s)	STC
<b>Assess for uniform sands or soil with Rapid to Very rapid profile permeability only</b> (X1) Depth to highest seasonal watertable <sup>5</sup> for sands with low phosphorus retention index (PRI ≤2 <sup>6</sup> at 0-150 cm). Subsoils are pale throughout (e.g. Munsell value/chroma 8/4, 7/2 or paler).		>5 m	2-5 m	1-2 m	<1 m
(X2) Depth to highest seasonal watertable <sup>5</sup> for sands with low phosphorus retention index (PRI 2-5 <sup>6</sup> at 0-80 cm). Subsoils are pale throughout.	>5 m	2-5 m	1-2 m	<1 m	<0.5 m
(Y) Depth to highest seasonal watertable <sup>5</sup> for sands with moderate to high phosphorus retention index (PRI >5, 0-80 cm). Subsoil colour and textures increase with depth (e.g. Munsell value/chroma 8/6, 7/3 or darker).	>2 m	0.8-2 m	<0.8 m	<0.5 m	<0.2 m

<sup>1</sup> See Table 2.19c.<sup>2</sup> See Table 2.2.<sup>3</sup> See Table 1.5e.<sup>4</sup> Swamps may be downgraded to low or moderate hazard where drainage from the swamp (e.g. saturation flows) are unlikely. Hillside seeps may be downgraded to low if they usually occur far from any drainage lines.<sup>5</sup> See Appendix A1.10.<sup>6</sup> Allen and Jeffery (1990) recommend a low value for phosphorus retention index of <5. This is supported by Summers *et al.* (1996) that indicates 30 per cent of phosphorus applied may be lost from soils with PRI = 4. PRI <5 is recommended as the cut off when considering intensive land use developments. A low value of PRI <2 is sometimes used as the cut off value for less intensive (agricultural) developments. See Appendix A1.12.



## 2.7 Physical crop rooting depth

Rooting depth is the depth to the layer within the soil where the growth and penetration of the majority of plant roots are restricted. This assessment of rooting depth considers the physical restrictions including the presence of watertables. It excludes chemical restrictions which can be detected using other land qualities. It is a general classification aimed at annual crops. The depth to a seasonal watertable (imperfectly or poorly drained areas) is particularly variable between seasons and soil types. The rooting depth is assumed to be at the lower depth of the seasonal watertable (saturated for less than three months), or any depth that restricts rooting, e.g. clay, pan or gravel.

This land quality appears to be of limited value for deep rooted perennial plants because there is an extremely wide variation in the depth of root growth between plant species and also in their tolerance of different soil physical conditions. There is very limited information about how the physical (and chemical) properties in the deeper subsoil or regolith layers are spatially distributed and the effect this has on rooting conditions.

**Method:** Each soil layer is assessed as to whether it meets all the non-limiting criteria (Table 2.7a). If one or more limiting properties are present then the rooting depth is where the restriction occurs. Note that many layers are not completely impenetrable, or the degree of penetration decreases with depth. For example, in a shallow sand with 40 cm of sand directly overlying granite the roots will be restricted at 40 cm giving an rooting depth of moderately shallow (MS). In contrast, in a duplex soil with 40 cm sand over sodic clay, significant root penetration may occur to a depth of 70 cm, resulting in moderate (M) rooting depth. It is always a good idea to look for evidence of root penetration and evidence of crop health to help confirm limiting criteria.

**Table 2.7a. Assessment of limiting values for rooting depth**

Soil property	When to assess	Non-limiting value	Limiting value
<b>Depth to watertable (&gt;3 months)<sup>2</sup></b>	All soils	Nil, low or very low risk of waterlogging.	Very high waterlogging is always limiting. For areas with moderate to high waterlogging, root growth is generally limited to the lower depth of the seasonal watertable (saturated for >3 months) or depth to the impermeable layer.
<b>Clayey subsoils</b>	Clay content >30% in subsoil (i.e. soil texture is CL, C, or HC)	Porous, earthy soils or moderate to strongly pedal subsoils with a granular, sub-angular blocky, polyhedral, angular blocky (<50 mm) structure.	Subsoils with a columnar or prismatic (>100 mm) subsoil and massive or weakly pedal subsoils that are not porous <sup>3</sup> . As a general guideline, assume that roots will penetrate 30 cm into these clays.
<b>Pans and other hard layers</b>	All layers	Weathered or fractured pans which roots can penetrate.	Presence of ferricrete and other cemented pans, saprolite or bedrock.
<b>Coarse fragments (% volume)</b>	All layers	<70% <sup>4</sup>	>70% <sup>4</sup>

<sup>1</sup> See Table 2.5 as a guide. Strongly alkaline soils can often contain sodium carbonate or high levels of exchangeable sodium (high ESP).

<sup>2</sup> See Table 2.21d as a guide to watertable depth.

<sup>3</sup> In clays or duplex soils look for evidence of root penetration as roots may penetrate into the clay layer, below where the initial texture contrast is observed.

<sup>4</sup> 70% by volume may be up to 90% (or more) by weight.

**Table 2.7b. Assessment of limiting values for rooting depth**

	Rooting depth rating					
	Very shallow (VS)	Shallow (S)	Moderately shallow (MS)	Moderate (M)	Deep (D)	Very deep (VD)
<b>Depth to root restricting layer</b>	<15 cm	15-30 cm	30-50 cm	50-80 cm	80-150 cm	>150 cm

## 2.8 Salinity hazard

This refers to the hazard of the land being affected by salinity in the future. It considers the maximum extent of saline land likely to develop given present land uses, clearing patterns and management practices. It is an estimate of the extent of salinisation when the water balance reaches a new (post-clearing) equilibrium (see also Section 2.16). McFarlane *et al.* (2004) report an estimate of over 5.4 million hectares in the south-west of Western Australia that have the potential to be affected by salinity in the future.

An accurate estimate of salinity risk is difficult because watertable rise is affected by climate, land use (vegetation), soil-landforms, hydrology and geology. This also has to be compared with current salinity information.

Estimating the extent of rising watertables on valley floors or drainage depressions is reasonably accurate. However, estimating the future extent of saline seeps, where groundwater is forced to the surface by bedrock highs or in areas with dissected or variable depth regolith is more difficult. Hence the accuracy of assessing salinity hazard will vary depending on the land units being assessed.

A general estimate of salinity hazard can be made using Table 2.8a (for more information see Moore 1998b). Table 2.8b provides an indication of the likely salinity hazard for different landforms according to rainfall. Ideally salinity risk should be refined using additional information. (See Land Monitor on the internet at [www.landmonitor.wa.gov.au/](http://www.landmonitor.wa.gov.au/).)

**Table 2.8a. General estimate of salinity hazard**

Salinity hazard rating				
No hazard <sup>1</sup> (NR)	Partial or low hazard <sup>1</sup> (PR)	Moderate hazard (MR)	High hazard (HR)	Presently saline (PS)
High positions in the landscape such as upland deep lateritic residuals, elevated coastal dunes, etc. Salinity will not develop because of the elevated position, low watertables, high permeability and/or the low salt store in the regolith.	Areas with small variation in local relief and geology where rising watertables may not affect all the land area, or where rising watertables are not presently saline, and the salt store in the regolith is low. Examples include areas on the Swan Coastal Plain, where watertables are at equilibrium but there is seasonal variation, or variation due to management in salinity levels.	Moderate hazard from deeper saline groundwater with a rising trend.  Often refers to land with rising watertables immediately adjacent to saline land but with slightly higher relief, or slightly better drainage. Examples include some low relief plains or the outer margins of valley floors.	Salinity already present in limited areas or high hazard from shallow saline groundwater that is close to the surface with a rising trend.  Often refers to land with rising watertables immediately adjacent to saline land with similar relief. Examples include very low relief plains or valley floors.	All areas where salinity status is moderate, high or extreme <sup>2</sup> (ECe >400 mS/m). Includes land units with Saline wet soils and Salt lake soils.

<sup>1</sup> No hazard or partial hazard areas can include smaller undulations or sandy rises on saline valley floors, stream channels, lower footslopes or where saline seeps occur (e.g. where groundwater is forced to the surface through high bedrock, mafic dykes and other variations in geology).

<sup>2</sup> See Table 2.16 for surface salinity ratings.

**Table 2.8b. General guidelines to salinity hazard of landforms in different rainfall zones**

Landform qualifier	High rainfall areas	Moderate rainfall areas	Low rainfall areas
BCH, BLO, CDE, CLI, FDH, FDL, LRI, LSP, RCR, RIS, ROC, SL_1, SL_3, SL_5, SL_C, SL_L, SL10, SL15, SL30, SPL, FOW	No hazard	No hazard	No hazard
DDP, DDW, FOS, FPD, FPP, FPW, FWD, GID, HSP, SWL, SWM, STC	No hazard, unless surface soils have slight salinity ( $EC_e > 200$ mS/m), then Partial or low hazard	Partial or low hazard	Partial or low hazard
FPWs, FWDs, GIDs	Moderate hazard	Moderate hazard	Moderate hazard
DDPs, FOSs, FPDs, FPPs, HSPs, STCs, SWMs	Moderate hazard	High hazard	High hazard
HSC, SAL, SAS	Presently saline	Presently saline	Presently saline

## 2.9 Salt spray exposure

This indicates exposure of land to salt spray drift from the ocean. The salt is carried in the wind and can harm plant growth and impact on the land capability for a range of agricultural uses. This land quality is relevant to coastal areas only. There are two ratings, N (none) and S (susceptible).

**Table 2.9. Salt spray exposure**

	Salt spray exposure rating	
	None (N)	Susceptible (S)
<b><i>Degree of exposure to salt spray</i></b>	Areas not exposed to regular ocean winds and salt spray	Areas exposed to regular ocean winds. Areas where salt spray is a recurring problem leading to regular plant damage only are included (landforms BCH, BLO, FDH, FDL).

## 2.10 Site drainage potential

For many developments it is important to have information about the relative drainage conditions of an area of land independent of the climate, which is referred to as *site drainage potential*. This is useful for land uses that require irrigation which may create waterlogging problems that would not occur naturally, or for developments which require drainage for existing problems. It is also generally related to assessment of salinity hazard (Section 2.8).

Site drainage potential provides an assessment of the suitability of the land for installing artificial drainage to remove excess water and reduce waterlogging and inundation. It is assessed independently of the current rainfall and waterlogging conditions.

The land qualities *site drainage potential* and *waterlogging/inundation* (Section 2.21) are related. In high rainfall areas in south-western Australia they are essentially the same, but in low rainfall areas can be different. For example, in low rainfall areas a soil with slowly permeable clayey subsoil may waterlog infrequently or for short periods only because of the low rainfall. However it would waterlog in a wet year, or if irrigated,.

Site drainage potential is influenced by:

- Internal drainage of the profile, which considers the *permeability* of the least permeable layer or the watertable depth. This may occur below the assessed soil profile (see Table 2.10a). It is also affected by the landscape position (Table 2.10b).

Permeability is an important property, especially when assessing land for irrigation potential. To minimise the risk of waterlogging and to ensure adequate leaching of salts from the profile, irrigated horticultural soils should have moderate or higher permeability. On the other hand, soils with rapid to very rapid permeability may result in excessive leaching of nutrients and be unable to supply adequate moisture to the crop without frequent irrigation. Hence rapid drainage is not always better.

- External drainage that is related to the landform pattern, i.e. slope and position in the landscape (see Table 2.10b).

Site drainage potential is assessed using an estimate based on Table 2.10a, or measured values where they are available. The assessment of permeability should be based on the hydraulic conductivity of the least permeable layer within the top 150 cm. This is regardless of whether or not it is a pedogenic soil horizon, an underlying substrate, or bedrock. This is then combined with consideration of landform (Table 2.10b) to obtain the final rating.

**Table 2.10a. Permeability classes (adapted from O'Neil 1952)**

Profile permeability class	Hydraulic conductivity <sup>1</sup> (mm/h)	Examples (general guide only)	Effect of impeding layer on internal drainage (general guide only) <sup>2</sup>
<b>Very slow</b>	<1	Duplex, gradational or clay soils with impermeable mottled and/or gleyed poorly structured clay soils and/or an extensive impermeable pan or bedrock.	Extensive impermeable layer. Water is removed very slowly through lateral movement and evaporation. Negligible percolation into deeper groundwater.
<b>Slow</b>	1-5	Duplex, gradational or clay soils with slowly permeable, poorly structured clays and/or a slightly permeable pan or bedrock.	Extensive impermeable layer. Water is removed slowly through lateral movement or evaporation. Minimal percolation into deeper groundwater.
<b>Moderately slow</b>	5-20	Duplex, gradational or moderately structured loams or clays, or soils where permeability is slightly increased by gravel or sand.	Impeding layer partially restricts water movement. Water is removed slowly. Main water movement is lateral. Minimal percolation into deeper groundwater.
<b>Moderate</b>	20-65	Duplex, gradational or well structured loams or clays, or soils where permeability is increased by a large amount of gravel or sand.	Impeding layer partially restricts water movement. Water is removed slowly. Main water movement is lateral, though some downward percolation is also likely.
<b>Moderately rapid</b>	65-130	Similar to above, but includes well structured loams, deep sandy gradational soils or deep sands over an impermeable layer at several metres.	No impermeable layer. Highly permeable soils mean that lateral water movement could still be effective in removing water. Main water movement is downward, though some lateral movement is also likely.
<b>Rapid</b>	130-250	Deep sands (e.g. sandplain with fine or medium sand and some clay at depth).	No effective impermeable layer. Minimal lateral water movement. Highly permeable soils mean that lateral water movement could still be effective in removing water. Main water movement is downward.
<b>Very rapid</b>	> 250	Deep coarse sands (e.g. sand dunes with minimal profile development).	No effective impermeable layer. Minimal lateral water movement.

<sup>1</sup> Use the most restrictive layer in the soil profile.

<sup>2</sup> Use as a general guide only. This is an attempt to assess how readily a soil would be drained if a significant amount of rainfall occurs. This is distinct to estimating local soil wetness conditions (e.g. McDonald *et al.* 1990), which identifies few soils in low rainfall areas.

**Table 2.10b. Guide for assessing site drainage potential based on landform and permeability (similar to Table 2.21b)**

Landform	Waterlogging/inundation risk rating in high rainfall districts					
	Nil (R)	Very low (W)	Low (MW)	Moderate (M)	High (P)	Very high (VP)
<b>W.</b> WAT	-	-	-	-	-	Very slow to Rapid
<b>A.</b> SAL, SWM, STC, DDP,	-	-	-	-	Very rapid	Very slow to Rapid
<b>B1.</b> FPD, FPP, SAS, GID	-	-	-	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow
<b>B2.</b> HSC, HSP				Moderate to Very rapid	Very slow to Moderately slow	
<b>B3.</b> FOS			Moderate to Very rapid	Very slow to Moderately slow		
<b>C.</b> BCH, CDE, FPW, FWD, SPL, SWL, LRI, DDW	-	Moderate to Very rapid	Very slow to Moderately slow		-	-
<b>D.</b> LSP, ROC, FOW	Rapid to Very rapid	Moderately slow to Moderately rapid	Very slow to Slow	-	-	-
<b>E.</b> SL_1, SL_L,	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow	-	-	-
<b>F.</b> RIS, SL_3, SL_C	Moderately slow to Very rapid	Very slow to Slow	-	-	-	-
<b>G.</b> BLO, CLI, FDH, FDL, RCR, SL_5, SL10, SL15, SL30	Very slow to Very rapid	-	-	-	-	-

1. The maximum waterlogging rating for all soils not in the wet soil groups (100-105, Table 1.5b) is moderate.
2. The minimum waterlogging rating for all in the wet soil groups (100-105, Table 1.5b) is moderate.

## 2.11 Soil absorption ability

Soil absorption is the ability of the soil to absorb a liquid. It is an important quality to consider in relation to the disposal of effluent, for example the disposal of waste water from septic tanks. Soil absorption is determined by the soil permeability, degree of waterlogging, soil depth and amount of stones in the soil. If the soil absorption ability at an effluent disposal site is inadequate there will be a high risk of surface ponding of water contaminated by microbes and a resultant risk to public health.

**Table 2.11. Assessment of soil absorption ability by the most limiting factor (adapted from Wells and King 1989)**

	Soil absorption rating			
	Very low (VL)	Low (L)	Moderate (M)	High (H)
<b>Waterlogging/inundation risk<sup>1</sup></b>	Very high	High	Moderate	Nil to low
<b>Permeability class<sup>2</sup></b>	Slow to Very slow	Moderately slow	Moderate	Moderately rapid to Very rapid
<b>Stones and boulders within profile<sup>3</sup> (% volume)<sup>1</sup></b>	-	Abundant (>50%)	Many (20-50%)	Very few to Common (<20%)
<b>Depth of profile<sup>4</sup></b>	Shallow to Very shallow (<30 cm)	Moderately shallow (30-50 cm)	Moderate (50-80 cm)	Deep to Very deep (>80 cm)

<sup>1</sup> See Section 2.21.

<sup>2</sup> See Table A1.3a.

<sup>3</sup> See Table A1.6. Note that 50% by volume can be as much as 80% by weight.

<sup>4</sup> See Table A1.2.



## 2.12 Soil water storage

Soil water storage (SWS) is the amount of water that can be stored, available for plant water use. It is a major factor determining the yield potential in areas with a summer-dominant rainfall, such as the wheat growing areas of southern Queensland. In a Mediterranean environment where most rain falls during the growing season, soil water storage can be less important, depending on seasonal conditions. For example, in seasons where regular light showers ensure a water supply to the plant that closely matches crop transpiration, then differences between soils will be minimal. In other seasons, where the rainfall is abnormally high or low or unevenly distributed through the growing season then differences between soils will be evident. Soils with very low water storage capacity or unfavourable chemical or physical properties that restrict root growth invariably limit yields.

The large variation in the maximum rooting depth of different crops and the tolerance of plants to different soil conditions results in soil depth/plant rooting depth being the major variable affecting plant available water in many soils. Soil water storage should always be related to a specific crop or a depth interval e.g. 0-100 cm. This depth interval is appropriate for a general assessment for dryland annual crops.

Here the soil water storage is defined as the difference between upper storage limit (i.e. field capacity) and the lower storage limit (i.e. wilting point), summed over the upper 100 cm of the soil profile or the rooting depth, whichever is less. (Note: AWC - available water capacity or PAW – plant available water are simply the difference between field capacity and wilting point given in mm/m without the rooting depth restriction.)

If SWS is estimated from soil texture, then coarse fragments or gravel must be considered. As any water contained within coarse fragments is generally assumed to be unavailable to plants, the SWS is reduced proportionally for that layer according to the volume percentage.

The ironstone gravels common in the south-west of Western Australia can store significant amounts of water. Although anecdotal evidence would suggest that some of this water may be used by crops and pastures, this has not currently been quantified. Gravel is assumed to provide no water hence SWS of soils containing ironstone gravel may be underestimated.

In some soils with an inherently low AWC, the soil water storage may remain high due to the presence of high watertables. In some cases moisture in the capillary fringe above the watertable may remain available to plants throughout the summer months.

### *Method*

1. Determine the rooting depth as shown in Section 2.7. If this is greater than 100 cm, use 100 cm as the rooting depth.
2. Use Tables 2.12b or 2.12c to estimate available water capacity in mm/m for each soil layer occurring within the rooting depth according to the texture and arrangement of that layer using the formula:  
**layer AWC (mm) = layer thickness (m) x AWC (mm/m) x (100 – vol% coarse fragments)/100**  
**Note:** Use measured values if available.
3. Sum the available water capacity for each soil layer to 100 cm or the rooting depth determined in step 1.  
**AWC (mm) = depth (m) x AWC (mm/m) x (100 – vol% coarse fragments)/100**
4. Use AWC (mm) value and Table 2.12a to assign the soil a soil water storage rating.
5. For soils with a rooting depth of 50 cm or more (see Table 2.7a) and a soil water storage rating of Very low to Moderate, increase the soil water storage rating if a permanent fresh watertable is present in the top 200 cm. Increase the rating to High if the minimum fresh watertable depth throughout the season is less than 150 cm, and to Moderate if the minimum fresh watertable depth throughout is between 150 and 200 cm.

**Table 2.12a. Soil water storage**

	Soil water storage rating				
	Very low (VL)	Low (L)	Moderately low (ML)	Moderate (M)	High (H)
Available water capacity of top 100 cm or to root restricting layer <sup>1</sup> (mm/m)	<35	35-70	70-100	100-140	>140

<sup>1</sup> See Tables 2.12b or 2.12c for guidelines.

### Examples

- 1: A soil has 0.3 m medium sand over a well structured fine sandy loam to 1 m.  
Soil water storage = (0.3 x 45 mm/m) + (0.7 x 195 mm/m) = 150 mm/m SWS which is classed as High.
- 2: A soil with 0.4 m medium sand with 40% gravel over an hardpan would normally be assessed to the rooting depth, e.g. 0.4 m x 45 mm/m x (100-40)/100 = 10.8 mm/m SWS, which is Very low.

**Table 2.12b. Estimation of available water capacity (mm/m) using soil texture, sand size and structure (from Moore *et al.* 1998c)**

Texture <sup>1</sup>	Clay %	Sand size fraction	Available water capacity AWC <sup>2</sup> (mm/m) (References <sup>3</sup> )	
			Moderate to strong structure	Weak structure or apedal
Sands (KS, SS, S, FS)	<5	Coarse to Very coarse	-	~20 <sup>a</sup>
		Medium to Coarse	-	30-45 <sup>b</sup>
		Medium	-	40-50
		Fine	-	50-70
Loamy sand/ Clayey sand (LS, CS)	5-10	Coarse	-	50-60 <sup>f</sup>
		Medium	-	60-90 <sup>f</sup>
		Fine	-	80-100 <sup>f</sup>
Sandy loam (SL)	10-20	Coarse	110-220 <sup>l</sup>	50-60 <sup>f</sup>
		Medium	110-170 <sup>l</sup>	60-100 <sup>c, d, f</sup>
		Fine	170-220 <sup>l</sup>	~140
Light sandy clay loam (L)	15-20	Coarse	120-150	50-60 <sup>e</sup>
		Medium	170-220 <sup>l</sup>	90-100 <sup>f</sup>
		Fine	~180	100-120
Loam (L)	~25	-	150-240 <sup>h, i</sup>	100-130 <sup>i</sup>
Sandy clay loam (CL)	20-30	-	130-190 <sup>l</sup>	100-130 <sup>g, i</sup>
Clay loam (CL)	30-35	-	120-210 <sup>l</sup>	~100
Sandy clay (C)	35-40	-	130-150 <sup>l</sup>	80-100 <sup>f, i</sup>
Clay (C)	>35	-	110-120 <sup>h, i</sup>	90-140 <sup>h, i</sup>
Self-mulching clay (C)	>35	-	~210 <sup>h</sup>	-

<sup>1</sup> See Table A1.8.

<sup>2</sup> Soil water storage (SWS) may be reduced in proportion to the volume of gravels or stones within the profile, hence deep loamy gravels will have low or very low SWS.

<sup>3</sup> References: a G. Luke (unpublished data) f C. Henderson (unpublished data)  
b Hamblin *et al.* (1988) g M. Hegney (unpublished data)  
c Hamblin and Hamblin (1985) h Williams (1983)  
d Hamblin and Tennant (1981) i Hollis and Jones (1987)  
e S. McKeague (unpublished data)

**Table 2.12c. Estimated average available water capacity (mm/m) for varying soil textures and arrangements (from Table 2.12b)**

Soil texture	Available water capacity (mm/m) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	Shrink-swell (SW)	Pans and rock
Coarse sand (KS)	20	25	22	-	-	-	-
Light sand (SS)	30	45	40	-	-	-	-
Sand (S)	40	50	45	-	-	-	-
Fine sand (FS)	50	70	60	-	-	-	-
Loamy sand (LS)	60	90	75	-	-	-	-
Clayey sand (CS)	80	100	90	-	-	-	-
Sandy loam (SL)	90	110	80	120	150	-	-
Loam (L)	100	130	130	170	220	-	-
Sandy clay loam (SCL)	-	130	100	140	180	-	-
Clay loam (CL)	-	120	100	140	190	-	-
Clay (C)	-	110	90	130	200	130	-
Heavy clay (HC)	-	130	90	110	120	110	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	10*
Weathered pan (PW)	-	-	-	-	-	-	10*
Weathered rock (PW)							10*
Solid rock or pan (PH, RH)							0

\* Estimates for use in theoretical calculations as there is limited information for root water use in rock. If possible, derived values should be checked against real data.

## 2.13 Soil workability

This refers to the ease with which soil can be cultivated for cropping assuming the use of a tractor and plough and 10-15 cm depth of tillage. Machinery trafficability is included in this assessment as tractor access is normally required for cultivation. However machinery trafficability is also assessed as a separate land quality, as for many land uses vehicle access is important, even though cultivation may not be required. The rating is determined by the most limiting property of the land unit.

**Table 2.13. Inherent limitations to soil workability (adapted from Wells and King 1989)**

Soil property	Soil workability rating			
	Good (G)	Fair (F)	Poor (P)	Very poor (VP)
<b>Waterlogging/inundation<sup>1</sup>:</b> Where soil texture <sup>2</sup> in the top 15 cm is a coarse sand to sandy loam	Nil to moderate	High	Very high	
Where soil texture <sup>2</sup> in the top 15 cm is a loam to heavy clay	Nil to low	Moderate	High	Very high
<b>Surface condition<sup>3</sup></b>	Loose, soft, firm, surface crust, saline or self-mulching. Hardsetting clayey or loamy sands	Cracking clays, Hardsetting sandy loams to clays		
<b>Soil texture and arrangement within top 15 cm</b>	All coarse sand to clay loams, Moderate to well structured clays, shrink-swell clays	Poorly structured clay or heavy clay layer present	-	-
<b>Profile stones or boulders &gt;200 mm (% volume)<sup>4</sup></b> (Include cemented gravels)	0-10%	10-20%	20-50%	>50%
<b>Rock outcrop<sup>5</sup></b> (% surface area)	<2%	2-20%	20-50%	>50%
<b>Depth to rock<sup>6</sup></b>	>30 cm	-	15-30 cm	<15 cm
<b>Slope<sup>7</sup></b>	Flat to Gentle 2 (0-10%)	Moderate 1 (10-15%)	Moderate 2 (15-30%)	Steep (>30%)
<b>Landform<sup>8</sup></b>	All others	DDP(s), DDW, GID(s), SL10	FDL, SL15	FDH, SL30, STC(s)

<sup>1</sup> See Section 2.21.

<sup>2</sup> See Table A1.8. Finer textured soils usually drain more slowly and are often workable over a narrow moisture range.

<sup>3</sup> See Table A1.7.

<sup>4</sup> See Table A1.6. 50% by volume may be 80% by weight.

<sup>5</sup> See Table A1.4.

<sup>6</sup> See Table A1.2.

<sup>7</sup> See Table A1.5.

<sup>8</sup> See Table 1.5e.

## 2.14 Subsurface acidification susceptibility

Subsurface acidification susceptibility is the hazard of the soil becoming acid below the cultivation layer (i.e. >10 cm below the surface) as a result of land management practices.

In WA, the major toxicity in acid soils is caused by aluminum (Al) as its solubility increases sharply when pH<sub>Ca</sub> is less than 4.5 (or pH<sub>w</sub> less than 5.6). However, Al is involved in reactions with organic matter (OM) to form non-toxic complexes, so toxicity tends to occur in the subsurface soil where OM concentrations are low. High concentrations of toxic Al reduce root elongation. A crop symptom is moisture stress due to the reduced root volume. Deficiencies of calcium, magnesium, molybdenum, nitrogen and phosphorus can also occur in acid soils.

In this manual, subsurface acidification susceptibility is assessed for the soil layer occurring directly below the normal depth of cultivation and below the surface horizon with maximum organic matter content (i.e. the horizon below the A1/AP horizon). The lower organic matter content in this layer increases its susceptibility and added lime typically only reaches this layer through leaching as it is below the cultivation depth. The layer assessed should be situated above the clayey subsoil where the plant roots are most active, and is usually found somewhere in the 10-70 cm depth range.

Susceptibility of the subsurface to acidification can be expressed in terms of the time taken before the subsurface acidifies to a critical pH where production losses are likely. Dolling *et al.* (2001) suggested the following formula to determine this time:

**Time (years) = [(pH current - pH critical) x pH buffering capacity]/acid addition rate.**

The assessment used in this manual assumes that the **pH critical** for the subsurface is pH<sub>Ca</sub> 4.5 and pH<sub>w</sub> 5.6. This is the case for cereal-lupin rotations, but not all crop-pasture rotations.

The **pH buffering capacity** (pHBC) of a soil is its ability to resist pH changes, either a pH decrease from an acid input (acidification) or an increase from the application of lime (lime requirement). Organic matter is the major factor, which influences pH buffering; clay content is the next important factor. The higher the organic matter or clay content the higher the soil's pHBC. Dolling *et al.* (2001) suggested the following formula to determine pHBC:

**pHBC (t CaCO<sub>3</sub>/ha.pH) = [0.955OC% + 0.011Clay%] x bulk density**

In this formula, pHBC is expressed in terms of tonnes of lime per hectare to decrease acidity in a 10 cm thick layer by one pH unit. OC% is the percentage organic carbon content of the soil measured by the Walkley-Black method and Clay% is the percentage clay fraction of the soil. ***It should be noted that this formula is yet to be proven accurate for subsurface soils.***

The **acid addition rate** is the rate in which the soil acidifies as the result of a particular land use or farming system. It can be expressed in terms of the amount of lime (t/ha) required to neutralise the acidity produced by agriculture. Data presented by Dolling *et al.* (2001) show published mean acid addition rates **to the surface layer** for temperate slopes and plains from 0.025 to 0.080 t/ha/yr for continuous pastures (dryland lucerne) to 0.080 t/ha/yr for continuous cropping. The acidification rate to the subsoil will be lower, and will be influenced by the soil properties, management (i.e. cultivation practices) and the existing acidity in the topsoil. It is possible to calculate subsoil acidification that includes topsoil acidity estimates. However the actual relationship is unknown and topsoil pH estimates based on conventional soil-landscape maps are very unreliable. To simplify the equation a lower rate of subsoil acidification is assumed because the high pH bulge which is common below the surface soil indicates acidification occurs simultaneously. The calculations below use a mean rate of acidification to the **subsurface** that could be neutralised by 0.05 t/ha/yr of lime.

The land quality 'subsurface acidification susceptibility' is **only a general indicator** of soils with a high inherent risk of subsoil acidity because management, productivity and crop rotation all affect the rate of subsurface acidification and because pH values for land units are very variable (see Section 2.5). The specific crop or pasture species affects the critical pH; and some soils supply higher or lower concentrations of toxic Al at the same pH (e.g. peaty sands and grey sands have lower concentrations of extractable Al than most soils). The method for calculating subsurface acidification susceptibility is not appropriate for calcareous soils which have a low rating.

## Method

1. Assess the pH buffering capacity of layer 2 of the soil (i.e. the horizon below the A1/AP and above the major texture increase in the top 80 cm, typically from 10 to 50 cm) using the formula:

$$\text{pHBC (t CaCO}_3\text{/ha.pH)} = [0.955\text{OC}\% + 0.011\text{Clay}\%] \times \text{bulk density}$$

This formula presents the pHBC in terms of tonnes of lime per hectare to decrease acidity in a 10 cm thick layer by one pH unit (OC% is the organic carbon per cent and Clay% is the clay per cent).<sup>14</sup>

If layer 2 lower depth is 20 cm or less, then pHBC is calculated for layer 3.

2. Using the pHBC values calculated above, the time in years for the soil layer to reach the critical pH<sub>w</sub> of 5.6 under a cropping/pasture rotation can be calculated using the following formula:

$$\text{Time (years)} = [(\text{pH}_w - 5.6) \times \text{pHBC}] \div 0.05 \text{ (where 0.05 is the assumed subsoil acidification rate that could be neutralised by 0.05 t/ha of lime)}$$

If the current pH<sub>w</sub> is 5.6 or less, the time in years will be 0 as the soil is already acid. Where pH<sub>ca</sub> values are available for the soil, the formula is altered to:

$$\text{Time (years)} = [(\text{pH}_{ca} - 4.5) \times \text{pHBC}] \div 0.05$$

If the pH<sub>w</sub> is 8.5 or more, or pH<sub>ca</sub> is 7.5 or more, the rate of acidification is automatically low (defaults to 100 years).

3. Estimate the rating from Table 2.14.

**Table 2.14. Subsurface acidification susceptibility ratings (no extra lime applied)**

Indicative time before subsurface soil reaches critical pH	Subsurface acidification susceptibility rating			
	Presently acid (P)	High (H)	Moderate (M)	Low (L)
Cropping/pasture rotation	0 years (pH <sub>w</sub> currently <5.6)	<10 years	10-20 years	>20 years

<sup>14</sup> PHBC (cmol H<sup>+</sup>/t/pH) = pHBC (t CaCO<sub>3</sub>/ha.pH) x bulk density/5.

## 2.15 Subsurface compaction susceptibility

Soil compaction describes the reduction in soil pore size and total pore space through applied stresses. The main cause on tilled soils is wheeled vehicular traffic, especially heavy dual-axle tractors<sup>15</sup>. The high strength of compacted soils restricts root elongation and results in a reduced soil volume available for water and nutrient uptake.

Traffic pans are common on many coarse-textured soils in the agricultural area of Western Australia. Ameliorating subsurface compaction through deep tillage improves yields.

Susceptibility to compaction relates to particle size distribution and the presence or absence of secondary structure and organic matter. Soils with a wide range of particle sizes, low organic matter and no secondary structure are particularly susceptible. If detailed particle size data is available the susceptibility to compaction should be determined using the *compaction index* developed by H. Daniel (Figure 4.2.2 in Needham *et al.* 1998b). Plough pans can also form under repeated cultivation, mostly in heavier textured soils, but are not dealt with in this land quality.

**Table 2.15. Susceptibility of soils to subsurface compaction based on field texture, arrangement, coarse fragments and organic matter (adapted from Needham *et al.* 1998b)**

Soil texture <sup>1</sup> (20–40 cm)	Subsurface compaction susceptibility rating		
	Low (L)	Moderate (M)	High (H)
<b>Layers with &gt;50% coarse fragments</b> All textures	All (G, E, P, M, S, SW)	-	-
<b>Layers with &lt;2.0% OC</b> Coarse sand to fine sand (KS, SS, S, FS)	-	All (G, E, P)	-
Loamy sand (LS)	-	Loose (G)	Earthy, Poorly structured (E, P)
Clayey sand (CS)	-	-	All (G, E, P)
Sandy loam (SL)	-	-	All (G, E, P, M, S)
Loam (L)	Moderately to Strongly structured (M, S)	Loose, Earthy, Poorly structured (G, E, P)	-
Sandy clay loam to clay loam (SCL)	Moderately to Strongly structured (M, S)	Earthy, Poorly structured (E, P)	-
Clay loam to heavy clay (C, HC)	All (E, P, M, S, SW)	-	-
<b>Layers with &gt;2.0% OC</b> Coarse sand to fine sand (KS, SS, S, FS)	All (G, E, P)	-	-
Loamy sand (LS)	Loose (G)	Earthy, Poorly structured (E, P)	-
Clayey sand (CS)	-	All (G, E, P)	-
Sandy loam (SL)	-	All (G, E, P, M, S)	-
Loam (L)	All (G, E, P, M, S)	-	-
Sandy clay loam to clay loam (SCL, CL)	All (E, P, M, S)	-	-
Clay to heavy clay (C, HC)	All (E, P, M, S, SW)	-	-

<sup>1</sup> See Table A1.9 for arrangement codes. It is assumed that the soil particles are well graded. If particles are narrowly graded (i.e. in the same size range) the rating should be reduced (e.g. from moderate to low).

<sup>15</sup> Compaction by cattle is not considered as it tends to be restricted to the top 5 to 15cm of the soil (Greenwood and McKenzie 2001).

## 2.16 Surface salinity

Salinity refers to an excess of soluble salts in the soil solution in the top 30 cm, which adversely affects plant growth. The development of secondary salinity in WA is a result of a change in the water balance and rising watertables following the clearing of deep-rooted native vegetation and their replacement with shallow-rooted annual crops and pasture. It is most common in low-lying landscape positions such as valley floors.

It has been estimated that about one million hectares of the south-west of Western Australia are affected by salinity, with an annual increase of around 14,000 ha (McFarlane *et al.* 2004).

The land quality 'surface salinity' is intended to reflect, as far as is possible, current salinity status. The potential for the land to become saline in the future as the water balance comes to a new equilibrium is not considered. This is covered by the land quality 'salinity hazard' (Section 2.8). It should be noted that, as surface salinity is in a state of flux, estimates of this form of land degradation extracted from the map unit database may not be entirely current. Estimates of the extent of salinity will be influenced by the date when the map units were last attributed.

Table 2.16 presents guidelines for assessing the surface salinity. Where inductive electromagnetic salinity measurements are not available, a variety of indicators may be used. An approximate range in E<sub>Ce</sub> (mS/m) is provided in Table 2.16, however due to large seasonal fluctuations measured soil samples may be misleading and should be compared with site observations, e.g. indicator plants or absence of sensitive species, to establish the salinity status of a land unit. (For more information see Moore 1998b.)

While the measurement of EC in a 1:5 soil:water (EC<sub>w</sub>) suspension is less reliable than the E<sub>Ce</sub>, these data are more widely available and can be measured in the field. The figures presented were converted using the equation  $E_{Ce} = (364 \times EC_w) / SP \text{ mS/m}$  where SP is the saturation percentage of the soil. The saturation percentage can be estimated as follows (see George and Wren 1985).

Soil texture	Saturation percentage (%w/w)
Sand to clayey sand	25
Sandy loam to sandy clay loam	32
Sandy clay to clay	45

It is important to remember that Table 2.16 is intended as a general guide only, and should be used to arrive at a best estimate of the degree of surface salinity.



Table 2.16. Assessment of surface salinity (0-30 cm)

	Surface salinity rating				
	Nil (N)	Slight (S)	Moderate (M)	High (H)	Extreme (E)
<b>Approx. soil salinity range<sup>1</sup></b> (ECe mS/m)	<200	200-400	400-800	800-1,600	>1,600
<b>Pasture salinity indicators<sup>2</sup></b>	Most agricultural pastures not affected.	Growth of sensitive species like yellow serradella, strand medic, rose and cupped clovers reduced	Clovers, medics and non-salt tolerant grasses reduced; patches of <i>H. maritimum</i> (sea barley grass)	Patches of grassed and bare ground; <i>H. maritimum</i> dominates, clovers and medics are usually absent	<i>H. maritimum</i> , bare ground and halophytes such as samphire
<b>Crop salinity indicators</b>	Most agricultural crops not affected.	Very sensitive crops affected, e.g. lupins	Wheat affected, barley more tolerant. Cereals yield satisfactorily when seasonal conditions are favourable	Significant reductions in crop yields	Too saline for any crops
<b>Approx. soil salinity range</b> (EC 1:5 mS/m)	0-15 (sand) 0-20 (loam) 0-25 (clay)	15-25 (sand) 20-35 (loam) 25-50 (clay)	25-50 (sand) 35-70 (loam) 50-100 (clay)	50-100 (sand) 70-150 (loam) 100-200 (clay)	> 100 (sand) > 150 (loam) > 200 (clay)
<b>Approx. EM38h reading<sup>3</sup></b> (ECa mS/m)	0-50	50-100	100-150	150-250	>250
<b>Approx. watertable salinity<sup>4</sup> where ≤30 cm for &gt;1 week</b> (e.g. at least moderate waterlogging risk) (EC mS/m)	<100	100-500	500-2000	2000-4000	>4000

<sup>1</sup> Use plant indicators as main guide. Soil salinity varies with seasonal conditions due to leaching by winter rains and capillary rise of salts over summer if the watertable is within 2 m of the surface. The degree of leaching is closely connected to the soil permeability and rainfall.

<sup>2</sup> Salinity can vary dramatically with minor changes in topography, hydrology or geology, so record the most common condition.

<sup>3</sup> This is the best method for assessing salinity is obtained by in situ measurements using inductive electromagnetic techniques. However this has not generally been done during soil-landscape surveys. Halve these values on deep sands, deep gravels, sandy earths and other profiles without a clayey subsoil by 80 cm.

<sup>4</sup> Use as a general indicator only. There is no direct correlation between soil and groundwater salinity.

## 2.17 Surface soil structure decline susceptibility

This describes the susceptibility of soils to have their surface structure altered due to disturbance. A crusting or hardsetting soil surface is characteristic indication of structure decline within the top 15 cm. This results in reduced movement of water into and through the topsoil (and mechanical impedance for young plants).

The structure of many medium to fine-textured agricultural soils in WA has deteriorated in the relatively short period (50-80 years) since clearing for agriculture. A major reason for this decline has been excessive tillage, but heavy traffic and stock trampling also contribute. The soils have reduced infiltration, resulting in increased run-off. They are more compact requiring more tractor power, and can only be cultivated over a narrow moisture range. Seedling emergence is also adversely affected.

Surface soil structure decline occurs when physical stresses are applied to the soil, especially when the soil is wet. The wetting and drying cycle can significantly contribute to these stresses (especially when conditions approach saturation). Susceptibility of the soil depends on a complex interaction of a number of chemical and physical properties of the soil matrix and soil solution affecting the soil stability. Soils with a high exchangeable sodium percentage, low exchangeable calcium to magnesium ratio or dominated by kaolinitic clays are less stable. High organic carbon or salinity levels can increase stability. Coarse-grained sands with low clay content are not affected, but may compact (see Section 2.15). Soil solutions with low solute levels (e.g. rainwater) can encourage electrochemical instability, but increase of dissolved salts (e.g. in saline situations) can reduce electrochemical instability; the dissolved salts restrict dispersion of the clay fraction.

To assess surface soil structure decline susceptibility, first calculate the soil structural stability for all of the soil layers within the top 15 cm. This will include all of the soil which is likely be mixed and brought to the surface when cultivating the soil. Although most cultivation is to a depth of 10 cm only, 15 cm is used here to allow for some potential loss of topsoil or natural variation of depth to clayey subsoils in shallow duplex profiles.

Using Table 2.17a, assign each layer the appropriate score (between –5 and +5) for each of the following properties: organic carbon, ESP, electrical conductivity, Ca:Mg ratio, slaking, dispersion and surface condition or soil arrangement according to soil texture. Surface condition is used for the surface layer only; soil arrangement is used for any underlying layers. Add the scores together to determine the overall score for the layer. The surface soil structure decline susceptibility is then determined based on the layer in the top 15 cm with the lowest overall score using Table 2.17b.

**Table 2.17a. Determining soil structure stability score (adapted from Needham *et al.* 1998a)**

	Soil structure stability score								
	-5	-3	-2	-1	0	+1	+2	+3	+5
<b>Organic Carbon%</b> <sup>1</sup>				<0.8	0.8-1.5	1.5-2.5	>2.5		
<b>Exchangeable sodium percentage</b> <sup>2</sup>		>15	6-15		< 6				-
<b>Electrical conductivity</b> <sup>2</sup> (ECe mS/m)			<50	50-100		100- 150	>150		
<b>Exchangeable Ca:Mg ratio</b> <sup>2</sup>				<1	1-3	>3			-
<b>Slaking</b> <sup>6</sup>			C (Complete)	P (Partial)		N (Nil)			-
<b>Dispersion</b> <sup>7</sup>	C (Complete)	-	P (Partial)			N (Nil)			
<b>Surface condition/Soil arrangement</b> <sup>3</sup> : <b>Coarse sand to Fine sand</b> (KS, SS, S, FS)						Hardset or crust (H, C)/ <i>Poor (P)</i>	Saline (Z)	Firm (F)/ <i>Earthy (E)</i>	Loose or soft (S, L)/ <i>Loose (G)</i>
<b>Loamy to clayey sand</b> (LS, CS)			Hardset or crust (H, C) <sup>4</sup> / <i>Poor (P)</i> <sup>4</sup>	Hardset or crust (H, C) <sup>5</sup> / <i>Poor (P)</i> <sup>5</sup>		Firm (F)/ <i>Earthy (E)</i>	Saline (Z)	Loose or soft (S, L) <i>Loose (G)</i>	-
<b>Sandy loam to Clay loam</b> (SL, L, SCL, CL)		Hardset or crust (H, C)/ <i>Poor (P)</i>		Firm (F) <i>Earthy, strong, moderate (E, M, S)</i>	Soft, loose, (S, L)/ <i>Loose (G)</i>		Saline (Z)		-
<b>Clay</b> (C, HC)			Hardset (H)/ <i>Poor (P)</i>		Soft, firm (S, F) <i>Earthy, strong, moderate (E, M, S)</i>		Saline (Z)	Self-mulching, cracking (M, K)/ <i>Shrink-swell (SW)</i>	-

<sup>1</sup> Organic carbon. Measured by the Walkley Black method, that is typically 20-25 per cent lower than the wet combustion methods (Rayment and Higginson 1992). See Table A1.11.

<sup>2</sup> Only assess in soils with more than 10 per cent clay.

<sup>3</sup> Assess surface condition (see Table A1.7) for surface layer only, assess soil arrangement (see Table A1.9) for other layers.

<sup>4</sup> If fine sand content is high.

<sup>5</sup> If fine sand content is low to moderate.

<sup>6</sup> See Table A1.14.

<sup>7</sup> See Table A1.13.

**Table 2.17b. Assessing surface soil structure decline susceptibility for soil layers using the soil stability score from Table 2.17a**

	Surface soil structure decline susceptibility rating		
	Low (L)	Moderate (M)	High (H)
<b>Cumulative soil stability score</b>	+1 to +15	-5 to 0	-6 to -15
<b>Exclusions</b>	Bare rock or very shallow soils (VSH, RST)		

Note: Soil structure decline does not apply to bare rock (soil group 201 – Table 1.5b). Additionally very shallow soils over rock, with a soil qualifier (Table 1.5c) of RST or VSH are automatically low.

Observations of the current field conditions under different management should be used to reinforce assessments based on limited chemical data. In general, field observations are useful, because susceptible soils are almost certain to show some decline. For more information on soil structure decline see Needham *et al.* (1998a).

## 2.18 Trafficability

Trafficability relates to the ease and safety of vehicle movement across the land surface. Vehicle access is important for many agricultural land uses. The use of tractors and other vehicles includes; cultivation, broadcasting fertilisers, spraying of pesticides or herbicides, mechanical harvesting and mustering livestock. Trafficability is considered separately from soil workability as there are a number of land uses which require vehicle access but do not require soil cultivation.

**Table 2.18. Assessment of trafficability (adapted from Tille and Lantzeke 1990)**

	Trafficability rating			
	Good (G)	Fair (F)	Poor (P)	Very poor (VP)
<b>Waterlogging/inundation<sup>1</sup> for topsoil texture(&lt;30 cm)<sup>2</sup>:</b> Coarse sand to sandy loam	Nil to moderate	High	Very high	-
Loam to clay	Nil to low	Moderate	High	Very high
<b>Rock outcrop<sup>3</sup> (% surface area)</b>	None (< 2%)	Slight (2-10%)	Rocky to Very rocky (10-50%)	Rockland (>50%)
<b>Slope<sup>4</sup></b> All soils except very deep sands	Flat to Gentle 2 (0-10%)	Moderate 1 (10-15%)	Moderate 2 (15-30%) and Mixed (MX)	Steep (>30%)
Very deep sands (>150 cm deep)	Flat to Gentle 1 (< 5%)	Gentle 2 (5-10%)	Moderate 1 (10-15%)	Moderate 2 to Steep (>15%) and Mixed (MX)
<b>Landform<sup>5</sup></b>	FOS, FOW, SL_1, SL_3, SL_5	DDP(s), GID(s), SL10	BEA, BLO, FDL, LSP, SL15	CLI, FDH, SL30, STC(s), WAT

<sup>1</sup> See Section 2.21.

<sup>2</sup> See Table A1.8.

<sup>3</sup> See Table A1.4.

<sup>4</sup> See Table A1.5.

<sup>5</sup> See Table 1.5e.

## 2.19 Water erosion hazard

Water erosion hazard is the inherent susceptibility of the land to the loss of soil as a result of water movement across the surface. It is a significant problem in WA affecting the long-term sustainability of agriculture in some areas and is a major source of water pollution including siltation and eutrophication, particularly in high rainfall areas. It is also an important cause of soil fertility decline as soil nutrients tend to be concentrated near the surface.

Water erosion is highly variable depending on seasonal and climatic factors with most soil loss occurring from a small proportion of the agricultural area. For example, a high rainfall event immediately after summer, when soil plant cover is low can result in a 'flush' of sediment and valuable topsoil nutrients into nearby drains. Management also affects erosion through the timing (and type) of cultivation, and frequency and intensity of waterlogging that affect saturation excess run-off.

The following general assessment is based on the *inherent erodibility* of a soil type (Tables 2.19a and 2.19b) and slope (Table 2.19c). As defined here water erosion hazard does not take into account land management practices (these are assessed in the land capability ratings tables). For more information see Coles and Moore (1998).

### Method:

- Table 2.19a provides guidelines for assessing erodibility of individual soil layers (Figure 6). Assign a score for each characteristic, and add up the scores.  
If the total score exceeds 10, the soil layer can be considered **highly erodible**.  
If the total score is between 5 and 10, the layer can be considered **moderately erodible**.  
If the total score is lower than 5, the soil layer can be considered to have **low erodibility**.
- To calculate the soil profile erodibility score, add the erodibility score from all the subsurface layers within the top 80 cm. This will give you a soil profile erodibility score. Note: For slaking, dispersion and soil moisture  $\leq 30$  cm the erodibility rating is doubled because these properties near the surface have a large influence on water erosion.
- Gravel and stones protect the soil surface from erosion. If the surface layer contains more than 50 per cent coarse fragments, reduce the profile erodibility score by 5. If the surface layer contains more than 20-50 per cent coarse fragments, reduce the profile erodibility score by 2.
- Use Table 2.19b to convert the soil profile erodibility score into a soil profile erodibility class.
- Using Table 2.19c, estimate the water erosion hazard rating from the soil profile erodibility class and the landform position of the soil. Adjust the rating according the degree of waterlogging experienced by the land unit as instructed in the note below the table.

**Table 2.19a. Soil layer erodibility scores**

	Soil layer erodibility score			
	0	1	2	3
<b>Organic carbon%</b> <sup>1</sup>	>2.0	0.8-2.0	<0.8	-
<b>Slaking</b> <sup>4</sup> If soil layer depth ≤30 cm erodibility score * 2	N (Nil)	-	P (Partial)	C (Complete)
<b>Dispersion</b> <sup>5</sup> (Not applicable for sands – KS to CS) If soil layer depth ≤30 cm erodibility score * 2	N (Nil) XX (Not applicable)	-	P (Partial)	C (Complete)
<b>Water repellence</b> <sup>6</sup> (For sands – KS to CS. Layer 1 only)	N, L	M	H	
<b>Soil structure or arrangement</b> <sup>2</sup> : <b>coarse sand (KS)</b>	Earthy, Poor, Loose (E, P, G)	-	-	-
<b>Light sand to clayey sand</b> (SS, S, LS, CS)	-	Earthy, Poor (E, P)	Loose (G)	-
<b>Sandy loam to clay loam</b> (SL, L, SCL, CL)	-	Strong (S)	Earthy, Moderate (E, M)	Loose, Poor (G, P)
<b>Clay</b> (C, HC)	Shrink swell, Strong (SW, S)	Earthy, Moderate (E, M)	Poor (P)	-
<b>Permeability of layers within or up to 30 cm below the layer being assessed</b> <sup>3</sup>	Moderately rapid to Very rapid (MR, R, VR)	Moderate (M)	Moderately slow (MS)	Slow to Very slow (S, VS)
<b>Soil moisture (year round)</b> If soil layer depth ≤30 cm erodibility score * 2	Variable (V)	-	-	Wet, Partially wet (W, pw)

<sup>1</sup> Organic carbon. Measured by the Walkley Black method, that is typically 20-25% lower than the wet combustion methods (Rayment and Higginson 1992). See Table A1.11.

<sup>2</sup> See Table A1.9.

<sup>3</sup> Low permeability (assume up to 30 cm) below the layer being assessed can affect lateral water movement in the soil layer. See Table A1.3.

<sup>4</sup> See Table A1.14.

<sup>5</sup> See Table A1.13.

<sup>6</sup> See Table 2.20.

**Table 2.19b. Soil profile erodibility classes**

	Soil profile erodibility class		
	Low (i)	Moderate (ii)	High (iii)
Soil profile erodibility score	<15 Bare rock, water	15-30	>30

**Table 2.19c. Susceptibility of land units to water erosion (based on soil erodibility and slope)**

Landform <sup>1</sup>	Water erosion hazard rating					
	Very low (VL)	Low (L)	Moderate (M)	High (H)	Very high (VH)	Extreme (E)
A. Flats, Very gentle slopes, Crests (<3%) (FWD, FPD, SL_C, SL_1)	(1), (2) <sup>2</sup>	(3) <sup>2</sup>		-	-	-
B. Gentle slopes (3-5%), Long slopes, Footslopes, Floodplains (SL_3, SL_L, FOS, FOW, FPP, FPW)	(1)	(2)	(3)	-	-	-
C. Gentle slopes (5-10%), Well drained drainage depressions (SL_5, DDW)		(1)	(2)	(3)	-	-
D. Moderate slopes (10-15%), Poorly drained drainage depressions (SL_10, DDP)			(1)	(2)	(3)	-
E. Moderate slopes (15-30%), Stream channels (SL_15, STC)			-	(1)	(2)	(3)
F. Steep slopes (>30%) (SL30)			-	-	(1)	(2), (3)

NOTE: Waterlogging is High or Very high, increase rating by one column (e.g. from High to Very high).

<sup>1</sup> See Table 1.5e.

<sup>2</sup> Soil profile erodibility class – See Table 2.19b. Increase soil erodibility class for waterlogged soils.

## 2.20 Water repellence susceptibility

Water repellence susceptibility describes the risk of the soil becoming resistant to wetting, resulting in an uneven soil wetting pattern at the break of the season. In the paddock, patches of wet soil alternate with dry soil, which results in poor germination of crops and pasture. Water repellence may also contribute to increased water erosion due to reduced infiltration and increased run-off.

The susceptibility of a soil to water repellence is related to two main factors:

- Particle surface area. Soil materials with small surface area are more susceptible
- The supply of hydrophobic compounds which varies with the productivity of the system and land use.

Soil materials with a low surface area are more susceptible to water repellence. For example, the amount of hydrophobic material to completely coat a sandy soil would only cover a small proportion of a clayey soil (surface area of sands, 0.01-0.2 m<sup>2</sup>/g, cf. clays 10-200 m<sup>2</sup>/g). Most soils with clay content above 5% (0-10 cm) have low water repellence susceptibility. In general, the surface area is too large to be coated with hydrophobic organic compounds so the soils absorb water. However, a few soils with 10-20 per cent clay are water repellent under native vegetation. Water repellence is not induced on these soils by agriculture. Known examples include soils associated with the Mallet Hills in the Great Southern, the highly calcareous 'fluffy' or kopi soils in the Zone of Ancient Drainage and the blackbutt loams near Manjimup. Another exception are the calcareous sands on the coastal dunes, which are rarely coated with hydrophobic compounds, and even in swales where organic matter has built up, water repellence is usually only moderate.

The specific surface area can be inferred from particle size analysis or field texture for most agricultural soils (Table 2.20). In general, most sandy soils containing <5 per cent clay (0-10 cm) have some water repellence susceptibility.

Laboratory measures of water repellence are desirable for consistency. The main tests include:

- molarity of ethanol droplet test or MED (King 1981);
- water droplet penetration time or WDPT (Letey 1969)<sup>16</sup>;
- angle of contact test or AC (Emerson and Bond 1963).

There are not many MED test results available for WA soils. The original work by King (1981) alerted users to large variation in test results due to soil temperature and soil moisture, which makes MED and WDPT unreliable in the field. A more recent paper by Doerr *et al.* (2002) indicates that high relative humidity<sup>17</sup> can increase the water repellence considerably. They concluded that comparisons between laboratory measures should be treated with caution if antecedent relative humidity prior to testing has not been recorded. They suggested that samples should be exposed to a period of high relative humidity before testing to best reflect critical field conditions. Table 2.20b indicates an approximate relationship between field derived water repellence measures and laboratory measures.

<sup>16</sup> Only applicable for slightly water repellent soils which cannot be distinguished by the MED test.

<sup>17</sup> As can occur just before rainfall.



**Table 2.20a. Susceptibility of soils to water repellence (adapted from Moore and Blackwell 1998)**

Surface texture <sup>1</sup>	Nominal Specific Surface area	Water repellence susceptibility rating			
		Nil (N)	Low (L)	Moderate (M)	High (H)
<b>Sand (&lt;2% clay)</b> Light sand (SS)	<b>&lt;0.1 m<sup>2</sup>/g</b>	Coarse calcareous sands with very low amounts of organic matter <sup>3</sup>		Coarse to medium calcareous sands with moderate amounts of organic matter <sup>3</sup>	Pale grey sands (including coloured sands with a bleached surface layer)
<b>Sand to weak clayey sand (2-5% clay)</b> sand, fine sand (S, FS)	<b>0.1-0.5 m<sup>2</sup>/g</b>		Some coloured sands and texture contrast soils with variable %clay (2-5%)	Coloured sands and texture contrast soils with a pale sandy surface and clay commonly only 2% (e.g. Esperance sandplain) <sup>2</sup>	-
<b>Loamy sand or finer (&gt;5% clay)</b> loamy sand to clay (LS, CS, SL, L, CL, C)	<b>&gt;0.5 m<sup>2</sup>/g</b>	Most soils	Some soils with lighter surface textures (e.g. texture contrast soils) with 5-10% clay	-	Soils which are water repellent before clearing (e.g. soils associated with certain vegetation such as mallet)

<sup>1</sup> See Table A1.8.<sup>2</sup> Moderate risk soils still require furrow sowing and press wheels to mitigate repellence effects.<sup>3</sup> See Table A1.11.**Table 2.20b. Relationship between field derived water repellence measures and laboratory measures (adapted from King 1981)**

For soils tested at 20 °C	Water repellence susceptibility rating			
	Nil (N)	Low (L)	Moderate (M)	High (H)
<b>MED values</b> (Molarity of ethanol which penetrates in 10 seconds)	Not applicable	<1	1-2	>2
<b>Contact angle</b> (between water drop and soil surface - degrees)	<75	75-86	87-92	>92
<b>WDPT</b> (seconds to penetrate)	<1	1-53	>53	Not applicable

## 2.21 Waterlogging/inundation risk

*Waterlogging* is excess water, in terms of saturated soil layers, in the root zone accompanied by anaerobic conditions. In saturated soils biological activity rapidly uses the available oxygen, retarding oxygen and water uptake and restricting root and plant growth.

Waterlogging for extended periods near the surface (e.g. <30 cm) can result in poor crops or plant death. The ability to tolerate different periods of waterlogging varies greatly between crops. Also in many situations, the presence of a saturated layer or watertable deeper in the soil can be advantageous because a water supply is available to the plant and adequate air is available in the topsoil to maintain root activity.

*Inundation* is water ponding on the soil surface. The effect on plant growth can be severe if plants are growing actively because all soil oxygen available to plant roots is rapidly depleted by biological activity.

In the agricultural areas of WA, waterlogging is widespread and a major factor reducing crop and pasture yields, especially in wet years. Its magnitude is difficult to measure given the large variation between seasons and the incidence is probably under-estimated because perched watertables can go unnoticed unless the soil profile is examined in winter.

The term *drainage* is used by McDonald *et al.* (1990) to summarise local soil wetness conditions, and is comparable to the waterlogging/inundation classes described in Table 2.21d.

Tables 2.21a to 2.21c present guidelines for estimating waterlogging/inundation risk rating in different rainfall districts (Table 1.6c and Figure 5) using landscape position and soil permeability. The assessment is based on the duration of waterlogging during the growing season and **assumes average seasonal rainfall**. Generally surficial watertables rise rapidly following the break of season (usually between April and June) and reach a maximum at the end of winter or during spring. Watertables can fall rapidly on sloping sites when the rains end. Perched watertables can also dry up rapidly. Watertables in flat, low lying landscapes tend to fall more gradually, and are often declining right up to the break of season.

Table 2.21d is the old method for estimating waterlogging/inundation risk. It is useful as a guide for the expected depth and duration of seasonal watertables. The reason Table 2.21d is no longer used to assess waterlogging/inundation risk is because in most cases there will be very little hard data for the assessment, and the surveyor will have to rely on experience and judgement. The use of indications in the soil profile such as the presence of mottled or gleyed layers is important, as is the presence of waterlogging indicator species, however, it will often be difficult to separate the effects of waterlogging and salinity.

Another reason Table 2.21d is no longer used is because the duration of waterlogging at different depths in the profile will vary considerably from the figures shown here in many situations.

**Table 2.21a. Estimating waterlogging/inundation risk rating in high rainfall districts (>600 mm, Table 1.6c) from landform and soil permeability**

Landform	Waterlogging/inundation risk rating in high rainfall districts					
	Nil (N)	Very low (VL)	Low (L)	Moderate (M)	High (H)	Very high (VH)
<b>W. WAT</b>	-	-	-	-	-	Very slow to Rapid
<b>A. SAL, SWM, STC, DDP</b>	-	-	-	-	Very rapid	Very slow to Rapid
<b>B1. FPD, FPP, SAS, GID</b>	-	-	-	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow
<b>B2. HSC, HSP</b>				Moderate to Very rapid	Very slow to Moderately slow	
<b>B3. FOS</b>			Moderate to Very rapid	Very slow to Moderately slow		
<b>C. BCH, CDE, FPW, FWD, SPL, SWL, LRI, DDW</b>	-	Moderate to Very rapid	Very slow to Moderately slow		-	-
<b>D. LSP, ROC, FOW</b>	Rapid to Very rapid	Moderately slow to Moderately rapid	Very slow to Slow	-	-	-
<b>E. SL_1, SL_L,</b>	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow	-	-	-
<b>F. RIS, SL_3, SL_C</b>	Moderately slow to Very rapid	Very slow to Slow	-	-	-	-
<b>G. BLO, CLI, FDH, FDL, RCR, SL_5, SL10, SL15, SL30</b>	Very slow to Very rapid	-	-	-	-	-

NOTE: 1. The maximum waterlogging rating for all soils not in the wet soil groups (100-105, Table 1.5b) is moderate.

2. The minimum waterlogging rating for all soils in the wet soil groups (100-105, Table 1.5b) is moderate.

**Table 2.21b. Estimating waterlogging/inundation risk rating in medium rainfall districts (350-600 mm, Table 1.6c) from landform and soil permeability**

Landform	Waterlogging/inundation risk rating in moderate rainfall districts					
	Nil (N)	Very low (VL)	Low (L)	Moderate (M)	High (H)	Very high (VH)
<b>W. WAT</b>	-	-	-	-	-	Very slow to Rapid
<b>A. SAL, SWM, STC, DDP,</b>	-	-	-		Rapid to very rapid	Very slow to Moderately rapid
<b>B1. FPD(s), FPP(s), SAS</b>	-	-	-	Moderate to Very rapid	Slow to Moderately slow	Very slow
<b>B2. HSC, HSP(s)</b>				Moderately slow to Very rapid	Very low to Slow	-
<b>B3. FOS</b>			Moderately slow to Very rapid	Very slow to Slow		
<b>C. BCH, CDE, FPW(s), FWD(s), GID(s), SPL, SWL, LRI, DDW</b>	Rapid to Very rapid	Moderate to Moderately rapid	Very slow to Moderately slow	-	-	-
<b>D. LSP, ROC, FOW</b>	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow	-	-	-
<b>E. SL_1, SL_L,</b>	Moderately slow to Very rapid	Very slow to Slow	-	-	-	-
<b>F. RIS, SL_3, SL_C</b>	Very slow to Very rapid	-	-	-	-	-
<b>G. BLO, CLI, FDH, FDL, RCR, SL_5, SL10, SL15, SL30</b>	Very slow to Very rapid	-	-	-	-	-

NOTE: 1. The maximum waterlogging rating for all soils not in the wet soil groups (100-105, Table 1.5b) is moderate.  
2. The minimum waterlogging rating for all in the wet soil groups (100-105, Table 1.5b) is moderate.

**Table 2.21c. Estimating waterlogging/inundation risk rating in low rainfall districts (<350 mm, Table 1.6c) from landform and soil permeability**

Landform	Waterlogging/inundation risk rating in low rainfall districts					
	Nil (N)	Very low (VL)	Low (L)	Moderate (M)	High (H)	Very high (VH)
<b>W. WAT</b>	-	-	-	-	-	Very slow to Rapid
<b>A. SAL, SWM, STC, DDP</b>	-	-	-	Very rapid	Moderately rapid to Rapid	Very slow to Moderate
<b>B1. FPD(s), FPP(s), SAS</b>	-	-	Very rapid	Moderately slow to Rapid	Very slow to Slow	-
<b>B2. HSC, HSP(s)</b>			Rapid to Very rapid	Very slow to Moderately rapid		
<b>B3. FOS</b>		Very rapid	Slow to Rapid	Very slow		
<b>C. BCH, CDE, FPW(s), FWD(s), GID(s), SPL, SWL, LRI, DDW</b>	Moderately rapid to Very rapid	Moderately slow to Moderate	Very slow to Slow		-	-
<b>D. LSP, ROC, FOW</b>	Moderately slow to Very rapid	Very slow to Slow		-	-	-
<b>E. SL_1, SL_L,</b>	Very slow to Very rapid		-	-	-	-
<b>F. RIS, SL_3, SL_C</b>	Very slow to Very rapid	-	-	-	-	-
<b>G. BLO, CLI, FDH, FDL, RCR, SL_5, SL10, SL15, SL30</b>	Very slow to Very rapid	-	-	-	-	-

NOTE: 1. The maximum waterlogging rating for all soils not in the wet soil groups (100-105, Table 1.5b) is moderate.

2. The minimum waterlogging rating for all in the wet soil groups (100-105, Table 1.5b) is moderate.

**Table 2.21d. Generic description of waterlogging classes in relation to duration of waterlogging and inundation and watertable depth (adapted from Moore and McFarlane 1998)**

	Waterlogging/inundation risk rating					
	Nil (N)	Very low (VL)	Low (L)	Moderate (M)	High (H)	Very high (VH)
<b>Inundation<sup>2</sup></b>	Never	< 1 day	< 4 days	< 2 weeks	< 2 months	> 2 months
<b>Watertable ≤30 cm<sup>2</sup></b>	Never	< 3 days	1-7 days	1-8 weeks	2-3 months	> 3 months
<b>Watertable ≤50 cm<sup>2</sup></b>	Never	< 1 week	1-4 weeks	1-3 months	3-6 months	> 6 months
<b>Watertable ≤80 cm<sup>2</sup></b>	Never	1-4 weeks	1-3 months	3-5 months	> 5 months	Most of year
<b>Pasture and crop indicators<sup>3</sup></b>	Healthy crops and pastures	Healthy crops and pastures	Reduced growth of lupins, lucerne	Reduced growth of wheat, canola	Very poor crop growth, root pruning of pastures	Annual pastures die, some perennials (e.g. kikuyu) are OK

<sup>1</sup> Watertable sitting above ground surface.

<sup>2</sup> Use data generated using Table A1.10 as a guide.

<sup>3</sup> Assume that watertable is not saline.

## 2.22 Wind erosion hazard

Wind erosion hazard is the inherent susceptibility of the land to the loss of soil as a result of wind movement across the surface. Wind erosion has many adverse effects: sandblasting damage to crops, loss of macro- and micro-nutrients, long-term loss of productivity, and atmospheric pollution. There are also off-site costs to both individuals and the community. The dust lost from paddocks is rich in nutrients and is carried high into the atmosphere before being deposited, possibly thousands of kilometres downwind.

All soils are subject to wind erosion given certain conditions. The key is the level of disturbance by mechanical or animal action required to bring a soil to an erodible condition.

The *susceptibility of a soil* can be assessed from a simple matrix of surface texture and surface condition (Table 2.22a). The five categories of wind erosion hazard relate to the level of disturbance needed to bring the soil to a loose and consequently erodible condition. Soils in category (v) are highly susceptible because they have a loose surface and control must rely on the use of windbreaks and/or maintenance of adequate vegetative cover. Categories (iv) to (i) have decreasing susceptibility. They are less fragile and require some disturbance by machinery or stock to loosen the soil. Gravel both physically protects the surface and increases roughness and this reduces the wind velocity at the soil surface. The surface condition should be assessed when the soil is dry.

To use the tables, first determine the percentage of coarse fragments present on the surface. If there are less than 20 per cent coarse fragments, use Table 2.22a, if 20-50 per cent use Table 2.22b and if more than 50 per cent use Table 2.22c. The *susceptibility of a land unit* to wind erosion is assessed by combining soil susceptibility (Tables 2.22a, b or c) with landform (Table 2.22d). Landform and location influence wind speed and exposure to high winds. As defined here wind erosion hazard does not take into account land management practices (these are assessed in the land capability ratings tables).

**Table 2.22a. Assessing susceptibility of bare soil to wind erosion from surface texture and surface condition for soils with <20% surface coarse fragments (adapted from Moore *et al.* 1998b)**

Loose (L) <sup>1</sup>	Soft, Surface flake (S, X) <sup>1</sup>	Firm, Crusting, Cracking, Saline (F, C, K, Z) <sup>1</sup>	Hardsetting (H) <sup>1</sup>	Self- mulching (M) <sup>1</sup>	Wind erodibility rating
-	-		Coarse sand and sandy loam to clay <sup>2</sup> (KS, SL, L, SCL, CL, C)	Clay <sup>3</sup>	(1)
-	-	Coarse sand and sandy loam to Clay (KS, SL, L, SCL, CL, C)	-	Clay <sup>3</sup>	(2)
-	Coarse sand and sandy loam to clay (KS, SL, L, SCL, CL, C)	Light sand to clayey sand (SS, S, FS, LS, CS)	Loamy sand to clayey sand (LS, CS)	Clay <sup>3</sup>	(3)
Coarse sand (KS)	Light sand to clayey sand (KS, SS, S, FS, LS, CS)	-	-	Clay <sup>3</sup>	(4)
Light sand to clay (SS, S, FS, LS, CS, SL, L, SCL, CL, C)	-	-	-		(5)

<sup>1</sup> Surface condition – see Table A1.7.

<sup>2</sup> Surface texture – see Table A1.8.

<sup>3</sup> Erodibility of self-mulching clays depends on the size of the particles created when clay mulches. The default value for self-mulching clays is (3).



**Table 2.22b. Assessing the susceptibility of bare soil to wind erosion from surface texture and surface condition for soils with 20-50% surface coarse fragments**

<b>Loose (L)<sup>1</sup></b>	<b>Soft, Surface flake (S, X)<sup>1</sup></b>	<b>Firm, Crusting, Cracking, Saline (F, C, K, Z)<sup>1</sup></b>	<b>Hardsetting (H)<sup>1</sup></b>	<b>Self- mulching (M)<sup>1</sup></b>	<b>Wind erodibility rating</b>
-	-	Sandy loam to clay (SL, L, SCL, CL, C)	Sandy loam to clay <sup>2</sup> (SL, L, SCL, CL, C)	Clay <sup>3</sup>	<b>(1)</b>
-	Sandy loam to clay (SL, L, SCL, CL, C)	Coarse sand to clayey sand (KS, SS, S, FS, LS, CS)	Loamy sand to clayey sand (LS, CS)	<b>Clay<sup>3</sup></b>	<b>(2)</b>
-	Coarse sand to clayey sand (KS, SS, S, LS, CS)	-	-	Clay <sup>3</sup>	<b>(3)</b>
Coarse sand to clay (KS, SS, S, FS, LS, CS, SL, L, SCL, CL, C)	-	-	-		<b>(4)</b>

<sup>1</sup> Surface condition – see Table A1.7.

<sup>2</sup> Surface texture – see Table A1.8.

<sup>3</sup> Erodibility of self-mulching clays depends on the size of the particles created when clay mulches. The default value for self-mulching clays is (2).

**Table 2.22c. Assessing susceptibility of bare soil to wind erosion from surface texture and surface condition for soils with >50% surface coarse fragments**

<b>Loose (L)<sup>1</sup></b>	<b>Soft, Surface flake (S, X)<sup>1</sup></b>	<b>Firm, Crusting, Cracking, Saline (F, C, K, Z)<sup>1</sup></b>	<b>Hardsetting (H)<sup>1</sup></b>	<b>Self- mulching (M)<sup>1</sup></b>	<b>Wind erodibility rating</b>
-	Sandy loam to clay (SL, L, SCL, CL, C)	Coarse sand to clay (KS, SS, S, LS, FS, CS, SL, L, SCL, CL, C)	Loamy sand to clay <sup>2</sup> (LS, CS, SL, L, CL, SCL, C)	Clay <sup>3</sup>	<b>(1)</b>
-	Coarse sand to clayey sand (KS, SS, S, FS, LS, CS)			<b>Clay<sup>3</sup></b>	<b>(2)</b>
Coarse sand to clay (KS, SS, S, FS, LS, CS, SL, L, SCL, CL, C)	-	-	-		<b>(3)</b>

<sup>1</sup> Surface condition – see Table A1.7.

<sup>2</sup> Surface texture – see Table A1.8.

<sup>3</sup> Erodibility of self-mulching clays depends on the size of the particles created when clay mulches. The default value for self-mulching clays is (2).

**Table 2.22d. Susceptibility of land units to wind erosion using landform and wind erodibility rating from Tables 2.22a, b, or c**

Landform <sup>1</sup>	Wind erosion hazard rating				
	Low (L)	Moderate (M)	High (H)	Very high (VH)	Extreme (E)
<b>A. Foredunes and blowouts (BEA, BLO, FDL, FDH)</b>	(1)	(2)	(3)	(4)	(5)
<b>B. Crests and rises (CLI, LRI, RCR, RIS, SL_C)</b>	(1), (2)	(3)	(4)	(5)	-
<b>C. Flats and slopes (FPD, FPP, FWD, FPW, SL_L, SL_1, FOS, FOW, SL3, SL_5, SL_10, SL_15, SL30, SAS) and larger swamps and salt lakes (SWM, SAL)</b>	(1), (2), (3)	(4)	(5)	-	-
<b>D. Depressions (CDE, DDP, DDW, SWL, STC) and smaller swamps and salt lakes (SWM, SAL)</b>	(1), (2), (3), (4)	(5)	-	-	-

<sup>1</sup> See Table 1.5e.

NOTE: (For soil-landscape system, map unit or site specific assessments)

1. If the landform experiences higher than average wind exposure, move up one row (e.g. from row C to row B).
2. If the landform experiences lower than average wind exposure, move down one row (e.g. from row C to row D).
3. If the landform experiences high waterlogging, the soil's erodibility is reduced by 1 unit, e.g. from (5) to (4). Excludes very shallow (VSH) soils which will dry off rapidly in summer.

### 3. LAND CAPABILITY ASSESSMENT

Land capability assessment, as used in Western Australia is similar to stage two suitability assessment described in FAO (1976, 1983). The term 'land resource suitability' has recently become the adopted national standard. Because of the prevailing use of the term land capability in WA, we continue to use it here.

Land capability refers to the ability of land to support a type of land use without causing damage (Austin and Cocks 1978). It thus considers both the specific requirements of the land use, e.g. rooting depth or soil water availability, plus the risks of degradation associated with the land use, e.g. phosphorus export hazard or wind erosion. Five land capability classes are used (Table 3).

**Table 3. Land capability classes for given land use types (adapted from Wells and King 1989)**

Capability class	General description
<b>1</b> Very high	Very few physical limitations present and easily overcome. Risk of land degradation is negligible <sup>18</sup> .
<b>2</b> High	Minor physical limitations affecting either productive land use and/or risk of degradation. Limitations overcome by careful planning.
<b>3</b> Fair	Moderate physical limitations significantly affecting productive land use and/or risk of degradation. Careful planning and conservation measures required <sup>19</sup> .
<b>4</b> Low	High degree of physical limitation not easily overcome by standard development techniques and/or resulting in high risk of degradation. Extensive conservation measures and careful ongoing management required.
<b>5</b> Very low	Severe limitations. Use is usually prohibitive in terms of development costs or the associated risk of degradation.

A good way to consider capability ratings is to imagine that you are looking to purchase some land to conduct a particular land use. Given that other factors such as price and location were suitable, your first choice would be land was rated capability classes 1 or 2.

Class 3 land would still be worth purchasing for the use, especially if suitable class 1 or 2 land was not available. You might even consider buying this land in preference to class 1 or 2 land if it was considerably cheaper to purchase, had better water supplies or was located in close proximity to your market<sup>20</sup>. However you should give careful consideration to the extra costs or management required to overcome its physical limitations. You may also have to weigh up the potential for lower returns if this land was not as productive as class 1 or 2 land.

You generally would not consider purchasing class 4 or 5 land for the proposed use. In the long term, the costs involved in managing this land in a sustainable manner are unlikely to be offset by the returns from your enterprise.

Of course most properties will consist of land of with a range of capability classes. What you would be looking for is something with large enough area of land that is rated class 1 and 2 for the proposed use with the balance being class 3. Alternative uses could be considered for the class 4 and 5 land.

<sup>18</sup> Experience has shown that very few land use developments have no negative effect on land degradation, hence capability class 1 will not occur for most land uses employing conventional management and development techniques.

<sup>19</sup> Class 3 is often the largest category of land. It can be highly productive agricultural land which requires the adoption of certain land management practices to minimise the risk of degradation (e.g. the establishment of wind breaks to reduce wind erosion). In other cases Class 3 land could be lower productivity than Class 2 land.

<sup>20</sup> When using a general rating for annual horticulture, class 3 land might be preferred to class 1 or 2 for a specific crop e.g. for summer-grown melons waterlogging is less restrictive.

### 3.1 Land capability ratings tables

The land capability ratings tables are the standard assessment adopted by the Department of Agriculture in WA for interpreting land resource mapping. They provide land capability ratings for each zone land unit (Section 1.5) by matching land use requirements with the land quality values (Section 2) assigned to that zone land unit. Each of the 22 land qualities has potential to affect the successful implementation of a particular land use, though it will not necessarily be relevant to every land use.

Land capability ratings tables are presented for the following land uses:

- Grazing
- Cropping
- Perennial horticulture
- Annual horticulture
- Septic tanks for rural residential developments (used in combination with other land capability classes to assess capability for specific rural residential developments).

These land capability ratings tables update those described by Wells and King (1989) and van Gool and Moore (1999). There is also a brief consideration of urban land capability.

In the tables, each value of the relevant land qualities is assigned a rating from 1 to 5 as shown in Table 3. The overall capability rating is determined by the most limiting factor or factors (i.e. the quality or qualities assigned the highest number).

The rating does not change according to how many most limiting factors there are. For example there is no difference in the overall rating for a zone land unit with a class 4 rating due only to waterlogging compared with another land unit where class 4 is due to waterlogging, salinity, flooding and water erosion hazard.

Most of the ratings tables are based on broad (generalised) land uses that reflect common current management practices. When using a land capability rating it is essential to be aware of the land use definition which takes into account assumed management practices of the use. A change in the land use definition will often lead to a change in the capability rating. For example, cultivation practices impact on the erosion hazards in dryland cropping, and some land will have a different rating for cropping with minimum tillage as opposed to traditional tillage.

Below each table is a description of how each land quality affects the land use and what management techniques can be employed to overcome the limitation.

#### *Land capability subscripts*

Wells and King (1989) identified codes for land qualities which could be used as a subscript when capability classes were recorded. For example land with a capability rating of “**5iy**” for perennial horticulture has very low capability due to waterlogging/inundation risk (i) and salinity hazard (y). Land qualities that are essentially the same as those described by Wells and King (1989) use identical subscript codes. New land qualities are prefixed by a “z” (e.g. za is water repellence susceptibility).

These optional land quality subscript codes are given in Table 2, and in the land capability ratings tables. Land capability subscripts may be useful for presenting large tables of information. Land quality subscripts are not currently produced routinely because there is no method for determining them developed within the map unit database as yet, and there has been little demand. Instead important qualities are usually presented as a separate thematic map and reported independently, for example on a map showing all areas subject to high waterlogging/inundation risk.

### 3.2 Land capability for annual horticulture

The assessment for annual horticulture covers the production of irrigated horticultural crops from plants with short-term life cycles (typically completed within the period of a year). Crops include annual fruits (strawberries, melons, etc.), vegetables (e.g. potatoes, lettuce, cabbages, tomatoes, pumpkins, etc.), commercial turf production and cut flowers.

The assumptions for the land use as assessed include:

- crops are grown for commercial production
- crops are shallow-rooted with most roots using only the top 50 cm of soil
- crops are irrigated using sprinkler or trickle systems
- mechanised cultivation occurs at least annually
- fertilisers and herbicides, fungicides and/or pesticides are broadcast at least annually
- crop rotation is practised
- considers physical requirements only and ignores socio-economic factors.

In this assessment preference is given to land suitable for year-round cropping and which would be able to support a wide variety of crops. Class 1 or 2 land has the greatest versatility, there being few production or environmental limitations for a wide range of crops. Capability class 3 has moderate to high limitations for some or all crops. Some class 3 land may have a high capability for individual crops that can tolerate a wide range of soil conditions, but be unsuited to other crops. Land well suited to summer cropping but suffering from winter waterlogging would also be rated as class 3.

Class 4 and 5 land will be unsuitable for commercial production of most crops, although there may be some individual crops with specific requirements and tolerance that can be grown on this land. For specific crops or summer cropping, a separate ratings table should be used.

It should be remembered that the ratings derived from these tables relate to the suitability of the land resource only. They do not take into account factors such as the availability and quality of water supplies for irrigation or climatic risks such as frost or heat stress. Such factors need to be considered as a separate layer of information.

**Table 3.2. Land capability ratings for annual horticulture**

Land quality and (capability subscript)	Land capability class				
	1	2	3	4	5
Flood hazard ( <i>f</i> )	N	L	M		H
Land instability ( <i>c</i> )	N, VL, L		M	H	
pH 0-10 cm ( <i>zf</i> )	Slac, N	Mac	Vsac, Sac, Malk, Salk		
pH 50-80 cm ( <i>zg</i> )	Slac, N	Mac	Vsac, Sac, Malk, Salk		
Phosphorus export ( <i>n</i> )	L	M	H	VH	E
Rooting depth ( <i>r</i> )	D, VD	M	MS	S	VS
Salinity hazard ( <i>y</i> )	NR		PR	MR, HR	PS
Salt spray exposure ( <i>zi</i> )	N			S	
Surface salinity ( <i>ze</i> )	N		S	M	H, E
Site drainage potential ( <i>zh</i> )	R, W, MW	M	P		VP
Soil water storage ( <i>m</i> )	M, H, ML	L	VL		
Soil workability ( <i>k</i> )	G	F		P	VP
Trafficability ( <i>zk</i> )	G	F	P	VP	
Water erosion ( <i>e</i> )	VL	L	M	H, VH	E
Water repellence ( <i>za</i> )	N, L, M	H			
Waterlogging ( <i>i</i> )	N, VL	L	M	H	VH
Wind erosion ( <i>w</i> )	L	M	H, VH		E

### *Land qualities used in the assessment*

**Flood hazard.** Flood waters can damage crops and infrastructure. The frequency and timing of flooding will determine the impact on the enterprise. Infrequent flood events (less frequent than 1:10 years) are not likely to have a major impact, especially if they occur when the flood occurs when there is no crop in the ground. On land with a moderate flood risk it would be advisable to crop only in summer and not establish permanent irrigation systems. For land with a high risk the best option would be to select another site.

**Land instability.** Highly instable land should be avoided as cropping can increase the risk of soil movement. This is likely to lead to the loss of crops and damage to infrastructure.

**pH** affects nutrient availability to plants and extremes can lead to toxicity or deficiencies. In horticultural enterprises, pH imbalances can be managed with the application of fertilisers, lime or gypsum.

**Phosphorus export.** Annual horticulture involves relatively high fertiliser inputs that increase risk of nutrient export. Some may feel that the ratings presented here are lenient. This is because the ratings are designed for broad-scale map units in which proximity to waterways has not been considered. Any on-site assessment should consider this. A soil with good nutrient retention properties located directly adjacent to a drain has a higher risk than a soil with poor retention qualities hundreds of metres away. Management options include soil amendment, subsoil drainage, buffer strips and efficient irrigation and fertiliser scheduling<sup>21</sup>. With low volume irrigation systems such as trickle there is a reduced risk of nutrients leaching below the root zone compared with high volume sprinklers.

<sup>21</sup>

More on management practices to limit nutrient export in Lantze and Galati (1997) and Section 11.3 of Tille *et al.* 2001

**Rooting depth.** As most annual crops are shallow-rooted, a moderate rooting depth (>50 cm) will not present a significant limitation to capability. For soils with a moderately shallow rooting depth (30-50 cm) management options will depend on the nature of the impeding layer. For example, limestone can be removed on some properties (even on shallow soils) or weak pans may be broken by deep ripping.

**Salinity.** Saline sites or those at hazard of becoming saline should be avoided as irrigation is likely to increase the risk. Some crops will tolerate slight salinity levels while in other crops yields will be significantly reduced<sup>22</sup>. On land with a partial or low hazard, salinity and watertables surveys could be used to identify areas that can be safely planted.

**Site drainage potential.** In high rainfall areas poor site drainage potential results in seasonal waterlogging and inundation, while in low rainfall areas land may be unsuitable for irrigation without remedial work such as soil amendment and provision of additional drainage.

**Soil water storage.** Shallow-rooted annual crops require regular irrigation in the summer. Careful irrigation scheduling is essential on soils with very low soil water storage such as the pale deep sands (i.e. high frequency applications of smaller volumes). Soil amendment with organic matter and other material is another solution.

**Soil workability** is an essential as at least 15 cm of soil is required regular cultivation.

**Trafficability** areas with very poor machinery access (due to slope, rock outcrop or waterlogging) are considered unsuitable due to the limited options for cultivation, harvesting and weed and pest control.

**Water erosion.** The risk of water erosion is relatively high due to regular soil disturbance through cultivation and harvesting activities. On most soils located on slopes with gradients in excess of 10% the risk is considered to be limiting. Management options on areas with a moderate hazard include cross slope working, minimising cultivation, the use of narrow-tyred implements, basin tillage and the establishment of cover crops after harvest<sup>23</sup>.

**Water repellence** is common on sandy soils. Though it can adversely affect production it is routinely managed by irrigation scheduling, land layout (e.g. furrows) and wetting agents.

**Waterlogging and inundation** can be major restrictions, especially in the winter months. Land with a moderate hazard is considered suitable for summer cropping only. Other management options include construction of artificial drainage or permanent raised beds.

**Wind erosion.** As with water erosion, regular soil disturbance through cultivation and harvesting increases the risk of wind erosion. Associated sand blasting can damage crops. Control measures include timing of cultivation, irrigation to keep soils moist and the use of wind breaks (trees, shrubs or artificial barriers such as shadecloth).

### *Other land use notes*

**Root crops.** In Table 3.2, a soil has suitable depth for annual horticulture if there is no physical barrier to root penetration in the top 50 cm. For some root crops in which the shape of the tuber is an important consideration for marketing (e.g. potatoes, carrots and Chinese radish) the presence of gravel and other coarse fragments will reduce the suitability of some soils. For such crops, the rating table should be modified to include the coarse fragment land characteristic (Section A1.1). For other root crops such as processing potatoes where tuber shape is not so important, the rating table may be adequate. However, gravels may also hamper harvesting, which again would require a modified rating for the presence of coarse fragments.

<sup>22</sup> Department of Agriculture Farmnotes 34/2004 'Water salinity and crop irrigation' and 71/1999 'Tolerance of plants to salty water' provide some indication of the tolerance of different horticultural crops to salinity.

<sup>23</sup> More details on management practices to limit water erosion can be found in Rose (1997) and Section 9.3 of Tille *et al.* (2001).

### 3.3 Land capability for perennial horticulture

The assessment for perennial horticulture covers production of irrigated horticultural crops on plants with long life-cycles (typically trees, shrubs or woody vines). Included are orchard crops (e.g. apples, citrus, stone fruit, avocados, nuts, etc.) and vineyard crops (e.g. grapes and kiwifruit). Although the plants are perennial, crops are harvested annually.

The assumptions for the land use as assessed include:

- crops are grown for commercial production
- plants are deep-rooted with roots typically extending to depths of 100 cm or more
- plants are irrigated using drip, micro-jet or mini-sprinkler systems
- fertilisers and herbicides, fungicides and/or pesticides are broadcast at least annually
- mechanised cultivation occurs only during crop establishment
- weeds are controlled by mowing, slashing or sprays
- machinery access to the crop is required for spraying, pruning and/or harvesting
- considers physical requirements only and ignores socio-economic factors.

Class 1 or 2 land has the greatest versatility in this assessment, there being few production or environmental limitations for a wide range of crops. Some class 3 has land has moderate limitations for most crops while some may have a high capability for individual crops that can tolerate a wide range of soil conditions (e.g. wine grapes), but be unsuited to other crops with more restrictive requirements (e.g. avocados). Class 4 and 5 land will be unsuitable for most crops, although there may be some individual crops with specific requirements and tolerance which can be grown on this land.

It should be remembered that the ratings derived from these tables relate to the suitability of the land resource only. They do not take into account factors such as the availability and quality of water supplies for irrigation or climatic risks such as frost or heat stress. Such factors need to be considered as a separate layer of information.



**Table 3.3. Land capability ratings for perennial horticulture**

Land quality and (capability subscript)	Land capability class				
	1	2	3	4	5
Flood hazard ( <i>f</i> )	N	L	M		H
Land instability ( <i>c</i> )	N, VL, L		M		H
pH 0-10 cm ( <i>zf</i> )	Slac, N	Mac, Sac, Malk	Vsac		
pH 50-80 cm ( <i>zg</i> )	Slac, N	Mac	Vsac, Sac, Malk, Salk		
Phosphorus export ( <i>n</i> )	L	M, H	VH	E	
Rooting depth ( <i>r</i> )	D, VD	(M)	M	MS	S, VS
Salinity hazard ( <i>y</i> )	NR		PR	MR	HR, PS
Salt spray exposure ( <i>zi</i> )	N			S	
Surface salinity ( <i>ze</i> )	N		S	M	H, E
Site drainage potential ( <i>zh</i> )	R, W	MW	M	P	VP
Soil water storage ( <i>m</i> )	H, M, ML	L	VL		
Soil workability ( <i>k</i> )	G	F	P	VP	
Subsurface compaction ( <i>zc</i> )	L, M	H			
Trafficability ( <i>zk</i> )	G	F	P	VP	
Water erosion ( <i>e</i> )	VL, L	M	H	VH	E
Water repellence ( <i>za</i> )	N, L, M	H			
Waterlogging ( <i>i</i> )	N	VL (L)	L (M)	M (H)	H, VH
Wind erosion ( <i>w</i> )	L	M, H	VH		E

Brackets ( ) indicate adjustments for wine grapes.

#### *Land qualities used in the assessment*

The major differences from annual horticulture are that plants are long-lived and generally deeper-rooted, irrigation systems are more permanent and regular cultivation is not necessary.

**Phosphorus export, Site drainage potential, Salinity, Soil water storage, Trafficability and Water repellence.** See comments for annual horticulture.

**Flood hazard and Land instability.** Flood waters and mass movement can damage crops and infrastructure. The impact may be greater than for annual horticulture as the crops and irrigation systems are more permanent. Levee banks could be considered to protect against flooding in some situations.

**pH** affects nutrient availability to plants and extremes of pH can lead to toxicity or deficiencies. In the topsoil, pH imbalances can be managed through the application of fertilisers, lime or gypsum. Subsoil pH can be difficult to manage once the crop is established though ameliorants can be deep ripped into the soil prior to planting. In some cases subsoil pH will be a limitation to rooting depth.

**Rooting depth.** Any soil less than 50 cm deep is considered unsuitable for most perennial crops. Having in excess of 80 cm of profile for the roots to exploit is preferable. In some cases mounding may be employed to increase available soil depth.

**Soil workability** is usually less limiting than for annual horticulture as soil is not cultivated following crop establishment.

**Subsurface compaction.** As traffic is confined to inter-row spaces, compaction and reduced root growth can result. Traffic pan can be treated through deep ripping though this may have detrimental impacts on the roots of some species.

**Water and Wind erosion.** Limited cultivation reduces erosion risk in comparison to annual horticulture. On slopes with gradients in excess of 10%, rows should be laid out on a slight gradient off the contour with ground cover being maintained between the rows. Inter-row cover can consist of sod culture (grasses), cover crops (e.g. oats or lupins), or mulches (e.g. straw). Slopes with gradients in excess of 15% should generally be avoided

**Waterlogging** tolerance varies between crops and land with a low waterlogging risk will be suitable for some crops but not others. Deciduous trees and vines (e.g. grapes) have a greater tolerance of winter waterlogging during crop dormancy than evergreen species such as citrus and avocados. Few crops are tolerant of waterlogging in late spring and summer. Careful assessment of waterlogging risk in spring from seasonal variations in rainfall is recommended.

#### *Other land use notes*

**Wine grapes.** The ratings table for perennial horticulture shows adjustments for wine grapes. These have a greater tolerance to waterlogging and shallower rooting depth requirement than most other crops. Some growers prefer soils with rooting depth limitations as this gives them more control over water availability and grape quality (e.g. through the practice of Regulated Deficit Irrigation).

Some good viticulture soils occur on land with >15% slopes. For smaller orchards, if machinery access is not essential, this land can be highly productive.

### 3.4 Land capability for grazing

This assessment covers the grazing of sheep and cattle on broadscale dryland (i.e. non-irrigated) pastures in agricultural areas (receiving an average annual rainfall more than 350 mm).

Pastures are typically based on annual species (such as sub-clover or ryegrass), but perennial species (such as kikuyu or perennial ryegrass) are often present in higher rainfall areas and may dominate some locations. This land use incorporates occasional reseeding and fertiliser topdressing using tractors or similar machinery.

This assessment does not apply to irrigated pastures or to intensively managed paddocks (where supplementary feeding is essential due to high stocking rates and windbreaks are necessary to control wind erosion). See notes on stocking rates, small holdings and horses below. Tables 3.4a considers physical requirements only and ignores socio-economic factors.

**Table 3.4a. Land capability ratings for grazing**

Land quality and (capability subscript)	Land capability class				
	1	2	3	4	5
Flood hazard ( <i>f</i> )	N, L	M	H		
Land instability ( <i>c</i> )	N, VL, L		M	H	
pH 0-10 cm ( <i>zf</i> )	Slac, N	Sac, Mac, Malk	Vsac, Salk		
pH 50-80 cm ( <i>zh</i> )	Slac, N	Mac, Malk, Salk	Sac	Vsac	
Phosphorus export ( <i>n</i> )	L, M	H	VH	E	
Rooting depth ( <i>r</i> )	VD, D, M	MS	S	VS	
Salinity hazard ( <i>y</i> )	NR	PR	MR	HR	PS
Salt spray exposure ( <i>zi</i> )	N		S		
Surface salinity ( <i>ze</i> )	N	S	M	H	E
Surface soil structure decline ( <i>zb</i> )	L, M	H			
Soil water storage ( <i>m</i> )	M, H	ML	L	VL	
Soil workability ( <i>k</i> )	G, F, P		VP		
Subsurface acidification ( <i>zd</i> )	L, M	P, H			
Subsurface compaction ( <i>zc</i> )	L, M	H			
Trafficability ( <i>zk</i> )	G, F	P	VP		
Water erosion ( <i>e</i> )	VL, L, M	H	VH	E	
Water repellence ( <i>za</i> )	N, L	M	H		
Waterlogging ( <i>i</i> )	N, VL, L	M	H	VH	
Wind erosion ( <i>w</i> )	L	M	H	VH	E

### *Land qualities used in the assessment*

**Flood hazard** is only severe if flooding would affect pasture production or endanger grazing animals.

**Land instability.** The clearing of native vegetation increases the risk of mass movement. The impact on a grazing system will not be great but there could be some loss of pasture and damage to fences. Increasing water use upslope (e.g. through tree planting) reduces risk of mass movement. Areas where landslides have already occurred should be fenced and revegetated<sup>24</sup>.

**pH.** Highly acid soils reduce production of most legume species. Management options include growing tolerant species and using acid-tolerant Rhizobia and/or applications of lime. Medics can be selected for highly alkaline soils.

**Phosphorus export.** Although grazing involves less intense fertiliser applications than horticulture, larger areas are fertilised. Livestock redistribute the nutrients by grazing pastures over a broad area then depositing manure and urine in concentrated patches. This can make a significant contribution to nutrient export, where nutrients are deposited close to waterways, especially in stock camps under shade trees along water courses. Management practices include matching fertilisers to pasture requirements, timing of fertiliser applications and the creation of buffer strips along waterways<sup>25</sup>.

**Rooting depth.** Except on very shallow soils, rooting depth is unlikely to be a significant limitation for shallow-rooted pastures. However, rooting depth does impact on soil water storage, hence pastures dry out rapidly.

**Salinity** can be a serious limitation to production while the establishment of low water use annual pastures contributes to development of salinity. Land with high to extreme surface salinity is generally unsuited to conventional grazing though some productivity from saltland pastures may be possible. Management of affected areas can include increasing plant water use in recharge areas, improving site drainage and establishment of salt tolerant pastures<sup>26</sup>.

**Soil water storage.** On soils with very low water storage, pastures are less productive and dry off rapidly. Poor ground cover increases the risk of wind and water erosion as well as contributing to recharge leading to the development of salinity.

**Surface soil structure decline, Subsurface acidification, Subsurface compaction and Water repellence** all affect pasture production but are rarely prohibitive. Management practices to control and alleviate these problems have been developed<sup>27</sup>. However wide scale adoption has yet to be achieved and land is still deteriorating in many areas. Adoption is more economic in higher rainfall areas where there is greater production per hectare.

**Trafficability.** Access for broadcasting fertiliser and herbicides/pesticides, as well as reseeding and stock management, is generally required. Alternatives to conventional tractors are available for areas with difficult access such as steep rocky slopes.

**Water erosion** and **Wind erosion** generally lead to a slow decline in productivity, though extreme events can have a more immediate impact. Management can include excluding

---

<sup>24</sup> More details on dealing with mass movement can be found in Section 10.3 of Tille *et al.* (2001).

<sup>25</sup> More details on combating nutrient export can be found in Section 11.3 of Tille *et al.* (2001).

<sup>26</sup> More details on managing salinity can be found in Moore (1998b) and Section 5.3 of Tille *et al.* (2001).

<sup>27</sup> See Sections 3.1, 3.2, 4 and 5.1 of Moore (1998a) for more details.

stock from highly susceptible areas, maintaining ground cover through control of stocking rates, the construction of earthworks to control runoff and the establishment of windbreaks<sup>28</sup>.

**Waterlogging** can limit pasture production with varying degrees of severity. The effects of waterlogging are often far from obvious. Mildly waterlogged pastures can look healthy but have significant yield reductions. Management options include the uses of waterlogging tolerant pasture species and the construction of surface drains<sup>29</sup>.

#### *Other land use notes*

**Cropping or hay production.** In many areas crops are grown in rotation with pastures. Land capability for cropping is assessed separately in the next section.

**Stocking rates.** Table 3.4b indicates the approximate correlation between the land capability classes derived above and the carrying capacity for improved clover pastures in high rainfall areas (>600 mm).

For **small holdings** such as rural residential developments of 1-2 ha (or more), the land use description for grazing differs from the one given above for Table 3.4a. As a result the capability ratings and stocking rates for a parcel of land will not necessarily be the same as those presented in Table 3.4b. On small holdings there tends to be a higher rate of management, with less reliance on pasture and more imported feed. Stock are often stabled overnight allowing for management of manure and pastures may be irrigated.

A 2 ha lot of class 5 land capable of supporting only one fifth of a horse according to Table 3.4b may be suitable to support one or two horses with suitable management. **Horses** are generally more active than other livestock and require better paddock management to prevent soil erosion. Horses also tend to be slightly more destructive to unprotected trees by eating the bark (ring barking in some seasons), even when adequate pasture is available. Issues such as manure handling, fly control and odour are common.

So when considering small rural holdings, such management factors are very important considerations. Planning or management guidelines for small rural holding should **not** be developed directly from the stocking rates in Table 3.4b, but need to consider the specific management options available to the stock being considered<sup>30</sup>.

**Table 3.4b. Correlation between land capability classes and carrying capacity for improved clover pastures in high rainfall areas (>600 mm)**

Capability class	Approximate carrying capacity (DSE*/ha)
1 - Very High	7-10
2 - High	7-10
3 - Fair	4-7
4 - Low	1-4
5 - Very Low	≤1

\* DSE is dry sheep equivalent. Stocking rates for other animals can be calculated as large horse = 10 DSE; pony = 8 DSE; milking cow = 10 DSE; heifer = 8 DSE; breeding ewe = 1.5 DSE; dairy goat = 2 DSE; Cashmere goat = 1 DSE; angora goat = 0.8 DSE; deer = 1-2 DSE.

<sup>28</sup> See Sections 7.1 and 7.2 of Moore (1998a) and Section 9.3 of Tille *et al.* (2001) for more details.

<sup>29</sup> See Sections Moore and McFarlane (1998) and Section 7.3 of Tille *et al.* (2001) for more details.

<sup>30</sup> More information on stocking rate guidelines for rural small holdings in van Gool *et al.* (2000).

### 3.5 Land capability for dryland cropping

This assessment covers the production of rain-fed (non-irrigated) field crops under a cropping system that incorporates minimal tillage practices and stubble retention.

Crops included in this general assessment are wheat, barley, oats, narrow-leafed lupins, field peas, canola, chickpea and faba beans.

Table 3.5 assumes that the cropping system incorporates minimal tillage practices. This involves the mechanised tillage of the entire topsoil in a single pass, usually at time of sowing. Typically, minimum tillage is carried out using wide points on a combine seed drill or air seeder, or using a culti-trash seeder or offset discs. The table also assumes that the stubble is retained after cropping on soils prone to wind erosion. Adjustments for assessments for traditional tillage (involving two weed-control workings before sowing using wide points and resulting in greater risk of erosion and non-wetting problems) are shown in brackets.

This is a general assessment for common dryland crops grown over extensive areas (i.e. hundreds of hectares). It is best suited to the 350-600 mm rainfall zone where most extensive crops are grown (i.e. the wheatbelt), though may be extended to include some slightly higher rainfall areas. Different crops have varying tolerance to soil properties such as pH, salinity and waterlogging, therefore separate land capability ratings tables can be prepared for each of the main crops. Land capability tables for wheat, barley, oats, canola and lupins can be found in Appendix 5.

In this assessment, class 1 or 2 land has the greatest versatility, there being few production or environmental limitations for a wide range of crops. Capability class 3 has moderate to high limitations for some or all crops. Some class 3 land may have a high capability for individual crops (such as cereals) that can tolerate a wide range of soil conditions, but be unsuited to other crops (e.g. lupins or faba beans). Class 4 and 5 land will be unsuitable for most crops, although there may be some individual crops with specific requirements and tolerance which can be grown on this land.

**Table 3.5. Land capability ratings for dryland cropping using minimum tillage**

Land quality and (capability subscript)	Land capability class				
	1	2	3	4	5
Flood hazard ( <i>f</i> )	N, L		M	H	
Land instability ( <i>c</i> )	N, VL, L		M	H	
pH 0-10 cm ( <i>zf</i> )	N, Slac	Mac, Malk	Sac, Vsac	Salk	
pH 50-80 cm ( <i>zg</i> )	N, Slac	Mac, Malk	Sac, Salk	Vsac	
Phosphorus export ( <i>n</i> )	L	M, H	VH (H)	E (VH)	
Rooting depth ( <i>r</i> )	D, VD	M	MS		S, VS
Salinity hazard ( <i>y</i> )	NR		PR	MR, HR	PS
Salt spray exposure ( <i>zi</i> )	N			S	
Surface salinity ( <i>ze</i> )	N		S	M	H, E
Surface soil structure decline ( <i>zb</i> )	L	M	H		
Soil water storage ( <i>m</i> )	H	ML, M	L	VL	
Soil workability ( <i>k</i> )	G	F		P	VP
Subsurface acidification ( <i>zd</i> )	L	M	H, P		
Subsurface compaction ( <i>zc</i> )	L	M, H			
Trafficability ( <i>zk</i> )	G	F		P	VP
Water erosion ( <i>e</i> )	VL	L	M	H	E, VH
Water repellence ( <i>za</i> )	N, L	M, H	(H)		
Waterlogging ( <i>l</i> )	N, VL	L	M	H	VH
Wind erosion ( <i>w</i> )	L	M	H, VH, (M)	(H)	E, (VH)

Brackets ( ) indicate adjustments for traditional tillage.

#### *Land qualities used in the assessment*

The most significant difference between grazing and dryland cropping is that cropping involves regular cultivation of the land. Crops tend to be deeper rooted than pasture species.

**Flood hazard.** Floods can damage crops greatly reducing the yield. Areas prone to flooding also have a higher risk of water erosion.

**Land instability.** Areas susceptible to mass movement would usually also have water or wind erosion limitations.

**pH.** Extremes of pH affect the availability of nutrients resulting in deficiencies and/or toxicities that adversely affect production. Management options are limited to growing tolerant crops or the use of lime to increase the pH of acid soils.

**Phosphorus export.** Cultivation for cropping increases susceptibility to erosion, the main mechanism for export in most soils except bleached sands, which do not readily bind phosphorus. Management practices to reduce the risk of nutrient export include reducing risk of soil erosion, matching fertilisers to crop requirements, the creation of buffer strips

along waterways and growing crops such as canola and chickpeas which use phosphorus more efficiently<sup>31</sup>.

**Rooting depth.** Shallow soils limit the volume that can be explored by roots and therefore impact on moisture availability. Most crops require at least 30-50 cm depth of soil, but moisture availability, not the rooting depth, will tend to restrict growth unless rainfall is plentiful. For this reason at least 50-80 cm is preferable.

**Salinity.** Crop tolerance to salinity varies, with lupins being highly sensitive and barley being more tolerant. It is the combination of salinity and waterlogging that has the greatest impact on crops. Management of affected areas can include increasing plant water use in recharge areas, improving site drainage and establishment of salt tolerant pastures<sup>32</sup>.

**Surface soil structure decline** can reduce infiltration, delay seeding because cultivation is restricted to a narrow range of water content and reduce seedling emergence. Management options include minimising tillage, increasing organic matter and the use of gypsum to help stabilise structure on dispersive soils<sup>33</sup>.

**Soil water storage.** Soils with very low water storage are likely to limit yields in most seasons, while those with low water storage are likely to limit yields in low rainfall seasons or where distribution of the rainfall is irregular. Poor ground cover associated with low yields increases the risk of wind and water erosion as well as contributing to recharge leading to the development of salinity. Deep-rooted crops such as lupins are an option on deep sands with low soil water storage.

**Soil workability.** Rock outcrops and large stones on or near the surface make cultivation difficult and can damage machinery. Small surface stones and rocks can be pushed into heaps in many areas so they do not hinder cultivation. Heavy soils can also be hard to work, especially if they are sodic.

**Subsurface acidification** results in increased solubility of aluminium which is toxic to plants and reduces the rate of root elongation, which limits crop access to water and mobile nutrients like nitrogen. Management options include growing tolerant crops and the application of lime. Subsurface acidification is a severe problem which takes many years to develop. Once developed it can take many years to ameliorate. Continual applications of lime on the surface will eventually have an effect on the subsoil, but not until the topsoil pH has been improved (Mike Bolland, pers. comm.)<sup>34</sup>. Deeper applications of lime so far have had limited success, but may become viable in some situations.

**Subsurface compaction** produces a barrier to root penetration and hence limits crop access to water and mobile nutrients such as nitrogen. Management may include deep tillage to disrupt the traffic pan<sup>35</sup>.

**Trafficability.** Mechanisation using large machinery is essential for broadscale cropping as practised in WA.

**Water erosion** can reduce crop yields; result in the loss of nutrients and reduce productive potential. As a general rule, the risk of water erosion is likely to become limiting on slopes with gradients in excess of 10 per cent. Management options include the adoption of no-till

<sup>31</sup> More details on combating nutrient export can be found in Section 11.3 of Tille *et al.* (2001).

<sup>32</sup> More details on managing salinity in Moore (1998b) and Section 5.3 of Tille *et al.* (2001).

<sup>33</sup> See Needham *et al.* (1998a) for more details on managing structure decline.

<sup>34</sup> See Moore *et al.* (1998a) for more details on managing soil acidification.

<sup>35</sup> See Section 4 of Moore (1998a) for more details on managing subsurface compaction.



systems, sowing on the contour and installing banks to control the length of slope and/or reduce waterlogging<sup>36</sup>.

**Water repellence** leads to uneven infiltration which can result in lower soil moisture, poor seedling germination, patchy crop growth and increased weed establishment. Increased run-off can contribute to soil erosion and nutrient loss and loss of applied herbicides. Furrow sowing, wetting agents and clay additions are the main management options<sup>37</sup>.

**Waterlogging** reduces crop yields especially if it occurs early in crop development or when the temperatures are higher in spring. Management options include cropping on raised beds, improved site drainage and/or growing tolerant crops such as oats or faba beans<sup>38</sup>.

**Wind erosion** can result in sand blasting, the loss of nutrients and long-term loss of productive potential. Crops should be sown into stubble on soils with high susceptibility<sup>39</sup>.

#### *Other land use notes*

This is a general assessment covering a wide range of crops. Ratings tables have been developed for five specific crops: wheat, barley, oats, canola and lupins. These ratings are presented in Appendix 5.

---

<sup>36</sup> See Coles and Moore (1998) and Section 9.3 of Tille *et al.* (2001) for more details on water erosion.

<sup>37</sup> See Moore and Blackwell (1998) for more details on managing non-wetting.

<sup>38</sup> See Moore and McFarlane (1998) and Section 7.3 of Tille *et al.* (2001) for more on waterlogging.

<sup>39</sup> See Moore *et al.* (1998b) for more details on managing wind erosion.

### 3.6 Land capability for septic tanks for rural residential development

This assessment covers the physical capability of land to absorb and purify effluent coming from traditional septic tanks servicing a single family dwelling on a block of 1 ha or larger.

**Table 3.6. Land capability ratings for septic tanks for rural residential developments**

Land quality and (capability subscript)	Land capability class				
	1	2	3	4	5
Ease of excavation ( <i>x</i> )	H	M	L	VL	
Flood hazard ( <i>f</i> )	N		L	M	H
Land instability ( <i>c</i> )	N	VL	L	M	H
Microbial purification ability ( <i>p</i> )	H	M	L	VL	
Soil absorption ( <i>zj</i> )	H	M	L	VL	
Waterlogging ( <i>i</i> )	N, VL	L	M	H	VH

#### *Land qualities used in the assessment*

**Ease of excavation** not only relates to the installation of septic tanks but will also affect house and road construction and provision of services.

Any land subject to **flood hazard** or **land instability** is not suited to septic tanks or housing developments. Management will depend on the nature and extent of the problem.

**Microbial purification ability** assesses the soils capacity to purify added effluent. Management options are similar to waterlogging.

**Waterlogging.** An insufficient volume of well aerated material reduces the soil's ability to purify septic tank effluent. Problems are encountered where the watertable is close to the surface. In these situations, preferred management options include alternative methods for handling household effluent such as aerobic treatment units or Ecomax™ which utilise leach drains where the soil is amended with bauxite residue, or small local treatment plants. Less desirable is the provision of a large sand pad to elevate leach drains 2 m above the highest seasonal watertable.

#### *Other land use notes*

**Rural residential developments.** Ratings for septic tanks can be combined with ratings for the relevant agricultural uses when undertaking assessments for rural residential developments. Most rural residential developments in WA use septic tank effluent disposal. Hence land capability for septic tanks should be a minimum requirement.

Where orchards, market gardening or grazing are part of the proposed development, these ratings should also be considered. However, the agricultural ratings may need to be adjusted depending on the land use assumptions associated with the rural residential developments. For example, small scale horticulture may not involve the same emphasis on machinery access as indicated in the ratings tables. Livestock and pasture management may be quite different to the assumptions for broad-scale grazing of non-irrigated pastures<sup>40</sup>. In such cases management and development requirements will determine suitability.

**Urban developments.** Urban developments usually include the construction of building and roads as well as the provision and maintenance of drains, sewers and garden areas. These are intensive land uses for which the land use and development assumptions are highly variable. The amount of capital normally invested means that engineering solutions are used

<sup>40</sup>

See notes on small holdings in Section 3.4.

more routinely than for less intensive land uses. As a result, considerations such as the relative land values and proximity to existing infrastructure play a much larger role in the ultimate selection of urban land irrespective of initial land capability.

Large developments can pay to overcome problems more readily than smaller developments. For example, in some coastal areas entire dunes are often removed or levelled, and even large swamps are filled or drained, hence issues such as wind erosion and waterlogging may not be considered serious impediments to development.

As a *general* guide, urban land capability suits similar areas to perennial horticulture, however a land capability ratings table is not provided because engineering solutions are used to overcome limitations.

Extensive land degradation problems can still be (or should have been) an impediment to urban development. Contemporary examples in WA are secondary salinity that now affects many rural towns prompting a rescue program as part of the Salinity Action Plan (Government of Western Australia 1996). Similarly, nutrient pollution problems in most streams and wetlands on the Swan Coastal Plain are well documented and have been funded under government programs including the Peel-Harvey Catchment Management Program (e.g. ERMP Stage 2, Kinhill Engineers 1988). This included the provision of the Dawesville Cut – a massive new channel for flushing the Peel Inlet and Harvey Estuary.

### 3.7 Displaying capability ratings on maps

Virtually all of the Department of Agriculture's soil-landscape mapping units comprise a number of unmapped land units covering the variation of soils and landscapes within the map unit (see Section 1.4 – Proportional mapping). As these land units typically have a range of capability ratings, it is uncommon for a single rating for any land use to apply to the entire map unit. This presents a challenge when representing capability ratings cartographically. Two methods of displaying capability ratings on maps that are used routinely in WA are discussed below (e.g. see the AGMAPS CDs e.g. DoA 2005).

#### ***Single value percentage capability maps***

When proportional mapping has been used the legend can either show high or low capability land greater or less than a particular per cent. For example a percentage map legend showing very high (class 1) and high (class 2) capability land.

##### **Map legend**

High or Very high land capability for 'land use x'

>70%

50-70%

30-50%

<30%

0%

The cut-off values used in the example are a good starting point for many regional scale surveys and the land uses described in this report. However it is not uncommon to introduce additional categories. Maps produced should be carefully considered before being used for important policy or planning decisions. It is not unusual for the look of a map to change dramatically depending on whether, for example >10 per cent or  $\geq 10$  per cent is used. This is because proportional allocations are often rounded to the nearest 5 or 10 per cent, hence 10 per cent is likely to be much more common than 11 per cent. In the absence of additional land resource information, it is now fairly common practice to utilise 'expert' opinion and local knowledge to help judge if maps are a good representation of reality.

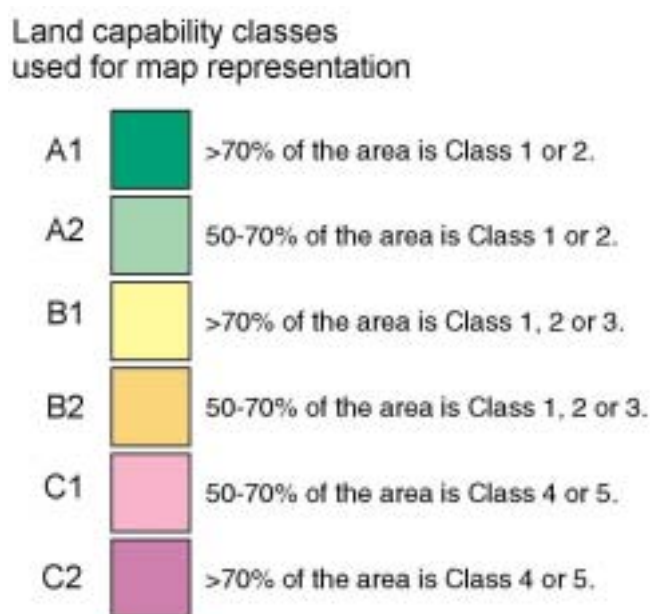
The advantage of single value percentage maps is that they are simple to interpret. It is often desirable to keep the null (0%) value to show map units where no high or very high capability land occurs at all. However, a disadvantage in the example above is that the map does not indicate if the remaining land is low or fair capability. For example a map might be 0 per cent classes 1 and 2, however all the remaining land might be class 3, hence 0 per cent classes 1 and 2 does not necessarily indicate low capability. To overcome this you might also prepare a map which shows classes 1, 2 and 3 grouped, as well as a map showing classes 4 and 5. Unfortunately the number of maps created quickly gets out of hand, particularly if considering several land uses. An alternative is to provide a coded range of values that combines high fair and low capability land on one map. This is considered in the following section.

### ***Coded proportional land capability maps***

A technique for displaying capability on maps involves reducing the five classes to three by combining classes 1 and 2 (high capability) and combining classes 4 and 5 (low capability). The map unit is then classified as:

- **Category A land** if there is 50% or more high capability zone land units (A1 if there is 70-100% high capability and A2 if there is 50-69%).
- **Category B land** if there is less than 50% high capability zone land units but 50% or more moderate or high capability zone land units (B1 if there is 70-100% moderate capability and B2 if there is 50-69%).
- **Category C land** if there is 50% or more low capability zone land units (C1 if there is 50-69% low capability and C2 if there is 70-100%).

For example 5% of one map unit may have a Class 1 rating for a given land use, with 35% having a Class 2 rating, 20% having a Class 3 rating, 30% having a Class 4 rating and 10% having Class 5 rating. The map unit described here has 40% high capability zone land units, 20% moderate capability and 40% low capability zone land units. This is not enough to qualify as Category A land, but as there is 60% moderate to high capability it becomes Category B2. Figure 7 shows a standard legend for a capability map, while Figure 8 demonstrates the categories graphically with the aid of a capability triangle.



**Figure 7. Standard capability map key**

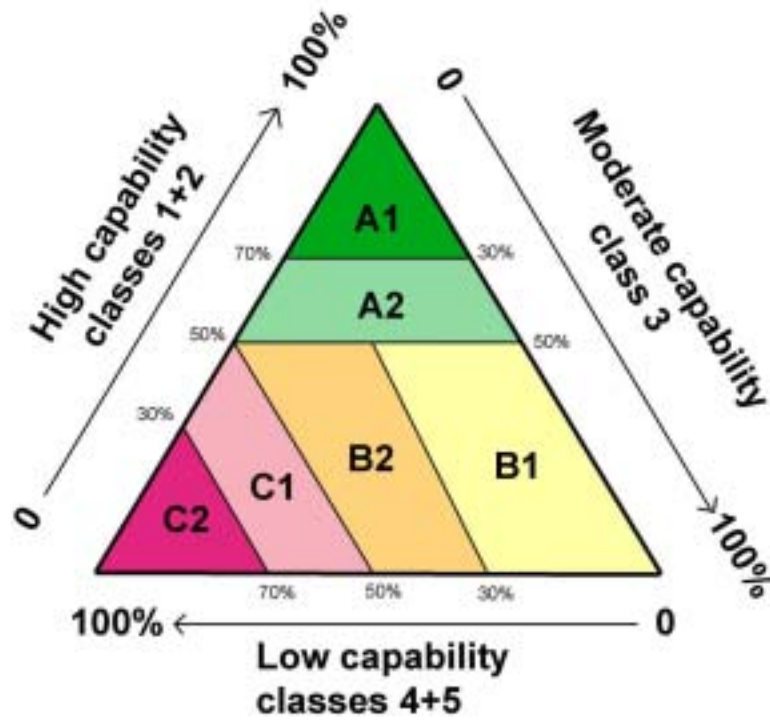


Figure 8. Land capability triangle

**Land capability SQL statements for six areas, combining class 1, 2 and 3 land**

lif([AH1 and 2 ] > 69, 'A1', lif ([AH1 and 2 ] > 49, 'A2', lif ([AH12 and 3] > 69,'B1', lif ([AH12 and 3] > 49, 'B2', lif ([AH12 and 3] > 29,'C1', 'C2'))))))

## REFERENCES

- Allen, D.G. and Jeffery, R.C. (1990). Methods for analysis of phosphorus in Western Australian soils. Report of investigation 37. Chemistry Centre, Perth, WA.
- Austin, M.P. and Cocks, K.D. (1978). Land use on the south coast of New South Wales. A study in methods acquiring and using information to analyse regional land use options. CSIRO, Melbourne.
- Beckett, P.H.T. and Bie, S.W. (1978). Use of soil and land-system maps to provide soil information in Australia. CSIRO Division of Soils, Technical paper No. 33.
- Brennan, R.F., Bolland, M.D.A. and Allen, D.G. (1997). Relationship between soil pH measured in water and calcium chloride. *In*: 'Soils 97 – Advances in soil science for sustainable land use.' Conference proceedings, Geraldton, WA, 30 September to 20 October 1997 p. 241.
- BSD Consultants (unpublished). Final, Rural Towns Rescue Program, Salinity Action Plan. Report prepared for Agriculture Western Australia, November 1997.
- Christiansen, G., Francis, J. and Sonter, B. (1994). Dryland Salinity 7: The Economic Picture. Department of Conservation and Land Management, WA.
- Churchward, H.M. and McArthur, W.M. (1978). Landforms and soils of the Darling System, Western Australia. *In*: 'Atlas of Natural Resources, Darling System, Western Australia'. Department of Conservation and Environment, Western Australia.
- Coles, N. and Moore, G. (1998). Run-off and water erosion. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia Bulletin 4343, pp. 223-242.
- CSIRO (1983). Soils: an Australian viewpoint. CSIRO Division of Soils, Melbourne and Academic Press: London.
- DoA (2005a). AGMAPS Land Manager for the Mortlock Catchment. Department of Agriculture, Western Australia and Natural Heritage Trust (Australia).
- DoA (2005b). Grass Patch-Salmon Gums Catchment Appraisal 2004. Resource Management Technical Report 278. Department of Agriculture, Western Australia.
- Doerr, S.H., Dekker, L.W., Ritsema, C.J., Shakesby, R.A. and Bryant, R. (2002). Water repellency of soils. The influence of ambient relative humidity. *Soil Science Society of America Journal* 66: 401-405.
- Dolling, P.J., Moody, P., Noble, A., Helyar, K., Hughes, B., Reuter, D. and Sparrow, L. (2001). Soil acidity and acidification. National Land & Water Resources Audit Project 5.4C.
- Dolling, P.J. and Porter, W.M. (1994). Acidification rates in the central wheatbelt of Western Australia. *Australian Journal of Experimental Agriculture* 34: 753-763.
- Emerson, W.W. and Bond, R.D. (1963). The rate of water entry into dry sand and calculation of the advancing contact angle. *Australian Journal of Soil Research* 1, 9-16.
- FAO (1976). A framework for land evaluation. FAO Soils Bulletin 32. Food and Agriculture Organisation of the United Nations, Rome.

- FAO (1983). Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bulletin 52. Food and Agriculture Organisation of the United Nations, Rome.
- FAO (1996). Control of water pollution from agriculture. FAO irrigation and drainage paper 55. Food and Agriculture Organisation of the United Nations.
- French, R.J. and Schultz, J.E. (1984). Water Use Efficiency of Wheat in a Mediterranean-type environment. The Relation between Yield, Water Use and Climate. *Australian Journal of Agricultural Research* **35**: 743-764.
- George, P.R. and Wren, B.A. (1985). Crop tolerance to soil salinity. Technote 6.85. Department of Agriculture, Western Australia,
- George, R., McFarlane, D. and Nulsen, R. (1997). Salinity threatens the viability of agriculture and ecosystems in Western Australia. *Hydrogeology Journal* **5**: 6-21.
- Government of Western Australia (1996). Salinity, a situation statement for Western Australia. Prepared by Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection and the Water and Rivers Commission.
- Greenwood, K.L. and McKenzie, B.M. (2001). Grazing effects on soil physical properties and the consequences for pastures: a review. *Australian Journal of Experimental Agriculture* **41**: 1231-1250.
- Gunn, R.H., Beattie, R.E., Reid, R.E. and van de Graaff, R.H.M. (1988). Australian Soil and Land Survey Handbook, Guidelines for conducting surveys, Inkata Press, Melbourne.
- Hallsworth, E.G. (1978). Purpose and requirements of land resource survey and evaluation. Commonwealth and State Government collaborative soil conservation study 1975-77 Report 3. Department of Environment, Housing and Community Development.
- Hamblin, A.P. and Hamblin, J. (1985). Root characteristics of some temperate legume species and varieties on deep, free-draining Entisols. *Australian Journal of Agricultural Research* **36**: 63-72.
- Hamblin, A., Richards, L. and Blake, J. (1988). Crop growth across a toposequence controlled by depth of sand over clay. *Australian Journal of Soil Research* **26**: 623-635.
- Hamblin, A.P. and Tennant, D. (1981). Influence of tillage on soil water behaviour. *Soil Science* **132**: 233-239.
- Hollis, J.M. and Jones, R.J.A. (1987). Technical aspects of soil water relationships and their application to agricultural land classification. Soil Survey and Land Research Centre, Silsoe.
- King, P.M. (1981). Comparison of methods for measuring severity of water repellence of sandy soils and assessment of some factors that affect its measurement. *Australian Journal of Soil Research*, **19**: 275-285.
- Kinhill Engineers Pty Ltd (1988). Peel Inlet and Harvey Estuary Management Strategy. Environmental Review and Management Programme – Stage 2. Prepared for Department of Agriculture, South Perth and Department of Marine and Harbours, Fremantle, Western Australia.
- Klingebiel, A.A. and Montgomery, P.H. (1961). Land capability classification. Soil Conservation Service, United States Department of Agriculture. Agricultural Handbook p. 210.



- Lantzke, N.C. and Galati, A. (1997). 'Codes of practice for vegetable production on the Swan Coastal Plain'. Vegetable Growers, Market Gardeners & Potato Growers Associations.
- Letey, J. (1969). Measurement of contact angle, water drop penetration time, and critical surface tension. *In*: 'Proceedings of the symposium on water-repellent soils', University of California, Riverside, May 6-10 1968 (eds L.F. Debano and J. Letey), pp. 43-48.
- McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990). 'Australian soil and land survey field handbook' 2nd edition. Inkata Press, Melbourne.
- McFarlane, D.J., George, R.J. and Caccetta, P.A. (2004). The extent and potential area of salt-affected land in Western Australia estimated using remote sensing and digital terrain models. *In*: 'Engineering Salinity Solutions: 1<sup>st</sup> National Salinity Engineering Conference 2004', Burswood International Resort, Perth, Western Australia, 9-12 November 2004, Institution of Engineers, Australia pp. 55-60.
- McKenzie, N.J. (1991). A strategy for coordinating soil survey and land evaluation in Australia. CSIRO Division of Soils, Divisional Report 114.
- McKenzie N.J., Ringrose-Voase A.J. and Grundy M.J. (In prep). Australian Soil and Land Survey Handbook. Guidelines for Conducting Surveys. CSIRO Australia.
- Moore, G. (1998a). 'Soilguide. A handbook for understanding and managing agricultural soils'. Agriculture Western Australia, Bulletin 4343.
- Moore, G. (1998b). Soil Salinity. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia. Bulletin. 4343, pp. 146-158.
- Moore, G. and Blackwell, P. (1998). Water repellence. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 53-63.
- Moore, G. and McFarlane, D. (1998). Waterlogging. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 94-108.
- Moore, G., Dolling, P., Porter, B. and Leonard, L. (1998a). Soil acidity. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore) Agriculture Western Australia, Bulletin 4343, pp. 127-140.
- Moore, G., Findlater, P. and Carter, D. (1998b). Wind erosion. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 211-222.
- Moore, G., Hall, D. and Russell, J. (1998c). Soil water. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 80-93.
- Needham, P., Moore, G. and Scholz, G. (1998a). Soil structure decline. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 64-79.
- Needham, P. Moore, G. and Scholz, G. (1998b). Subsurface compaction. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore). Agriculture Western Australia, Bulletin 4343, pp. 116-124.

- O'Neil, A.M. (1952). A key for evaluating soil permeability by means of certain field clues. *Proceedings of Soil Science Society of America* **16**: 312-315.
- Pilgrim, A.T. and Conacher, A.J. (1974). Causes of earthflows in the Southern Chittering Valley, WA. *Australian Geographical Studies* 12 (1) pp. 38-56.
- Rayment, G.E. and Higginson, F.R. (1992). Australian Laboratory Handbook of Soil and Water Chemical Methods. An Australian Soil and Land Survey Handbook. Inkata Press, a Division of Butterworth-Heinemann, North Ryde, NSW.
- Rose, B. (1997). Preventing erosion and soil structure decline: a soil management practices guide for horticultural farmers in the south west high rainfall hills. Agriculture Western Australia, Miscellaneous Publication 23/97.
- Runge, W. and van Gool, D. (1999). Land qualities in the south-west of Western Australia: a summary of land degradation and land capability. Department of Geography, University of WA, Geowest 30.
- SCARM (1995). Evaluation report on the decade of landcare plan – National Overview. Standing Committee on Agriculture and Resource Management, Land Resources Division, Department of Primary Industries and Energy, Canberra.
- Schoknecht, N. (2002). Soil groups of Western Australia – A guide to the main soils of Western Australia – Edition 3. Agriculture Western Australia, Resource Management Technical Report 246.
- Schoknecht, N., Tille, P. and Purdie, B. (2004). Soil–landscape mapping in south-western Australia. Overview of methodology and outputs. Department of Agriculture, Resource Management Technical Report 280.
- Scholz, G. and Moore, G. (1998). Soil alkalinity and soil sodicity. In: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 141-159.
- Shields, P.G., Smith, C.D. and McDonald, W.S. (1996). Agricultural Land Evaluation in Australia – A Review. Australian Collaborative Land Evaluation Program (ACLEP), CSIRO, Canberra.
- SLCC (1992). Decade of Landcare plan, Western Australia. Department of Agriculture, Western Australia and Soil and Land Conservation Council, Western Australia.
- Smith, S.T., Stoneman, T.C. and Malcolm, C.V. (1969). Cultivation and traffic hardpans in Swan Valley vineyards. Western Australian Department of Agriculture, Technical Bulletin No. 1.
- Summers, R.N., Smirk, D.D. and Karafilis, D. (1996). Phosphorus retention and leachates from sandy soil amended with bauxite residue (red mud). *Australian Journal of Soil Research* **34**: 555-567.
- Summers, R.N., van Gool, D., Guise, N.R., Heady, G.J. and Allen, T. (In prep). Phosphorus run-off from the coastal catchments of the Peel Inlet and Harvey Estuary. *Agriculture Ecosystems and Environment*.
- Tille, P.J., and Smolinski, H. (2003). Lower Gascoyne Land Resources Survey. Department of Agriculture, Western Australia. Land Resources Series No. 17.

- Tille, P. and Lantzke, N. (1990). Busselton-Margaret River-Augusta Land Capability Study; Methodology and Results, Vol. 1, Technical Report 109, Division of Resource Management, Department of Agriculture, Western Australia.
- Tille, P.J., Mathwin, T.W. and George, R.J. (2001). The South-west hydrological information package – Understanding and managing hydrological issues on agricultural land in the south-west of Western Australia. Agriculture Western Australia, Bulletin 4488.
- United States Department of Agriculture (1993). Soil Survey Manual. Handbook No. 18.
- van de Graaf, R.H.M. (1988). *In* Australian soil survey guidelines, R.H. Gunn, J.A. Beattie, R.E. Reid, and R.H.M. van de Graaf (eds) Inkata Press, Melbourne.
- van Gool, D. and Maschmedt, D. (In press). Land evaluation. *In* 'Australian Soil and Land Survey Handbook. Guidelines for Conducting Surveys' (eds N.J. McKenzie, A.J. Ringrose-Voase and M.J. Grundy). CSIRO Australia.
- van Gool, D. and Moore, G. (1999). Land evaluation standards for land resource mapping – Guidelines for assessing land qualities and determining land capability in south-west Western Australia, 2nd edition. Resource Management Technical Report 181.
- van Gool, D. and Vernon, L. (2005). Potential impacts of climate change on agricultural land use suitability: Wheat. Resource Management Technical Report 295. Department of Agriculture Western Australia, South Perth.
- van Gool, D. and Vernon, L. (2006a). Potential impacts of climate change on agricultural land use suitability: Lupins. Resource Management Technical Report. Department of Agriculture, Western Australia, South Perth.
- van Gool, D. and Vernon, L. (2006b). Potential impacts of climate change on agricultural land use suitability: Barley. Resource Management Technical Report. Department of Agriculture, Western Australia, South Perth.
- van Gool, D., White, P., Schoknecht, N., Bell, R. and Vance, W. (2004). Land evaluation for pulse production in WA (pp 60-62) in Agribusiness Crop Updates 2004.
- van Gool, D. and Payne, A. (unpublished). Map unit attributes for rangelands surveys.
- Vernon, L. and van Gool, D. (2006a). Potential impacts of climate change on agricultural land use suitability: Canola. Resource Management Technical Report. Department of Agriculture, Western Australia, South Perth.
- Vernon, L. and van Gool, D. (2006b). Potential impacts of climate change on agricultural land use suitability: Oats. Resource Management Technical Report. Department of Agriculture, Western Australia, South Perth.
- Weaver, D. and Summers, R. (1998). Soil factors influencing eutrophication. *In*: 'Soilguide. A handbook for understanding and managing agricultural soils' (ed. G. Moore), Agriculture Western Australia, Bulletin 4343, pp. 243-250.
- Wells, M.R. (1987). Assessment of land capability for on-site septic tank effluent disposal. Department of Agriculture, Division of Resource Management Technical Report 63.
- Wells, M.R. and King, P.D. (1989). Land capability assessment methodology. Land Resource Series No. 1, Western Australian Department of Agriculture.
- Williams, J. (1983). Physical properties and water relations. Soil hydrology. *In*: 'Soils: an Australian viewpoint', CSIRO Division of Soils, Melbourne/Academic Press, London.

## ACKNOWLEDGEMENTS

Special thanks, for reviewing this report, go to:

David Maschmedt  
Soil and Land Information Group  
Department of Water, Land and Biodiversity Conservation  
South Australia

This publication replaces the land evaluation standards (Resource Management Technical Report 181) which was funded by the Department of Agriculture, Western Australia and the National Landcare Program.

Many officers from the Department have contributed to the standards described including:

- Natural Resources Assessment Group staff, especially Ted Griffin and Noel Schoknecht
- Land use planning project – Ian Kininmonth (now working for Environmental Knowledge Systems Australia)
- A very patient editor, Georgina Wilson.

## APPENDIX 1. LAND CHARACTERISTICS

Land characteristics are soil and landform features that can be explicitly observed (a qualitative estimate) or measured (quantitative) during a land resource survey. Some land qualities are based on a single land characteristic, such as pH. Usually several soil or landform characteristics are combined to estimate a land quality. For example, wind erosion combines surface condition of the soil with an exposure factor based on the landform, such as a dune, or a flat.

The land characteristics below are used to derive many of the land qualities in Section 2. In addition, each land characteristic may be used by itself to create interpretive maps (e.g. a map of surface soil texture) or can be used directly in the land capability ratings tables to create land capability maps for specific crops.

Appendix A1 identifies 16 land qualities (see Table A1).

**Table A1. Land characteristics used to determine land qualities**

Section	Description	Acceptable codes (ratings)*
A1.1	Coarse fragments in profile	<b>VF</b> (very few), <b>F</b> (few), <b>C</b> (common), <b>M</b> (many), <b>A</b> (abundant)
A1.2	Depth of profile	<b>VS</b> (<15), <b>S</b> (<30), <b>MS</b> (30-50), <b>M</b> (50-80), <b>D</b> (>80), <b>VD</b> (>150) cm
A1.3	Permeability	<b>VS</b> (very slow), <b>S</b> (slow), <b>MS</b> (moderately slow), <b>M</b> (moderate), <b>MR</b> (moderately rapid), <b>R</b> (rapid), <b>VR</b> (very rapid)
A1.4	Rock outcrop	<b>N</b> (none), <b>S</b> (slight), <b>R</b> (rocky), <b>VR</b> (very rocky), <b>RL</b> (rockland))
A1.5	Slope	<b>F</b> (flat), <b>VG</b> (very gentle), <b>G1</b> (gentle 1), <b>G2</b> (gentle 2), <b>M1</b> (moderate 1), <b>M2</b> (moderate 2), <b>S</b> (steep)
A1.6	Stones and boulders in profile	<b>VF</b> (very few), <b>F</b> (few), <b>C</b> (common), <b>M</b> (many), <b>A</b> (abundant)
A1.7	Surface condition	<b>C</b> (surface crust), <b>F</b> (firm), <b>HS</b> (hardsetting), <b>K</b> (cracking), <b>L</b> (loose), <b>SM</b> (self-mulching), <b>S</b> (soft), <b>X</b> (surface flake), <b>Z</b> (saline)
A1.8	Soil texture	<b>KS</b> (coarse sand), <b>SS</b> (light sand), <b>S</b> (sand), <b>FS</b> (fine sand), <b>LS</b> (loamy sand), <b>CS</b> (clayey sand), <b>SL</b> (sandy loam), <b>SCL</b> (sandy clay loam), <b>L</b> (loam), <b>CL</b> (clay loam), <b>C</b> (clay), <b>HC</b> (heavy clay)
A1.9	Soil arrangement	Loose ( <b>G</b> ), Earthy ( <b>E</b> ), Poor structure ( <b>P</b> ), Moderate structure ( <b>M</b> ), Strong structure ( <b>S</b> ), Shrink-swell ( <b>SW</b> ), Fractured pan ( <b>PF</b> ), Hard pan ( <b>PH</b> ), Weathered pan ( <b>PW</b> ), Fractured rock ( <b>RF</b> ), Hard rock ( <b>RH</b> ), Weathered rock ( <b>RW</b> )
A1.10	Watertable depth	<b>0</b> (shallow), <b>50</b> (moderate), <b>100</b> (deep), <b>150</b> (very deep), <b>200</b> (extremely deep), <b>500</b> (none)
A1.11	Organic carbon	<b>VL</b> (very low), <b>L</b> (low), <b>M</b> (moderate), <b>H</b> (high)
A1.12	Phosphorus adsorption	<b>VL</b> (very low), <b>L</b> (low), <b>M</b> (moderate), <b>MH</b> (moderately high), <b>H</b> (high)
A1.13	Soil dispersion	<b>N</b> (Nil), <b>P</b> (Partial), <b>C</b> (Complete)
A1.14	Soil slaking	<b>N</b> (Nil), <b>P</b> (Partial), <b>C</b> (Complete)
A1.15	Available water capacity, lower storage limit and upper storage limit	Values in mm/m
A1.16	Bulk density	Dry weight in grams of 1cc

\*\* **XX** or **-999** are the default **NOT APPLICABLE** values.

## A1.1 Coarse fragments in profile

Coarse fragment includes all gravel, cobbles, stones and boulders over 2 mm in diameter present in the profile. The amount of fine earth (soil size particles) in the profile decreases in proportion to the amount of coarse fragments. It is from the fine earth that plants obtain most of their water and nutrients. The assessment of coarse fragments used here is on a percentage volume basis. It needs to be remembered that the weight percentage of coarse fragments may be significantly higher than the volume percentage. Table A1.1 presents the ratings for the land characteristic 'coarse fragments in the profile' which is used when determining the following land qualities:

- rooting depth; and
- soil water storage.

**Table A1.1. Assessment of coarse fragments in profile (adapted from McDonald *et al.* 1990)**

<b>Stones and gravel (&gt; 2 mm) in profile(by volume)</b>	<b>Coarse fragments in profile rating</b>
0%	<b>Nil (N)</b>
<2%	<b>Very few (VF)</b>
2-10%	<b>Few (F)</b>
10-20%	<b>Common (C)</b>
20-50%	<b>Many (M)</b>
50-90%	<b>Abundant (A)</b>

## A1.2 Depth of profile

Depth of profile is the depth to bedrock or an impenetrable hardpan. It differs from the rooting depth that can be affected by physical characteristics such as soil chemistry, or impermanent factors, such as the depth to a watertable. Table A1.2 presents the ratings for the land characteristic 'depth of profile' which is used when determining the following land qualities:

- Rooting depth
- Soil workability
- Microbial purification
- Ease of excavation
- Soil absorption ability.

**Table A1.2. Assessment of depth of profile**

<b>Depth to bedrock or impenetrable pan</b>	<b>Depth of profile rating</b>
<15 cm	<b>Very shallow (VS)</b>
15-30 cm	<b>Shallow (S)</b>
30-50 cm	<b>Moderately shallow (MS)</b>
50-80 cm	<b>Moderate (M)</b>
80-150 cm	<b>Deep (D)</b>
>150 cm	<b>Very deep (VD)</b>

### A1.3 Permeability

Permeability is the capacity of a material to transmit a fluid such as water. A material that is highly permeable will have few restrictions to the passage of water. A material with low permeability (often referred to as poor permeability) will provide major restrictions to the movement of water. Permeability is an important characteristic as the movement of water through the soil has widespread impacts on erosion hazards, soil water storage and the movement of nutrients, salt and pollutants. Table A1.3a presents the ratings for the land characteristic 'permeability' which is used when determining the following land qualities:

- site drainage potential;
- microbial purification; and
- ease of excavation.

The assessment of permeability should be based on the hydraulic conductivity of the least permeable layer within the top 150 cm, regardless of whether or not it is a pedogenic soil horizon (including underlying substrate or bedrock occurring within the top 150 cm).

**Table A1.3a. Assessment of permeability classes (from O'Neil 1952)**

Hydraulic conductivity <sup>1</sup> (mm/h)	Examples (These are a general guide only)	Profile permeability rating
<1	Duplex, gradational or clay soils with impermeable mottled and/or gleyed poorly structured clay soils and/or an impermeable pan or bedrock.	<b>Very slow (VS)</b>
1-5	Duplex, gradational or clay soils with slowly permeable, poorly structured clays and/or a slightly permeable pan or bedrock.	<b>Slow (S)</b>
5-20	Duplex, gradational or moderately structured loams or clays, or soils where permeability is slightly increased by gravel or sand.	<b>Moderately slow (MS)</b>
20-65	Duplex, gradational or well structured loams or clays, or soils where permeability is increased by a large amount of gravel or sand.	<b>Moderate (M)</b>
65-130	Similar to above, but includes well structured loams, deep sandy gradational soils or deep sands over an impermeable layer at several metres.	<b>Moderately rapid (MR)</b>
130-250	Deep sands (e.g. sandplain, with fine or medium sand and some clay at depth).	<b>Rapid (R)</b>
>250	Deep coarse sands (e.g. sand dunes with minimal profile development).	<b>Very rapid (VR)</b>

<sup>1</sup> Use the most restrictive layer in the soil profile.

**Table A1.3b. Estimated saturated hydraulic conductivity (mm/hr) for varying soil textures and arrangements**

Soil texture	Ksat (mm/hr) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	(Shrink-swell (SW)	Pan or rock
Coarse sand (KS)	400	300	-	-	-	-	-
Light sand (SS)	240	160	-	-	-	-	-
Sand (S)	230	150	-	-	-	-	-
Fine sand (FS)	220	140	-	-	-	-	-
Loamy sand (LS)	220	140	-	-	-	-	-
Clayey sand (CS)	210	135	-	-	-	-	-
Sandy loam (SL)	120	110	70	90	110	-	-
Loam (L)	110	100	70	90	100	-	-
Sandy clay loam (SCL)	-	60	40	50	70	-	-
Clay loam (CL)	-	50	30	40	60	-	-
Clay(C)	-	15	3	15	25	2	-
Heavy clay (HC)	-	6	0.5	3	6	2	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	15
Weathered pan (PW)	-	-	-	-	-	-	10
Weathered rock (PW)							300
Solid rock or pan (PH, RH)							0.2



## A1.4 Rock outcrop

The characteristic rock outcrop describes the proportion of the land surface within a land unit that is occupied by bare rock. The assessment of rock outcrop only applies where the rock is interspersed within a land unit, otherwise the land unit bare rock applies. Rock outcrop is considered to be a limitation where the spacing between the outcrops is less than 3 metres. Where outcrops are more than 3 m apart, the soil area is large enough to access with machinery. For example, a map unit with 15 per cent bare rock (as the landform) and 85 per cent yellow deep sand, may have 85 per cent high capability for horticulture. However this rating may be misleading if the rock outcrop is dispersed throughout the dominant land units within the map unit. Yellow deep sand with common rock outcrop as a soil group qualifier would have a lower overall rating. Tables A1.4a and A1.4b present the ratings for the land characteristic 'rock outcrop' which is used when determining the following land qualities:

- Soil workability
- Ease of excavation; and
- Soil absorption ability.

**Table A1.4a** Assessment of rock outcrop, where it is generally distributed throughout a land unit with spacing < 3 metres (adapted from McDonald *et al.* 1990)

% of rock outcrop	Rock outcrop rating
<2%	None (N)
2-10%	Slight (S)
10-20%	Rocky (R)
20-50%	Very rocky (VR)
>50%	Rockland (RL)

**Table A1.4b.** Values based on zone land unit properties (where better information from the map unit description is not available)

Zone land unit attribute	Rating
Bare rock (201), or where the landform is Rockland	Rockland
Where the landform is Breakaway/Cliff or Disturbed land	Very Rocky
Stony soils (202 or 203) or any soil with hard (RH) fractured (RF) or weathered rock (RW) in layer 1 or layer 2	Rocky
Any soil with hard (RH) fractured (RF) or weathered rock (RW) in layer 4	Slight
All other option	None

## A1.5 Slope

The slope gradients of an area of land has a major impact on the movement of water in the landscape which will affect site drainage and erosion hazards. Steeper slope are unsuitable for operating machinery. Table A1.5 presents the ratings for the land characteristic 'slope' which is used when determining the following land qualities:

- Water erosion hazard
- Site drainage potential
- Ease of excavation
- Trafficability.

**Table A1.5. Assessment of slope (adapted from McDonald *et al.* 1990)**

Slope gradient	Slope rating
<2%	Flat (F)
1-3%	Very gentle slope(VG)
3-5%	Gentle 1 (G1)
5-10%	Gentle 2 (G2)
10-15%	Moderate 1(M1)
15-30%	Moderate 2 M2)
>30%	Steep slope (S)
Mixed gentle and steep???	Mixed (MX)

### A1.6 Stones and boulders in profile

Stones and boulders include all coarse fragments over 20 cm (200 mm) in diameter. The assessment of coarse fragments used here is on a percentage volume basis. It needs to be remembered that the weight percentage of coarse fragments may be significantly higher than the volume percentage. Table A1.6 presents the ratings for the land characteristic 'stones and boulders in profile' which is used when determining the following land qualities:

- Soil workability.
- Ease of excavation; and
- Soil absorption ability.

**Table A1.6. Assessment of stones and boulders in profile (adapted from McDonald *et al.* 1990)**

% of stones and boulders (> 200 mm) in profile	Profile stone rating
0%	Nil (N)
< 2%	Very few (VF)
2-10%	Few (F)
10-20%	Common (C)
20-50%	Many (M)
50-90%	Abundant (A)

### A1.7 Surface condition

Surface condition describes the physical state of the soil surface. The surface condition often changes as the soil moisture status alters. For example, a soil that is soft when moist, can become hardsetting when dry. Surface condition should be based on assessments of the soil in the dry state. Table A1.7 presents the ratings for the land characteristic 'surface condition' which is used when determining the following land qualities:

- Surface soil structure decline susceptibility;
- Wind erosion hazard; and
- Soil workability.

**Table A1.7. Assessment of surface condition (from McDonald *et al.* 1990)**

Nature of soil surface when dry	Surface condition rating
Incoherent mass of individual particles or aggregates. Surface easily disturbed by pressure of forefinger.	<b>Loose (L)</b>
Coherent mass of individual particles or aggregates. Surface easily disturbed by pressure of forefinger.	<b>Soft (S)</b>
Strongly pedal loose surface mulch forms on wetting and drying. Peds commonly less than 5 mm in least dimension.	<b>Self-mulching (SM)</b>
Coherent mass of individual particles or aggregates. Surface disturbed or indented by moderate pressure of forefinger.	<b>Firm (F)</b>
Compact, hard, apparently apedal condition forms on drying but softens on wetting. When dry, the material is hard below any surface crust or flake that may occur, and is not disturbed by pressure of forefinger.	<b>Hardsetting (HS)</b>
Distinct surface layer, often laminated, up to tens of mm thick which is hard and brittle when dry and is not easily separated from underlying soil.	<b>Surface crust(C)</b>
Cracks at least 5 mm wide extending from the surface to the base of any plough layer or thin surface horizon.	<b>Cracking (K)</b>
Surface has visible salt, or salinity is evident from the absence or nature of the vegetation or from soil consistence. These conditions are characterised by their notable difference from adjacent non-saline areas.	<b>Saline (Z)</b>

## A1.8 Soil texture

The texture of the layers within a profile is a very important characteristic affecting many soil properties. Surface texture refers to the proportion of sand, silt and clay in the top 10 cm of the soil profile. Soil texture is used when determining the following land qualities:

- Surface texture
- Water repellence susceptibility
- Surface soil structure decline susceptibility
- Susceptibility to subsoil compaction
- Wind erosion hazard
- Water erosion hazard
- Soil water storage
- Soil workability
- Trafficability.

**Table A1.8. Assessment of soil texture (adapted from McDonald *et al.* 1990)**

Texture of surface horizon	Clay content	Surface texture rating
Coarse sand	< 5%	<b>Coarse sand (KS)</b>
Medium sands (-)	< 2%	<b>Sand (light) (SS)</b>
Medium sands	2-5%	<b>Sand (S)</b>
Very fine sand, Fine sand	< 5%	<b>Fine sand (FS)</b>
Very fine to medium loamy sands	5%	<b>Loamy sand (LS)</b>
Very fine to medium clayey sands	5-10%	<b>Clayey sand (CS)</b>
Sandy loam Light sandy clay loam	10-20%	<b>Sandy loam (SL)</b>
Loam, Silty loam, and	20-25%	<b>Loam (L)</b>
Sandy clay loam	20-30%	<b>Sandy clay loam (SCL)</b>
Sandy clay loam, Clay loam, and Silty clay loam	30-35%	<b>Clay loam (CL)</b>
Sandy clay, Light clay, Medium clay, and Silty clay	35-50%	<b>Clay (C)</b>
Heavy clay	> 50%	<b>Heavy Clay (HC)</b>
Rock or hardpan	Not applicable	<b>(XX)</b>

## A1.9 Soil arrangement

Soil arrangement is an assessment of the manner in which the soil particles are arranged in the profile as this relates to water movement through the soil and root penetration. Table A1.9 presents the ratings for the land characteristic 'Soil arrangement'. It is generally considered along with soil texture to help determine the following land characteristics and land qualities:

- Ease of excavation
- Soil water storage, available water capacity, wilting point and field capacity
- Soil workability
- Subsurface compaction susceptibility
- Surface soil structure decline susceptibility
- Water erosion risk
- Bulk density
- Hydraulic conductivity and permeability.

**Table A1.9. Assessment of soil arrangement**

Nature of soil layer	Soil arrangement rating
Soil materials with which are apedal, <b>single grained</b> . These material are loose, typically with a sandy fabric	<b>Loose (G)</b>
Soil materials with which are apedal, massive with an earthy fabric or porous nature	<b>Earthy (E)</b>
Soil materials with <b>poor structure</b> . Includes materials that are apedal, massive and dense (not porous) as well as some soils with strong structure consisting of large dense columnar or blocky peds. Many, but not all, of the materials falling into this category will be sodic clays.	<b>Poor structure (P)</b>
Soil materials with a weak to moderate structure. Includes materials that are considered apedal and massive but are still slightly porous.	<b>Weak to Moderate structure (M)</b>
Soil materials that are strong (well) structured. Excludes large blocky or columnar peds	<b>Strong structure (S)</b>
Clays with shrink-swell properties	<b>Shrink-swell (SW)</b>
Fractured (solid but not continuous) pan	<b>Fractured pan (PF)</b>
Hard (solid-continuous) pan	<b>Hardpan (PH)</b>
Weathered pan	<b>Weathered pan (PW)</b>
Fractured or porous rock (e.g. limestone or fractured sandstone)	<b>Fractured rock (RF)</b>
Hard (solid) rock	<b>Hard rock (RH)</b>
Weathered rock	<b>Weathered rock (RW)</b>

### A1.10 Watertable depth (to highest seasonal watertable)

The depth to the highest seasonal watertable describes the height to which the watertable rises and remains for a period of at least one week in the average season. Table A1.10 presents the ratings for the land characteristic 'depth to highest seasonal watertable' which is used when determining the following land qualities:

- Phosphorus export hazard
- Waterlogging/inundation risk
- Microbial purification.

**Table A1.10. Assessment of depth to highest seasonal watertable**

Depth to highest seasonal watertable, where water remains within the depth range for 1 week after rainfall	Watertable depth rating
0-30 cm	<b>Shallow (0)</b>
30-50 cm	<b>Moderately shallow (30)</b>
50-100 cm	<b>Moderate (50)</b>
100-150 cm	<b>Deep (100)</b>
150-200 cm	<b>Very deep (150)</b>
200-500 cm	<b>Extremely deep (200)</b>

### A1.11 Organic carbon

Organic carbon content is assessed using the method described by Walkley-Black. The results obtained are typically 20-25 per cent lower than the wet combustion methods (Rayment and Higginson 1992). Table A1.11 presents the ratings for the land characteristic 'Organic carbon' which is used when determining the following land qualities:

- Subsurface acidification susceptibility
- Subsurface compaction susceptibility
- Surface soil structure decline susceptibility
- Water erosion susceptibility of soil, Water erosion risk
- Water repellence.

**Table A1.11. Assessment of organic carbon (topsoil only)**

Organic carbon % (Walkley-Black)	Organic carbon rating
<0.4%	Very low (VL)
0.4-1.2%	Low (L)
1.2-2.0%	Moderate (M)
>2.0%	High (H)

### A1.12 Phosphorus retention index

Phosphorus retention index (PRI) is a measure that correlates reasonably well with phosphorus buffering capacity (PBC) of the soil (Allan and Jeffery 1990). PRI is used because it is more straightforward to measure than PBC. Table A1.12 presents the ratings for the land characteristic 'Phosphorus retention index' which is used when determining the phosphorus export hazard.

**Table A1.12a. Assessment of Phosphorus adsorption**

Phosphorus retention index value	Phosphorus adsorption rating
<2	Very low (VL)
2-5	Low (L)
5-20	Moderate (M)
20-100	Moderately high (MH)
>100	High (H)

### A1.13 Soil dispersion

Soil dispersion refers to the scattering of primary soil particles in water. Table A1.13 presents the ratings for the land characteristic 'Soil dispersion' which is used when determining the following land qualities:

- Surface soil structure decline susceptibility
- Water erosion susceptibility of soil, Water erosion risk.

**Table A1.13. Assessment of soil dispersion**

<b>Soil aggregate dispersion</b>	<b>Soil dispersion rating</b>
Soil aggregate does not disperse	<b>Nil (N)</b>
Soil aggregate disperses partially	<b>Partial (P)</b>
Soil aggregate disperses completely	<b>Complete (C)</b>

### A1.14 Soil slaking

Soil slaking refers to the collapsing or disintegration of dry soil aggregates or peds into micro-aggregates and primary particles when they are immersed in water. Note that some soils slake, but do not disperse (see Section A1.13). Table A1.14 presents the ratings for the land characteristic 'Soil slaking' which is used when determining the following land qualities:

- Surface soil structure decline susceptibility; and
- Water erosion susceptibility of soil, Water erosion risk.

**Table A1.14. Assessment of Soil slaking**

<b>Soil aggregate slaking</b>	<b>Soil slaking rating</b>
Soil aggregate does not slake	<b>Nil (N)</b>
Soil aggregate slakes partially	<b>Partial (P)</b>
Soil aggregate slakes completely	<b>Complete (C)</b>

### A1.15 Available water capacity, lower and upper storage limits

Available water capacity (AWC) is the difference between the upper storage limit (USL) and lower storage limit (LSL) per unit depth (v/v) or mass (w/w). The upper storage limit is the water content following saturation, when free drainage has stopped (previously known as field capacity). The lower storage limit is the lowest water content to which plants can extract water (previously known as permanent wilting point). AWC is used in assessment of the land quality:

- Soil water storage.

**Table A1.15a. Estimated available water capacity (mm/m) for varying soil textures and arrangements (e.g. see Table 2.12b)**

Soil texture	Available water capacity (mm/m) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	(Shrink-swell (SW)	Pans and rock
Coarse sand (KS)	20	25	22	-	-	-	-
Light sand (SS)	30	45	40	-	-	-	-
Sand (S)	40	50	45	-	-	-	-
Fine sand (FS)	50	70	60	-	-	-	-
Loamy sand (LS)	60	90	75	-	-	-	-
Clayey sand (CS)	80	100	90	-	-	-	-
Sandy loam (SL)	90	110	80	120	150	-	-
Loam (L)	100	130	130	170	220	-	-
Sandy clay loam (SCL)	-	130	100	140	180	-	-
Clay loam (CL)	-	120	100	140	190	-	-
Clay (C)	-	110	90	130	200	130	-
Heavy clay (HC)	-	130	90	110	120	110	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	10*
Weathered pan (PW)	-	-	-	-	-	-	10*
Weathered rock (PW)							10*
Solid rock or pan (PH, RH)							0

\* Estimates for use in theoretical calculations as there is limited information for root water use in rock. If possible derived values should be checked against real data.



**Table A1.15b. Estimated lower storage limit (mm/m) for varying soil textures and arrangements**

Soil texture	Wilting point (mm/m) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	(Shrink-swell (SW))	Pan or rock
Coarse sand (KS)	30	25	27	-	-	-	-
Light sand (SS)	40	45	43	-	-	-	-
Sand (S)	60	70	65	-	-	-	-
Fine sand (FS)	80	90	85	-	-	-	-
Loamy sand (LS)	85	95	90	-	-	-	-
Clayey sand (CS)	100	110	105	-	-	-	-
Sandy loam (SL)	110	115	150	125	115	-	-
Loam (L)	140	110	200	140	110	-	-
Sandy clay loam (SCL)	-	140	220	180	140	-	-
Clay loam (CL)	-	140	220	180	140	-	-
Clay (C)	-	150	260	200	140	200	-
Heavy clay (HC)	-	160	300	220	160	220	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	150*
Weathered pan (PW)	-	-	-	-	-	-	150*
Weathered rock (PW)							150*
Solid rock or pan (PH, RH)							0

\* Estimates for use in theoretical calculations as there is limited information for root water use in weathered or fractured rock. If possible derived values should be checked against real data.

**Table A1.15c. Estimated upper storage limit (mm/m) for varying soil textures and arrangements**

Soil texture	Wilting point (mm/m) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	Shrink-swell (SW)	Pan or rock
Coarse sand (KS)	50	50	49	-	-	-	-
Light sand (SS)	70	90	83	-	-	-	-
Sand (S)	100	120	110	-	-	-	-
Fine sand (FS)	130	160	145	-	-	-	-
Loamy sand (LS)	145	185	165	-	-	-	-
Clayey sand (CS)	180	210	195	-	-	-	-
Sandy loam (SL)	200	225	230	245	265	-	-
Loam (L)	240	240	330	310	330	-	-
Sandy clay loam (SCL)	-	270	320	320	320	-	-
Clay loam (CL)	-	260	320	320	330	-	-
Clay (C)	-	260	350	330	340	330	-
Heavy clay (HC)	-	290	390	330	280	330	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	160*
Weathered pan (PW)	-	-	-	-	-	-	160*
Weathered rock (PW)	-	-	-	-	-	-	160*
Solid rock or pan (PH, RH)	-	-	-	-	-	-	0

\* Estimates for use in theoretical calculations as there is limited information for root water use in weathered or fractured rock. If possible derived values should be checked against real data.

## A1.16 Bulk density

Bulk density is the weight of a unit volume of soil including its pore space. Bulk density and pore space affect water and aeration status, and root penetration and development. Bulk density is used when determining the following land quality:

- Subsurface acidification risk.

**Table A1.16. Estimated Bulk Density for varying soil textures and arrangements**  
(Based on values manually extrapolated from 171 WASG profiles in the soil profile database, plus a general consideration of values from the literature.)

Soil texture	Bulk Density (t/M3) for different soil arrangements						
	Loose (G)	Earthy or porous (E)	Poorly structured (P)	Moderately structured (M)	Strongly structured (S)	Shrink-swell (SW)	Pan or rock
Coarse sand (KS)	1.6	1.65	-	-	-	-	-
Light sand (SS)	1.4	1.5	-	-	-	-	-
Sand (S)	1.45	1.55	-	-	-	-	-
Fine sand (FS)	1.45	1.55	-	-	-	-	-
Loamy sand (LS)	1.3	1.4	-	-	-	-	-
Clayey sand (CS)	1.5	1.8	-	-	-	-	-
Sandy loam (SL)	1.25	1.45	1.45	1.45	1.25	-	-
Loam (L)	1	1.35	1.3	1.3	1.1	-	-
Sandy clay loam (SCL)	-	1.5	1.3	1.4	1.5	-	-
Clay loam (CL)	-	1.35	1.45	1.45	1.35	-	-
Clay (C)	-	1.65	1.7	1.7	1.3	1.65	-
Heavy clay (HC)	-	1.35	1.55	1.55	1.35	1.5	-
Fractured rock or pan (PF, RF)	-	-	-	-	-	-	2.4*
Weathered pan (PW)	-	-	-	-	-	-	2.4*
Weathered rock (PW)							2.4*
Solid rock or pan (PH, RH)							2.65*

\* Indicative value for use in theoretical calculations

## APPENDIX 2. SUITABLE SOILS FOR COMMERCIAL PINE PLANTATIONS (*PINUS PINASTER*)

This assessment is based on *Pinus pinaster* using information used by the Forest Products Commission when evaluating new plantation sites (Owen Donovan, pers. comm.)

This is a generic assessment for commercial pine plantations grown over extensive areas (i.e. hundreds of hectares). It is a regional assessment and neither the soil group qualifier or the landscape position is considered. Commercial pines are grown where annual average rainfall >400 mm. For commercial plantations, pines require deep sandy or gravelly soils (e.g. >3 m). **Other soils may be suitable but for economic reasons are normally used for other farming activities.**

A significant limitation to the assessment is information about soils deeper than 1.5 metres, which is generally sufficient for assessments of most other agricultural crops. To overcome this limitation, first a default set of 'ideal soils' was established. Regional differences of the suitability of different soils were then collated from Forest Products Commission field officers to identify zones where soil ratings vary from the default values. This information came from field knowledge of plantation growth and auger holes dug from to 3 to 5 m<sup>1</sup>. The resulting map is shown below Table A2.1 in Map A2.1.

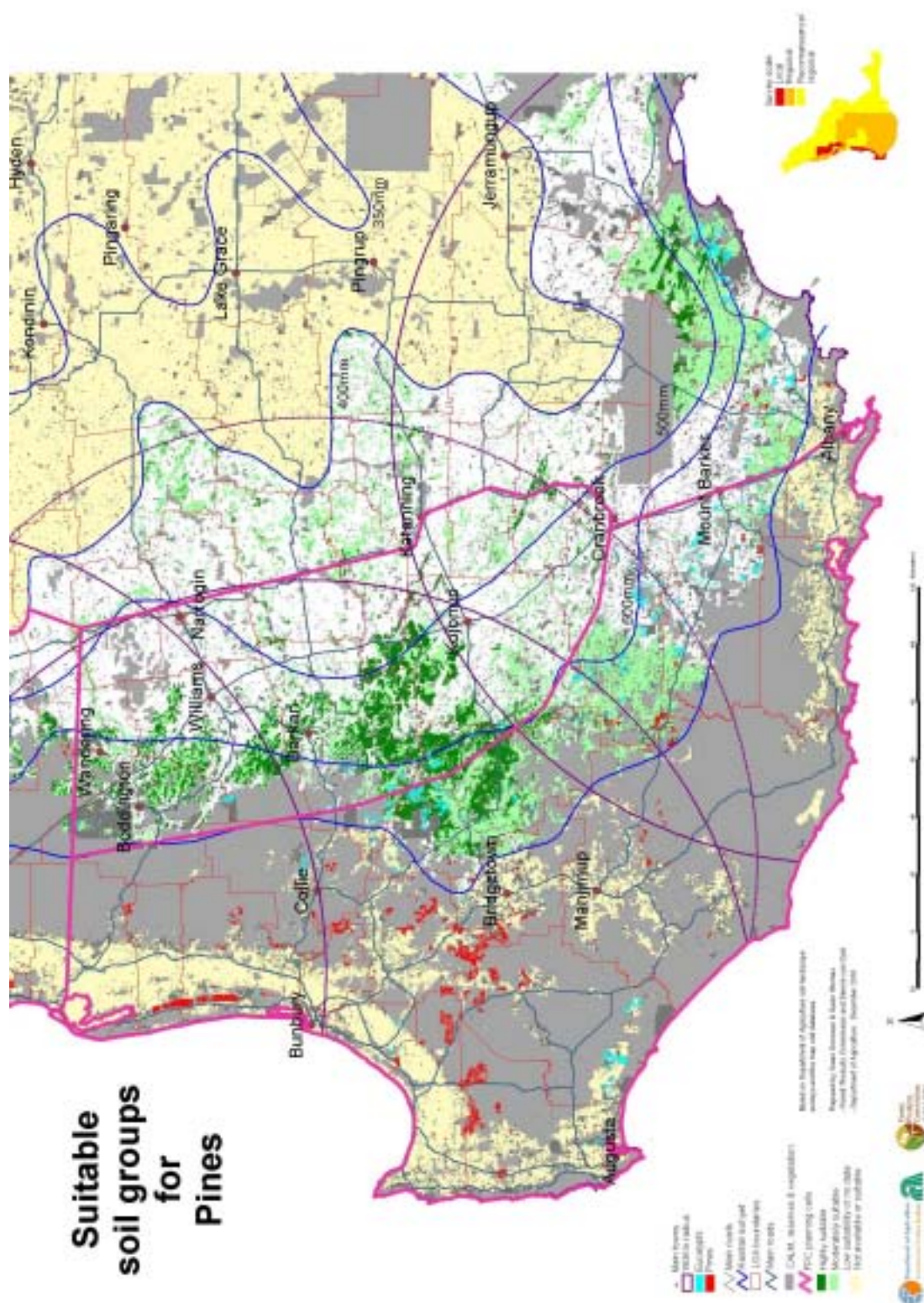
**Table A2.1 Zone soil group ratings for *Pinus pinaster***

Soil group	Any zone	Zone specific adjustments						
	Default value	213	244	245	246	253	254	256
100	No chance							
101	No chance							
102	No chance							
103	No chance							
104	No chance							
105	No chance							
201	No chance							
202	No chance							
203	No chance							
300	No chance							
301	Excellent							
302	No chance	Good				Good		
303	No chance	Good				Good	Good	Good
304	No chance							
400	No chance							
401	No chance		Good	Good	Good			
402	No chance							
403	No chance		Good	Good	Good			
404	No chance							
405	No chance							
406	No chance							
407	No chance		Good					

<sup>1</sup> These auger holes are predominantly recorded on paper and have yet to be collated into a database. Many were collated before GPS, hence accurate locations may be problematic.

Soil group	Any zone	Zone specific adjustments						
	Default value	213	244	245	246	253	254	256
408	No chance							
409	No chance		Good					
420	No chance							
421	No chance							
422	No chance							
423	No chance							
424	Good		No chance					
440	Good							
441	Excellent							
442	No chance		Good	Good				
443	Excellent							
444	Excellent							
445	Good							
446	Excellent							
460	No chance							
461	No chance							
462	No chance							
463	No chance							
464	No chance							
465	No chance							
500	No chance							
501	No chance							
502	No chance							
503	No chance							
504	No chance							
505	No chance							
506	No chance							
507	No chance							
508	No chance							
520	No chance							
521	No chance							
522	No chance							
523	No chance							
540	No chance							
541	No chance							
542	No chance							
543	No chance							
544	No chance							
545	No chance							
600	No chance							
601	No chance							
602	No chance							
620	No chance							
621	No chance							

Soil group	Any zone	Zone specific adjustments						
	Default value	213	244	245	246	253	254	256
622	No chance							
701	No chance							
702	No chance							
703	No chance							



## APPENDIX 3. AVAILABILITY OF DIGITAL LAND RESOURCE SURVEYS (MAY 2005)

Current land resource and rangeland maps are prepared in digital form. Digital copies of most of the older maps have also been captured. The following tables list, by location, surveys for which digital maps have been (or are being) prepared. The locations of most of these surveys are shown in Maps A3.1 and A3.2. Bibliographic references for these surveys and related reports are provided at the end.

Access to some mapping may be restricted, especially for surveys still in progress.

### Key to table headings

*Survey location:* Abbreviated survey title/approximate location.

*Survey code:* The code is only given for surveys with zone land unit/land capability attribution. Note some surveys that used similar mapping methods have been amalgamated and share a survey code in the map unit database.

*Map number:* Publication reference number of the maps (may differ from the report number).

*Publication status:*

P:	Published
NP:	Not published
IP:	In preparation
NS:	Not started
NSP:	No survey planned

*Publication scale:* Scale at which the map is published or planned to be published. This reflects the detail or intensity of the survey.

*Survey type:* Indicates type or purpose of the survey.

A question mark (?) attached to a date indicates that the exact date is uncertain.

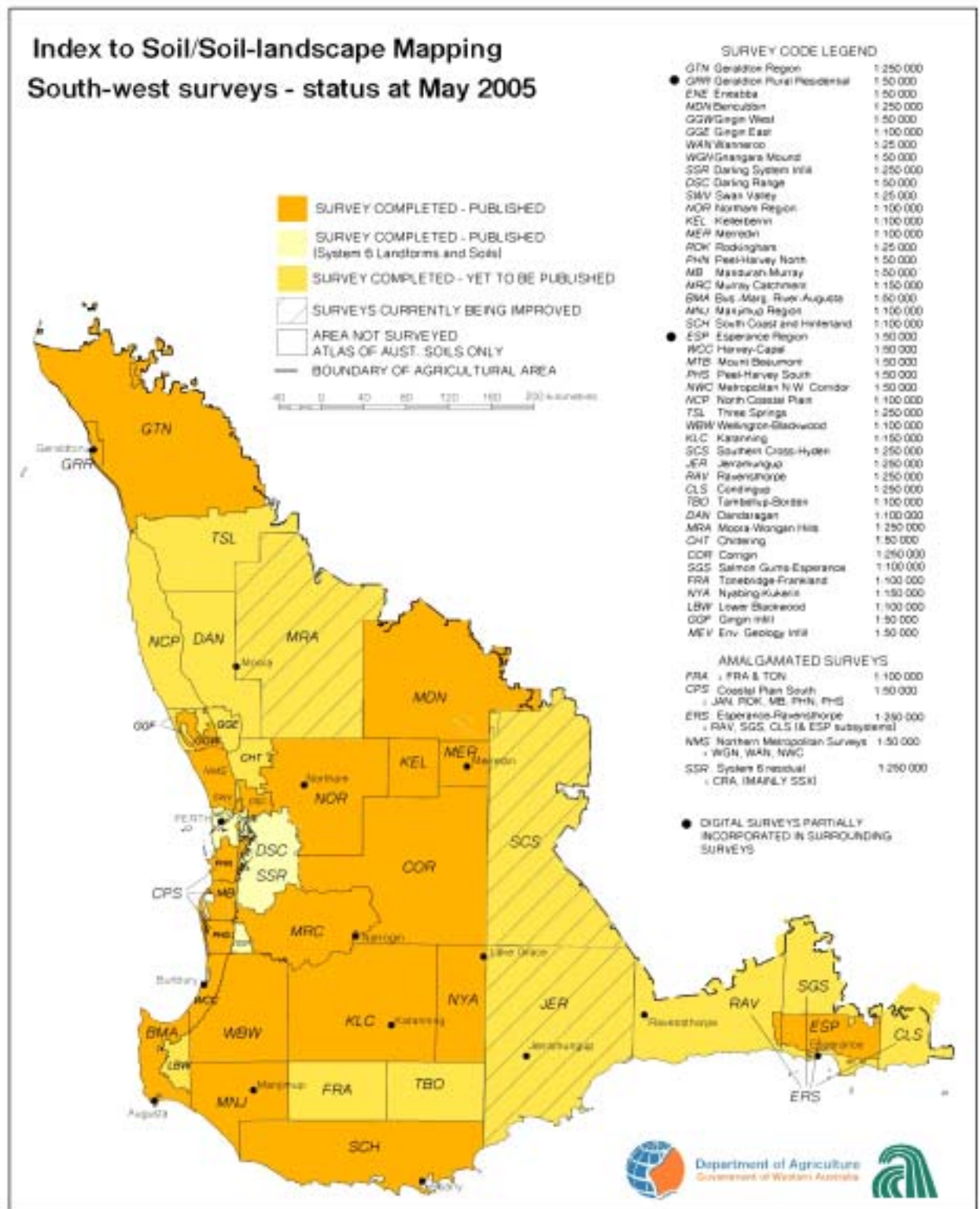
## South-west surveys (Map A3.1)

Survey location (map number)	Survey code	Report author/s (publication date)	Status	Scale	Survey type
Bencubbin	MDN	Grealish and Wagnon (1995)	P	1:250,000	Soil-landscape
Busselton-Margaret River-Augusta	BMA	Tille and Lantzke (1990)	P	1:50,000	Soil-landscape
Cascades	Not used	Scholz (1990 - unpublished)	IP	1:50,000	Soil-landscape
Chittering	CHT	Bessell-Browne (in prep.)	IP	1:50,000	Soil-landscape
Coastal dunes survey - Port Gregory to Cliff Head	Not used	Oma and Moore (1989)	NP	1:50,000	Soil-landscape
Condungup	Not used	Overheu (in prep.)	IP	1:100,000	Soil-landscape
Corrigin	COR	Verboom and Galloway (2005)	P	1:150,000	Soil-landscape
Coujinup Creek	Not used	Scholz (1987)	NP	1:20,000	Soil-landscape
Dandaragan	DAN	Griffin (in prep.)	IP	1:100,000	Soil-landscape
Darling Landforms	SSR (or CRA)	Mainly Churchward and McArthur (1978), plus Smolinski <i>et al.</i> (Unpublished)	P	1:250,000	Land system
Darling Range	DSC	King and Wells (1990)	P	1:50,000	Soil-landscape
Eneabba soil conditions	Not used	Scholz and Smolinski (1987?)	NP	1:50,000	Soil-landscape
Esperance	ESP	Overheu <i>et al.</i> (1993)	P	1:50,000	Soil-landscape
Geraldton region	GTN	Rogers (1996)	P	1:250,000	Soil-landscape
Geraldton rural residential	GRR	Dye <i>et al.</i> (1990)	P	1:50 000	Soil-landscape
Gingin east	GGE	van Gool (1998 - unpublished), based on work by Scholz (1995 - unpublished)	NP	1:100,000	Soil-landscape
Gingin west	GGW	Smolinski and Scholz (1997)	P	1:50,000	Soil-landscape
Gingin infill	GGF	Bessel-Browne (unpublished)	NP	1:50,000	Soil-landscape
Gnangara Mound	NMS	McArthur and Matiske (1985)	P	1:50,000	Soil-landscape
Harvey-Capel	WCC	Barnesby <i>et al.</i> (in prep.)	IP	1:50,000	Soil-landscape
Jandakot	CPS	Wells <i>et al.</i> (1986 updated by van Gool 1990)	P	1:50,000	Soil-landscape
Jerdacuttup catchment	Not used	Moore <i>et al.</i> (1990)	P	1:50,000	Soil



Survey location (map number)	Survey code	Report author/s (publication date)	Status	Scale	Survey type
Jerramungup	JSI	Overheu (in prep.)	IP	1:250,000	Soil-landscape
Katanning	KLC	Percy (2000)	IP	1:150,000	Soil-landscape
Kellerberrin	KEL	McArthur (1992)	P	1:100,000	Soil-landscape
Lake Brown	Not used	Burvill (1932)	NP	1:25,000	Soil-landscape
Lower Blackwood	LBW	Smith and Smolinski (1997)	NP	1:100,000	Soil-landscape
Mandurah-Bunbury	Not used	McArthur and Bartle (1980a)	P	?	Soil-landscape
Mandurah-Murray	MB	Wells (1989)	P	1:50,000	Soil-landscape
Manjimup	MNJ	Churchward (1992)	P	1:100,000	Soil-landscape
Merredin	MER	Bettenay and Hingston (1961)	P	1:126,720	Soil-landscape
Metropolitan region (API infill mapping on rural land)	API	Barnesby (1991) Wells (1992) Bessell-Browne (1998)	NP	1:50,000	Soil-landscape
Metropolitan, north-west corridor	NMS	McArthur and Bartle (1980b)	P	1:25,000	Soil-landscape
Metropolitan environmental geology	MEV	Van-Gool (1998?)	NP	1:50,000	Geology with crude match to soil-landscape
Moora-Wongan Hills	MRA	Griffin <i>et al.</i> (in prep.)	IP	1:250,000	Soil-landscape
Mount Beaumont	Not used	Scholz and Smolinski (1996)	P	1:50,000	Soil
Murray Catchment	MRC	McArthur <i>et al.</i> (1977)	P	1:150,000	Land system
North Coastal Plain	NCP	Schoknecht and Bessell-Browne (in prep.)	IP	1:100,000	Soil-landscape
Northam	NOR	Lantzke and Fulton (1993)	P	1:100,000	Soil-landscape
Nyabing-Kukerin	NYA	Percy (2003)	IP	1:150,000	Soil-landscape
Peel-Harvey North	CPS	van Gool (1990).	P	1:50,000	Soil-landscape
Peel-Harvey South	CPS	van Gool and Kipling (1992)	P	1:50,000	Soil-landscape
Ravensthorpe	RAV	Nicholas and Gee (in prep.)	IP	1:250,000	Soil-landscape
Rockingham	CPS	Wells <i>et al.</i> (1985)	P	1:50,000	Soil-landscape
Salmon Gums-Esperance	ERS	Nicholas and Gee (in prep.)	IP	1:100,000	Soil-landscape

Survey location (map number)	Survey code	Report author/s (publication date)	Status	Scale	Survey type
Salmon Gums detail	Not used	Burvill (1988)	IP	1:15,840	Soil
Salmon Gums District	Not used	Burvill (1935, 1988)	IP	?	Soil-landscape
South Coast and hinterland	SCH	Churchward <i>et al.</i> (1988)	P	1:100,000	Land system
Southern Cross-Hyden	SCS	Verboom <i>et al.</i> (in prep.)	IP	1:250,000	Soil-landscape
Swan Valley	SWV	Campbell Clause and Moore (1991), Pym (1955)	P	1:25,000	Soil-landscape
Tambellup-Borden	TBO	Stuart-Street, A. and Marold, R. (in prep.)	IP	1:100,000	Soil-landscape
Three Springs	TSL	Grose (in prep.)	IP	1:250,000	Soil-landscape
Tonebridge-Frankland	FRA	Stuart-Street. (2005)	IP	1:100,000	Soil-landscape
Wanneroo	NMS	Wells and Clarke (1986)	P	1:25,000	Soil-landscape
Wellington-Blackwood	WBW	Tille (1996)	P	1:100,000	Soil-landscape

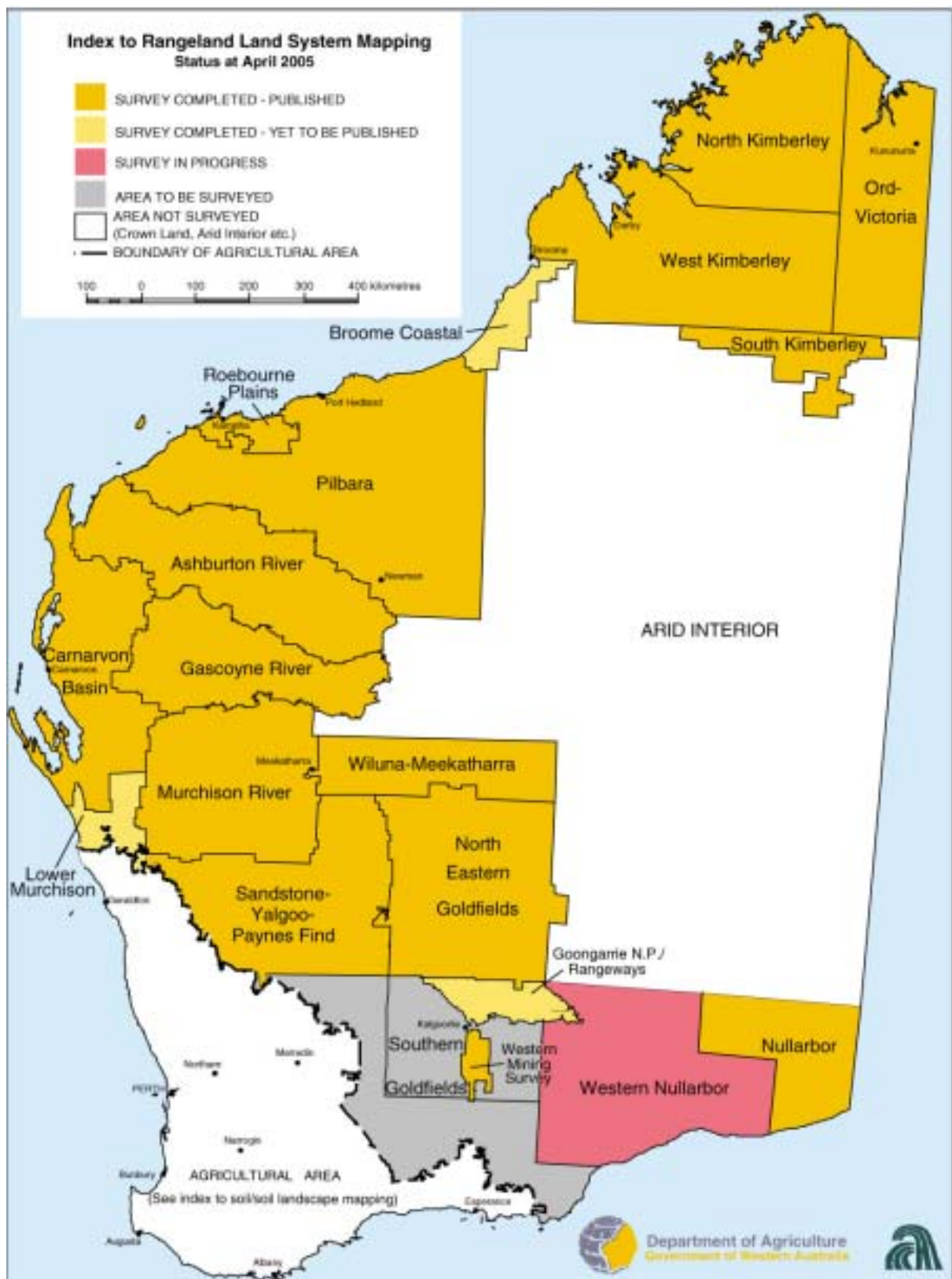


Map A3.1. Survey areas in the south-west agricultural area of Western Australia

**Rangeland surveys (Map A3.2)**

Survey location	Report author/s (publication date)	Status	Scale	Survey type
Ajana		NS		
Arid Interior		NSP		
Ashburton River	Payne <i>et al.</i> (1982)	P	1:250,000	Land system
Broome Coastal	Cotching (2006)	NP	1:100,000	Land system
Carnarvon Basin	Payne <i>et al.</i> (1987)	P	1:250,000	Land system
Gascoyne River	Wilcox and McKinnon (1972)	P	1:250,000	Land system
Gascoyne River near Carnarvon	Bettenay (1971)	P	1:150,000	Soil
Kambalda (part of Southern Goldfields)	Payne <i>et al.</i> (1998)	IP	1:150,000	Land system
Lake Johnston		NS		
Murchison River	Curry <i>et al.</i> (1994)	P	1:250,000	Land system
North Kimberley	Speck <i>et al.</i> (1960)	P	1:250,000	Land system
North-Eastern Goldfields	Pringle <i>et al.</i> (1994)	P	1:250,000	Land system
Nullarbor	Mitchell <i>et al.</i> (1979)	P	1:250,000	Land system
Ord-Victoria	Stewart <i>et al.</i> (1970)	P	1:250,000	Land system
Pilbara	Van Vreeswyk <i>et al.</i> (2004)	IP	1:250,000	Land system
Roebourne Plains	Payne and Tille (1992)	P		Land system
Roy Hill-Ethel Creek (part of Pilbara)	Payne and Mitchell (1992)	NP	1:250,000	Land system
Sandstone-Yalgoo-Paynes Find	Payne <i>et al.</i> (1998)	P	1:500,000*	Land system
Southern Goldfields		NS	1:250,000	Land system
West Kimberley	Speck <i>et al.</i> (1964)	P	1:250,000	Land system
Western Nullarbor		NS	1:250,000	Land system
Wiluna-Meekatharra	Mabbutt <i>et al.</i> (1963)	P	1:250,000	Land system

\* Mapping conducted for 1:250,000 publication scale.



Map A3.2. Rangeland survey areas in Western Australia

**Carnarvon and East Kimberley areas (medium to high intensity surveys)**

Survey location (map number)	Report author/s (publication date)	Status	Scale	Survey type
Carlton plain (58)	Stoneman (1988)	P	1:75,000 (approx.)	Soil
Carnarvon Irrigation District (63)	Wells and Bessell-Browne (1990)	P	1:50,000	Soil-landscape
Carnarvon regional (30)	Wells <i>et al.</i> (1992)	P	1:100,000	Soil-landscape
Carnarvon, North Common (64)	Wells <i>et al.</i> (1987)	NP	1:25,000	Soil-landscape
Groundnut survey (62)	Dixon and Petheram (1979)	P	1:20,000	Soil
Ivanhoe north west (65)	Dixon and Holman (?)	NP	1:25,000	Soil
Ivanhoe Plain (37)	Aldrick <i>et al.</i> (1990)	P	1:25,000	Soil
Ivanhoe West Bank (59)	Schoknecht and Grose (1996a)	P	1:25,000	Soil
King Location 369	Sherrard (1993)	NP	1:15,000	Soil
Knox Creek Plain (61)	Schoknecht and Grose (1996b)	P	1:25,000	Soil
Lower Weaber and Keep Plains, N.T. (39)	Aldrick and Moody (1977)	P	1:20,000	Soil
Mantina Flats/Goose Hill (35)	Burvill (1991)	P	1:125,000 (approx.)	Soil
Mantina Loop (57)	Schoknecht and Grose (1996c)	P	1:50,000	Soil
Maxwell-Biyogoong Plain (60)	Schoknecht (1993)	NP	1:50,000	Soil-landscape
North-west Packsaddle (66)	Schoknecht (1996a)	P	1:20,000	Soil
Packsaddle infill (67)	Schoknecht (1996b)	P	1:20,000	Soil
Packsaddle Plain (36)	Stoneman (1972)	P	1:80,000 (approx.)	Soil
Weaber Plain (38)	Dixon (1996)	P	1:50,000	Soil

**Broad overview surveys**

Survey location	Report author/s (publication date)	Status	Scale	Survey type
Atlas of Australian soils	Northcote <i>et al.</i> (1967)	P	1:2,000,000	Soil
Soil groups of WA	Schoknecht (1998)	NP	1:2,000,000	Soil

## Survey references

- Aldrick, J.M. and Moody, J.M. (1977). Report on the soils of the lower Weaber and Keep Plains, NT. Department of NT, Animal Industry and Agriculture Branch. Technical Bulletin 19.
- Aldrick, J.M., Clarke, A.J., Moody, P.W., van Cuylenburg, M.H.R. and Wren, B.A. (1990). Soils of the Ivanhoe Plain, East Kimberley, Western Australia. Technical Bulletin No. 82. Department of Agriculture, Western Australia.
- Barnesby, B.A. (1991). API infill mapping prepared for the metropolitan rural policy (unpublished).
- Barnesby, B.A. and Proulx-Nixon, M.E. (2000). Land resources from Harvey to Capel on the Swan Coastal Plain, Western Australia - Sheet 2. Land Resources Map 23/2. Agriculture Western Australia.
- Bessell-Browne, J.A. (in prep.). Chittering area land resources survey.
- Bettenay, E. (1971). Soils adjoining the Gascoyne River near Carnarvon, Western Australia. CSIRO Division of Soils. Soils and land use series No. 51.
- Bettenay, E. and Hingston, F.J. (1961). The soils and land use of the Merredin area, Western Australia. CSIRO Division of Soils. Soils and Land Use Series No. 41.
- Burvill, G.H. (1932). Lake Brown soil survey (unpublished).
- Burvill, G.H. (1935). Salmon Gums soil and alkali survey. Maps (scale 1:15,840, 42 map sheets). Unpublished internal report. Department of Agriculture, Western Australia.
- Burvill, G.H. (1988). The soils of the Salmon Gums District, Western Australia. Western Australian Department of Agriculture, Technical Bulletin No. 77.
- Burvill, G.H. (1991). Soil surveys and related investigations in the Ord River area, East Kimberley, 1944. Technical Bulletin No. 80. Western Australian Department of Agriculture.
- Campbell Clause, J. and Moore, G.A. (1991). Land capability study for horticulture in the Swan Valley. Department of Agriculture Western Australia. Land Resources Series No. 6. (See also Pym 1955.)
- Churchward, H.M. (1992). Soils and landforms of the Manjimup area. Western Australian Department of Agriculture, Land Resources Series No. 10.
- Churchward, H.M. and McArthur, W.M. (1978). Landforms and soils of the Darling System, Western Australia. *In*: 'Atlas of Natural Resources, Darling System, Western Australia'. Department of Conservation and Environment, Western Australia.
- Churchward, H.M., McArthur, W.M., Sewell, P.L. and Bartle, G.A. (1988). Landforms and soils of the south coast and hinterland, Western Australia. Northcliffe to Manypeaks. CSIRO Australia. Division of Water Resources Divisional Report 88/1.
- Cotching, W.E. (2006). An inventory of rangelands in part of the Broome Shire, Western Australia. Technical Bulletin No. 93. Department of Agriculture.

- Curry, P.J., Payne, A.L., Leighton, K.L., Hennig, P. and Blood, D.A. (1994). An inventory and condition survey of the Murchison River catchment, Western Australia. Western Australian Department of Agriculture, Technical Bulletin No. 84.
- Dixon, J. and Holman, W.F. (1980). Land capability study of sandy soils north-west of the Ivanhoe Plains, Kununurra, WA. Department of Agriculture, Western Australia report (unpublished).
- Dixon, J.C. (1996). Soils of the Weaber Plain, East Kimberley, Western Australia. Resource Management Technical Report 152. Agriculture Western Australia.
- Dixon, J.C. and Petheram, R.J. (1979). Soil Survey Report 65 (3 map sheets). Department of Agriculture, Western Australia.
- Dye, R.A., van Vreeswyk, A.M.E. and Moore, G.A. (1990). Geraldton rural-residential land capability study. Land Resources Series No. 4. Department of Agriculture, Western Australia.
- Grealish, G. and Wagon, J. (1995). Land resources of the Bencubbin area. Agriculture Western Australia, Land Resources Series No. 12.
- Griffin, E.J. and Frahm, M.A. (in prep.) Moora-Wongan Hills land resources survey.
- Griffin, E.A. (in prep.). Dandaragan land resources survey.
- Grose, C. (in prep.). Three Springs area land resources survey.
- King, P.D. and Wells, M.R. (1990). Darling Range land capability study. Western Australian Department of Agriculture, Land Resources Series No. 3.
- Lantzke, N. and Fulton, I. (1993). Land Resources of the Northam region, Land Resources Series No. 11, Department of Agriculture Western Australia.
- Mabbutt, J.A., Litchfield, W.H., Speck, N.H., Sofoulis, J., Wilcox, D.G., Arnold J.A., Brookfield, M. and Wright, R.L. (1963). General report on the lands of the Wiluna-Meekatharra area, Western Australia, 1958. CSIRO Land Research Series No. 7.
- Marold, R. and Roberts, M. (in prep.). Tambellup-Borden land resources survey
- McArthur, W.M. (1992). Land resources of the Kellerberrin region. Western Australian Department of Agriculture, Division of Resource Management Technical Report 134.
- McArthur, W.M. and Bartle, G.A. (1980a). Soils and land use planning in the Mandurah-Bunbury coastal zone, Western Australia. CSIRO Land Resources Management Series No. 6.
- McArthur, W.M. and Bartle, G.A. (1980b). Landforms and soils as an aid to urban planning in the Perth metropolitan northwest corridor, Western Australia. Maps (scale 1:25,000, 4 map sheets). CSIRO Australia, Land Resources Management Series No. 5.
- McArthur, W.M. and Mattiske, E.M. (1985). The Gngangara mound groundwater area landforms, soils and vegetation. Soil-landscape map (scale 1:50,000). Appendix C *In* 'Gngangara mound groundwater resources, environmental review and management programme'. Report by Dames and Moore, November 1986.
- McArthur, W.M. and Stoneman, T.C. (1991). Landforms and soils of the south coast and hinterland, Western Australia. Northcliffe to Manypeaks. Supplementary data. Department of Agriculture, Western Australia, Land Assessment Group.



- McArthur, W.M., Churchward, H.M. and Hick, P.T. (1977). Landforms and soils of the Murray River catchment area of Western Australia. CSIRO Australia. Division of Land Resources Management Series No. 3.
- Mitchell, A.A., McCarthy, R. and Hacker, R.B. (1979). A range inventory and condition survey of part of the Western Australian Nullarbor Plain, 1974. Western Australian Department of Agriculture, Technical Bulletin No. 47.
- Nicholas, B.D. and Gee, S.T. (in prep.). Ravensthorpe land resources survey.
- Nicholas, B.D. and Gee, S.T. (in prep.). Salmon Gums-Esperance land resources survey.
- Northcote, K.H., Bettenay, E., Churchward, H.M. and McArthur, W.M. (1967). Atlas of Australian soils, Sheet 5, Perth-Albany-Esperance area with explanatory data. CSIRO Australia, Melbourne University Press, Melbourne.
- Oma, V.M. and Moore, G.A. (1989). Mapping for assessing erosion in the coastal Dune system, Shire of Greenough (unpublished).
- Payne, A.L., Curry, P.J. and Spencer, G.F. (1987). An inventory and condition survey of the Carnarvon Basin, Western Australia. Western Australian Department of Agriculture, Technical Bulletin No. 73.
- Payne, A.L. and Tille, P. (1992). An inventory and condition survey of the Roebourne Plains and surrounds, Western Australia. Department of Agriculture, Western Australia, Technical Bulletin No. 83.
- Payne, A.L., Mitchell, A.A. and Hennig, P. (1998). Land systems of the Kambalda area and surrounds (report prepared for WMC Resources Ltd).
- Payne, A.L., Mitchell, A.A. and Holman, W.F. (1982). An inventory and condition survey of the Ashburton River catchment, Western Australia. Western Australian Department of Agriculture, Technical Bulletin No. 62.
- Payne, A.L., Van Vreeswyk, A.M.E., Pringle, H.J.R., Leighton, K.A. and Hennig, P. (1998). An inventory and condition survey of the Sandstone-Yalgoo-Paynes Find area, Western Australia. Agriculture Western Australia, Technical Bulletin No. 90.
- Percy, H. (in prep). Katanning area land resources survey.
- Percy, H. (2003). Nyabing-Kukerin area land resources survey. Land Resources Series No. 18. Department of Agriculture, Western Australia.
- Pringle, H.J.R., Van Vreeswyk, A.M.E. and Gilligan, S.A. (1994). An inventory and condition survey of rangelands in the north-eastern Goldfields, Western Australia. Department of Agriculture, Western Australia, Technical Bulletin No. 87.
- Pym, L.W. (1955). Soils of the Swan Valley vineyard area, Western Australia. CSIRO Division of Soils, Soils and Land Use Series No. 15.
- Rogers, L.G. (1996). Geraldton region land resources survey. Agriculture Western Australia, Land Resources Series No. 13.
- Schoknecht, N. (1996a). Assessment of the suitability for Agriculture of the North-west Packsaddle area Kununurra. Agriculture Western Australia. Resource Management Technical Report 156.

- Schoknecht, N. (1996b). Assessment of the suitability for agriculture of the Packsaddle infill area, Kununurra. Agriculture Western Australia. Resource Management Technical Report 157.
- Schoknecht, N. (1997). Soil groups of Western Australia. A simple guide to the main soils of Western Australia. Agriculture Western Australia, Resource Management Technical Report No. 171.
- Schoknecht, N. and Grose, C. (1996a). Soils of the Ivanhoe West Bank, East Kimberley, Western Australia. Agriculture Western Australia, Resource Management Technical Report 155.
- Schoknecht, N. and Grose, C. (1996b). Soils of the Knox Creek Plain, East Kimberley Western Australia and Northern Territory. Agriculture Western Australia. Resource Management Technical Report 153.
- Schoknecht, N. and Grose, C. (1996c). Soils of the Mantinea Loop, Ord River Valley, East Kimberley Western Australia. Agriculture Western Australia. Resource Management Technical Report 154.
- Schoknecht, N.R. (1993). Maxwell-Biyooogoong Plains survey, East Kimberley (unpublished).
- Schoknecht, N. (in prep.). North Coastal Plain land resources survey.
- Scholz, G.G.H. and Smolinski, H.J. (1987). Eneabba sand textural map (unpublished).
- Scholz, G. (unpublished). Soil morphology and chemistry of the cascades area, Western Australia.
- Scholz, G.G.H. (unpublished). Coujinup Creek Land Resource Survey. Map (scale 1:20,000). Department of Agriculture, Western Australia. Unpublished internal report.
- Scholz, G.G.H. and Smolinski, H.J. (1996). Soils of the Mount Beaumont area, Western Australia. Agriculture Western Australia, Land Resources Series No. 7.
- Sherrard, J.H. (1993). Land capability study of King Location 369, adjoining reserve 36951 and freehold location 599. Agriculture Western Australia (unpublished).
- Smith, R. and Smolinski, H.J. (1997). Soils and landforms of the Lower Blackwood. (unpublished).
- Smolinski, H. and Scholz, G. (1997). Soil assessment of the West Gingin area. Agriculture Western Australia, Land Resources Series No. 15.
- Smolinski, H. (unpublished). Soils of the south west forest region, Western Australia. Unpublished AGWEST Land Management report. Agriculture Western Australia. (Rapid assessment of State forest areas using existing mapping and aerial photography.)
- Speck, N.H., Bradley, J., Lazarides, M., Paterson, R.A., Slatyer, R.O., Stewart, G.A. and Twidale, C.R. (1960). Lands and pastoral resources of the North Kimberley area, Western Australia. CSIRO Land Research Series No. 4.
- Speck, N.H., Wright, R.L., Rutherford, G.K., Fitzgerald, K., Thomas, F., Arnold, J.M., Basinski, J.J., Fitzpatrick, E.A., Lazarides, M. and Perry, R.A. (1964). General report on lands of the West Kimberley area, Western Australia. CSIRO Land Research Series No. 9.

- Stewart, G.A., Perry, R.A., Paterson, S.J., Traves, D.M., Slatyer, R.O., Dunn, P.R., Jones, P.J. and Sleeman, J.R. (1970). Lands of the Ord-Victoria area, Western Australia and Northern Territory. CSIRO Land Research Series No. 28.
- Stoneman, T.C. (1972). Packsaddle Plains soil survey. Western Australian Department of Agriculture. Technical Bulletin No. 55.
- Stoneman, T.C. (1988). Carlton Plains soil survey in the Shire of Wyndham, East Kimberley. Western Australian Department of Agriculture, Division of Resource Management Technical Report 76.
- Stuart-Street, A. and Marold, R. (in prep.) Tambellup-Borden land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
- Stuart-Street, A. (2005). Tonebridge-Frankland land resources survey. Land Resources Series No. 19. Department of Agriculture, Western Australia
- Tille, P.J. (1996). Land capability assessment for the Wellington-Blackwood survey. Resource Management Technical Report 162. Agriculture Western Australia.
- Tille, P.J. (1996). Wellington-Blackwood land resources survey. Agriculture Western Australia, Land Resources Series No. 14.
- Tille, P.J. and Lantzke, N.J. (1990). Busselton-Margaret River-Augusta land capability study. Western Australian Department of Agriculture, Land Resources Series No. 5.
- Tille, P. and Lantzke, N. (1990). Busselton-Margaret River-Augusta Land Capability Study; Methodology and Results, Vol. 1, Technical Report 109, Division of Resource Management, Department of Agriculture, Western Australia.
- van Gool, D. (1990). Land resources in the northern portion of the Peel-Harvey Coastal Catchment, Swan Coastal Plain. Department of Agriculture. Miscellaneous Publication.
- van Gool, D. (1992). Land resources in the southern portion of the Peel-Harvey Coastal Catchment, Swan Coastal Plain. Department of Agriculture. Miscellaneous Publication.
- van Gool, D. (unpublished). Remapping of Gingin East soil survey using aerial photograph and existing linework from other sources. Based on work by Scholz, G. (1995). Land resource map of East Gingin.
- van Gool (unpublished). Soil-landscape map unit correlation of published environmental geology mapping.
- van Vreeswyk, A.M.E., Payne, A.L., Leighton, K.A. and Hennig, P. (2004). An inventory and condition survey of the Pilbara Region, Western Australia. Department of Agriculture Technical Bulletin No. 92.
- Verboom, W. and Frahmnd, M.A. (in prep.). Southern Cross-Hyden land resources survey.
- Verboom, W. and Galloway, P. (2005). Corrigin area land resources survey. Land Resources Series No. 19. Department of Agriculture, Western Australia.
- Wells, M.R., Keating, C.D.M. and Bessell-Browne, J.A. (1992). Land resources of the Carnarvon Land Conservation District and part of Boolathana station, Western Australia. Department of Agriculture. Land Resources Series No. 9.

- Wells, M.R. (1989). Land capability study of the shires of Mandurah and Murray. Western Australian Department of Agriculture, Land Resources Series No. 2.
- Wells, M.R. (1992?). Land resource infill mapping for the Armadale local rural strategy. (unpublished).
- Wells, M.R. and Bessell-Browne, J.A. (1990). Horticultural capability study of soils adjacent to plantations at Carnarvon, Western Australia. Western Australian Department of Agriculture. Division of Resource Management Technical Report 115.
- Wells, M.R. and Clarke, A.J. (1986). Shire of Wanneroo, a study of land resources and planning considerations. Soil-landscape map (scale 1:25 000, 4 map sheets, included in the report as microfiche copies: maps. 408, 409, 410, 411). Division of Resource Management, Technical Report 47. Department of Agriculture, Western Australia.
- Wells, M.R., Oma, V.P.M. and Richards, N.L.B. (1985). Shire of Rockingham, a study of land resources and planning considerations. Maps (scale 1:25,000: soil-landscape map plus two interpretive maps). Division of Resource Management, Technical Report 44. Department of Agriculture, Western Australia.
- Wells, M.R., Richards, N.L.B. and Clarke, A.J. (1986). Jandakot groundwater scheme - a study of land resources and planning considerations. Soil-landscape map (scale 1:25,000: one map sheet, included as a microfiche copy: map 458). Resource Management Technical Report 48. Department of Agriculture, Western Australia.
- Wells, M.R. (unpublished). Metropolitan infill mapping, prepared for the Armadale Local Rural Strategy. City of Armadale.

## General references

- Bettenay, E. and Hingston, F.J. (1964). Development and distribution of the soils in the Merredin area, Western Australia. *Australian Journal of Soil Science* **2**: 173-186.
- Bettenay, E., McArthur, W.M. and Hingston, F.J. (1960). The soil associations of part of the Swan Coastal Plain, Western Australia. CSIRO Australia, Soils and Land Use Series 35.
- Blood, D.A. (1995). Rangeland reference areas. Department of Agriculture, Western Australia, Resource Management Technical Report 141.
- Burnside, D., Holm, A., Payne, A. and Wilson, G. (1995). Reading the rangeland: a guide to the arid shrublands of Western Australia. Department of Agriculture, Western Australia.
- Hingston, F.J. and Bettenay, E. (1960). A laboratory examination of soils of the Merredin area, Western Australia. CSIRO Australia. Division of Soils, Divisional Report 7/60.
- Hosking, J.S. and Greaves, G.A. (1936). A soil survey of an area at Gingin, Western Australia. *Journal of the Royal Society of Western Australia* **22**: 71-112.
- Lantzke, N.C. (1992). Soils of the Northam Advisory District, Vol. 1, The Zone of Ancient Drainage. Western Australian Department of Agriculture, Bulletin No. 4244.
- Lantzke, N.C. (1993). Soils of the Northam Advisory District, Vol. 2, The Zone of Rejuvenated Drainage. Western Australian Department of Agriculture, Bulletin. 4245.
- Lantzke, N.C. (1993). Soils of the Northam Advisory District, Vol. 2, Darling Range and Kokeby Zones. Western Australian Department of Agriculture, Bulletin 4245.
- McArthur, W.M. (1958). Further Investigation of the Soils of the Harvey and Waroona areas, Western Australia. CSIRO Division of Soils. Division report 4/58.
- McArthur, W.M. (1991). 'Reference soils of South-Western Australia'. Australian Soil Science Society of Australia Inc. (WA Branch), Perth, Western Australia.

- McArthur, W.M. and Bettenay, E. (1956). The soils and irrigation potential of the Capel-Boyanup area, Western Australia. CSIRO Division of Soils. Soils and Land Use Series No. 16.
- McArthur, W.M. and Bettenay, E. (1957). Soils of the proposed extension of the Collie Irrigation District, Western Australia. CSIRO Division of Soils. Divisional report 7/57.
- McArthur, W.M. and Bettenay, E. (1974). Development and distribution of soils of the Swan Coastal Plain, Western Australia, 2nd edition. CSIRO Australia. Soil Publication 16.
- McArthur, W.M., Bettenay, E. and Hingston, F.J. (1959). The soils and irrigation potential of the Pinjarra-Waroona area, Western Australia. CSIRO Division of Soils. Soils and Land Use Series No. 31.
- Nicholas, B.D., Overheu, T.D. and Needham, P.J. (1996). Soil information sheets for the Mount Beaumont, Mallee and Esperance agricultural areas. Miscellaneous Publication 21/96. Agriculture Western Australia.
- Overheu, T.D. (1996). Soil information sheets for part of the Jerramungup agricultural area. Miscellaneous Publication 20/96. Agriculture Western Australia.
- Overheu, T.D., Muller, P.G., Gee, S.T. and Moore, G.A. (1993). Esperance land resources survey. Western Australian Department of Agriculture, Land Resources Series No. 8.
- Overheu, T.D. (1995). Soil information sheets for Ravensthorpe and part of the Jerramungup agricultural area. Miscellaneous Publication 16/95. Agriculture Western Australia.
- Patabendige, D.M. and Rogers, L.G. (1997). Soil information sheets for the Northern agricultural areas. Miscellaneous Publication 13/97. Agriculture Western Australia.
- Payne, A.L. (1985). Maps showing pastoral potential in the Kimberley region of Western Australia. Western Australian Department of Agriculture.
- Payne, A.L. and Mitchell, A.A. (1992). An assessment of the impact of Ophthalmia dam on the floodplains of the Fortescue River on Ethel Creek and Roy Hill stations. Department of Agriculture, Western Australia. Technical Report 124.
- Payne, A.L., Kubicki, A. and Wilcox, D.G. (1974). Range condition guides for the West Kimberley area in Western Australia. Western Australia Department of Agriculture.
- Payne, A.L., Wilcox, D.G. and Short, L.C. (1972). A report on the erosion and rangeland condition in the West Kimberley area of Western Australia. Western Australian Department of Agriculture, Technical Bulletin No. 42.
- Pringle, H.J.R. (1991). Rangeland survey in Western Australia - history, methodology and applications. Department of Agriculture, Western Australia. Miscellaneous Publication 22/91.
- Pringle, H.J.R. (1994). Pastoral resources and their management in the north-eastern Goldfields, Western Australia. Department of Agriculture, Western Australia Miscellaneous Publication 22/94.
- Pym, L.W. (1951). Soil survey of Wokalup State Research Farm, Western Australia. CSIRO Division of Soils. Divisional Report 6/51.
- Stoneman, T.C. (1990). Soils of the Albany Advisory District. Bulletin 4203. Department of Agriculture, Western Australia.
- Stoneman, T.C. (1990). Soils of the Geraldton Advisory District. Bulletin 4181. Department of Agriculture, Western Australia.
- Stoneman, T.C. (1990). Soils of the Jerramungup Advisory District. Bulletin 4201. Department of Agriculture, Western Australia.
- Stoneman, T.C. (1990). Soils of the Moora Advisory District. Bulletin 4182. Department of Agriculture, Western Australia.

- Stoneman, T.C. (1990). Soils of the Three Springs Advisory District. Bulletin 4180. Department of Agriculture, Western Australia.
- Stoneman, T.C. (1991). Soils of the Katanning Advisory District. Bulletin 4202. Department of Agriculture, Western Australia.
- Stoneman, T.C. (1992). Soils of the Merredin Advisory District. Bulletin 4235. Department of Agriculture, Western Australia.
- Teakle, L.J.H. (1953). Soil survey of the Many Peaks District, Albany Road Board, Western Australia. Western Australian Department of Agriculture, Leaflet No. 2070.
- Van Vreeswyk, A.M.E. and Godden, P.T. (1998). Pastoral resources and their management in the Sandstone-Yalgoo-Paynes Find area, Western Australia, Agriculture Western Australia, Miscellaneous Publication 1/98.

## APPENDIX 4. LAND EVALUATION TERMINOLOGY

This lists the main terms used in land evaluation and their definitions as used by the Department of Agriculture in Western Australia. The Department uses terminology similar to the New South Wales glossary of terms used in soil conservation (Houghton and Charman 1986) for land evaluation purposes.

The terminology has varied over time, and differences occur between the Australian States. For example there is no consensus on the use of common terms such as land capability and land suitability which are often used interchangeably.

Readers should be aware that multiple definitions are in common usage.

A reading list of some publications relevant to land evaluation terminology is also provided.

**Land attribute:** A specific property of the land that has been identified and described and which can be associated with a soil or land mapping unit. Land attributes used in WA include land qualities, land characteristics, soil series and soil group attributes.

**Land capability: Land resource suitability:** In Australia land capability is often used interchangeably with land suitability.

Land capability, as used in Western Australia is: 'The ability of land to support a type of land use without causing damage' (Austin and Cocks 1978). Dixon (1986) expanded this definition slightly to emphasise that damage referred to both on-site and off-site effects. The term land capability was adopted in Western Australia from the Land Capability Methodology described by Wells and King (1989). Although this work refers to the 'Land-Capability Classification' (Klingebiel and Montgomery 1961, Olson 1973), the methods described are closer to a stage I land suitability assessment described in 'A framework for land evaluation' (FAO 1976).

Although land capability will probably continue to be used in WA for some time, the term **Land resource suitability** is suggested to accord with the nationally adopted standard. Physical has been added to the definition of 'land suitability' to distinguish it from the all encompassing FAO definition of land suitability (below) which also includes social and economic considerations.

Land capability in WA has five classes for a defined land use and the final capability rating is simply determined by the most limiting land quality or qualities. Class 1 is essentially non-limiting and the ratings decrease gradually to class 5 which is severely limiting.

**Land degradation:** Describes the decline in quality of natural land resources, commonly caused through poor land management practices.

Land degradation encompasses soil degradation and the deterioration of natural landscapes and vegetation. It includes the adverse effects of overgrazing, excessive tillage, over-clearing, erosion and sediment deposition.

The definition also encompasses off-site effects. These also include nutrient pollution which may result from erosion or drainage from a given land unit.

**Land evaluation:** The determination of the extent of one or more land attributes, the assessment of potential land uses, and the effect upon the environment and the resource resulting from these uses.

The process of interpreting the technical information associated with land resource maps summarises those resources. Examples include land capability maps (general and specific),

land degradation susceptibility maps and maps showing the distribution of land qualities such as average soil depth or average soil pH.

**Landform:** The shape and form of the land surface.

**Land qualities:** Those attributes of land that influence its capability for a specified use (Wells and King 1989). Land qualities can be applied to map units or defined components of map units, and are used directly in the preparation of degradation hazard maps. They may be combined to prepare land capability maps. Land qualities may be single characteristics such as soil permeability, or they may be derived from some combination of soil and landscape characteristics. For example the inherent erodibility of a soil is combined with the landscape position to derive susceptibility to wind erosion.

Land qualities are classified (e.g. low, moderate or high), and may be applied directly to map units, to components of map units, or assessed as a proportion of a map unit.

**Land resource (survey):** A survey of land resources, sometimes called natural resources and covering one or more of soil, landform, vegetation and regolith/geology.

Recent surveys in the south-west of Western Australia map soil-landscapes and utilise taxonomic soil series in the map unit descriptions. Rangeland mapping is based on land systems that give more emphasis to vegetation and less to soils.

**Land suitability:** The potential uses of the land based upon consideration of prevailing physical, technical and socio-economic conditions (FAO 1976). Land suitability evaluation involves a multi-disciplinary approach to land evaluation and includes a basic inventory of land resource data; an understanding of the ecological requirements of the land use contemplated; basic data on the economics of land use, land improvement, new technologies, marketing and transport, and a knowledge of the attitudes and goals of people affected by the proposed changes.

**Land system:** A mapping unit that identifies a recurring pattern of topography, soils and vegetation. May be subdivided into land facets or land units that are described but not mapped.

**Land units and zone land units:** Land units described in this report are an area of common landform and similar soils that occur repeatedly at similar points in the landscape. They usually have similar vegetation and geology. Land units are components of map units. At relatively detailed scales (e.g. 1:25,000) the land unit may be synonymous with the map unit, though this can vary according to the complexity of the soils and landforms. More commonly, land units are described as a proportion or percentage of a map unit.

The land units that are attributed in the map unit database in WA are called zone land units, as they are differentiated according to the soil-landscape zone in which they occur.

**Map unit:** A set of map polygons having common land attributes. The homogeneity of the map unit will depend on the scale and purpose of mapping.

For some more detailed mapping (1:25,000 scale), land qualities are applied directly to mapping units. However for most surveys component land units (unmapped) are described as a proportion of a mapping unit.

**Minimum dataset:** A user-defined minimum set of information required to achieve a specific set of outcomes. (e.g. 22 land qualities)

The term is often discussed by users of geographic information systems without being defined.

It is possible to create many land qualities, however 20 have been selected as a minimum dataset used for a wide range of rural and agricultural land capability interpretations. These 20 land qualities are a base reference for land use interpretation. They can be determined



from the data available for most surveys and are described in detail in Section 2. Land qualities include the major land degradation and land management considerations and are used for a wide range of land capability assessments, including those listed in Section 3.

**Land resource suitability:** (See land capability).

**Proportional mapping:** Refers to map units that are defined and described as unmapped components of mapping units so that interpretations can be presented as percentages of a given mapping unit.

**Soil association:** A soil mapping unit in which two or more soil taxonomic units occur together in a characteristic pattern. The units are combined because the scale of the map, or the purpose for which it is being made, does not require delineation of individual soils. The soil association may be named according to the units present, the dominant unit, or given a geographic name based on a locality where the soil association is well developed.

**Soil classification:** The systematic arrangement of soils into groups or categories on the basis of similarities and differences in their characteristics. Soils can be grouped according to their genesis (taxonomic classification), their morphology (morphological classification), their suitability for different uses (interpretative classification) or according to specific properties.

The purposes of soil classification are:

- As a means of grouping soils into useful categories so that statements about one particular soil are likely to apply to other soils in the same group
- With experience, the identification and categorising may lead to the inference of other soil properties (apart from those used in the classification)
- A formal system of classification encourages the scientific and logical study of soils
- The standardisation and objectivity involved are desirable for communication purposes.

**Soil-landscape:** A mapping unit that is defined in terms of landform and soils. In WA a hierarchy of soil-landscape mapping units has been defined (regions, provinces, zones, systems, subsystems and subsystem phases).

**Soil profile class:** A survey-specific grouping of soil profiles based on the frequency distribution of attributes.

**Soil series:** A unit of soil classification (or a soil taxonomic unit) for describing soils which are alike in all major profile characteristics. Each soil series is developed from a particular *parent material*, or group of parent materials, under similar environmental conditions. The name is geographic in nature and indicates a locality where the series is well developed (adapted from Houghton and Charman 1986).

**Soil taxonomic unit:** A conceptual soil unit with defined class limits. Usually identified within a national soil classification system.

**Soil type:** An obsolete term used to describe subdivisions of a soil series based on variants in soil texture.

**Soil variant:** A soil taxonomic unit with properties that exclude it from the named unit which it is associated, but which are not extensive enough to warrant a taxa identification in its own right.

## Terminology references

- McKenzie, N.J., Ringrose-Voase, A.J. and Grundy, M.J. (in press). Australian Soil and Land Survey Handbook. Guidelines for Conducting Surveys. CSIRO Australia.
- Austin, M.P. and Cocks, K.D. (1978). Land use on the south coast of New South Wales. A study in methods acquiring and using information to analyse regional land use options. CSIRO Melbourne.
- Dixon, J. (1986). Classification of land capability. Department of Agriculture Technote 2/86.
- FAO (1976). A framework for land evaluation. Food and Agriculture Organisation of the United Nations, Rome. Soils Bulletin 32.
- Houghton, P.D. and Charman, P.E.V. (1986). A glossary of terms used in soil conservation. Soil Conservation Service of New South Wales, Sydney.
- Klingebiel, A.A. and Montgomery, P.H. (1961). 'Land capability classification.' Soil Conservation Service, United States Department of Agriculture. Agricultural Handbook p. 210.
- Olson, G.W. (1973). Soil survey interpretation for engineering purposes. FAO Soils Bulletin 19.
- Wells, M.R. and King, P.D. (1989). Land capability assessment methodology. Land Resource Series No. 1, Western Australian Department of Agriculture.

## APPENDIX 5. LAND CAPABILITY TABLES FOR LUPINS, OATS, BARLEY, CANOLA AND WHEAT

**Table A5.1 Lupin capability (from van Gool and Vernon 2006a)**

Land Quality	LC1	LC2	LC3	LC4	LC5
Permeability	R VR	M MR	MS	S	VS XX
pH at 0-10 cm (zf)	Mac Slac N	Sac	Vsac		Malk Salk XX
pH at 50-80 cm (zg)	Slac N	Sac Mac	Vsac	Malk	Salk XX
Salinity hazard (y)	NR PR MR	HR			PS XX
Surface salinity (ze)	N			S	M H E XX
Salt spray exposure (zi)	N				S XX
Surface condition	L S F LG SG SM FG SL	X K	C		HS XX
Trafficability (zk)	G F		P		VP XX
Rooting depth (r )	VD D		M	MS	S VS XX
Waterlogging / inundation risk (i)	N	VL	L		M H VH XX
Water repellence susceptibility (za)	N L M		H XX		
Soil water storage (m)	H M	ML L	VL XX		
Soil workability (k)	G F P VP XX				

**Table A5.2. Oats capability (from Vernon and van Gool 2006b)**

Land Quality	LC1	LC2	LC3	LC4	LC5
Flood hazard (f)	N L		M	H XX	
pH at 0-10 cm (zf)	Slac N	Mac	Sac	Vsac Malk XX	Salk
pH at 50-80 cm (zg)	Slac N	Sac Mac	Vsac Malk XX		Salk
Phosphorus export risk (n)	L	M H	VH	E XX	
Salinity hazard (y)	NR		PR	MR HR	PS XX
Surface salinity (ze)	N		S	M	H E XX
Salt spray exposure (zi)	N			S XX	
Surface soil structure decline susceptibility (zb)	L	M	H XX		
Subsurface acidification susceptibility (zd)	L	M	H P	XX	
Subsurface compaction susceptibility (zc)	L	M H XX			
Trafficability (zk)	G	F		P	VP XX
Rooting depth (r )	VD D	M	MS		S VS XX
Water erosion hazard (e)	VL L	M	H	VH	E XX
Waterlogging / inundation risk (i)	N VL L	M	H	VH XX	

Land Quality	LC1	LC2	LC3	LC4	LC5
Water repellence susceptibility (za)	N L	M H XX			
Soil water storage (m)	H	M ML	L	VL XX	
Wind erosion risk (w)	L	M	H VH		E XX

**Table A5.3 Barley capability (from van Gool and Vernon 2006b)**

Land quality	LC1	LC2	LC3	LC4	LC5
Flood hazard (f)	N L		M	H XX	
pH at 0-10 cm (zf)	Slac N	Mac Malk	Sac	Vsac Salk XX	
pH at 50-80 cm (zg)	Slac N	Mac Malk	Salk	Sac XX	Vsac
Phosphorus export risk (n)	L	M H	VH	E XX	
Salinity hazard (y)	NR		PR	MR HR	PS XX
Surface salinity (ze)	N	S	M		H E XX
Salt spray exposure (zi)	N			S XX	
Surface soil structure decline susceptibility (zb)	L	M	H XX		
Subsurface acidification susceptibility (zd)	L	M	H		P XX
Subsurface compaction susceptibility (zc)	L	M XX	H		
Trafficability (zk)	G	F		P	VP XX
Rooting depth (r )	VD D	M	MS		S VS XX
Water erosion hazard (e)	VL L	M	H	VH	E XX
Waterlogging / inundation risk (i)	N	VL	H	M H	VH XX
Water repellence susceptibility (za)	N L	M H XX			
Soil water storage (m)	H M	ML L		VL XX	
Wind erosion risk (w)	L	M	H	VH	E XX

**Table A5.4 Canola capability. (from Vernon and van Gool 2006a)**

Land quality	LC1	LC2	LC3	LC4	LC5
Flood hazard (f)	N L		M	H XX	
pH at 0-10 cm (zf)	Slac N	Mac	Sac Malk	Vsac Salk XX	
pH at 50-80 cm (zg)	Slac N	Sac Mac Malk	Vsac XX	Salk	
Phosphorus export risk (n)	L	M H	VH	E XX	
Salinity hazard (y)	NR		PR	MR HR	PS XX
Surface salinity (ze)	N		S	M	H E XX
Salt spray exposure (zi)	N			S XX	
Surface soil structure decline susceptibility (zb)	L	M	H XX		

Land quality	LC1	LC2	LC3	LC4	LC5
Subsurface acidification susceptibility (zd)	L	M	H P	XX	
Subsurface compaction susceptibility (zc)	L	M XX	H		
Trafficability (zk)	G	F		P	VP XX
Rooting depth (r )	VD D		M	MS	S VS XX
Water erosion hazard (e)	VL L	M	H	VH	E XX
Waterlogging/inundation risk (i)	N	VL	L M	H	VH XX
Water repellence susceptibility (za)	N L	M H XX			
Soil water storage (m)	H	M ML	L	VL XX	
Wind erosion risk (w)		M	H VH		E XX

**Table A5.5 Wheat capability (from van Gool and Vernon 2005)**

Land quality	LC1	LC2	LC3	LC4	LC5
Flood hazard (f)	N L		M	H XX	
pH at 0-10 cm (zf)	Slac N	Mac Malk	Sac	Vsac Salk XX	
pH at 50-80 cm (zg)	Slac N	Sac Mac Malk	Vsac Salk XX		
Phosphorus export risk (n)	L	M H	VH	E XX	
Salinity hazard (y)	NR		PR	MR HR	PS XX
Surface salinity (ze)	N	S		M	H E XX
Salt spray exposure (zi)	N			S XX	
Surface soil structure decline susceptibility (zb)	L	M	H XX		
Subsurface acidification susceptibility (zd)	L	M	H P	XX	
Subsurface compaction susceptibility (zc)	L	M H XX			
Trafficability (zk)	G	F		P	VP XX
Rooting depth (r )	VD D	M	MS		S VS XX
Water erosion hazard (e)	VL L	M	H	VH	E XX
Waterlogging/inundation risk (i)	N	VL L	M	H	VH XX
Water repellence susceptibility (za)	N L	M H XX			
Soil water storage (m)	H	M ML	L	VL XX	
Wind erosion risk (w)	L	M	H VH		E XX

The five publications by van Gool and Vernon listed above can be accessed through the website:

[www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/RPM/LANDCAP/WHEAT\\_AND\\_CLIMAT\\_E.PDF](http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/RPM/LANDCAP/WHEAT_AND_CLIMAT_E.PDF). (Accessed, 19 October 2005)