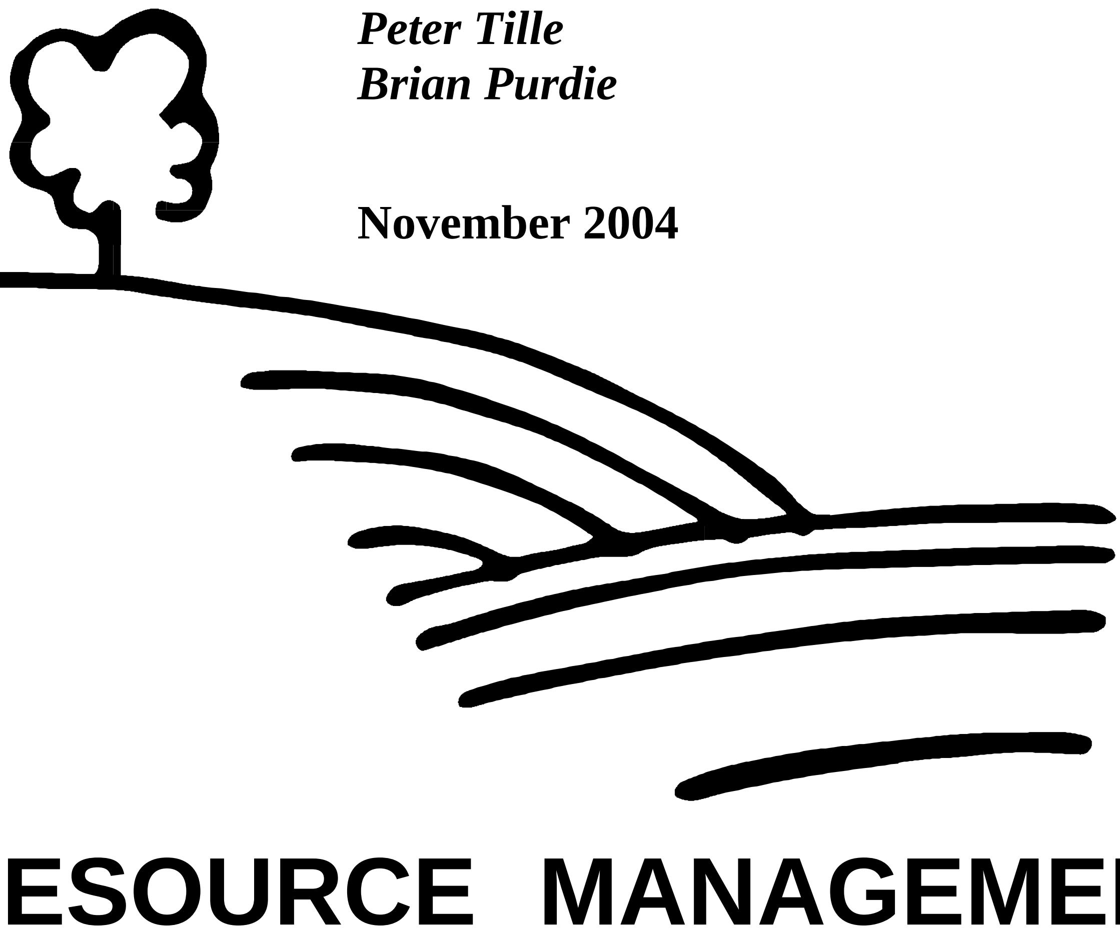
Department of Agriculture
Government of Western Australia

SOIL-LANDSCAPE MAPPING IN SOUTH-WESTERN AUSTRALIA

OVERVIEW OF METHODOLOGY AND OUTPUTS

Noel Schoknecht
Peter Tille
Brian Purdie

November 2004



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Soil-landscape mapping in south-western Australia

An overview of methodology and outputs

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Disclaimer:

The contents of this report were based on the best available information at the time of the publication. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

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“When the only tool in your toolbox is a hammer, you tend to see every problem as a nail."

Buddy Wheaton, Narrogin, November 2003

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Preface

The soil-landscape mapping program began in earnest in the mid-1980s with funding from the National Soil Conservation Program (later the National Landcare Program and the Natural Heritage Trust). Prior to this time, soil and soil-landscape surveys were done in a relatively *ad hoc* fashion. With the arrival of Brian Purdie in 1990, standards were enforced and databases created to store the information.

This seems an obvious and logical approach now, but at the time Brian was breaking new ground, and the benefits we see today with fully integrated relational databases for soil and map unit information are a tribute to Brian's foresight.

Unfortunately Brian didn't get to see the mapping program finished as he unexpectedly passed away at work in 1999. He was working on this document at the time. The publication of this report, detailing the whole soil-landscape mapping program, is dedicated to his memory.

Acknowledgements

Many people over a number of years have contributed to success of the soil-landscape mapping survey program. They are too numerous to mention here, but our thanks go to them all.

Phil Goulding provided most of the figures included in this report. Dennis van Gool and Heather Percy provided an internal review; Dr Neil McKenzie from CSIRO Land and Water in Canberra provided external editorial comments. Georgina Wilson edited the report.

1. Introduction

The Department of Agriculture in Western Australia, with support from the National Soil Conservation Program (NSCP), National Landcare Program (NLP) and Natural Heritage Trust (NHT), has completed a 15-year mapping program to provide a soil and land resource inventory for approximately 25 million hectares in the south-west agricultural areas of Western Australia[1].

This report provides on overview of the soil-landscape mapping program for south-western Australia. It outlines the techniques and standards used in describing the soil-landscape as well as the outputs of the mapping program and their uses. It also describes how this land resource information can be used for land assessment and land capability purposes.

This publication is based on the unpublished report 'Standardisation and quality control for regional soil and land resource mapping in Western Australia' (Purdie 1993, revised 1998). This was initially produced as a standards guide for surveyors involved in the mapping program and underwent a number of minor changes as the survey progressed. This publication takes a less procedural view of the mapping program, and instead focuses on its outputs, how they are stored in databases and how they can be used for better interpretation of the land resource in south-western Australia.

The emphasis is on the outputs of the Department of Agriculture's former Natural Resources Assessment Group. While reference is made to other land resource datasets held by the Department, it concentrates specifically on the soil-landscape mapping of agricultural districts and the information contained in the Soil Profile Database and the Map Unit Database.

1.1 Soil-landscape mapping in south-western Australia

1.1.1 Brief history

Prior to commencement of National Soil Conservation Program (NSCP) in the mid-1980s, south-western Australia was covered partly by an assortment of soil and soil-landscape surveys. The more detailed soil surveys were usually conducted in areas where the land was being cleared for development (or more intensive land uses were being considered on previously cleared land) and some assessment of its suitability was required. An example is the soil survey of the Salmon Gums area conducted by Burvill and Teakle in the 1930s. CSIRO was also active in the 1970s and 1980s doing regional land system-style assessments around Manjimup, in the Murray River catchment and along the South Coast.

In 1982 the Department of Agriculture's regional scale mapping program was initiated with the Mandurah and Murray survey. Surveys of the Darling Range, Esperance and Busselton-Margaret River districts started around 1985 with the establishment of the Land Assessment Group (later the Natural Resources Assessment Group and now Land Resource Assessment). These three surveys were undertaken on a mixture of NSCP and State funding and largely conducted in isolation from each other, with the survey methodology adapted to local conditions.

An accelerated mapping program started under the National Landcare Program (NLP) in 1989 after a landmark decision to undertake a national inventory of land resources before

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[1] While the mapping phase of this program has been completed, up-scaling, attribution and publication are on-going. The maps and data produced are dynamic and continually being improved.

attempting to assess land degradation on a national scale. With an increasing number of surveys, the need for better co-ordination of surveys and their outputs was apparent.

In 1990 Brian Purdie was appointed as a correlator to standardise the soil-landscape mapping program methods and outputs. One of Brian's innovations was the development of a nested **hierarchy of soil-landscape mapping units**. This deals with the varying levels of information resulting from varying scales of mapping, permits correlation between different surveys and enables computer processing of data on a Statewide (or national) level. It also provided a means by which the pre-existing surveys could be incorporated into a seamless map across the agricultural districts.

The regional mapping program continued through the 1990s and was completed, at least in a linked digital coverage, in 2003. An index to surveys is shown in Figure 1.1 and references are contained in the publications section. **Improving the accuracy** of the mapping and data is an on-going process.

1.1.2 Soil-landscape mapping methodology

The following sequence is typical of the methodology adopted for soil-landscape surveys conducted in the 1990s is shown on Figure 1.1:

1) Collation of existing land resource information of the survey area and adjacent areas. This includes any broad scale (e.g. the *Atlas of Australian Soils*, Northcote *et al*. 1967) or detailed (e.g. CSIRO spot surveys) soil mapping, any other reports on soil investigations, mapping from the Geological Survey of Western Australia and vegetation mapping (most commonly 1:250,000 scale mapping by J.S. Beard).
2) Field reconnaissance survey to identify major subdivisions of mapping units to province, zone and system level (see Section 2.2.4). These boundaries were often drawn on a satellite image of the survey area where available.
3) Preliminary map unit boundaries identified with the aid of the above and the interpretation of stereo aerial photography (typically 1:25,000 to 1:50,000 scale).
4) Field survey with sites being selected using the free survey technique (Gunn *et al.* 1988). The preliminary mapping and ease of access influenced site selection. Fieldwork included the description of sites and soil profiles (mainly from hand auger borings) using the terminology of McDonald *et al.* (1990). Site locations were either marked on aerial photographs or recorded using a global positioning system (GPS).
5) Site data recorded manually on site cards and later entered onto the Soil Profile Database (Purdie 1993).
6) Soil profiles classified using the Australian Soil Classification (Isbell 1996) and/or the Soil Groups of Western Australia (Schoknecht 2002).
7) The development of conceptual models which relate the various sources of evidence (field data, previous resource data, photo interpretation, published soil process and development models) to soil variation. A synthesis of this material was used to adjust the map boundaries and predict which soils occur within them.
8) Sites with representative soils selected and examined in soil pits with samples being taken and sent for chemical and physical analysis.
9) Descriptions of map units and main soil types written up in a standard format and correlated with units and soils identified in other surveys. The description includes the proportion of Soil Groups of Western Australia (Schoknecht 2002) within each map unit. This information was then entered into the Map Unit Database.

10) Final map unit boundaries drawn on aerial photographs or satellite imagery, and then captured digitally (along with site locations) using a computer aided mapping system. Map unit boundaries were then matched to those on adjoining surveys.

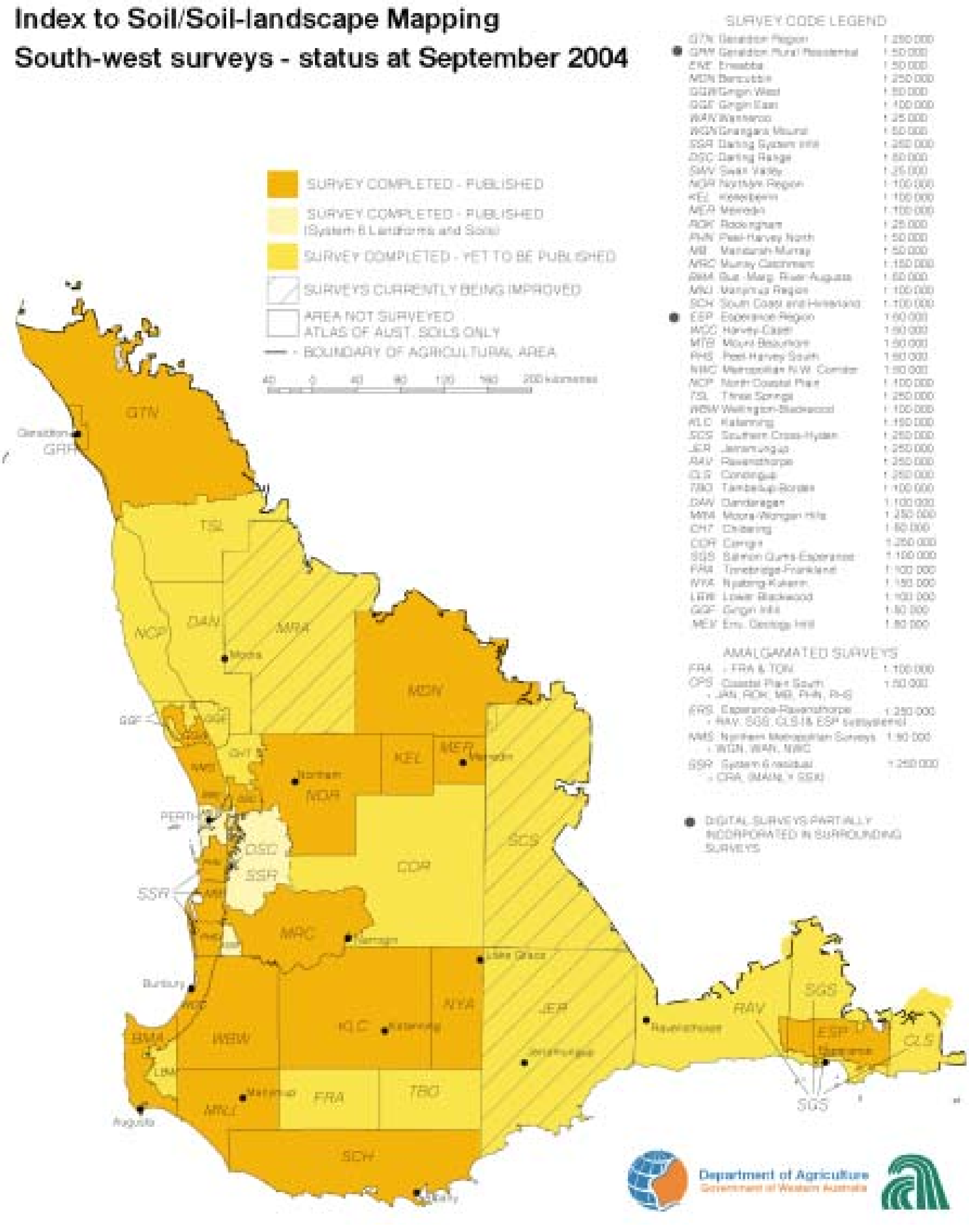

Figure 1.1: Location and scale of regional soil and soil-landscape survey in south-western Australia (details of publications in Section 4.1)

1.1.3 Quality control of surveys

Quality control for the regional mapping program required a series of checks as the surveys progressed. The key steps required by this process were:

1. Mapping conducted according to standards set by soil correlator
2. Mapping to fit the map unit hierarchy and edge-matched with adjacent surveys
3. All mapping digitised and labelling completed
4. All site and soil information entered into Soil Profile Database
5. All map unit information entered into Map Unit Database
6. Soil samples from representatives and other sites submitted for analysis
7. Mapping unit descriptions and soil series/main soils descriptions to agreed format
8. Report prepared for publication
9. All air photos maps, reports etc. collected during the course of the survey to be archived.

It needs to be noted that by these standards a number of the surveys are currently incomplete and work to finalise them is continuing.

1.1.4 Improving the accuracy of soil-landscape mapping

New and powerful computer-based tools for soil-landscape mapping become increasingly accessible around the turn of the 21st century. These tools make it possible to increase the detail and accuracy of existing mapping, enabling this to be done relatively quickly and cheaply. They also provide assistance when improving the map unit descriptions. The main tools currently used to improve existing surveys are digital elevation models (DEMs), data from ground or airborne radiometric surveys and digital satellite imagery.

For a number of surveys these tools are being used to up-scale both the boundaries and soil-landscape mapping units and the quality of the map unit descriptions. They are also being used to provide more detailed maps in some locations as needed.

2. Types of soil-landscape information

Information about the soils and landscapes of Western Australia, collected and stored in a digital format by Department of Agriculture, can be divided into three main categories:

- **Point data** which include site specific information such as soil profile descriptions, the results of laboratory analyses and photographs. These are stored in the **Soil Profile Database**.
- **Map unit polygons** which are boundaries drawn around areas containing similar soil and landscape patterns. Collectively these polygons are stored as **Digital linework.**
- **Map Unit Database** which contains descriptions of the map unit polygons and relates to broad areas rather than a specific point.

The details of these three basic datasets are described in Sections 2.1 to 2.3. A broad range of interpretive data can be derived from these datasets. The interpretive data, which include land capability assessments, are discussed in Section 3. The relationship between the three basic datasets is shown schematically in Figures 2.1 and 2.2.

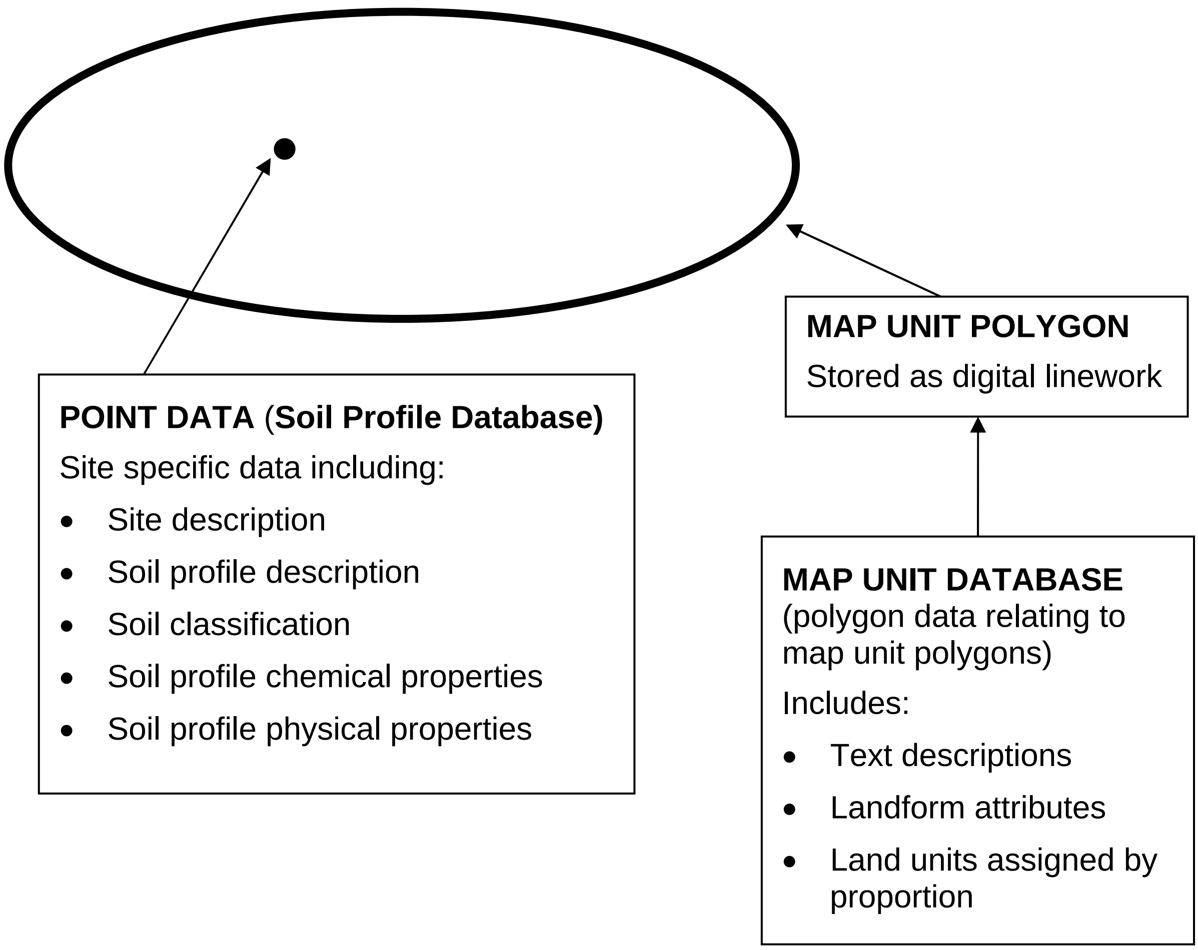

Figure 2.1: Stylised diagram of soil-landscape data assigned to points and polygon datasets

2.1 Point data (and the Soil Profile Database)

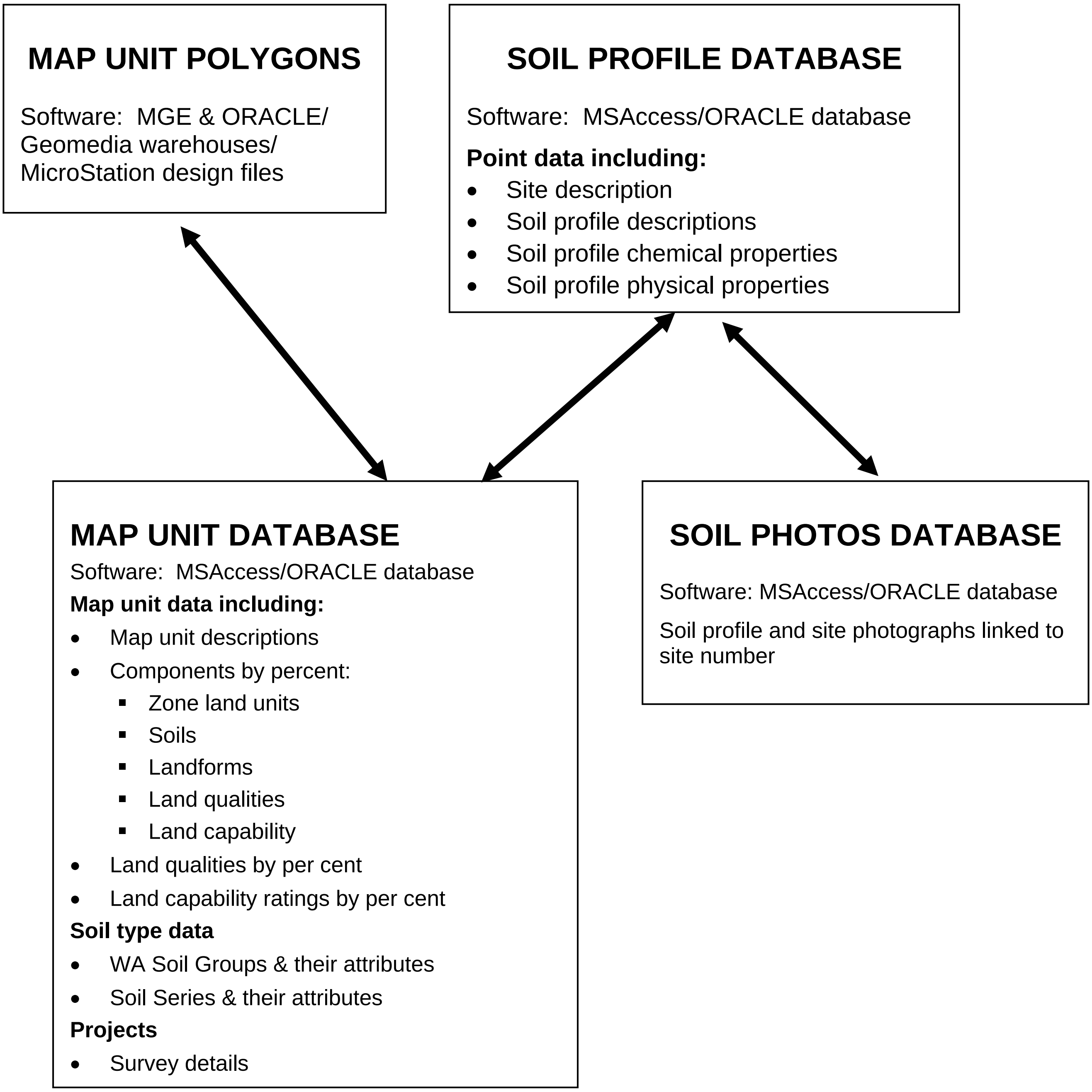

Figure 2.2: Relationships between the digital soil-landscape mapping datasets

Point data are usually collected as part of field survey and include all the soil-landscape information that relates to a specific site. This is a fundamental dataset and is typically collected at sites where a soil profile has either been described or sampled for analysis. Point data also include general observations made about a site where the soil profile was not examined (**observation points**), the results of laboratory analyses of soil samples collected from the site and soil classifications made using profile and laboratory data (where available).

Point data are stored digitally in Department of Agriculture's **Soil Profile Database** (MSAccess and ORACLE). The database is compatible with the SITES data model developed through the Australian Collaborative Land Evaluation Program (Kidston and McDonald 1995). Some of these data can also be found in published or unpublished reports.

Point data have two main components – general information about the site – the **site data**, and specific information about a soil profile – the **profile data** and **laboratory data**. More specifically point data include:

- Site data (field descriptions of landforms, vegetation, land surface and land use)
- Soil profile data (field descriptions of soil horizons)
- Soil classification
- Soil chemistry data (from laboratory analysis of samples collected in the field)
- Soil physics data (from laboratory analysis of samples collected in the field)
- Site and soil profile photographs.

2.1.1 Collection of field data

The collection of field data is conducted according to procedures stipulated in the *Australian Soil and Land Survey Field Handbooks* (Gunn *et al*. 1988 and McDonald *et al*. 1990). The standards for field description of sites and soil profiles are those defined by McDonald *et al*. (1990). Site and profile data are usually recorded manually on site cards and later entered into the Soil Profile Database (Purdie 1993).

Sites are chosen primarily using free survey techniques (Gunn *et al*. 1988). Point data collected directly in the field have two main components – **site data** that describe information about the site (site number, date, surveyor, location, landform, vegetation etc.) and the **profile data** that describe information about the soil (profile description, soil classification etc.). An added component is any landscape or profile **photographs** taken at the site.

Site locations are recorded either using a Global Positioning System (GPS) or marked onto an aerial photograph. Site data recorded routinely include landform pattern, landform element, slope gradient (usually measured with a clinometer), surface condition and the presence of rock outcrops, surface coarse fragments and native vegetation. They are recorded using the terminology of McDonald *et al.* (1990) modified and coded for local conditions by Purdie (1993).

Soil profiles are described from pits, exposures or hand auger borings to a depth of at least 1 metre, where possible. Soil attributes described include horizon depth and boundary type, soil colour, mottling, field texture, structure and the presence of coarse fragments. Soil colours are described according to standard Munsell colour chart notation (Munsell Colour Company 1994) and usually recorded for moist soil. Soil pH is often tested in the field using an indicator mixed with soil into a paste, and barium sulfate powder (Raupach and Tucker 1959). Soil salinity and pH may also be recorded in the field using a pocket meter and a 1:5 mixture of soil and water[2]. Profile data are recorded using the terminology of McDonald *et al.* (1990) slightly modified for local conditions and then coded by Purdie (1993).

[2] Occasionally calcium chloride for pH.

2.1.2 Sampling for laboratory analyses

Sampling of soil profiles for subsequent laboratory analysis generally follows the following procedure described by Purdie (1993, revised 1998):

Identification for samples collected for laboratory analyses uses the site identification for soil profile descriptions followed by a single letter to identify the sample. Letter A is used for the first sample, and B, C, etc. are used for subsequent samples. The letter does not give any indication of the horizon sampled; a letter is used to avoid confusion with the site number which precedes it. Z is reserved for composite surface samples. If samples were replicated, a number was added after the letter (e.g. C1, C2). The database table that links soil profiles to lab data also requires the depth interval of the sample (upper and lower depth). This may not be identical to the horizon depth interval, thick horizons may be sub-sampled, or the sample may be collected from a fixed depth interval. Bulk density samples will have a depth interval that corresponds to the upper and lower depth of the core taken sent off, and the laboratory sample identification added as soon as the sample are received. A typical sample identification thus read NYA0285B (Nyabing survey, site 258, sample B). The sample submission sheet would also note that the sample depth was 10-40 cm.

*Continuous channel sampling was required which means that the sample was collected evenly across the sample interval indicated, and was **not** a grab sample collected from somewhere within the depth range specified[3]. Wherever possible, samples were collected **by horizon** (any layer with a horizon designation that differs from the layers above and below it). Thicker horizons were sub-sampled if the thickness exceeded the guidelines provided below, usually by dividing the horizon in to two or more approximately equal depth increments.*

Horizon name	***Depth***
A1 horizon	*Maximum sample depth interval is 30 cm, it is recommended that the top 10 cm be sampled separately*
A2 (or E) horizon	*Maximum sample depth interval is 40 cm*
A3 or B1 horizon	*Maximum sample depth interval is 40 cm*
B2 horizons	*Maximum sample depth interval is 40 cm*
	*In soils with a **clear** or **abrupt textural B horizon**, sample the top 20 cm with further samples as required*
Other B2 horizons	*Maximum sample depth interval is 40 cm*
B3 horizons	*Maximum sample depth interval is 40 cm*
C horizons	*Maximum sample depth interval is 60 cm*

In soils with a domed clay B2 horizon, the ‘surface crust’ of the domes (5 cm thickness) was sampled, then the next 15 cm, then as for other B2 horizons.

The sample volume required was sufficient to give at least 500 g of air dried <2 mm material. Any coarse fragments (>2 mm) were removed and their air dry weight recorded as a percentage of the ‘whole soil’ sample. If undisturbed samples were required for bulk density, water retention or hydraulic conductivity measurements, then specialist help was sought. Ideally these samples were taken when the soil water potential was about -10 KPa.

[3] In practice this does not always happen.

2.1.3 Laboratory analyses

Following is a list of the analyses most commonly conducted on soil samples collected during soil-landscape mapping surveys:

Al ($CaCl_2$)	Aluminium (Al) extracted in 0.01M $CaCl_2$
$CaCO_3$	Calcium carbonate, soluble in dilute acid
CEC	Cation Exchange Capacity
Exchangeable cations	Al (Aluminium), Ca (Calcium), Mg (Magnesium), Mn (Manganese), K (Potassium), Na (Sodium) Three methods were used depending on the soil pH a. Soil pH 6.5-8.0 - extracted in 1M NH_4Cl pH 7.0 b. Soil pH <6.5 - extracted in 0.1M $BaCl_2$ c. Soil pH >8.0 - extracted in 1M NH_4Cl pH 8.5
EC (1:5)	Electrical conductivity (1:5) at 25°C
K ($HCO_{3)}$	Potassium extracted in 0.5M $NaHCO_3$ (1:100)
Org C W/B	Organic carbon, Walkley and Black method
P HCO_3	Phosphorus, extracted in 0.5M $NaHCO_3$ (1:100)
P PRI	Phosphorus Retention Index
P Total	Phosphorus, total
Particle size analysis	Separation of particles less than 2 mm in diameter
pH H_2O 1:5	pH measured in water
pH $CaCl_2$	pH measured in 0.01M $CaCl_2$
N Total	Nitrogen, total

Of 60,000 profiles currently in the database, just over 900 have detailed analyses and a further 14,500 have limited analyses. The proportion of laboratory analyses to profiles described varies between surveys. In the Katanning Survey (Percy 2000) approximately 2,500 profiles were described, samples from 1700 profiles were sent for limited analysis (mostly pH only) while full analyses were conducted on 75 profiles. By contrast, only 10 of the 2600 profiles described in the Northam Survey (Lantzke and Fulton 1993) were analysed in the laboratory.

Although most samples have been analysed by the Government Chemistry Centre, other laboratories have been used. For more detail on method of soil analysis conducted for the Department of Agriculture, see *Understanding and Interpreting soil chemical and physical data* (Purdie 1998).

2.1.4 Soil types and classification

A wide range of classification and naming systems have been applied to soil profiles in Western Australia including:

- International classification systems such as the *World Reference Base for Soil Resources* (FAO 1998) and *Soil Taxonomy* (Soil Survey Staff 1999 and 2003).
- National classifications systems such as the *Australia Soil Classification, Revised Edition* (Isbell 2002), *A Factual Key for the Recognition of Australian Soils* (Northcote 1979) and *A Handbook of Australian Soils* (Stace *et al*. 1968).
- Local systems such as *Soil Groups of Western Australia* (Schoknecht 2002).

- Soil names, based on locality and surface texture such as Houghton sandy loam, Forest Grove gravelly loam, Muchea sand and Bangalup sand used in old Department of Agriculture and CSIRO soil surveys.
- Informal local names, typically based on vegetation type, such as Mallee soils, Kopi soils, York gum soils, Karri loams, Banksia sands.

Some of these name classifications can be applied to profiles for which only field data are available, others require the addition of laboratory analysis.

The soil-landscape mapping program uses two concepts of soil type. A simple system that uses common names and general soil morphology is the *Soil Groups of Western Australia* (Schoknecht 2002). A more rigorous technical system using the term 'Soil Series' is based on the *Australia Soil Classification, Revised Edition* (Isbell 2002). The concepts behind these two methods of categorising soils are described below and information about these soil types is stored in the **Map Unit Database**.

2.1.4.1 Soil Groups of Western Australia

The Soil Groups of Western Australia describe the 60 main soil types in simple terms. They are detailed in *Resource Management Technical Report 246* (Schoknecht 2002) and provide a standard way of giving common names to the main soils of the State, and a simple method to identify them. They also assist with communication of soil information at a general level. The soils are named and described at two levels, **Soil Supergroups** and **Soil Groups**.

Thirteen **Soil Supergroups** are defined using three primary criteria:

- surface texture and the change in texture (or permeability profile) with depth
- presence of coarse fragments (stone or ironstone gravels)
- water regime (waterlogging).

Sixty **Soil Groups** are defined by further divisions of the Soil Supergroups based on one or more of the following secondary and tertiary criteria:

- calcareous layer (presence of carbonates)
- colour
- depth of horizons/profile
- structure
- salinity status
- pH (acidity/alkalinity)
- cracking.

Each Soil Group has a range of soil properties. In many circumstances the Soil Group alone may not convey all the information necessary to distinguish local soils or soil properties relevant to land management. An appended **Soil Group qualifier** gives flexibility needed in these situations while retaining standardised names.

The extra information provided by the Soil Group qualifiers falls into five main categories: texture; structure; subsurface; subsoil; and substrate-related. The Soil Group qualifiers relate to soil properties relevant to land management, and defined sets of qualifiers, applied in a set order, are available for each Soil Group. Details on the Soil Group qualifiers are published in the *Resource Management Technical Report 246* (Schoknecht 2002).

Soil Groups or qualified Soil Groups may be assigned to individual profiles in the Soil Profile Database. Soil Groups and their qualifiers are also an important component of the **zone land units** which are assigned to **map unit polygons** at the Subsystem and Phase level of the soil-landscape map unit hierarchy in the **Mapping Unit Database**. These zone land units form the basis of **land capability assessments**.

2.1.4.2 Soil Series

A soil series is a taxonomic unit that defines soils with a limited range of morphological, chemical, physical and mineralogical properties that can be managed as a single unit for most present and anticipated land uses. Soil series are used to describe soils in some of the more recent land resource series reports in Western Australia (e.g. Grealish and Wagnon 1995 and Percy 2000).

The Department of Agriculture in Western Australia has adopted Soil Series primarily for technical or research-related uses. Purdie (1993, revised 1998) closely linked soil series to the Australian Soil Classification (Isbell 1996). Two categories of soil series are currently used in Western Australia: formal and informal.

Formal soil series match the standardised criteria of Purdie (1993, revised 1998). Formal soil series description is a rigorous technical method of describing soils within a survey. As well as a summary description, each formal soil series must address the following description criteria:

- Australian Soil Classification
- Qualified Soil Group of Western Australia
- Texture group/depth class description
- Descriptions of texture and substrate
- Diagnostic horizons
- Reference profiles.

The following properties are also recorded for each formal soil series:

- pH, electrical conductivity (EC), cation exchange capacity (CEC), Phosphorus Retention Index (PRI) and pH buffering capacity ratings for subsurface soil
- Unrestricted rooting depth
- Permeability, infiltration and drainage classes
- Available and readily available water capacity
- Perched water storage/waterlogging susceptibility classes
- Hardsetting and non-wetting properties.

It should be noted that the concept of a formal soil series adopted by the Department of Agriculture differs somewhat from the concept used by CSIRO and others in the 1940s and 1950s. The current soil series are rigorously defined according to set criteria (of which the Australian Soil Classification forms an essential component) whereas previous soil series comprised more conceptual groupings. The CSIRO soil series were locally defined taxon classes “taken from the country” with a certain degree of internal variation. For example the Scotsdale Series (Hosking and Burvill 1938) includes soils which would classify as both Chromosols and Kandosols. Some of these pre-existing series are now recognised in the database as informal soil series.

Informal soil series are similar to formal soil series, but have not been as rigorously defined or correlated with other soil series. They may be based on formal soil series previously identified or a combination of the survey in which they were first identified and a qualified Soil Group of Western Australia. An example of the former is Tutunup2, based on the Tutunup soil series first described by Tille (1996), but with a sandy rather than loamy texture. An example of the latter is Buntine-101-CLY, a clayey saline wet soil identified in the Buntine survey.

Informal soil series are used either:

- Where insufficient data are available for the soil type to match the standardised criteria, or correlation process not undertaken; or
- Where the data are available but the soil series is yet to be correlated with existing formal soil series.

Soil series may be assigned to individual profiles in the Soil Profile Database. They are also identified as **main soils** occurring in **zone land units** which are assigned to **map unit polygons** at the Subsystem and Phase level of the soil-landscape map unit hierarchy in the **Mapping Unit Database**.

2.1.5 The Soil Profile Database

The Soil Profile Database is the repository for all point data. These data are stored in ORACLE tables, with an MSAccess front end to enter, retrieve and interrogate the data. Off-line copies of the ORACLE database can be created, amended and interrogated in MSAccess.

Along with site data collected during the regional soil-landscape surveys, the **Soil Profile Database** also contains:

- Project-specific soil descriptions previously collected by the Department of Agriculture such as soil characterisation and sampling for Cultivar Variety Trial (CVT) sites or the Soil Carbon Paired Sites project (SC2)
- Current Department of Agriculture projects and surveys such as Sustainable Grazing on Saline Lands and AGWEST Land Management commercial soil surveys
- Some historical site data including that from CSIRO and Department of Agriculture surveys conducted in the 1980s or earlier
- More recent data from other agencies such as the Department of Conservation and Land Management (CALM).

2.1.5.1 Site data

The dataset and code definitions for site are published in *Resource Management Technical Report 140* (Purdie 1993). Each site is assigned a unique alpha-numeric identifier, consisting of a three letter code for the relevant survey (e.g. KLC for Katanning Land Capability Survey) followed by a four digit number (e.g. KLC0054).

In the database, there are four mandatory site data fields which enable the site to be properly identified. These fields are:

- *Agency:* The agency or group responsible for conducting the survey
- *Project:* A code which identifies the project
- *Site number:* The identifier of the site, usually a number
- *Described by:* The person collecting the data.

Non-compulsory, but very important, associated fields are date and geographic location. Without the preceding details any other information about the site and soil profile is largely useless. Other fields, either categorical or descriptive, identify the main biophysical attributes of the site (location, landform, land use, vegetation, soils, geology and observed land degradation).

Site data can be viewed in the database through the ***Site Data*** form[4].

2.1.5.2 Profile data

Profile data include field information about the soil profile, as discussed in the previous section about field data. Most soil profile information is recorded by soil horizon. The standards used for soil profile descriptions are those defined in the *Australian Soil and Land Survey Field Handbook* (McDonald *et al*. 1990). Provision is made in *Resource Management Technical Report 140* (Purdie 1993) for encoding additional data, including some soil properties described in the *USDA soil survey manual* (Soil Survey Staff 1993).

Profile data can be viewed in the database through the ***Horizons*** form[5].

2.1.5.3 Laboratory data

All soil laboratory data associated with a site, or soil profile horizons are stored in the Soil Profile Database. When collected, laboratory data are attached to the soil profile information by the sample's upper and lower depth. This enables retrieval of data on the basis of fixed sampling depths (e.g. 20-40 cm) as well as soil layers or horizons.

A wide range of laboratory data can be stored in the Soil Profile Database, including the results of analyses shown in Section 2.1.3. Among other information recorded is the laboratory name where the samples were processed and methods used to analyse them.

Laboratory data can be viewed in the database through the ***Samples*** form[6].

2.1.5.4 Soil Photos Database

Where available, representative photographs taken of the general site and the soil profile are scanned and stored on CD and a thumbnail (small preview image) stored in a database. This database is linked to the site information by project code and site number.

The Soil Photos Database is a separate ORACLE database linked to a site in the **Soil Profile Database** by the mandatory fields of Agency, Project and Site number. It is accessed through the Soil Profile Database that contains thumbnails of photographs taken at the site, or of the soil profile. It can also be accessed via soil types in **Map Unit Database**. In the Soil Photos Database the full photograph is stored as a TIF file.

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[4] Site data are stored in the ***Sites*** table and the linked ***Observations*** table.

[5] Profile data are stored in the ***Horizons*** table (linked to the ***Sites*** table) and the following linked tables: ***Colours***, ***Mottles***, ***Coarse_Fragments***, ***Structures***, ***Cutans*** and ***Segregations***.

[6] Laboratory data are stored in the ***Samples*** table and the following linked tables: ***Lab samples*** and ***Lab_results*** tables.

During soil surveys pits are dug to examine representative soils, with samples taken and sent for chemical and physical analysis.

The Soil Photos Database stores low resolution previews of soil profile photographs. The high resolution images are stored on CD-ROMs. Site NSS1 is an Alkaline grey shallow sandy duplex near Newdegate.

Often the Soil Photos Database provides low resolution previews of landscape photographs related to the soil profiles. The high resolution images are stored on CD-ROMs and can be accessed if required. The landscape above is near site NSS1.

2.1.5.5 Soil classification data

The following soil classifications can be attached to soil profiles in the Soil Profile Database:

- Soil Groups of Western Australia and qualifier (Schoknecht 1997 or 2002)
- Australia Soil Classification (Isbell 1996) or Revised Edition (Isbell 2002)
- Soil series
- Factual Key for the Recognition of Australian Soils (Northcote 1979)
- Soil Taxonomy (Soil Survey Staff 1975, 1983, 1990, 1992, 1994 and 1996)
- World Reference Base for Soil Resources (FAO 1974 and 1998)
- Map Unit Database link label.

For classifications that have been revised since they were first published, the version (year in which the revision was published) needs to be attached to the classification. Some caution is needed comparing classifications from different versions.

Soil classification data can be viewed in the database through the ***Site data*** form[7].

2.2 Map unit polygons (and digital linework)

Map unit polygons are boundaries drawn around areas containing similar soil and landscape patterns). Collectively these cartographic representations of the map units are stored and stored in the form of **digital linework** (typically as vector polygons). Map unit polygons may also be stored as raster grids.

2.2.1 Mapping units

The regional mapping program in south-western Australia uses **soil-landscape mapping units** for the spatial component of the soil-landscape resource inventory. Some older surveys showing soil mapping units have also been captured and converted into soil-landscape units.

2.2.1.1 Soil-landscape mapping units

Soil-landscape mapping is a survey of land resources which delineates repeating patterns of landscapes and associated soils. The term soil-landscape has previously been defined by Northcote (1980). Native vegetation, where available, is often also incorporated into the mapping process as it is often a good predictor/indicator of soil type and landscape position.

Soil-landscape mapping differs from soil mapping in that the landscape component is an explicit part of the mapping. In a *soil* map, soil types are mapped solely on soil criteria independent of landscape position, vegetation and lithology[8]. In a *soil-landscape* map a combination of soil and landscape is embedded in the map unit so that one soil type may occur in more that one map unit by its association with a landscape component.

Soil-landscape mapping also recognises the natural complexity of soil distribution with a number of different soil types often occurring within one mapping unit. While scale and field time constraints are a major factor in the adoption of soil-landscape mapping, this approach also adds non-soil specific information relevant to land capability and management.

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[7] Soil classification data are stored in the ***Observations*** table.

[8] Though it needs to be recognised that these are likely to have a major influence on the soil type.

A soil-landscape mapping unit allows for soil forming processes to be considered in the map unit. In addition to the key parameters of soil and landscape, geology plays a part at broad levels through the influence of tectonics on landform, and at more detailed levels through the influence of lithology on topography and soil parent material. Other environmental factors such as climate and native vegetation also play a major role in the distribution of soil and landscapes and are incorporated into the mapping units.

2.2.2 Procedure for delineating and capturing mapping units

Map unit polygon boundaries are captured via MicroStation design files and stored in MGE with links to ORACLE and usually manipulated using Geomedia warehouses. They have been captured using the following methodology:

- Soil-landscape mapping units were delineated by the survey team using interpretation of remotely sensed data (typically aerial photographs and Landsat images), other published data (e.g. geology, vegetation and previous soil surveys), site data points and field observations.
- Aerial photographs or Landsat imagery with the interpreted boundaries marked on them were geo-referenced to cadastral and topographic boundaries. For historical surveys either the published maps or, where available, compilation sheets (typically drawn on 1:50,000 scale topographic maps), were used.
- The boundaries were then captured using stream digitising techniques[9]. A suitable stream tolerance was used, depending on the scale of capture which varied between 1:20,000 and 1:100,000. A process was then run to remove redundant vertices in the digitised boundaries. This had the effect of making the spatial datasets smaller in size with no significant loss in definition of the polygon boundaries.
- Polygon labels were placed in MicroStation, one **database link label** per polygon for creating linkages to the **Map Unit Database**, and another set of **display labels** for map production with multiple labels per polygon where required (see Section 2.2.5).
- Polygon boundaries were processed to correct intersections and free endpoints using the Poly or Mappa MDL applications in MicroStation. Polygons were then created and labels loaded to ensure that all polygons had one unique label.
- When satisfied that boundaries and labels were topologically correct, the data were loaded into Intergraph MGE with database linkages to ORACLE.
- A point-in-polygon query is run to determine the map unit polygons to which the data points belong. The relevant database link label is then loaded into the Soil Profile Database for each site occurring within the survey area.

2.2.3 Map unit complexity and scale

The complexity of a soil-landscape map unit is usually scale-dependent. At smaller scales (less detailed maps e.g. 1:250,000) the units are larger and the internal cartographic complexity of the mapping is usually greater than at larger cartographic scales (more detailed maps e.g. 1:50,000).

The standards for scale of mapping largely follow the methodology described by Gunn *et al*. (1988). Table 2.1 shows a reformatting of Gunn *et al*.'s Table 5.2 of ground observation densities based on the scale of survey.

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[9] New techniques employ digitising on screen, but this option was not available during the main phase of the mapping program. These techniques and digital terrain models are currently being employed to update some of the mapping.

Table 2.1: Ground observation densities for soil-landscape surveys (adapted from Gunn *et al.* 1988)

Mapping	Recommended ha/site			Recommended sites/ha		
	High	Low (middle)	Minimum	High	Low (middle)	Minimum
1:10,000	1	2	4	1	0.5	0.25
1:25,000	6.25	12.5	25	0.16	0.08	0.04
1:50,000	25	50	100	0.04	0.02	0.01
1:100,000	100	200	400	0.01	0.005	0.0025
				sites/km^2		
1:250,000	625	1,250	2500	0.16	0.08	0.04
1:500,000	2,500	5,000	10,000	0.04	0.02	0.01

The observation density (1 observation/2 cm^2 of the final map) is at the *lower end* of the range recommended by Gunn *et al*. (p. 65). According to Gunn *et al*. data points that include detail site and soil descriptions typically range from 10 to 90 per cent of the total observations depending on the detail of mapping, with the percentage increasing with decreasing detail. As most surveys in Western Australia have been conducted at a reconnaissance or regional level, detailed descriptions made up most site data (Soil Survey Methodology Group 1991). This varies between surveys, and recent survey reports record average site density and include a plot of site locations as an indication of map reliability.

The nominal scale of soil-landscape surveys for south-western Australia is shown in Figure 2.3.

2.2.4 The soil-landscape mapping unit hierarchy

A nested hierarchy of soil-landscape mapping units has been established to deal with the varying levels of information resulting from varying scales of mapping. This hierarchy is consistent with the national hierarchy being adopted by Australian Soil Resource Information System (ASRIS 2004). The hierarchy permits correlation[10] between different surveys, allows information to be presented at different scales (1:25,000,000 to 1:50,000), and enables computer processing of data on a statewide (or national) level. The hierarchy maintains a consistent approach with different mapping scales and varying levels of complexity in both landscape and soil patterns.

The mapping hierarchy has six levels. The first two levels, ***regions*** and ***provinces,*** are based on the descriptions and framework introduced by the CSIRO Division of Soils (1983) for the whole of Australia (see Figure A2). The remaining four levels, ***zones, systems, subsystems*** and ***phases,*** are based on mapping conducted by the Department of Agriculture, Western Australia, mostly as part of a National Landcare Program-funded initiative between 1988 and 2000.

The levels of the soil-landscape mapping unit hierarchy are defined in more detail in Table 2.2. Appendix 1 provides maps showing the distribution and description of soil-landscape regions, provinces and zones in Western Australia.

[10] Correlation involves the matching of map unit linework and descriptions from different surveys to produce consistent coverage of soil-landscapes. See Section 2.2.6 for more details.

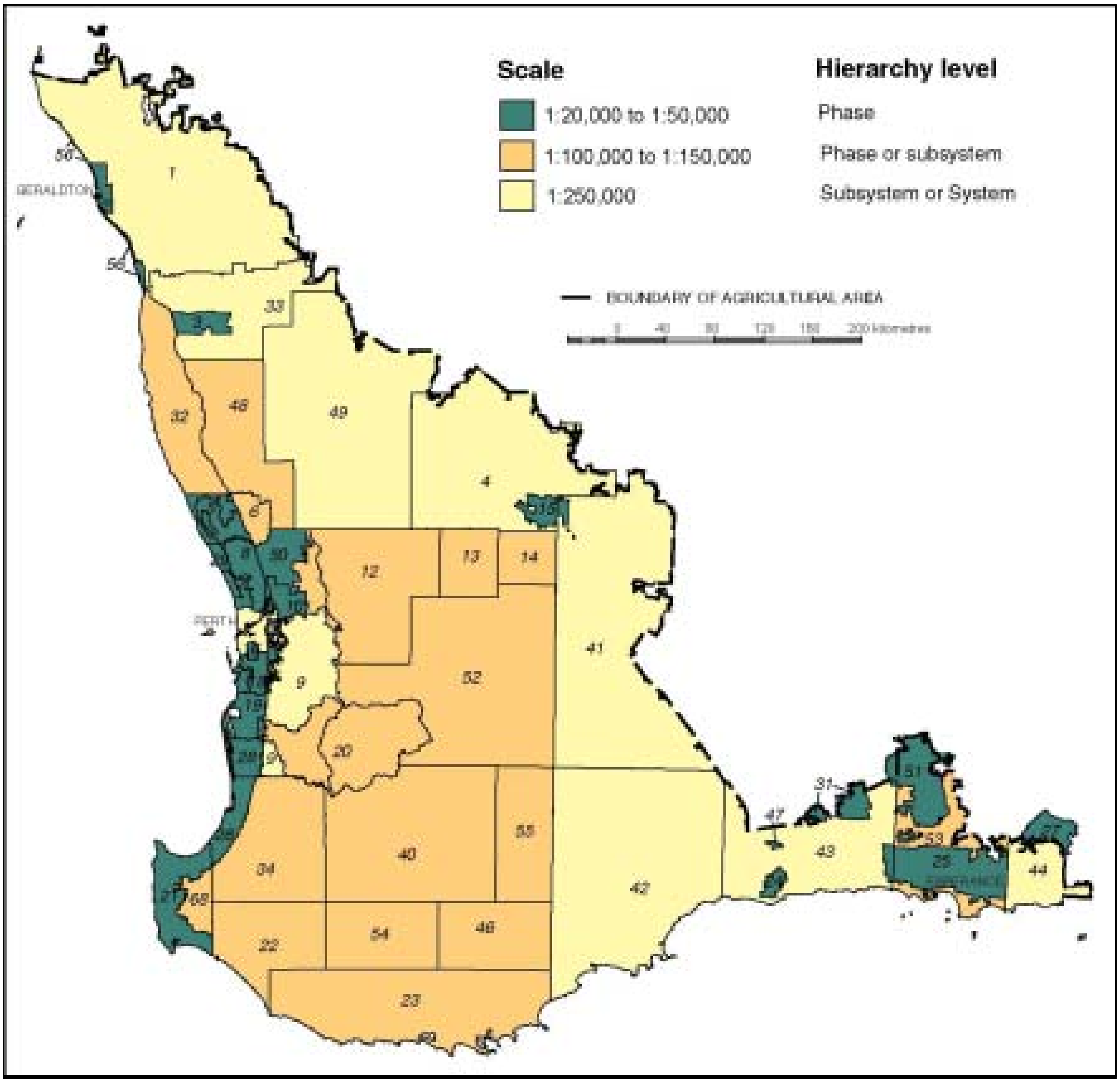


Figure 2.3: Nominal scale of soil-landscape mapping

Examples of nested levels of the soil-landscape map unit hierarchy are provided below and represented in Figure 2.4:

1. The Western **Region** (2), which covers all of the agricultural districts, comprises the Yilgarn and Pilbara Cratons and the intervening Hamersley Basin. The Carnarvon and Perth Basins to the west are included because they are too small to form their own region (but are distinguished as provinces). The area has been continuously exposed to weathering and denudation since the Precambrian period.
2. The Avon **Province** (25) comprises Precambrian granites and gneisses subjected to deep weathering and the formation of the lateritic profile. Soils may be calcareous, but red-brown hardpans are uncommon (Duric Great Groups).
3. The South-western **Zone** of Ancient Drainage (259), an ancient plain of low relief on weathered granites with sluggish drainage systems and uplands dominated by sands and gravels. Lateritic uplands dominated by grey sandy gravel plain with predominantly Proteaceous species.
4. The Kukerin **System** (259Kk) comprises gently undulating rises, in the South-western Zone of Ancient Drainage, with Grey sandy duplex and Ironstone gravelly soils. Mallee scrub and heath.

5. Kukerin **Subsystem** 1 (259Kk_1) comprises gravelly crests and slopes, at times extending down lower slopes. Deep sandy and loamy gravels, shallow gravels with minor sandy duplex soils, deep sands and sandy earths. Heath and mallee vegetation.
6. Kukerin Subsystem 1 sandy **phase** (259Kk_1s). Sandy slopes and depressions in the Kukerin 1 Subsystem. Mainly pale deep and shallow sands with significant areas of Gravelly pale deep sands and Yellow deep sands.

Below the level of subsystem phases are the unmapped **zone land units**. These are based on a combination of Soil Groups of Western Australia (and their qualifiers) with landform position and are specific to individual soil-landscape zones. Zone land units are usually not mapped but are assigned to map units proportionally. Each zone land unit may occur in a number of different map units within the soil-landscape zone. Zone land units are an integral part of the hierarchy and play a major role in the attribution of land quality and capability data. They are discussed in more detail in Section 2.3.2.2.

As the hierarchy is a nested system, it is possible to use the same map unit boundaries to create maps at the scales and levels of detail required. The boundaries and properties of mapping at any level in the hierarchy are made up of the boundaries and properties of the best available more detailed mapping.

For example, a map at zone level may be suitable for differentiating areas suited to certain farming systems; a map of the systems could be used to display the distribution of a different soil type; while a map at the subsystem or phase level shows the greatest level of detail available.

Table 2.2: Definitions of the soil-landscape map unit hierarchy

Level of the hierarchy	Polygon size	Mapping scale	Landscape criteria	Soil pattern described using:
1 – Region: a broad morphogenetic unit	>10^6 km^2	1:25,000,000	Continental scale tectonic regions, major climate zones	Orders[11]
2 – Province: a broad-scale unit	10^4 - 10^6 km^2	1:5,000,000	Geology (lithology and stratigraphy) and regolith	Orders and Suborders[9] or Supergroups[10]
3 – Zone: a regional unit	10^3 - 10^4 km^2	1:1,000,000	Geomorphology, relief (reflecting erosion/ deposition patterns and landscape maturity)	Orders and Great Groups[9] or Supergroups[10]
4 – System: a regional unit	10^3 - 10^5 ha	1:250,000	Relief/modal slope class, landform pattern, generic type of soil parent material	Great Groups, Subgroups[9] or associations of WA Soil Groups[12] or soil series[13]
5 - Subsystem: a local unit	10^2 - 10^4 ha	1:100,000	Landform element and morphological type	WA Soil Group with qualifier[10] or associations of soil series[11]
6 - Phase: a local unit based on land use interpretation requirements	10 - 1000 ha	1:50,000 to 1:20,000	One or more of drainage, salinity, slope and erosion	WA Soil Group with qualifier[10] or soil series[11]

[11] Australian Soil Classification (Isbell 2002).

[12] Soil Groups of Western Australia (Schoknecht 2002).

[13] Purdie (1993, revised 1998).

1. Regions
Broad subdivisions of the Australian continent (Division of Soils, CSIRO 1983).
e.g. ***The Western Region (2)***

2. Provinces
Provides a broad overview of the whole state suitable for maps at scales of about 1:5,000,000 (Division of Soils, CSIRO 1983).
e.g. ***The Avon Province (25)***

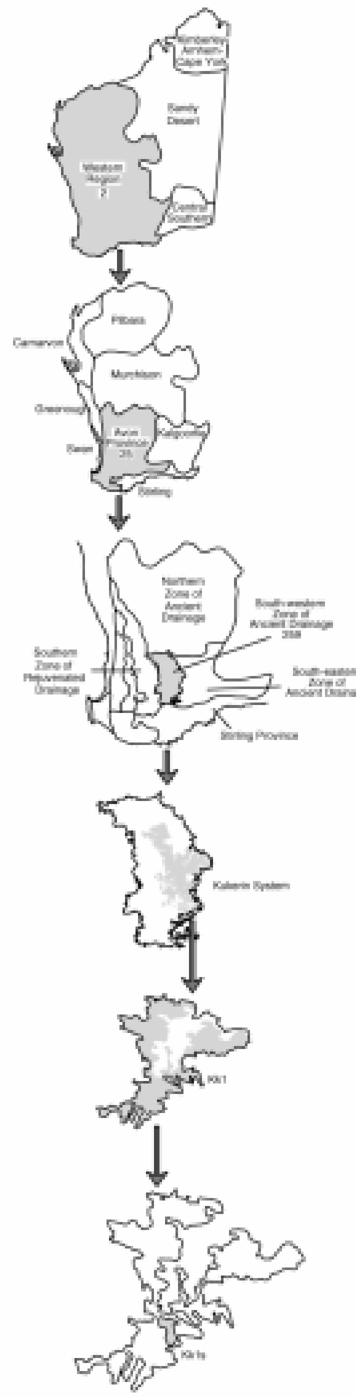
3. Zones
Areas defined on geomorphologic or geological criteria, suitable for regional perspectives.
e.g. ***South-western Zone of Ancient Drainage (259)***

4. Systems
Areas with recurring patterns of landforms, soils and vegetation, suitable for regional mapping at scales of 1:250,000.
e.g. ***Kukerin System (259Kk)***

5. Subsystems
Areas of characteristic landforms features containing definite suites of soils, suitable for mapping at regional scales of 1:100,000.
e.g. ***Kukerin 1 Subsystem (259Kk_1)***

6. Subsystem phases
Division of subsystems based on land use interpretation requirements.
e.g. ***Kukerin 1 sandy phase (259Kk_1s)***

7. Zone land units
Areas of land with similar soils, slopes and landforms. These are unmapped at regional scale mapping.
e.g. ***259-422-PSR-SL_1***[14]



See Figure 2.5 for a cross-section diagram showing zone land units in map unit 259Kk_1s.

Figure 2.4: Levels of the soil-landscape mapping hierarchy (example from Percy 2003)

[14] Pale shallow sand (422) with poor sand and a rock substrate (PSR) on slopes of 1-3% gradient in the South-western Zone of Ancient Drainage(259).

2.2.5 Polygon labels

There are two types of map unit labels applied to the map unit polygons:

- **Database link labels** creating linkages to the Map Unit and Soil Profile Databases.
- **Map unit display labels** based on the database link labels and used for map production.

The database link label contains all the relevant information about the polygon's place in the map unit hierarchy and is unique for that particular map unit across the whole State. The display label is a shorter subset of the database link label and is only required to identify that unit on a local scale (i.e. it only needs to be unique across the extent of any map produced). Only one database link label is placed in each polygon while there can be multiple display labels per polygon where required.

2.2.5.1 Database link labels

The main function of the database link label is to create a link between the map unit polygon and the Map Unit and Soil Profile Databases. It is unique for that particular map unit across the whole State. The same label is applied to all polygons belonging to that map unit, but only one database link label is placed in each individual polygon.

The level of map unit in the hierarchy is implicit in the database link label. The *first* character of the label is the **Region**, 2nd = **Province**, 3rd = **Zone**, 4th and 5th = **System**, 6th and 7th = **Subsystem**, and the remainder (up to 12 characters) = **Phase**. This is demonstrated in Table 2.3.

Table 2.3: Symbols used for map unit labels

Level	*Unit name*	*Unit symbol*	*Examples*	
1	Region	single-digit number	**2**	**2**
2	Province	single-digit number	2**5**	2**1**
3	Zone	single-digit number	25**6**	21**5**
4	System	2 characters, alpha, title case	256**Jc**	215**Sr**
5	Subsystem	2 characters, numeric or alpha upper case	256Jc_**3**	215Sr**BL**
6	Phase	Up to 13 characters, alphanumeric	256Jc_3**d**	215SrBL**wy**

An example of the mapping hierarchy is shown in Figure 2.4 while Table 2.4 displays a range database link labels and their associated display labels. Many surveys use a single digit number as a subsystem symbol, which will be preceded by an under-score in the database link label (e.g. subsystem 3 is represented by the two character code "_3"). Some older surveys used a single-letter code in the subsystem display label, represented by a two-character symbol in the full hierarchy symbol (e.g. in the Darling Range Survey the Dwellingup subsystem was originally assigned the symbol "D", but is now represented by the two character code "DW").

A number of surveys were completed before implementation of the map unit hierarchy, most notably on the Swan Coastal Plain, where the pre-existing map units have been recognised at phase level with no subsystem identified. In these cases the subsystem is represented by a double under-score, for example the P1b unit on the Pinjarra Plain from the Mandurah-Murray survey has been assigned the database link label 213Pj__P1b.

2.2.5.2 Map unit display labels

The function of the map unit display label is to enable users of digital or hardcopy maps to quickly identify map units. It is not linked to a database and more than one display label is placed in larger polygons to improve the ease identification. As it is only required to identify map units across the map that they appear on, the display label does not need to be unique across the State.

The display label is usually an abbreviation or subset of the database link label, most commonly the subsystem and, if relevant, phase components. Any under-scores appearing in the database link label are left out (e.g. Ta_5 becomes Ta5).

Because the display label is a subset of the database link label, the same display label may apply to more than one different map unit. For example the display label BR is applied to the Boree (253BvBR), Barlee (214GvBR) and Booran (258KyBR) Subsystems.

All of the CSIRO surveys and some Department of Agriculture surveys were completed before the development of the map unit hierarchy. As a result, there was usually no attempt made at the time of the survey to determine the extent of zones and systems within survey area. Since this has been done at a later date, some the original map units at subsystem level have now been recognised as occurring in a number of different systems. This is especially the case on the western South Coast and central wheatbelt. For example, the Bevan Subsystem (display label BE) occurs in the Dwalganup (254DwBE), Manjimup (254MpBE) and Perup (254PpBE) Systems[15].

Where two subsystems sharing the same name occur within two or more different systems on the same map, the display label may be differentiated by including the system symbol in the display label (KyUL, TaUL and WyUL) or by using colour to identify different systems on the map.

[15] Where Bevan was originally mapped in the Kent System its name has been changed to Mallawillup (254KeMW).

Table 2.4: Examples of database link labels and map unit display labels

Database link label	Display label	Map unit hierarchy decode
Zones:		
242	242	Western Region (2), Stirling Province (4), Albany Sandplain Zone (2)
Systems:		
225Aj	Aj	Western Region (2), Greenough (2), Chapman Zone (5), Ajana System (Aj)
258Tr	258Tr	Western Region (2), Avon Province (5), Northern Zone of Ancient Drainage (8), Trayning System (Tr)
Subsystems		
258TaUL	TaUL	Western Region (2), Avon Province (5), Northern Zone of Ancient Drainage (8), Tandegin System (Tr), Ulva Subsystem (UL)
259Ek_3	Ek3	Western Region (2), Avon Province (5), South-western Zone of Ancient Drainage (9), East Katanning System (Ek), Subsystem 3 (_3)
254MpKP	KP	Western Region (2), Avon Province (5), Warren-Denmark Zone (4), Manjimup Plateau System (Mp), Kapalarup Subsystem (KP)
Phases:		
216GrKPr	KPr	Western Region (2), Swan Province (1), Leeuwin Zone (6), Gracetown Ridge System (Gr), Kilcarnup Subsystem (KP), rocky dune phase (r)
257Ca_1s	Ca1s	Western Region (2), Avon Province (5), Southern Zone of Rejuvenated Drainage (7), Carrolup System (Ca), Subsystem 1 (_1), sandy phase (s)
214WsYLvw	YLvw	Western Region (2), Swan Province (1), Donnybrook Sunkland Zone (4), Whicher Scarp System (Ws), Yelverton Subsystem (YL), wet valley phase (vw)
213Fo__F1b	F1b	Western Region (2), Swan Province (1), Pinjarra Zone (3), Forrestfield System (F3), undefined subsystem (__), F1b phase (F1b)

2.2.6 Correlation between surveys

Soil-landscape mapping for south-western Australia comprises a compilation of a variety of different surveys (see Figure 1.1 for survey coverage). The process of correlation firstly involved the placement of the **map unit polygons** into the **soil-landscape map unit hierarchy**. A number of the surveys were completed before the hierarchy was implemented and in some cases correlation has involved alterations to the original mapping.

For example, the south coast and hinterland mapping (Churchward *et al.* 1988) was completed over a decade before the hierarchy was first developed. Many of the original map units have since been sub-divided because of their broad geographical distribution. For example the Bevan map unit had been mapped as extending from the Darling Scarp to Mt Barker. The nature of this unit varied across this range and it is now recognised as occurring in four soil-landscape systems (as four different subsystems) [16]. Within the Kent System, areas originally mapped as Bevan were changed to the Mallawillup Subsystem to retain consistency with the adjoining surveys.

In the second stage of correlation, the linework from different surveys was matched. This process involved some changes to map unit boundaries and the total remapping of portions

[16] An even more extreme example is Churchward's Collis map unit. This has now been subdivided between two soil-landscape zones and 11 systems.

of some surveys[17]. For mapping at the soil-landscape **system** level and above (**zone**, **province** and **region**) the linework has been edge-matched to be seamless across the surveys. For mapping at the **subsystem** and **phase** level the linework has been matched as much as possible but may not be completely seamless due to changes in mapping style or scale of survey (e.g. one survey may be mapped to phase level and the adjacent survey only to subsystem level).

The correlation process also involves matching the data presented in different surveys. While many map units occur in more than one survey, the properties of the map units at all levels of the hierarchy are survey independent. Some significant alterations have been made to the originally published soil-landscape map unit descriptions in order to match with data from adjacent surveys and cover the full variation within the unit's geographical extent.

The map descriptions from many of the older surveys also require updating to standardise terminology. This is especially the case of soil descriptions with Soil Groups of Western Australia having been assigned to all map units, many of which originally had soils described only in general terms.

2.2.7 Map unit polygon dataset

Map unit polygons are stored digitally as Bentley Systems MicroStation design files and the data have been loaded into Intergraph MGE (Modular Geographical Information System Environment) with database linkages to ORACLE. Individual files are based on **projects**, in most cases based on the survey in which the mapping was conducted. Each project has a three letter code for which makes up the file name. For example, the three-letter code for the Corrigin Survey is 'COR' and the design file containing the map unit polygons linework is named '*corsoil_g.dgn*', where *g* denotes GDA94 datum.

Digital storage of map unit polygons is in the GDA94 datum. Almost all soil-landscape spatial data were captured in the AGD84 datum and when the change was made to the new GDA94 datum (circa. 2000). Intergraph Projection Manager was used to transform the datasets to the new datum.

While all soil-landscape spatial data are maintained in MicroStation/MGE/ORACLE, an up-to-date version of each project is also held in an Intergraph GeoMedia format. GeoMedia provides a process for importing MGE data from MicroStation design files and working with it to conduct spatial analysis. It can be used to prepare area statements of map units and link the map unit polygons with other datasets (e.g. catchment or local government area boundaries, remnant vegetation etc.). Intergraph GeoMedia also has the capability to export to a number of vector formats, including MicroStation design file, ArcView shapefile and MapInfo exchange format.

2.3 Map unit and soil type data (and the Map Unit Database)

Map unit and soil type data describe the map unit polygons discussed in Section 2.2 and soil types discussed in Section 2.1.4. They are primarily based on the point data collected as part of field survey and the results of laboratory analysis, but usually apply over broad geographical areas.

It is important to understand the differences between **point data** and **map unit** and **soil type data**. Whereas point data come from actual descriptions of individual profiles made in the

[17] For example the Scott River System within the Manjimup survey was remapped to match the style from the Busselton-Margaret River-Augusta survey.

field (and analysed in the laboratory) and relate to one specific point only, map unit and soil type data describe an idealised or conceptual soil profile or landscape. These conceptual units are a generic compilation constructed using point data from many sites, more general observations and disciplinary knowledge.

Map unit and soil type data are stored digitally in the Department of Agriculture's **Map Unit Database** (MSAccess and ORACLE). Some of these data can also be found in published or unpublished reports.

2.3.1 Map Unit Database

The Map Unit Database is the repository of map unit and soil type data as well as information about individual surveys. Data relevant to the regional soil-landscape mapping program include:

- **Map unit data** that provide descriptions of the map unit polygons in generic terms along with other data including the proportional allocation of zone land units.
- **Soil type data** that provide generic information about the soil groups and soil series attached in the map unit data and individual soil profiles.
- **Project data** that provide information about individual surveys.

The Map Unit Database is also a repository for Rangeland Survey data covering non-agricultural areas of WA (Pringle 1991, Curry and Payne 1992, Pringle and Payne 1995).

The data are stored in ORACLE tables, with an MSAccess front end to retrieve and interrogate the data. Off-line copies of the ORACLE database can be created, amended and interrogated in MSAccess.

2.3.2 Map unit data

The Map Unit Database includes all the information relating to map unit polygons. It has four main components:

- Written **map unit descriptions** including general information about the map unit
- **Components by per cent** estimating the proportion of zone land units (based on soil types and landforms) within the map unit
- **Area statements** of the total extent of the map unit and its occurrence within different surveys
- **Land qualities and capability data** assigned to the map unit[18].

Map unit data from recent surveys were entered directly into the Map Unit Database. Data from surveys completed prior to the mid-1990s have been adapted or transferred from published reports. Some of the details from historical surveys are yet to be uploaded while data from some yet to be published surveys are currently undergoing revision.

2.3.2.1 Map unit descriptions

The mapping units are defined in terms of landform pattern, relief, modal slope and soils; the geology and vegetation patterns within them are also described. Definitions of units are mutually exclusive. The narrative description identifies characteristics distinguishing adjacent units.

[18] Land qualities and land capability data are dealt with separately in Section 3.

The map unit description contains five categories of information about a map unit:

- **Map unit identifier:** The map unit symbol (the database link label which links other data to the map unit polygons) and the full map unit name as well as information about the units level in the map unit hierarchy (referred to as its rank in the Map Unit Database) and its status (current, provisional or discontinued).
- **Map unit description:** Text descriptions of the characteristics of the map units including brief descriptions of landform/geomorphology, geology, location, soils and vegetation. There is provision for a summary map unit description or this can be derived from a concatenation of the brief descriptions.
- **Map unit notes:** Allowing for detailed expansions of the brief descriptions of landform/geomorphology, geology, soils and vegetation as well as general map unit notes, land use notes and information about similar map units.
- **Landform attributes:** Categoric landform attributes of the map unit taken from McDonald *et al.* (1990) including landform pattern, relief modal slope class and element morphology type.
- **Area statements:** Total area of the map unit in hectares and number of individual polygons as well as a break-up of the information on a project-by-project basis.

2.3.2.2 Components by per cent (and zone land units)

By presenting the components as per cent, a description of the map unit is produced using the concept of **proportional mapping**. Soil-landscape map units at all levels of the mapping hierarchy are rarely pure – that is they are rarely composed of one soil only or one combination of soil and landscape position. The reality is that they comprise a number of unmapped soil and landscape components, the number and variety of unmapped components varying with scale and nature of the map unit.

In proportional mapping, the unmapped components (e.g. **zone land units**, Soil Groups of Western Australia, soil series or landforms) are described as a percentage of the total map unit. This shows the variability associated with map units and helps identify high or low values which are significant to land use or management.

A difficulty in the past has been that most conventional survey maps only show the average condition. Significant high or low values associated with minor components of the map unit (e.g. a saline hillside seep or rock outcrop) remained hidden.

- **Zone land units**

Zone land units have been allocated to map units from all major surveys in the south-western Australia and form the basis of proportional mapping. They link the map units to soil property, land quality and land capability data. In this way land units are used to produce most of the interpretive maps and statistics (such as those denoting degradation hazards) generated from the Map Unit Database.

Zone land units comprise a combination of landform and Soil Groups of Western Australia. As soil and landform properties vary across the agricultural districts[19], separate land units for each soil-landform combination are recognised in each of the soil-landscape zones.

[19] For example, the properties of Grey deep sandy duplex soils occurring on the Esperance Sandplain differ from those in the Katanning district. In Esperance Grey deep sandy duplexes are more likely to have a loose surface condition while around Katanning the topsoil is more coherent. This has a major impact on the risk of wind erosion.

Each zone land unit consists of four components:

1. The **soil-landscape zone** in which the unit is found. This will relate directly to the database link label of the map unit polygon. As an example, the soil-landscape zone for a zone land unit occurring within map unit 245Co_1 will be 245.
2. The **Soil Group of Western Australia** which typifies the zone land unit (Schoknecht 2002).
3. The **Soil Group qualifier** which defines the soil properties of the soil group in more detail (Schoknecht 2002).
4. The **landform position** which characterises the zone land unit. Codes for these landform positions are shown in van Gool *et al.* (in prep).

Figure 2.5 shows an example of unmapped zone land units occurring in the map unit shown in Figure 2.4.

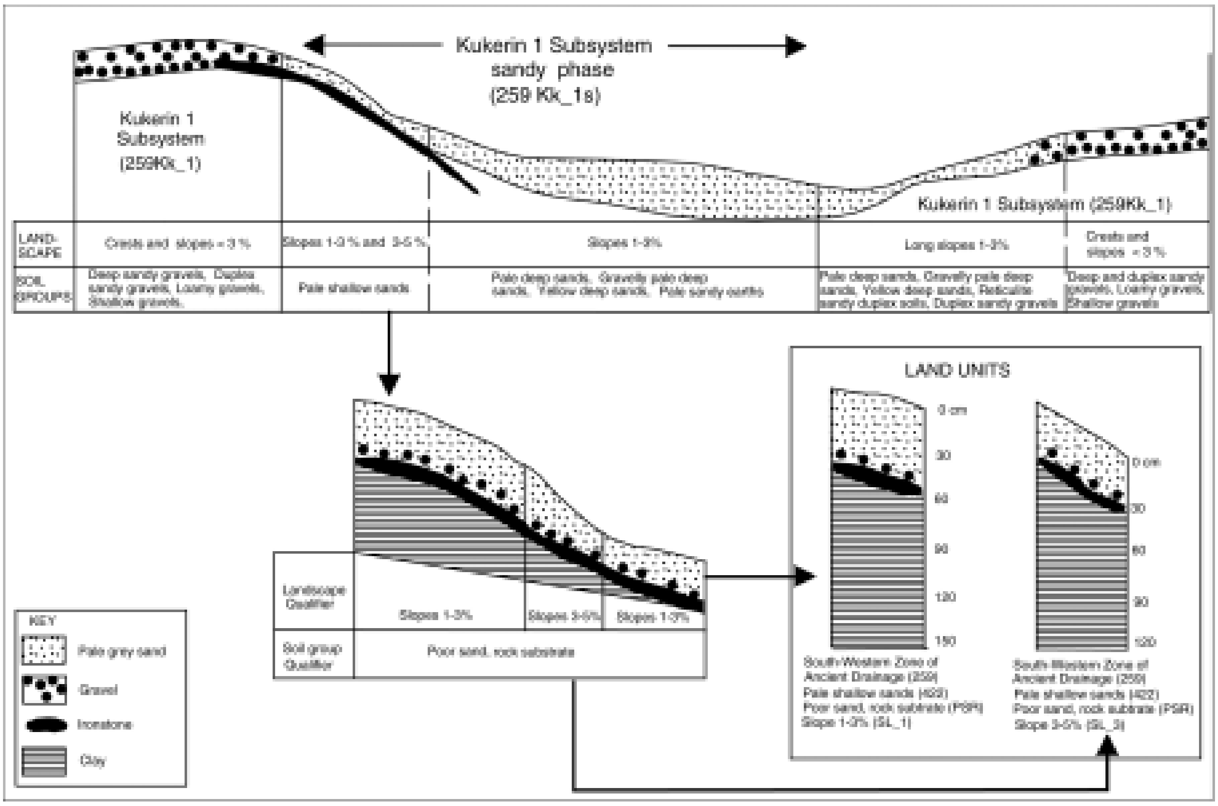


Figure 2.5: Relationship between mapping units in the Kukerin Subsystem and zone land units

Each soil-landscape map unit will consist of one or more zone land units. Zone land units are assigned to map units by percentage (as an integer from 1–100%). At higher levels in the soil-landscape hierarchy there will be many zone land units within a map unit, but in more detailed soil-landscape mapping (i.e. phase level), the map unit may sometimes be a single zone land unit. Table 2.5 gives an example of the zone land units occurring in the map unit shown in Figure 2.5.

A **main soil** is often assigned to each **zone land unit** within a map unit. This is either a formal or informal soil series and provides a link to the **soil type data**. The main soil for a particular zone land unit may vary from map unit to map unit, but is more commonly the same within a zone. The presence of other soil series in the zone land unit may be recorded in the land unit notes. The main soil is often linked to a representative profile (with laboratory data and a site photograph) in the **Soil Profile Database**.

Table 2.5: Component zone land units of map unit 259Kk_1s

Zone	Soil Group of Western Australia	Soil Group qualifier	Landform	% of map unit	Main soil
259	Pale deep sand	Poor* sand, very deep	slopes 1-3%	35	Kauring 2
259	Pale shallow sand	Poor* sand over rock	slopes 1-3%	25	Kauring 1
259	Pale shallow sand	Poor* sand over rock	slopes 3-5%	5	Kauring 1
259	Gravelly pale deep sand	Poor* sand, very deep	slopes 1-3%	15	Kauring
259	Yellow deep sand	Good* sand, very deep	slopes 1-3%	15	Jarrahwood
259	Pale sandy earth	Neutral subsoil	slopes 1-3%	5	

* Although the terms *poor* and *good* are value judgements, they have broad acceptance and understanding in the rural community and suit the level of sophistication required within the Soil Group concept.

From the allocations of **zone land units**, the **proportion of Soil Groups** or the **proportions of landform positions** for each map unit are derived and expressed as a percentage. From the example in Table 2.5 the proportions of Soil Groups in map unit 259Kk_1s are:

- Pale deep sand – 35%
- Pale shallow sand – 30%
- Gravelly pale deep sand –15%
- Yellow deep sand – 15%
- Pale sandy earth – 5%.

The proportion of landforms in 259Kk_1s is:

- Slopes with gradients of 1-3% – 95%
- Slopes with gradients of 3-5% – 5%.

A set of zone land units has been generated for agricultural districts of Western Australia. Each zone land unit is unique, but may occur within a number of different map units in a soil-landscape zone. Individual zone land units can also be found in a number of different survey areas.

Each zone land unit has been assigned a standard set of properties (**land qualities** and characteristics) that are used in **land capability assessments.** As these properties are assigned to zone land units and zone land units are assigned proportionally to map units, map units also have proportions of land qualities or characteristics (see Section 3 for more detail).

- **Land management units**

At present, about 10,000 zone land units have been defined for south-western Australia. While these form suitable vehicles for reasonably accurate land capability assessments, this number is too large for individual units to be effective communication and extension tools.

By grouping similar zone land units, a more manageable number of unmapped units can be obtained. Within most regional areas it is possible to reduce the zone land units in the database to about 20 or 30 unmapped units which are relevant to land management. These are often referred to as land management units (LMUs).

A land management unit can be defined as an area of land with common soils and landforms which should be managed in a similar manner (as a single unit) in order to maximise production and minimise land degradation (Percy 1992). The LMU suits certain enterprises and may necessitate certain management practices, such as drainage.

LMUs can be mapped at farm scale and used as a basis for farm planning or other forms of more detailed mapping. They were used widely in the 1990s in farm and catchment planning workshops (including Focus Catchments) and more recently in the Rapid Catchment Appraisal program. The proportion by per cent of zone land units can be auto-generated in the Map Unit Database from the zone land units.

- **Soil series**

While the main soils attached to the zone land units provide an indication of soil series present within a map unit, the proportion by per cent of soil series is recorded as a separate dataset for map units from some surveys.

- **Land characteristics and land qualities**

Because zone land units are based on landform and soil information, they can be attributed with land characteristics and land qualities. A **land characteristic** is an attribute which can be measured or estimated and which can be employed as a means of describing land qualities (FAO 1983). **Land qualities** are “those attributes of land that influence its capability for a specified use” (Wells and King 1989). Land qualities are properties of the soils or zone land units relevant to land management and are usually derived from one or more land characteristic. Land qualities are used to determine capability.

Each land characteristic and quality has a range of possible values. For example values for the land quality *water repellence* are high, moderate, low and nil. While land characteristics and qualities can be useful in their own right, they are also used to undertake land capability assessments (see Section 3.2).

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. Conversely several land characteristics e.g. surface texture, surface condition and landform position will influence the land quality *wind erosion*.

Future developments in the mapping program are likely to add more land characteristics. Examples of possible additions include information about regolith depth and nature, and the levels of aluminium and boron in the soil profile.

Land qualities and characteristics are described in more detail in *Land Capability Assessment Methodology* (Wells and King 1989) and *Land Evaluation Standards for Land Resource Mapping* (van Gool and Moore 1999). A new edition of *Land Evaluation Standards* (van Gool *et al.* in prep.) details the characteristics and qualities currently stored against zone land units in the map unit database.

Land qualities and characteristics can apply to soil type, a combination of soil and landform or the landform position only. Table 2.6 identifies the 22 land qualities assigned to zone land units (and therefore proportionally to map units) in the Map Unit Database. Table 2.7 identifies land characteristics assigned to zone land units. Section 3.2.2 provides further details of the soil and landform specific characteristic data stored against zone land units.

Table 2.6: Zone land unit qualities

Land quality	***Soil-related***	Soil and landform-related	***Landform-related***
Ease of excavation		✓	
Flood hazard			✓
Land instability		✓	
Microbial purification		✓	
pH at 20-25 cm & 50-80 cm	✓		
Phosphorus export		✓	
Rooting depth		✓	
Salinity hazard		✓	
Salt spray exposure			✓
Site drainage potential		✓	
Soil absorption ability		✓	
Surface soil structure decline	✓		
Soil water storage		✓	
Soil workability		✓	
Subsurface acidification	✓		
Subsurface compaction	✓		
Surface salinity	✓		
Trafficability		✓	
Water erosion hazard		✓	
Water repellence	✓		
Waterlogging/inundation		✓	
Wind erosion hazard		✓	

Table 2.7: Zone land unit characteristics

Land characteristic	***Soil-related***	Soil and landform-related	***Landform-related***
Coarse fragments in profile	✓		
Depth of profile	✓		
Permeability	✓		
Rock outcrop			✓
Slope			✓
Stones and boulders in profile	✓		
Surface condition	✓		
Surface texture	✓		
Water erosion susceptibility of soil	✓		
Watertable depth		✓	
Wind erosion susceptibility of topsoil	✓		

2.3.3 Soil type data

Soil type data are the generic information underlying the soil series and Soil Groups of Western Australia. Soil type data for both are stored in the Map Unit Database and appear in individual survey reports. Schoknecht (2002) presents the soil type data for the Soil Groups of Western Australia.

For the soil series, along with criteria listed in Section 2.1.4.2, data on the classification in Soil Groups of Western Australia, Soil Taxonomy and World Reference Base for Soil Resources are included.

For Soil Groups of Western Australia, a soil description, distinguishing characteristics, local names, Australian Soil Classification, main occurrences in Western Australia, and land qualities are stored.

2.3.4 Projects

Information about the various soil-landscape, soil and rangeland surveys is stored in the Map Unit Database. This includes:

- project name
- managing agency
- survey type
- scale of mapping
- finishing date
- area surveyed in hectares
- bibliographic reference to any publications
- survey notes
- area and number of polygons of each map unit in the survey.

2.3.5 Land uses

Information about the various land uses assessed for land capability (see Section 3.3) is stored along with capability rating tables. The written information includes a definition of the land use and the management practices assumed when assessing capability. In the capability ratings, a capability class is assigned to each value of the relevant land qualities.

2.4 Other related datasets

Other land resource datasets available are not a direct result of the soil-landscape mapping program. Some of these are used to improve the accuracy of soil-landscape surveys. They can also be used in conjunction with information from existing land resource surveys to produce interpretive data.

Many of these other land resource datasets are maintained by the Department of Agriculture's Client and Resource Information System (CRIS) and include:

- **Satellite** and **orthophoto imagery** that is digitally rectified and can be combined with the map unit polygons
- Digital copies of **vegetation maps**
- Digital copies of **geological maps**
- Digital maps of **remnant native vegetation**
- **Climatic data** including rainfall isohyet maps
- Thematic maps of **Australian Bureau of Statistics data**
- **Digital cadastral maps** showing property and lot boundaries and information on their ownership
- **Digital contour maps**
- The **Land Monitor** dataset highlights areas of low productivity as an indicator of the present extent of salinity and areas likely to be affected by future watertable rises
- **Digital elevation model** (DEM) products derived from the contour maps (produced as part of the Land Monitor dataset) including **DEM sunshade image**s and **slope maps**
- Geophysical survey datasets including **radiometrics**, **magnetics** and EM (Section 1.1.4)
- **AGBORES,** an ORACLE database of bores and groundwater levels.

3. Using the data

Three primary uses of land resource data collected during the soil-landscape mapping program are to:

- Reduce risk in decision-making (ensuring that change in land management, if it occurs, is the result of land resource information reducing the uncertainty about impacts of different strategies[20])
- Improve our understanding of biophysical processes
- Design large-scale land use change (e.g. targeted revegetation to control dryland salinity).

Other directions for future uses include:

- Environmental regulation and trading systems
- Mapping and monitoring land condition to support national policies on natural resource management
- International agreements (e.g. Kyoto Protocol demands for predictions of the distribution and dynamics of soil carbon at a range of scales)
- Environmental management systems.

3.1 Limitations of the data

The potential uses of land resource mapping are limited by several factors largely related to scale, but also influenced by the survey method (including the technologies used), mapping date (an indicator of the spatial reliability of the information) and land complexity. While the published survey report can be used to provide some indication of map reliability, it needs to be recognised that many maps and the associated data have been updated since publication of the original reports. Table 3.1 indicates the appropriate use of land resource survey maps based on the scale of mapping.

A new system of assessing the reliability of soil-landscape maps and their underlying data is in development. It is hoped this will take into account the published scale of the mapping, the scale of photography used to draw the boundaries, the number of sites described and site density, and the manner in which zone land units were attributed to the maps units[21].

When using the land resource information, one should consider its date of preparation. Some significant alterations have been made to the originally published soil-landscape map unit descriptions in order to match with adjacent surveys. Descriptions have also been updated as the accuracy of mapping has been improved through the availability of new point data or the application of new technologies. Because map unit or soil type data are dynamic, the date that the information was prepared should always be checked before it is used as a basis for any decision-making. More recent data will often be available.

[20] For example, identifying areas of agricultural significance or areas suitable for rural residential development.

[21] Including whether they were assigned by: the surveyor at the time of the survey; the surveyor at a later date; another surveyor with local experience; or someone with limited familiarity of the mapping or the district.

Table 3.1: Effect of map scale on use of land resource mapping (adapted from Gunn *et al.* 1988, McKenzie 1991)

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

* Resolution is based on 1 cm^2 on the map. This figure is an indicator of the size of land use developments that can be planned for. The minimum resolution is assumed to be 0.5 cm^2 in the *Australian Land Survey Guidelines* (Gunn *et al.* 1983) however the average resolution of map units in practice is usually much larger.

3.2 Interpretive data

3.2.1 Map unit polygons

One of the major advantages of digital linework linked to databases with proportional data is that this not only enables the production of soil-landscape maps of any given area or maps showing the **distribution of certain soil types**, but it allows for the production of interpretive maps and associated data.

Maps or calculations of the proportional areas of **land qualities** and **characteristics** can be generated relatively easily. For example, a map of an area could be generated showing the proportion of soils with a rooting depth in excess of 80 cm.

The **soil layer characteristics** may also be used to produce maps of soil conditions at specified depths or soil specific themes such as available water content.

As many of the land qualities relate to **degradation hazards** such as water erosion, it is quite simple to generate maps of degradation risks. From these maps statements of risk for specified catchments, shires or industries may be calculated by linking the capability maps with maps of hydrological boundaries, statutory boundaries or land use in geographical information systems.

Other types of interpretive maps show **land capability**. These are derived by matching land qualities to land use requirements. Similar area statements to those described above can be generated from these maps. More details on land capability assessment are presented in Section 3.3.

Interpretive soil-landscape maps combined with climatic data have many other potential uses such as **scenario modelling** (e.g. assessing the potential impacts of climate change or creating predictive yield maps for specific crops). One use under investigation is to predict potential run-off rates in different rainfall zones.

3.2.2 Point data

As well as the map unit polygons, point data can be used to produce interpretive maps and statistics where ‘actual data’ are required. Field and laboratory data from soil profiles can be used to highlight areas of certain potential or hazard. For example, point data could be used to provide an indication of soil pH trends across an area, highlight areas with hardsetting topsoils or sodic subsoils, and identify areas with concentrations of low values for the Phosphorus Retention Index.

Point data can be used to verify information entered into the Map Unit Database or field test interpretations of radiometric data. Point data are particularly useful when combined with other data as inputs to bio-physical modelling.

When using point data in this way it is important to understand potential limitations. Some knowledge of the purpose and methods of the survey from which it was obtained will indicate the quality of the data and any bias in the spread of the samples. For example, if most of the point data from a particular area were collected during the Sustainable Grazing on Saline Lands project, you would expect a disproportionably high representation of saline soils which might not typify the district as a whole.

3.3 Land capability assessment[22]

Land capability is the ability of the land to sustain a specific land use without undesirable on-site or off-site effects. The essence of land capability assessment is a comparison of the biophysical requirements for a particular land use with the biophysical attributes (or qualities) of the land (Wells and King 1989). Land capability assessment considers both the specific requirements of the land use (e.g. unrestricted rooting depth or soil water availability) plus the risks of degradation associated with the land use (e.g. susceptibility to phosphorus export or wind erosion).

3.3.1 The five-class rating system

The Department of Agriculture uses a five-class rating system for assessing land capability ranging from Class 1 land (very high capability, few limitations and negligible degradation risk) to Class 5 land (with very low capability and severe limitations in relation to production and/or degradation risk). Table 3.2 presents the five capability classes.

Table 3.2: Land capability classes for given land use types (adapted from Wells and King 1989)

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

Capability can be assessed for a wide variety of land uses. Land uses routinely assessed in the Map Unit Database are:

- Annual horticulture
- Dryland cropping (minimal and traditional tillage)
- Grape vines
- Grazing
- Perennial horticulture
- Septic tanks.

Other land uses can be added to this list as required. They can include assessments for specific crops or management practices.

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[22] **Land capability** may also be referred to as **physical land suitability**. The use of terms can vary significantly. For the past 25 years in Western Australia, land capability has related to the physical capacity of the land to support a specified land use, while the term suitability has taken this into consideration along with social-economic factors not directly related to the land.

The capability rating is derived by matching information about land use requirements contained in ratings tables with the land quality values of the zone land units. For more details on this process see *Land Evaluation Standards for Land Resource Mapping* (van Gool *et al.*).

3.3.2 Land characteristics and qualities

While the capability assessments are based on land qualities (see Section 2.3.2.2 above) stored in the Map Unit Database, these in turn are generated from soil and landform characteristics currently stored and calculated in a separate ACCESS database[23].

For each qualified Soil Group of Western Australia in each soil-landscape zone a range of properties has been assigned to four standard soil layers. These soil layers are:

- Layer 1 – **The surface horizon,** basically the A1 horizon[24] containing high organic matter. Characteristics of this layer affect the soil-atmosphere interface (e.g. infiltration, wind erodibility etc.).
- Layer 2 – **Topsoil**, basically the A2 or A3 horizon. Characteristics of this layer typify the topsoil below the organic A1 horizon.
- Layer 3 – **Subsoil**, usually the B2 horizon[25]. Characteristics of this layer typify the upper subsoil below the main texture change within the top 80 cm of the profile.
- Layer 4 – **Substrate**, occurring at 80-200 cm**,** usually the B3, C or D horizon. May be sand, clay or rock.

For each of these layers the typical characteristic value for each of the following is assigned:

- Lower depth
- Texture
- Structure/Arrangement
- Per cent coarse fragments
- Per cent stones
- Organic carbon percentage
- pH in water
- Slaking
- Dispersion
- Electrical conductivity
- Exchangeable sodium percentage (ESP)
- Phosphorus Retention Index (PRI)
- Soil moisture regime.

[23] The intention is that this data will eventually be held as a module within the Map Unit Database.

[24] There is an exception for the Sandy earths supergroup where Layer 1 comprises a combined A1 and A2/3 horizon (i.e. all the sandy topsoil unless clayey horizon is not present within 80 cm).

[25] In shallow profiles layers 2 or 3 may be the Bm or R horizons in which case the texture can be described as hardpan or rock.

These soil characteristics are then used to generate characteristic and quality data for the whole profile such as rooting depth, available water content, soil erodibility.

This profile data are then matched with landform specific data to determine land qualities for each **zone land unit**. For each of the landform positions appearing in the Map Unit Database, the following set of characteristics has been assigned:

- Slope gradient
- Rock outcrop
- Instability landform-ranking
- Phosphorus loss landform-ranking
- Salt exposure
- Trafficability landform-ranking
- Workability landform-ranking
- Drainage landform-grouping
- Water erosion landform-grouping
- Wind erosion landform-grouping.

These soil and landform characteristics are then combined to derive the overall land qualities for each of the zone land units. These land quality data are auto-generated within the separate ACCESS database and then transferred into the Map Unit Database. More details on these characteristics and their effect on land qualities are contained in *Land Evaluation Standards for Land Resource Mapping* (van Gool *et al.*).

3.3.2 Proportional capability ratings

Because capability is assessed for individual zone land units, capability of a map unit is expressed in proportional terms. 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 fact that the map units can have land capability ratings assigned to them proportionally presents a challenge for graphical presentation on maps.

The standard 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 and 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%)[26].

The map unit described above 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

[26] These rules are defined by an SQL statement in ORACLE enabling semi-automated interrogation of the Map Unit Database.

A land, but as there is 60% moderate to high capability it becomes Category B2. Figure 3.1 shows a standard legend for a capability map, while Figure 3.2 demonstrates the categories graphically with the aid of a capability triangle.

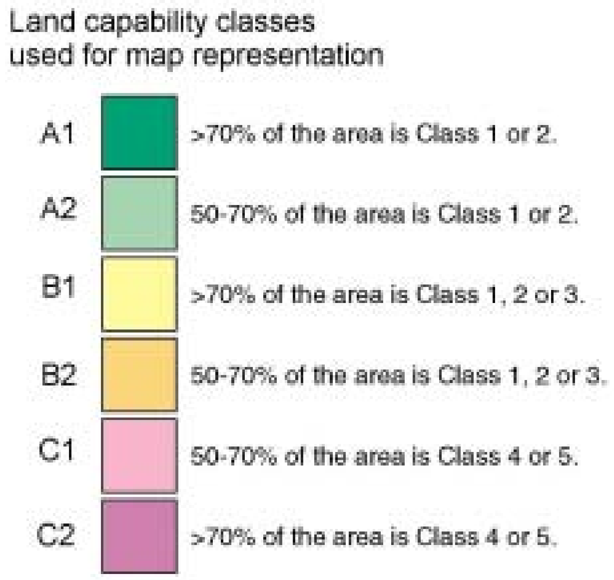

Figure 3.1: Standard capability map key

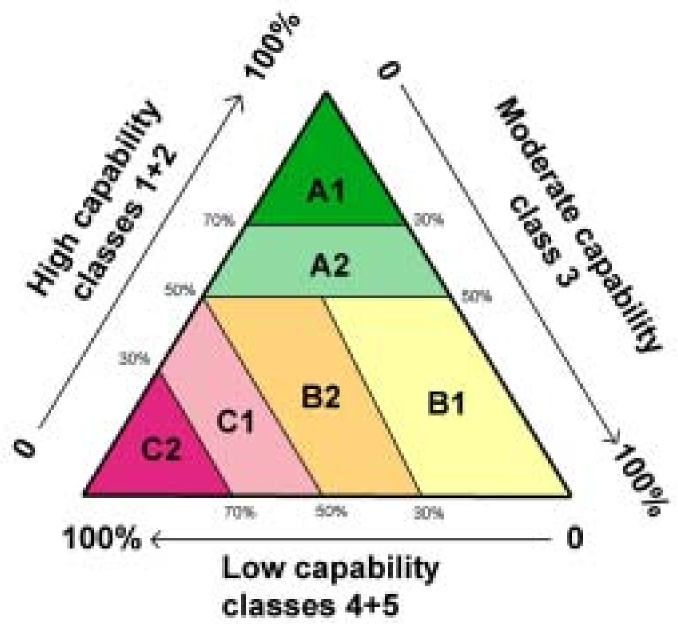

Figure 3.2: Land capability triangle

3.3.4 Capability data in the Map Unit Database

Land capability data for map unit polygons are presented in the Map Unit Database in the **Map Unit Land Capability Summary Form**. For each land use, the proportion of each map unit falling into each of the capability classes is shown with the overall map unit capability code.

For each component map unit the relevant land qualities and their impact on the capability are then presented. For example, Water Erosion Hazard may be very high giving rise to a rating of Class 4, while flood risk may be very low and have no impact on the capability (a Class 1 rating). In this way it is possible to identify the limiting factors in the capability rating.

The data in the Map Unit Land Capability Summary Form is semi auto-generated, and each time zone land unit allocations to the map units or land capability ratings tables are altered, these calculations must be rerun to be updated.

An indication of the reliability of the land quality and capability data attached to individual units is given by the **completeness code** viewed in the Map Unit Land Capability Summary Form. The completeness code is based on the number of zone land units within the map unit that have land qualities assigned. The values range from high (a) to low (f) as follows:

a	Qualities assigned directly to all zone land units within map unit
b	Qualities assigned directly to most zone land units within map unit; remainder are assigned from same zone land unit in similar zone
c	Qualities assigned directly to some zone land units within map unit; most are assigned from same zone land unit in similar zone
d	Qualities assigned directly to a qualified soil group; all assumed to be in the same typical landform position
e	Qualities assigned directly to a unqualified soil group; all assumed to be in same typical landform position
f	Over-allocation errors – zone land units add up to more than 100%

3.4 Published soil-landscape data

Soil-landscape maps and data are available in a variety of formats.

3.4.1 Hard copy reports and maps

Hard copies of recent soil-landscape mapping and the accompanying reports are mostly available in the Department of Agriculture's **Land Resources Series**. These include the surveys of Mandurah and Murray, Darling Range, Geraldton, Busselton-Margaret River, Swan Valley, Mount Beaumont, Esperance, Manjimup, Bencubbin, Wellington-Blackwood, West Gingin and Katanning. Department of Agriculture offices usually stock copies of published surveys covering their local areas. Alternatively contact:

Department of Agriculture
3 Baron-Hay Court
SOUTH PERTH WA 6151

Postal address:
Locked Bag 4
BENTLEY DELIVERY CENTRE WA 6983
*Phone: (*08) 9368 3333
Email: enquiries@agric.wa.gov.au

For some surveys on the Swan Coastal Plain, mapping has been published as **Land Resources Maps** but no accompanying report is available. These include Peel-Harvey North, Peel-Harvey South and Waroona to Capel. Many of the units shown in this mapping are described by Wells (1989).

Some recent surveys are yet to be published. These include Tonebridge-Frankland, Corrigin, Tambellup-Borden, Ravensthorpe-Esperance-Salmon Gums, Three Springs, Dandaragan, Chittering, North Coastal Plain, Southern Cross-Hyden, Jerramungup and Moora East.

Some older surveys (Wanneroo, Jandakot, Rockingham and Kellerberrin) have been published as Department of Agriculture **Resource Management Technical Reports**.

Many of the **CSIRO surveys** (including Swan Valley, Merredin, South Coast and Hinterland, Perth metropolitan northwest corridor and Murray Valley), are no longer in print but copies can be viewed in library collections.

3.4.2 CD-ROMs

The Nyabing-Kukerin survey and all future **Land Resource Series** publications are being produced in a different format to preceding surveys. A shortened hard copy report is accompanied by an interactive CD-ROM containing the soil-landscape map (in web-enabled format), interpretive maps, detailed map unit descriptions and point data. The next two reports due to be published on CD-ROM are the Tonebridge-Frankland and Corrigin surveys.

A program is underway to present land resource data on CD-ROM in the **AGMAPS Land Profiler** series. These products use seamless mapping to combine data from various surveys for particular areas of interest and enable the presentation of updated mapping and map unit descriptions from historical surveys.

Areas presently covered by these AGMAPS CD-ROMs are the Peel-Harvey Catchment, Waroona-Harvey-Dardanup, Capel to Augusta, Frankland-Gordon Catchment and Dumbleyung Catchment.

3.5 Accessing unpublished data

Further information can be obtained from the land resource assessment pages accessible from the Department of Agriculture website (www.agric.wa.gov.au). Alternatively contact:

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4. PUBLICATIONS

Below is a listing of soil-landscape and related publications and unpublished reports for south-western Australia:

4.1 Surveys shown on Figure 1.1

Code	Full reference
B+T	Burvill, G.H. (1988). The soils of the Salmon Gums District, Western Australia. Technical Bulletin No. 77. Department of Agriculture - Western Australia.
BMA	Tille, P.J. and Lantzke, N.C. (1990). Busselton-Margaret River-Augusta land capability study. Land Resources Series No. 5. Department of Agriculture - Western Australia.
BMA	Tille, P. and Lantzke, N.C. (1990). Busselton-Margaret River-Augusta Land Capability Study; Methodology and Results. Resource Management Technical Report 109. Department of Agriculture - Western Australia.
CAS	Scholz, G.G.H. (Unpub.). Soil morphology and chemistry of the Cascades area, Western Australia. Western Australian Department of Agriculture.
CHT	Bessell-Browne, J.A. (in prep.). Chittering area land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
CLS	Condingup survey. *To be incorporated into:*
ERS	Nicholas, B.D. and Gee, S.T. (in prep.) Salmon Gums-Esperance-Ravensthorpe land resource survey. Land Resources Series. Department of Agriculture, Western Australia.
COR	Verboom, W and Galloway, P. (In press). Corrigin area land resources survey. Land Resources Series No. 19. Department of Agriculture, Western Australia.
COU	Scholz, G.G.H. (1987 Unpub.). Soil survey of the Coujinup area, East Ravensthorpe. Unpublished internal report. Agriculture Western Australia.
DAN	Griffin, E.A. (in prep.) Dandaragan land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
DSC	King, P.D. and Wells, M.R. (1990). Darling Range rural land capability study. Land Resources Series No. 3. Western Australian Department of Agriculture.
ENE	Scholz, G.G.H. and Smolinski, H.J. (1987, unpub.). Sand textual map of the Eneabba-Three Springs Pilot Project (Midlands Sandplain). Unpublished internal report. Western Australian Department of Agriculture*.
ESP	Overheu, T.D., Muller, P.G., Gee, S.T. and Moore, G.A. (1993). Esperance land resource survey. Land Resources Series No. 8. Department of Agriculture – Western Australia. *To be incorporated into:*
ERS	Nicholas, B.D. and Gee, S.T. (in prep.) Salmon Gums-Esperance-Ravensthorpe land resource survey. Land Resources Series. Department of Agriculture, Western Australia.
FRA	Stuart-Street, A. (in prep). Tonebridge-Frankland land resources survey. Land Resources Series. Department of Agriculture, Western Australia
GCO	Oma, V.M. and Moore, G.A. (1989 Unpub.). Mapping for assessing erosion in the coastal dune system, Shire of Greenough. Department of Agriculture, Western Australia.

* Digital mapping is available from the Department of Agriculture.

Code	Full reference
GGE	Scholz, G. (1995, Unpub.). Land resource map of East Gingin area. Agriculture Western Australia. Includes amendments by Dennis van Gool and Ted Griffin.
GGF	Bessell-Browne, J.A. (Unpub.). Gingin infill soil-landscape map. Department of Agriculture, Western Australia.
GGW	Smolinski, H. and Scholz, G. (1997). Soil assessment of the West Gingin area. Land Resources Series No. 15. Agriculture Western Australia.
GRR	Dye, R.A., van Vreeswyk, A.M.E. and Moore, G.A. (1990). Geraldton rural-residential land capability study. Land Resources Series No. 4. Western Australian Department of Agriculture.
GTN	Rogers, L.G. (1996). Geraldton region land resources survey. Land Resources Series No. 13. Agriculture Western Australia.
JAN	Wells, M.R., Richards, N.L.B. and Clarke, A.J. (1986). Jandakot groundwater scheme - a study of land resources and planning considerations. Resource Management Technical Report 48. Department of Agriculture. *Now incorporated into:*
CPS	Coastal Plain Survey digital map.
JDA	Moore, G.A., Gee, S.T. and Vincent, D. (1990). Jerdacuttup land resource and capability study. Resource Management Technical Report 101. Western Australian Department of Agriculture.
JER	Overheu, T.D. (in prep). Jerramungup land resources survey. Land Resources Series. Agriculture Western Australia.
KEL	McArthur, W.M. (1992). Land resources of the Kellerberrin region. Division of Resource Management Technical Report No. 134. Western Australian Department of Agriculture.
KLC	Percy, H. (2000). Katanning area land resources survey. Land Resources Series No. 16. Agriculture Western Australia.
LBN	Burvill, G.H. (1932 Unpub.). Lake Brown soil survey.
LBW	Smith, R. and Smolinski, H.J. (1997 Unpub.). Soils and landforms map of the Lower Blackwood. Department of Agriculture, Western Australia.
MB	Wells, M.R. (1989). Land capability study of the shires of the shires of Mandurah and Murray. Land Resources Series No. 2. Western Australian Department of Agriculture. *Now incorporated into:*
CPS	Coastal Plain Survey digital map.
MDN	Grealish, G.J. and Wagnon, J. (1995). Land resources of the Bencubbin area. Land Resources Series No. 12. Agriculture Western Australia.
MER	Bettenay, E. and Hingston, F.J. (1961). The soils and land use of the Merredin area, Western Australia. Soils and Land Use Series No. 41. CSIRO Division of Soils, Melbourne.
MNJ	Churchward, H.M. (1992). Soils and landforms of the Manjimup area. Land Resources Series No. 10. Department of Agriculture - Western Australia.
MRA	Frahmand, M.A. (in prep.) Moora-Wongan Hills land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
MRC	McArthur, W.M., Churchward, H.M. and Hick, P.T. (1977). Landforms and soils of the Murray River catchment area of Western Australia. Management Land Resources Management Series No. 3. CSIRO Division of Land Resources.
MTB	Scholz, G.G.H. and Smolinski, H.J. (1996). Soils of the Mount Beaumont area. Land Resources Series No. 7. Agriculture Western Australia.

Code	**Full reference**
NCP	Schoknecht, N.R. and Bessell-Browne, J.A. (in prep.) North Coastal Plain land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
NOR	Lantzke, N.C. and Fulton, I. (1993). Land Resources of the Northam region. Land Resources Series No.11. Department of Agriculture Western Australia.
NWC	McArthur, W.M. and Bartle, G.A. (1980). Landforms and soils as an aid to urban planning in the Perth metropolitan northwest corridor, Western Australia. Land Resources Management Series No. 5. CSIRO Australia. *Now incorporated into:*
NMS	North Metropolitan Survey digital map.
NYA	Percy, H. (2003). Nyabing-Kukerin area land resources survey. Land Resources Series No. 18. Department of Agriculture, Western Australia.
PHN	van Gool, D. (1990). Land resources in the northern section of the Peel-Harvey catchment, Swan Coastal Plain, Western Australia. Land Resource Map. Western Australian Department of Agriculture. *Now incorporated into:*
CPS	Coastal Plain Survey digital map.
PHS	van Gool, D. and Kipling, B.A. (1992). Land resources in the southern section of the Peel-Harvey catchment, Swan Coastal Plain, Western Australia. Land Resource Map No. 13. Department of Agriculture - Western Australia. *Now incorporated into:*
CPS	Coastal Plain Survey digital map.
RAV	Ravensthorpe survey. *To be incorporated into:*
ERS	Nicholas, B.D. and Gee, S.T. (in prep.) Salmon Gums-Esperance-Ravensthorpe land resource survey. Land Resources Series. Department of Agriculture, Western Australia.
ROK	Wells, M.R., Oma, V.P.M. and Richards, N.L.B. (1985). Shire of Rockingham - a study of land resources and planning considerations. Resource Management Technical Report 44. Western Australian Department of Agriculture. *Now incorporated into:*
CPS	Coastal Plain Survey digital map.
SCH	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. Division of Water Resources Divisional Report 88/1. CSIRO Australia
SCS	Frahmand, M.A. (in prep.). Southern Cross-Hyden land resources survey. Land Resources Series. Agriculture Western Australia.
SGS	Salmon Gums survey. *To be incorporated into:*
ERS	Nicholas, B.D. and Gee, S.T. (in prep.) Salmon Gums-Esperance-Ravensthorpe land resource survey. Land Resources Series. Department of Agriculture, Western Australia.
SSR	Churchward, H.M. and McArthur, W.M. (1980). Soils and landforms of the Darling System, Western Australia. *In* 'Atlas of Natural Resources, Darling System, Western Australia'. Department of Conservation and Environment.
SSR	Smolinski, H.J. (1998). Soils of the South West Forest Region, Western Australia. Unpublished AGWEST Land Management Report. Agriculture Western Australia.
SWV	Pym, L.W. (1955). Soils of the Swan Valley vineyard area, Western Australia. Soils and Land Use Series No. 15. CSIRO Division of Soils.
SWV	Campbell Clause, J. and Moore, G.A. (1991). Land capability study for horticulture in the Swan Valley. Land Resources Series No. 6. Department of Agriculture - Western Australia.

Code	Full reference
TBO	Stuart-Street, A. and Marold, R. (in prep.) Tambellup-Borden land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
TSL	Grose, C. (in prep.) Three Springs area land resources survey. Land Resources Series. Department of Agriculture, Western Australia.
WAN	Wells, M.R. and Clarke, A.J. (1986). Shire of Wanneroo - a study of land resources and planning considerations. Division of Resource Management, Technical Report No. 47. Western Australian Department of Agriculture. *Now incorporated into:*
NMS	North Metropolitan Survey digital map.
WBW	Tille, P.J. (1996). Wellington-Blackwood land resources survey. Land Resources Series No. 14. Agriculture Western Australia.
WCC	Barnesby, B.A. and Proulx-Nixon, M.E. (2000). Land resources from Harvey to Capel on the Swan Coastal Plain, Western Australia - Sheet 1. Land Resources Map No. 23/1. Agriculture Western Australia.
WCC	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 No. 23/2. Agriculture Western Australia.
WGN	McArthur, W.M. and Mattiske, E.M. (1985). The Gnangara mound groundwater area landforms, soils and vegetation. Soil-landscape map (scale 1:50,000). Appendix C in Gnangara mound groundwater resources, environmental review and management program. Report by Dames and Moore, November 1986. *Now incorporated into:*
NMS	North Metropolitan Survey digital map.

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Appendix 1: Soil-landscape regions, provinces and zones for Western Australia

Soil-landscape regions and provinces are those identified by Division of Soils CSIRO (1983) although the actual boundaries are being placed more accurately as the area covered by regional mapping is extended. Figure A1 shows the regions and provinces for the State. Zones for the south-west agricultural area are shown in Figure A2. A hierarchical list of regions, provinces and zones for Western Australia is presented below. Summary descriptions for these units, extracted from the Map Unit Database, are included in the text after the maps.

1 SANDY DESERT REGION

11 Ayers-Canning Province

12 Gibson Province

13 Simpson-Victoria Province

14 Macdonnell Province

15 Broadhurst Province

16 Amadeus Province

17 Stuart-Burt Province

18 Murchison Province (same as 27)

2 WESTERN REGION

21 Swan Province
- 211 Perth Coastal Zone
- 212 Bassendean Zone
- 213 Pinjarra Zone
- 214 Donnybrook Sunkland Zone
- 215 Scott Coastal Zone
- 216 Leeuwin Zone

22 Greenough Province
- 221 Geraldton Coastal Zone
- 222 Dandaragan Plateau Zone
- 223 Victoria Plateau Zone
- 224 Arrowsmith Zone
- 225 Chapman Zone
- 226 Lockier Zone

23 Carnarvon Province
- 231 Port Gregory Coastal Zone
- 232 Kalbarri Sandplain Zone
- 234 Victoria-Yalbalgo Sandplain Zone
- 235 Alluvial Zone
- 236 Wandagee Hills and Plains Zone
- 237 Shark Bay Zone
- 238 Giralia-Cape Coastal Zone
- 239 Yanrey Plains Zone

24 Stirling Province
- 241 Pallinup Zone
- 242 Albany Sandplain Zone
- 243 Jerramungup Zone
- 244 Ravensthorpe Zone
- 245 Esperance Sandplain Zone
- 246 Salmon Gums-Mallee Zone
- 248 Stirling Range Zone

25 Avon Province
- 250 South-eastern Zone of Ancient Drainage
- 253 Eastern Darling Range Zone
- 254 Warren-Denmark Southland Zone
- 255 Western Darling Range Zone
- 256 Northern Zone of Ancient Drainage
- 257 Southern Zone of Rejuvenated Drainage
- 258 Zone of Ancient Drainage
- 259 South-western Zone of Ancient Drainage

26 Kalgoorlie Province
- 261 Southern Cross Zone

27 Murchison Province
- 270 Undifferentiated Murchison Province
- 271 Irwin River Zone
- 273 Muggon Plains and Hills Zone

28 Pilbara Province

3 KIMBERLEY-ARNHEM-CAPE YORK REGION

30 Peninsula Province

31 Littoral Province

34 Kimberley-Arnhem-Macarthur Province

36 Daly Province

37 Victoria River Province

38 Ord-Fitzroy Province

5 CENTRAL SOUTHERN REGION

55 Nullarbor Province

58 Tarcoola-Quondong Province

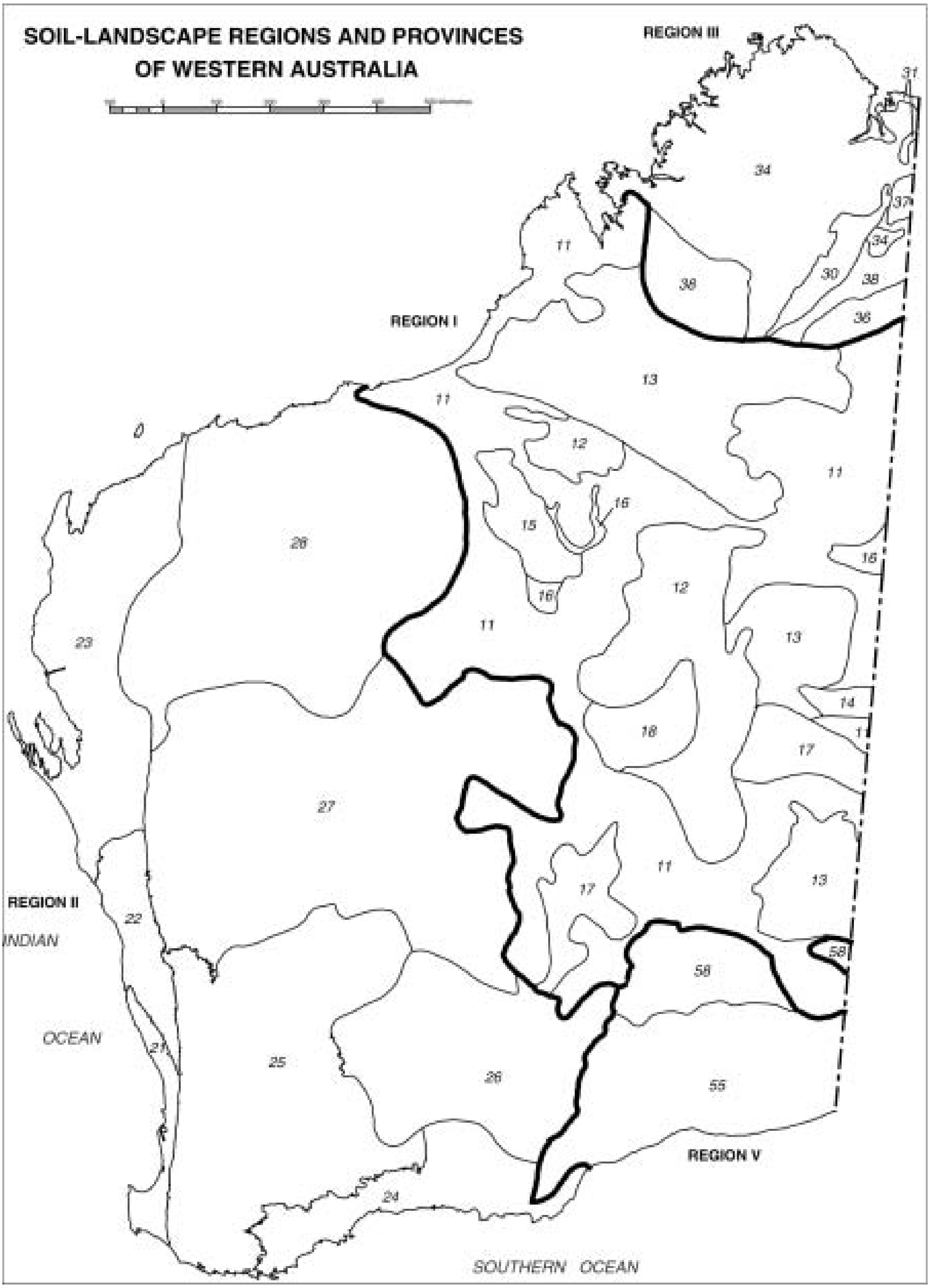

Figure A1: Soil-landscape regions and provinces in Western Australia (CSIRO 1983)

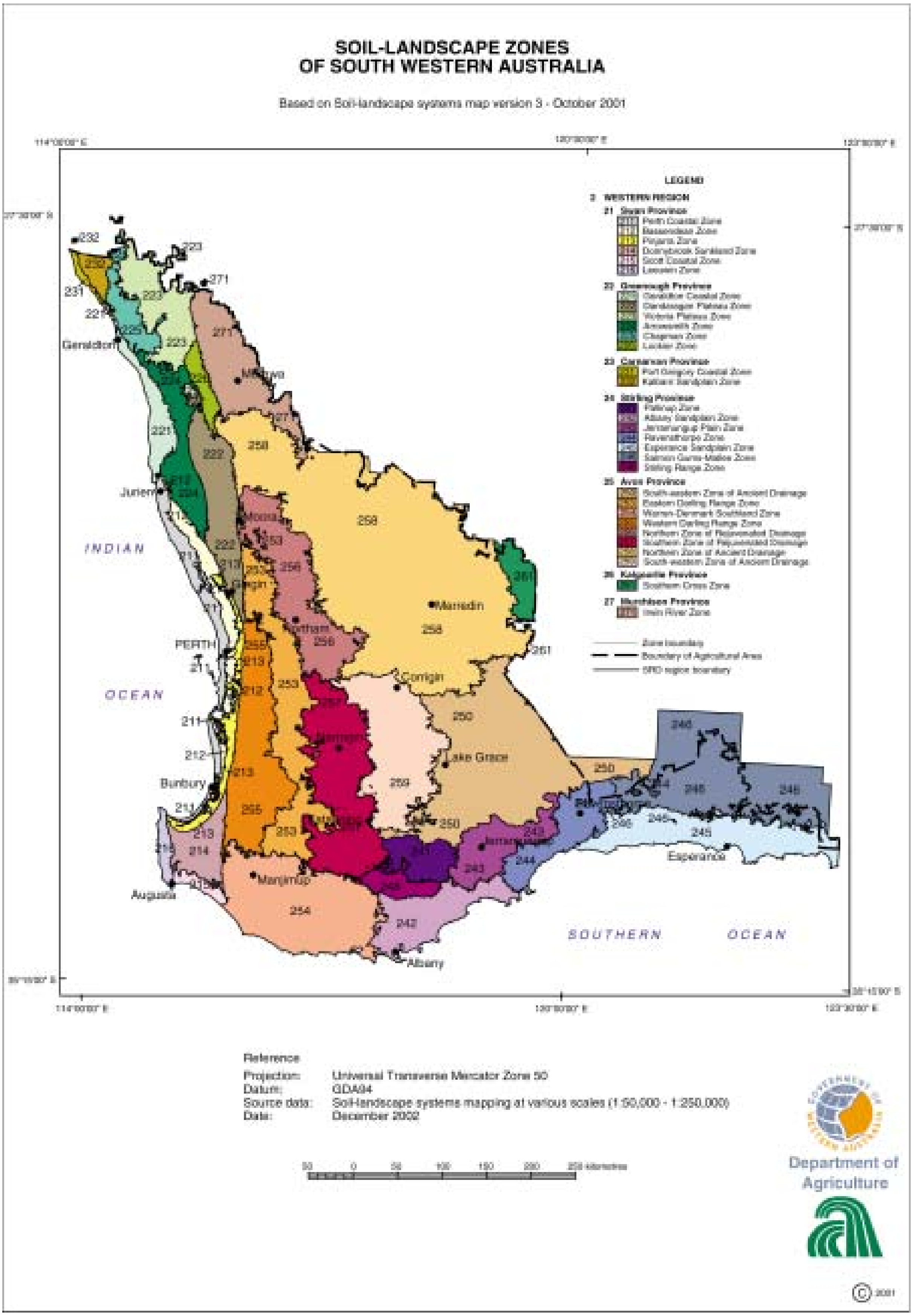

Figure A2: Soil-landscape zones of south-western Australia

Descriptions of regions, provinces and zones in WA (from Map Unit Database, Sept. 2004)

Code	Name	Description
1	Sandy Desert Region	Extensive erosional and depositional plains with salt lakes and sandy dunefields, out of which mesas, buttes and ranges rise sharply. A series of depositional basins that formed early in geological history and have persisted to the present.
11	Ayers-Canning Province	Low tablelands of ferruginous and kaolinised materials with laterite and silcrete, resulting from deep weathering of Permian, Jurassic and Cretaceous sandstone and Tertiary siltstones.
12	Gibson Province	Low tablelands of ferruginous and kaolinised materials with laterite and silcrete from deep weathering of Cretaceous sediments.
13	Simpson-Victoria Province	Large, long-established basin plains with sands derived from erosion of deep-weathering profiles and re-sorted during the Quaternary.
14	Macdonnell Province	High, rugged ranges of various Proterozoic to Devonian rocks. Localised plains at foot of ranges developed on alluvium derived from Proterozoic basalts.
15	Broadhurst Province	Narrow terraces bordering drainage lines and old watercourses. Calcrete common. Calcareous soils and sands.
16	Amadeus Province	Plains with playa lakes on alluvium periodically deposited in ancient valleys, deflated and resorted by wind. Saline and gypsiferous soils and sands.
17	Stuart-Burt Province	Stepped (terraced) plains on mixed sediments from weathering and reworking of Proterozoic to Ordovician rocks.
18	Murchison Province	Extensive plains with residuals of laterite or Precambrian igneous rocks. Drainage lines have extensive saline or calcrete deposits. Soils with red-brown hardpan (duripan) are common.
2	Western Region	Most of the region is a stable Precambrian shield with marginal depositional basins to the west. The shield has been continuously exposed to weathering and denudation since the Precambrian period.
21	Swan Province	Swan Coastal Plain from Busselton to Jurien. Pale and Yellow deep sands, semi-wet and wet soil, sandy and loamy gravel, Calcareous deep sands and Grey deep sandy duplex.
211	Perth Coastal Zone	Coastal sand dunes and calcarenite. Late Pleistocene to Recent (Quindalup and Spearwood Systems). Calcareous and siliceous sands and calcarenite.
212	Bassendean Zone	Mid-Pleistocene Bassendean sand. Fixed dunes inland from coastal dune zone. Non-calcareous sands, podsolised soils with low-lying wet areas.
213	Pinjarra Zone	Alluvial deposits (early Pleistocene to Recent) between the Bassendean Dunes Zone and the Darling Scarp, colluvial and shelf deposits adjacent to the Darling Scarp. Clayey to sandy alluvial soils with wet areas.
214	Donnybrook Sunkland Zone	Moderately dissected lateritic plateau on Perth Basin sedimentary rocks. Soils are formed in lateritic colluvium, sedimentary rocks weathered *in-situ* and alluvium (poorly drained sandy alluvial plain in the south).
215	Scott Coastal Zone	Pleistocene to Recent coastal barrier dunes and backplain. Non-calcareous sands dominate with podsolised soils with low-lying wet areas.
216	Leeuwin Zone	Leeuwin Block (tectonic geology), moderately dissected lateritic plateau on granite. Colluvial soils in the valleys. On the western margin the granite is overlain by Tamala Limestone and there are some coastal dunes.
22	Greenough Province	Lateritised plateau developed on Jurassic and Permian sediments and Proterozoic granites; dissected at fringes. There is a narrow coastal plain with Quaternary sands and calcarenite on the western margin.
221	Geraldton Coastal Zone	Dunes with alluvial plains and sand sheets. Low hills of Pleistocene Tamala Limestone, Recent calcareous and siliceous dunes.

Code	Name	Description
222	Dandaragan Plateau Zone	Gently undulating plateau with areas of sandplain and some laterite. On Cretaceous sediments. Broad u-shaped valleys 80-150 m deep, smaller v-shaped east of the Gingin Scarp in the south. Soils are formed in colluvium and weathered rock.
223	Victoria Plateau Zone	Gently undulating sandplain on Silurian sandstone and Proterozoic granulite with laterite exposed at dissected margins.
224	Arrowsmith Zone	Dissected lateritic sandplain on Cretaceous and Jurassic sediments. Bounded in the east by the Dandaragan Scarp and in the south and west by the Gingin Scarp. Sandy and gravelly soils formed in colluvium and rock weathered *in-situ*.
225	Chapman Zone	Mesas of Triassic and Jurassic sediments on undulating Proterozoic granulite and migmatite with numerous dolerite dykes. Soils formed in rock weathered *in-situ*, and lateritic colluvium on the sedimentary rocks (mesas).
226	Lockier Zone	River valleys of the Irwin, Lockier and Arrowsmith Rivers. Alluvial valley plains underlain by Proterozoic granulites, Permian and Jurassic sediments. Outliers of Victoria Plateau Zone occur within zone. Clayey to silty soils.
23	Carnarvon Province	Plains with some seif dunes, developed on Tertiary, Mesozoic and Palaeozoic sediments of the Carnarvon Basin.
231	Port Gregory Coastal Zone	Coastal dunes, calcareous in places. Undulating sandplain on limestone (Pleistocene calcarenite).
232	Kalbarri Sandplain Zone	Undulating sandplain on Silurian and Devonian sediments of the Gascoyne Sub-Basin (Carnarvon Basin), some Cretaceous sediments. Moderately dissected in places with laterite remnants.
234	Victoria-Yalbalgo Sandplain Zone	Sandplains and ridge dunes. Acacia shrub vegetation dominant, some spinifex in north.
235	Alluvial Zone	Alluvial flats and sandplain.
236	Wandagee Hills and Plains Zone	Stony hills and plains.
237	Shark Bay Zone	Partly dissected calcrete-duricrusted plateau, undulating limestone plains, undulating sandplain and coastal dunes.
238	Giralia-Cape Coastal Zone	Not described.
239	Yanrey Plains Zone	Sandplains and alluvial flats. Spinifex and tussock grasses.
24	Stirling Province	Lateritised plateau on Tertiary sediments, dissected at fringes. Emergent quartzite ranges, coastal headlands of gneisses and migmatites. Coastal dune systems in places.
241	Pallinup Zone	Undulating rises on Archaean granitic rocks in the Upper Pallinup catchment. Shallow duplex soils, commonly with sodic and alkaline subsoils. Woodlands of York and salmon gums, wandoo and yate dominate.
242	Albany Sandplain Zone	Gently undulating plain dissected by a number of short rivers flowing south. Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Soils are sandy duplex soils, often alkaline and sodic, with some sands and gravels.
243	Jerramungup Zone	Level to gently undulating plain dissected by a number of short rivers flowing south. On Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Alkaline sandy duplex soils with some clays, sands and gravels.
244	Ravensthorpe Zone	Rolling low hills on greenstone (mafic and ultramafic). Moderately dissected with south-flowing rivers. Red fine-textured soils.
245	Esperance Sandplain Zone	Level to gently undulating plain dissected by a number of short rivers flowing south. Formed on Eocene marine sediments overlying Proterozoic granitic and metamorphic rocks. Soils are grey fine sandy duplex soils and fine sands.

Code	Name	Description
246	Salmon Gums-Mallee Zone	Level to gently undulating plain, with Tertiary sediments over Proterozoic granites. Salt lakes, scattered or in swarms are a common feature. Drainage lines become indistinct towards the north.
248	Stirling Range Zone	Mountains on metasediments with associated rises and poorly drained plains to the north. Rocky and gravelly soils occur on the mountains and sandy duplexes on the rises and plain. Shrublands dominate the mountains and woodlands the rises.
25	Avon Province	The Avon Province comprises Precambrian granites and gneisses with past lateritic weathering. Soils may be calcareous, but red-brown hardpans are uncommon (Duric Great Groups).
250	South-eastern Zone of Ancient Drainage	A smooth to irregularly undulating plain dominated by salt lake chains in the main valleys with duplex and lateritic soils on the uplands. Mallee vegetation on duplex soils, Proteaceous vegetation on gravels and sands.
253	Eastern Darling Range Zone	Moderately to strongly dissected lateritic plateau on granite with eastward-flowing streams in broad shallow valleys, some surficial Eocene sediments. Soils are formed in laterite colluvium or granite weathered *in-situ*.
254	Warren-Denmark Southland Zone	Rises in a series of broad benches from the Southern Ocean north to the Blackwood Valley. Deeply weathered granite and gneiss overlain by Tertiary and Quaternary sediments in the south. Swampy in places.
255	Western Darling Range Zone	Moderately dissected lateritic plateau on granite with deeply incised valleys; includes the Darling Scarp on the western margin. Soils are formed in laterite, lateritic colluvium, granite weathered *in-situ* and gneiss.
256	Northern Zone of Rejuvenated Drainage	Erosional surface of gently undulating rises to low hills. Continuous stream channels that flow in most years. Colluvial processes are active. Soils formed in colluvium or rock weathered *in-situ*. Mainly from Jimperding Metamorphic Rocks.
257	Southern Zone of Rejuvenated Drainage	Erosional surface of gently undulating rises to low hills. Continuous stream channels that flow in most years. Colluvial processes are active. Soils formed in colluvium or rock weathered *in-situ*.
258	Northern Zone of Ancient Drainage	An ancient plain with low relief on weathered granite. There is no connected drainage, salt lake chains occur as remnants of ancient drainage systems which now only function in very wet years. Lateritic uplands dominated by yellow sandplain.
259	South-western Zone of Ancient Drainage	An ancient plain of low relief on weathered granites with sluggish drainage systems and uplands dominated by sands and gravels. Lateritic uplands dominated by grey sandy gravel plain predominately with Proteaceous species.
26	Kalgoorlie Province	Laterised plateau on Precambrian granites and gneisses with greenstone belts. Salt lake chains with much dissection near major salt lakes. Aeolian dust present. Soils may be calcareous, but red-brown hardpans are uncommon.
261	Southern Cross Zone	Rises and low hills on Archaean greenstones, with broad valleys often containing salt lake chains. Soils are usually red, loamy to clayey and calcareous.
27	Murchison Province	Extensive plains with residuals of laterite or Precambrian igneous rocks. Drainage lines have extensive saline or calcrete deposits. Soils with red-brown hardpan (duripan) are common.
270	Undifferentiated Murchison Province	Not described.
271	Irwin River Zone	The Irwin and Lockier River catchments within the Yilgarn Craton. Archaean granites, gneisses, metasediments and basic igneous rocks.
273	Muggon Plains and Hills Zone	Sandplains, saline plains and stony hills. On Carboniferous/Permian sediments of the Carnarvon Basin (and small portion of Perth Basin and Bangemall Group).

Code	Name	Description
28	Pilbara Province	Rugged ranges and hills with well-defined river valleys developed in a terrain of Precambrian granites and metamorphics, and Palaeozoic sediments. Narrow coastal plains.
3	Kimberley-Arnhem-Cape York Region	Landscapes are undulating plains, rugged dissected plateaux and ranges. Varied geology, Archaean to Cainozoic. Monsoonal climate with little rain in the May-October period.
30	Peninsula Province	Erosional strongly undulating to mountainous landscape formed in Proterozoic metamorphics and Palaeozoic granitic rocks and acid volcanics. Small areas of plains on Cainozoic sediments.
31	Littoral Province	Depositional landscape of estuarine and riverine alluvial deposits with some beach ridge development.
34	Kimberley-Arnhem-Macarthur Province	Erosional landscape of rugged, dissected tablelands and plateaux formed in mainly siliceous Proterozoic sandstones. Some interbedded basic volcanics.
36	Daly Province	Part of a largely undissected, deeply laterised Early or Mid-Tertiary surface formed on Cretaceous sediments.
37	Victoria River Province	A mainly erosional undulating landscape derived from calcareous, arenaceous and argillaceous Proterozoic sediments and Lower Cretaceous volcanics. Some alluvial plains formed by major rivers.
38	Ord-Fitzroy Province	Mainly rugged topography of considerable relief derived from Lower Cambrian basalt and associated limestone, and Lower Proterozoic steeply folded metasediments, metavolcanics and associated intrusions. Small areas of alluvial plains.
5	Central Southern Region	Proterozoic and Cambrian rocks overlain in the north and west by Cretaceous and Miocene marine sediments. Winter-dominant rainfall.
55	Nullarbor Province	Flat plain on Miocene limestone. Calcrete common. Calcareous soils.
58	Tarcoola-Quondong Province	Plains and dunes of Cainozoic calcareous sediments.