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Agricultural sub-regions of the Avon River basin

Paul D. Galloway

Department of Agriculture
Government of Western Australia

AGRICULTURAL SUB-REGIONS OF THE AVON RIVER BASIN

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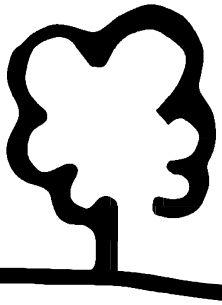

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Agricultural sub-regions of the Avon River Basin

by Paul Galloway

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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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Summary

This report identifies, describes and locates nine sub-regions within the land cleared for agricultural uses in the Avon River Basin (ARB). The sub-regions are:

- Darling Range
- Dale/Upper Avon
- Avon Valley
- Yealering Lakes
- Mortlock
- Northern Sandplain
- South-east Lakes
- Carrabin
- Southern Cross.

Such sub-division is considered necessary and appropriate for regional-scale agricultural planning and for natural resource management related to agriculture. It also facilitates the spatial interpretation of the status of natural resources used by agriculture. These agricultural sub-regions are, in essence, planning units and could be used for other regional planning purposes.

The sub-regions are described in terms of their distinguishing biophysical characteristics of:

- soils and related original vegetative cover;
- general topography;
- surface and sub-surface hydrological status;
- underlying geology; and
- rainfall and evapo-transpiration range.

Current dominant land use, economic drivers and land use pressures are identified for each sub-region.

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1. Introduction

The Avon River Basin (ARB) forms the catchment of the Avon River and tributaries, and is defined by the Water and Rivers Commission as basin 615 (WRC 1996). It covers nearly 12 million hectares of heterogeneous landscape and is afflicted by numerous forms of environmental degradation caused largely by inappropriate management. In the past, numerous geographical sub-divisions have been applied to the basin with the aim of better understanding and managing the land, social groups, infrastructure and bio-physical assets, by grouping similar features together to create units that are more homogeneous and / or manageable. However, as summarised below, these sub-divisions are not appropriate for regional-scale agricultural planning or reporting on the natural resource issues affected by and affecting agriculture.

The first sub-division within the basin was the creation of local government authorities (LGAs), mostly shires, mainly to maintain roads. The basin encompasses and/or intersects some 44 local government authorities (see Figure 1). These authorities still manage many roads within their jurisdictions. They also collect rates from landholders and fund Community Landcare Coordinators (CLCs). They often form the boundaries for Land Conservation District Committees (LCDCs). Most landholders strongly associate with a shire. For these reasons, they are a useful sub-division for the social aspects. However, shire boundaries are not based on bio-physical attributes of the land and so the sub-division does not group areas affected by similar natural resource issues.

The Avon Catchment Council (ACC) is the regional governing body for natural resource management of the basin. The ACC adopted the long-established Avon, Lockhart and Yilgarn sub-catchments (cited in Kenny 1996) to ensure local communities were properly represented in Avon Catchment Council matters. These sub-catchments follow major watersheds and group landscapes very broadly. However, their scale (useful at 1:1,000,000) is such that many significant differences in bio-physical attributes and farming landscapes are not differentiated. Consequently, they have limited value for regional-scale strategic agricultural planning and the bio-physical aspects of natural resource management. They do, however, provide a useful grouping for social aspects.

Kenny (1996) conducted sub-catchment mapping for the Water and Rivers Commission, which defined all sub-catchments containing a third-order terminal stream. This mapping distinguished areas in the order of 10,000 to 250,000 hectares, which are suitable for local-scale catchment planning (i.e. 1:25,000 to 1:50,000 scale), and have been used widely to define ‘catchment groups’ for landcare purposes. Some 726 sub-catchments have been defined within the basin, far too many to be useful for strategic planning purposes.

The Department of Agriculture has divided the area by climatic parameters, to assist delivery of crop variety and suitability information to farmers. These Crop Variety Trial (CVT) areas are based on average annual isohyets intersected by annual evapo-transpiration isopleths. This sub-division broadly suits agronomic purposes and is applicable at scales suitable for regional planning. However, it does not account for other bio-physical attributes that impact on agricultural and natural resource management.

The Department of Agriculture has also conducted soil-landscape mapping across the basin. In the area cleared for agriculture, this mapping groups landscapes according to landforms, topography, soil types and related native vegetation associations. It is hierarchical and so can be amalgamated as necessary to suit the scale required (Schoknecht and Tille 2002). An amalgamation of soil-landscape units to ‘zone’ level best suits regional-scale agricultural planning and resource condition assessment. However, this is not ideal, as it fails to properly account for climatic gradients, particularly in the east of the cleared area. The alternative, an

amalgamation of units to 'system' level, accounts for climatic gradients but introduces excessive complexity for regional planning purposes.

Department of Agriculture hydrologists have defined hydrological zones (HDZs), which derive from the soil-landscape mapping (Ghauri 2004). The HDZs are based mostly on soil-landscape zones, but group soil-landscape systems where appropriate in the east, in part to account for the climatic gradients. Each HDZ has broadly similar hydrological regimes – a result of similar geology, topography, soils and climate. Seventeen HDZs exist in the basin, too many divisions for regional planning. Furthermore, some occupy very small areas, which introduces unnecessary detail and confounds regional planning exercises.

The divisions described above serve the purposes for which they are intended. However, they are unwieldy to define areas considered similar in an agricultural sense, at regional scales. Thus, 'agricultural sub-regions' are needed to report on natural resource issues and to plan for sustainable agriculture.

Agricultural sub-regions must address the following criteria to initiate further agronomic differentiation and to promote more ecologically and socially sustainable management:

- Separate areas with distinct bio-physical characteristics that affect agriculture.
- Differentiate between areas that are threatened by distinct resource degradation issues at regional scale. (This is necessary despite some degradation processes being widespread, largely due to similar and ubiquitously inappropriate agricultural management.)

As resource management issues often prevail on a sub-regional basis, management strategies are often best directed to specific sub-regions to deliver the greatest return from public funds. Recommended management is usually best delivered at the local (catchment, farm and/or paddock) scale, following site assessment.

Understanding of the unique bio-physical attributes of each agricultural sub-region should enable the development of more specialised farming systems particularly suited to the characteristics and issues of each sub-region.

In the following three sections the location and physiography of the Avon River Basin is briefly described; the data and methods used to define the agricultural sub-regions are discussed; and the agricultural sub-regions are described and mapped.

2. Overview of regional geography

2.1 Location and area

The Avon River Basin (ARB) occupies 11.8 million hectares of the central and eastern wheatbelt and southern rangelands of WA (see Figure 1).

The western two-thirds of the catchment, some 8.3 million hectares, has been largely cleared of native vegetation for crop and pasture production in dryland agricultural systems. This area is defined as the Intensive Land-use Zone or ILZ (Graetz *et al*. 1995, Beeston *et al.* 2002). Over 1.1 million hectares (15%) of the ILZ retains its original vegetation cover, including 648,000 hectares of Crown land reserved for conservation, recreation and production purposes. Remnant vegetation on private land occupies 491,000 hectares (6.7%) of the ILZ. Other land uses are negligible (NLWRA 2001).

The remaining 3.5 million hectares in the east is known as the Extensive Land-use Zone or ELZ (Graetz *et al*. 1995). It retains pre-European vegetation communities and comprises vacant Crown land and rangelands leased for 'low-intensity' grazing. The ELZ is not considered further in this report.

Figure 1 shows local government authorities in relation to the Avon River Basin and the demarcation line between the Intensive and Extensive Land-use Zones.

2.2 Basin physiography

The Avon River Basin forms part of the Great Plateau of Western Australia. It lies largely on crystalline rocks of Archaean age that have weathered variably to produce deep (commonly 10 to 30 metres) and shallow regolith profiles. The rocks mostly comprise granite plutons surrounded by gneisses (Gee 1978). Ancient metamorphosed volcanic sediments persist at the western and eastern margins of the ILZ. In the west, the Avon Valley intersects the Jimperding metamorphic belt. In the east, belts of greenstone traverse the basin in a generally north-south direction. These lie mostly in the ELZ, with one significant occurrence in the eastern-most part of the ILZ around Marvel Loch and Southern Cross, and one small outlier between Bencubbin and Koorda. Dolerite dyke suites of Proterozoic age that generally trend in a south-west to north-east direction have intruded these older granitic, gneissic and metamorphic rocks. Most valleys have been extensively in-filled with unconsolidated sediments of Tertiary age (Salama 1997).

Topography across most of the basin is gently undulating with broad, generally low-relief uplands and flat-bottomed valleys. Most of the basin is internally drained, with salt lake chains low in the landscape which flow to the Avon and Mortlock Rivers only in wetter years. In contrast, the western margin has undulating hills with actively eroding valleys, through which flow the Dale River, Toodyay Brook and lower reaches of the Avon River, along with the tributaries of these water courses (Lantzke and Fulton 1993, Verboom and Galloway 2004). These rivers flow regularly and the waters ultimately reach the Indian Ocean via the Swan River.

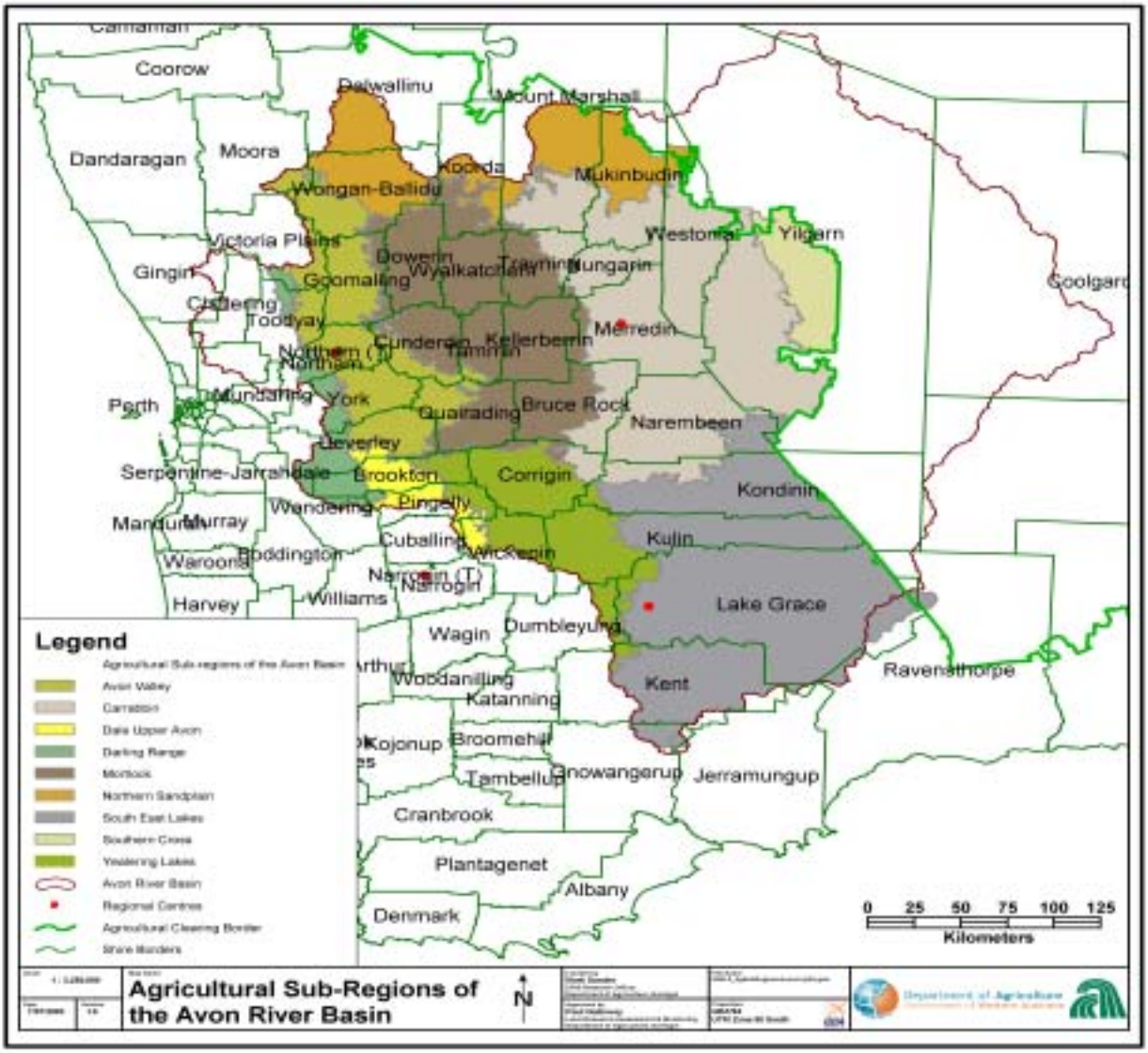

Figure 1: Geographic extent of Avon River Basin, showing local government authority boundaries and extent of agricultural sub-regions

Broad valley floors of the central and eastern basin contain mostly loamy duplexes, loamy earths and clay soils, all with calcareous subsoils. These were originally vegetated by eucalypt woodlands, principally salmon gums and gimlets with various mallee-types increasing further east. Slopes in the east are dominated by sandy duplexes with sodic subsoils, originally vegetated by mallee-form eucalypts. Lateritic terrain of ironstone gravel and sandplain occupies crests and slopes across the basin with the original vegetation being a diverse flora dominated by proteaceous heath. Lateritic terrain in the north is dominated by yellow sandplain, while in the south by grey sands overlying ironstone gravels. The hills in the west have ironstone gravelly soils vegetated by jarrah and marri forest with a heath-type understorey. Sandy duplex soils on slopes and valley floors in the west are vegetated by wandoo woodland. Table 1 lists the main soils, as classified by Schoknecht (2002) and documented in Department of Agriculture databases. The main soils of each agricultural sub-region are presented in tabular form in Appendix 1.

Table 1: Main soil types of the ARB in decreasing order

Soil type	Brief description	Area	
		('000 ha)	(%)
Deep sandy duplexes	Sandy surface and a texture or permeability contrast at 30-80 cm	977	13
Shallow loamy duplexes	Loamy surface and a texture contrast at 3-30 cm	964	13
Sandy earths	Sandy surface, grading to loam by 80 cm. May be clayey at depth	937	13
Loamy earths	Loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm	924	13
Shallow sandy duplexes	Sandy surface and a texture or permeability contrast at 3-30 cm	870	12
Ironstone gravels	Ironstone gravels or duricrust dominant within the top 15 cm	792	11
Deep sands	Sands greater than 80 cm deep	546	7
Wet or waterlogged	Seasonally wet within 80 cm of the surface for a major part of the year	390	5
Shallow sands	Sands less than 80 cm deep over rock, hardpan or other cemented layer	236	3
Rocky or stony	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile.	168	2
Non-cracking clays	Clay surface at least 30 cm thick that does not crack strongly when dry	163	2
Cracking clays	Clay surface at least 30 cm thick that does crack strongly when dry	119	2
Shallow loams	Loam 80 cm deep, over rock, hardpan or other cemented layer	117	2
Deep loamy duplexes	Loamy surface and a texture contrast at 30 to 80 cm	116	2
Miscellaneous soils	Other minor soils	45	<1
TOTAL		**7,377**	**100**

3. Agricultural sub-regions

3.1 Data and methods used

The ILZ has been sub-divided into nine agricultural sub-regions (see Table 2), each with distinct bio-physical characteristics. Descriptions of the characteristics of each agricultural sub-region were collated from various sources. Geological descriptions are simplified derivations of Geological Survey of Western Australia reports, an overview of which is contained in the map by Gee (1978). More detailed information was gleaned from Gee (1979), Wilde and Low (1980), Thom *et al.* (1984), Blight *et al*. (1984), Chin *et al.* (1984) and Chin (1986a, 1986b). Soil and landscape descriptions are simplified derivations of soil-landscape mapping from Department of Agriculture databases (Department of Agriculture 2003a), which in turn derive from the following reports:

- Bettenay and Hingston (1961)
- Churchward and McArthur (1978)
- Frahmand (unpublished data)
- Grealish and Wagnon (1995)
- Lantzke and Fulton (1993)
- McArthur (1992)
- Overheu (unpublished data)
- Percy (2000)
- Percy and Roberts (2003)
- Verboom and Galloway (2004)
- Verboom and Frahmand (unpublished data).

Vegetation descriptions are much-simplified overviews of each sub-region, derived from information in Shepherd *et al*. (2002), Beeston *et al*. (2002), and several soil-landscape reports, mentioned above. Climatic information derives from summary information from the Bureau of Meteorology and held under licence by the Department of Agriculture (extracted from Department of Agriculture database by D. Shepherd, 2003).

The spatial extent of the sub-regions was defined by the extent of 17 hydrological zones (HDZs) that lie within the ARB (see Ghauri 2004). The spatial relationship between hydrological zones, isohyets and evapo-transpiration isopleths is shown in Figure 2.

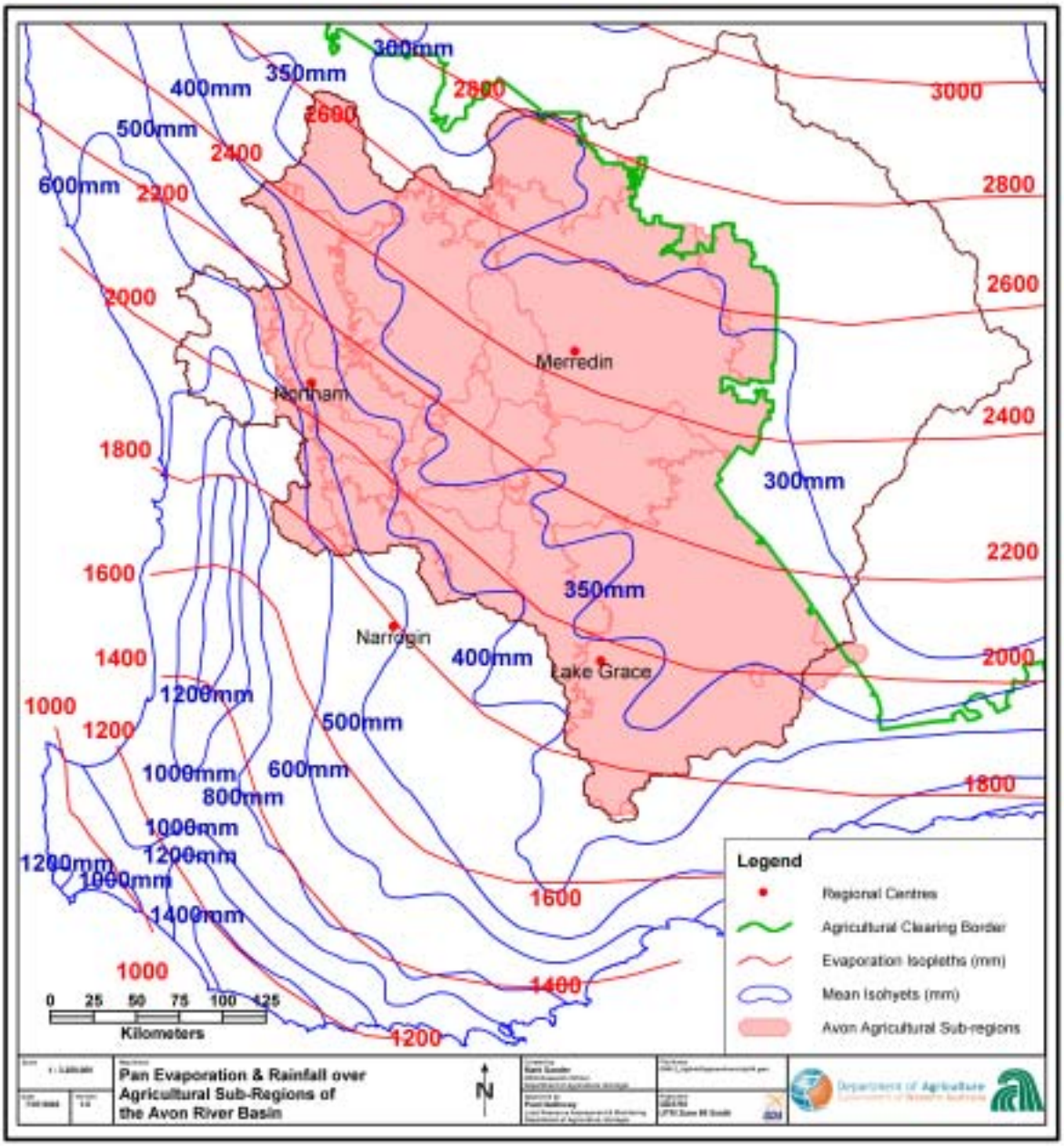

Figure 2: Hydrological zones, isohyets and evapo-transpiration isopleths in the Avon River Basin (produced by D. Shepherd, 2003

Table 2 lists the hydrological zones that have been used to create agricultural sub-regions and which of these have been amalgamated to form meaningful regional-scale areas for agriculture. Descriptions of hydrologic characteristics of each sub-region derive from Ghauri (2004), experience of the author and personal communication with local hydrologists. Ghauri suggests that dividing the landscape into the above 'hydrozones' does not necessarily assist interpretation of hydrological processes at a regional scale. Nevertheless, I have attempted to fit his regional prognoses into agricultural sub-regions to define each sub-region as explicitly as possible.

Broad agronomic systems and land use trends of each of the agricultural sub-regions are described from personal local experience and the experience of other local agronomists.

Local Department of Agriculture officers assigned names to agricultural sub-regions subjectively, using derivations and combinations of names already in common use wherever possible (e.g. SOUTH-EAST LAKES for the Lakes District of the Lockhart catchment). Where confusion with previously defined regions could occur (e.g. Avon, Lockhart, Yilgarn) extensions were given (e.g. Avon VALLEY) to distinguish the sub-region from a previously defined region. Alternatively, the name of a siding, central to the area, was adopted (e.g. CARRABIN in the Yilgarn area).

The area of each sub-region used for agriculture (Table 2) has been calculated from the National Land and Water Resources Audit land use theme (NLWRA 2001). These areas form the spatial basis for reporting on the condition of natural resources used and directly affected by agriculture. This is documented in Resource Management Technical Report 288.

Note that apparent (small) errors in the areas may result from:

- methods used to generate National Land and Water Resources Audit datasets, where all remnant vegetation of less than 50 ha on private land was classed as 'agricultural land';
- 'smoothing' (vector weeding) the NLWRA land use spatial data to simplify the dataset;
- rounding numbers from more precise figures in original datasets.

Table 2: Agricultural sub-regions and parent hydrological zones within the Intensive Land-use Zone of the Avon River Basin, listed in descending area

Agricultural sub-region	Parent Hydrological Zones	Total area ('000 ha)	Agricultural area	
			('000 ha)	(% of total)
Darling Range	253a	224	148	2
Dale/Upper Avon	257a	169	163	2
Avon Valley	256	833	813	11
Yealering Lakes	259a and 259b	679	661	9
Mortlock	258c	1,370	1,326	18
Northern Sandplain	258b	738	687	9
South-east Lakes	250a, 250b, 241a, 241e, 243a, 243d, 243f	2,018	1,606	22
Carrabin	258d	2,033	1,794	24
Southern Cross	261	249	189	3
Total ILZ part of Avon Basin		**8,313**	**7,387**	**100.0**

3.2 Descriptions of agricultural sub-regions

Each of the agricultural sub-regions is described below, listed from the higher rainfall west to the lower rainfall east and south to north. Key agronomic parameters are compared in Table 3 (main soils); Figure 3 (rainfall range); and Figure 4 (evapo-transpiration).

3.2.1 Darling Range

The Darling Range sub-region occupies the west of the Avon River Basin and encompasses the towns of Westdale, Clackline and Bakers Hill. Average annual rainfall ranges from 700 to 450 mm and evaporation from less than 1800 to 2200 mm/yr. It overlies gneissic and granitic basement of the western margin of the Yilgarn Craton with rolling hills that have been variably dissected by the eastward-flowing tributaries of the Dale and Avon Rivers. The dominant soils are ironstone gravels originally vegetated by jarrah forest. Topographic and hydrologic gradients are enough to maintain discharge and limit salinity to narrow valley floors and hydrologic constrictions, such as bedrock highs and dolerite dykes.

Major land uses are grazing for wool and meat production, and forestry. Agriculture is diversifying, with a focus on perennial horticulture and plantation forestry. New crops include wine grapes, citrus, olives and pistachios. Sub-division of agricultural land for rural-residential use is occurring in parts and likely to become much more prominent, which has implications for agricultural production and local demography. The increasing intensity of land use and generally decreasing experience of land managers has particular implications for biosecurity of private and public land.

3.2.2 Dale/Upper Avon

The Dale/Upper Avon sub-region lies on granites in the western wheatbelt and woolbelt and includes the towns of Brookton and Pingelly. Average annual rainfall ranges from 450 to 380 mm and evaporation from 1800 to nearly 2000 mm/yr. The Dale River and south branch of the Avon River have incised the landscape, forming undulating hills with common granite rock outcrops and sandy and loamy duplex soils. These soils were originally vegetated by York gum, wandoo and jam woodlands with jarrah/marri woodlands in the west and flooded gums on the river flats. Rivers and streams flow to the Swan River regularly. Groundwater hydrology has not been adequately characterised but is likely to be intermediate between the Dale/Upper Avon and Darling Range sub-regions.

Farm production varies from west to east, with the west having more animal-dominated enterprises (wool and sheepmeat), oats and hay, although cropping has increased significantly in recent years. Farms to the east and north are generally balanced cropping/livestock enterprises. Frosts occur commonly, but the risk of catastrophic crop damage is effectively managed by delaying sowing and growing tolerant crops.

Rural-residential small-holdings are increasing on transport routes between Perth and the population nodes of Brookton and Beverley. Pingelly also has a small number of small-holdings.

3.2.3 Avon Valley

The Avon Valley sub-region lies on the metamorphosed volcanic rocks of the Jimperding metamorphic belt in the western wheatbelt and northern woolbelt. This encompasses the towns of Beverley, Bolgart, Goomalling, Meckering, Northam, Toodyay, Wongan Hills and York. Average annual rainfall ranges from 450 to 350 mm and evaporation from 1900 to 2400 mm/yr. The landscape has been incised by the Avon River and Toodyay Brook, forming undulating hills with rocky outcrops. Dominant soils are red loams, known as the

Avon Valley loams, originally vegetated by York gum and jam woodlands, with flooded gums along river flats. Rivers and streams flow to the Swan River regularly and ephemeral streams are often mildly saline, particularly towards the east and north. External drainage and topographic gradients result in a low risk of much-increased salinity expression. Groundwaters in the west have electrical conductivity readings of typically less than 1000 mS/m, while those of the east increase to around 1500 mS/m.

Farm production varies from west to east, with the west having more animal-dominated enterprises (wool and sheepmeat), oats and hay production, although cropping has increased significantly in recent years. Farms to the east and north are generally balanced cropping/livestock enterprises. Rural-residential small-holdings are significant and increasing land uses around population nodes, especially York, Northam and Toodyay, and on transport routes to Perth.

3.2.4 Yealering Lakes

Yealering Lakes lies on granites and gneisses in the central wheatbelt and Great Southern, encompassing the towns of Corrigin, Kulin, Wickepin and Yealering. Average annual rainfall ranges from 400 to 340 mm and evaporation from 1900 to 2100 mm/yr. The area is characterised by low relief landscapes. Uplands are dominated by lateritic gravelly grey sandplain originally vegetated by diverse heath. Flat valleys (2-3 km wide) are dominated by sandy duplex soils originally vegetated by salmon gum and wandoo woodland. The sub-region forms the upper reaches of the main branch of the Avon River, which has sluggish drainage that improves towards the north-west. Salinity has mostly become apparent since the 1940s and most lakes were fresh prior to clearing (Verboom and Galloway 2004). Electrical conductivity of local groundwater is commonly between 2000 and 4000 mS/m. Regional groundwater is often hypersaline, but acid groundwater is not as common as in sub-regions to the east and north.

Agriculture is balanced between cropping of annual cereals (mainly wheat, with some barley) and grain legumes, and grazing sheep. Frosts are common, but the risk of catastrophic crop damage is effectively managed by delaying sowing of susceptible crops and accepting the yield penalties that this risk management strategy incurs (ConsultAg 2001).

3.2.5 Mortlock

Mortlock lies on granites and gneisses in the central wheatbelt and encompasses the towns of Bruce Rock, Cunderdin, Dowerin, Kellerberrin, Koorda, Quairading, Tammin, Trayning, and Wyalkatchem. Average annual rainfall is 350 to 300 mm and evaporation ranges from 2000 to 2500 mm/yr. The sub-region is characterised by gently undulating and low relief landscapes with sluggish drainage through salt lake systems in broad valley floors (5–8 km wide). Drainage improves towards the western margin. Crests and upper slopes are typically yellow sands and sandy earths originally vegetated by diverse heath. Lower slopes are sandy duplex soils and valley floors are loamy earths and loamy duplexes. Lower slopes and valleys were originally vegetated by eucalypt woodlands dominated by York and salmon gums. Perched aquifers are extensive and common in the west, a consequence of the extensive sandy soils. Salinity of regional groundwater varies from about 2000 mS/m in the west to 5000 mS/m in the east. Groundwater in valley palaeo-channels is often hypersaline and acid.

Agriculture is dominated by cropping annual cereals and grain legumes, with a recent decline in animal husbandry caused by low sheep prices. This may change with improving economic circumstances for livestock.

3.2.6 Northern Sandplain

The Northern Sandplain lies on granites and gneisses in the north-eastern wheatbelt and encompasses the towns of Ballidu, Beacon, Bonnie Rock, Cadoux, Dalwallinu, Gabbin and Pithara. Average annual rainfall varies from 350 to 300 mm and evaporation ranges from 2400 to 2800 mm/yr. During summer, much of this area is regularly affected by both localised thunderstorms and remnants of more widespread cyclonic activity. Thus, a higher proportion of rainfall falls over the summer than other sub-regions. The landscape is characterised by very low relief with slow-moving drainage through salt lake systems in broad valley floors (5–8 km wide). Crests and upper slopes are dominated by yellow sands and sandy earths, originally vegetated with diverse heath. Lower slopes and valley floors are typically loamy earths and loamy duplexes, both with calcareous subsoils, originally vegetated by salmon gum and gimlet woodland. Perched aquifers are more extensive and common, a consequence of the extent of sandy soils and prevalence of summer rainfall which infiltrates to groundwater. The salinity of regional groundwater varies from about 2000 mS/m in the west to 5000 mS/m in the east, although groundwater in valley palaeo-channels can be hypersaline (Ghauri 2004).

Agriculture is dominated by cropping annual cereals and grain legumes, with a recent decline in animal production caused by low sheep prices. This may change with improving economic circumstances for livestock.

3.2.7 South-east Lakes

The South-east Lakes sub-region lies on granites and gneisses in the south-eastern wheatbelt and encompasses the towns of Kondinin, Holt Rock, Hyden, Lake Grace, Lake King, Newdegate, Pingrup and Varley. Average annual rainfall varies from 400 to 320 mm and evaporation ranges from 1800 to 2200 mm/yr. The sub-region is characterised by gently undulating and low relief landscapes with sluggish drainage through salt lake systems in broad valley floors (5–8 km wide). Crests and slopes are typically duplex soils with some gravels, originally vegetated by mallee-form eucalypts, interspersed with scattered heath. Lower slopes and valley floors are typically sandy and loamy duplexes, usually with sodic and calcareous subsoils. These soils were originally vegetated by salmon gum, melaleuca, moort and yate woodland. Electrical conductivity of local groundwater is commonly 4000 mS/m. Regional groundwater is often hypersaline, but acid groundwater is only common in the far north. Elsewhere, pH trends towards neutral.

Agricultural production is driven by cropping annual cereals (mainly wheat, with some barley) and grain legumes. In recent years cropping has increased and grazing of sheep has decreased. Frost is a significant risk to annual grain yields (particularly wheat) in this sub-region. The high proportion of sandy-surfaced soils in low-lying areas increases frost risk. Management options to bypass the damaging effects of frost are limited because the window of opportunity for profitably sowing crops corresponds to crop-maturation during times of high frost risk (ConsultAg 2001).

3.2.8 Carrabin

Carrabin sub-region lies on granites and gneisses in the eastern wheatbelt and encompasses the towns of Bencubbin, Merredin, Mukinbudin, Muntagin, Narembeen, Nungarin, and Westonia. Average annual rainfall varies from 320 to 300 mm and evaporation from 2200 mm/yr to nearly 2800 mm/yr. A significant proportion of rain falls over summer in localised storms and cyclonic depressions from the north. The sub-region is characterised by very low relief with sluggish drainage through salt lake systems in broad valley floors (5–8 km wide). Crests and upper slopes are typically yellow sands, sandy earths and gravels. Original vegetation on these soils was diverse heath. Lower slopes and valley floors have loamy earth

and loamy duplex soils, both with calcareous subsoils, originally vegetated by salmon gum and gimlet woodland. Groundwater has electrical conductivity levels about 5000 mS/m and is regularly hypersaline and strongly acid in regional valley floors.

Agriculture is dominated by cropping annual cereals and grain legumes, with a recent decline in animal production caused by low sheep prices. This may change with improving economic circumstances.

3.2.9 Southern Cross

The Southern Cross sub-region lies on greenstone terrain with some granitic inclusions in the far eastern wheatbelt. It encompasses the towns of Marvel Loch and Southern Cross. Average annual rainfall is about 300 mm and evaporation ranges from 2500 to 2700 mm/yr. The landscape is characterised by very low relief with sluggish drainage and isolated salt lakes in broad valley floors (5–8 km wide). The characteristic greenstone terrain has crests, slopes and broad valley floors of red loamy earth and clay soils, originally vegetated by eucalypt woodland of morrel, salmon gum and gimlet. The hydrologic regime within the greenstone terrain appears significantly different to that of the granitic terrain that dominates the geology of the basin. Watertable levels within mines in greenstone terrain are commonly 10 to 20 metres deep, although these observations should be treated with caution as data are very limited (Ghauri 2004). Within the smaller areas of granitic terrain, broad crests and upper slopes are typically yellow sands, sandy earths and gravels originally vegetated by 'wodjil' - a tall *Grevillea* and *Acacia* spp. shrubland. Lower slopes and valleys in granitic terrain have duplex soils originally vegetated by mallee-form eucalypts.

Agriculture is dominated by cropping of annual cereals and grain legumes, with a recent decline in animal husbandry caused by low sheep prices. This may change with improving economic circumstances for livestock.

3.3 Comparison of agricultural sub-regions

Table 3 and Figures 3 and 4 compare the soils, average rainfall and evapo-transpiration of the nine regions.

Table 3: Comparison of main soils within each sub-region by percentage and overview of the ARB*

Main soils (derived from WA Soil Groups)	Total ARB	Darling Range	Dale/Upper Avon	Avon Valley	Yealering Lakes	Mortlock	Northern Sandplain	South-east Lakes	Carrabin	Southern Cross
Cracking clays	<2	-	-	2	-	-	3	-	-	7
Deep loamy duplexes	<2	4	6	6	-	-	-	-	-	-
Deep sands	7	8	13	10	8	10	8	4	6	13
Deep sandy duplexes	13	16	26	24	22	12	-	15	9	4
Ironstone gravelly soils	11	39	9	6	18	8	9	10	12	6
Loamy earths	13	3	6	4	8	9	21	11	18	29
Non-cracking clays	2	-	3	3	-	-	-	4	-	6
Rocky or stony soils	2	5	5	3	-	-	3	-	4	-
Sandy earths	13	3	8	12	5	13	35	6	15	11
Shallow loams	<2	2	3	2	-	-	-	-	3	-
Shallow loamy duplexes	13	6	6	7	10	22	12	7	18	7
Shallow sands	3	4	4	7	-	3	-	6	-	4
Shallow sandy duplexes	12	4	8	9	19	10	4	23	7	7
Wet or waterlogged soils	5	4	3	5	4	7	-	10	3	3

* The summary column documenting percentages of soils within the Avon River Basin is shaded pale-grey. Boxes shaded dark-grey represent the most common soil in each sub-region. Boxes shaded mid-grey represent the second-most common soil in each sub-region.

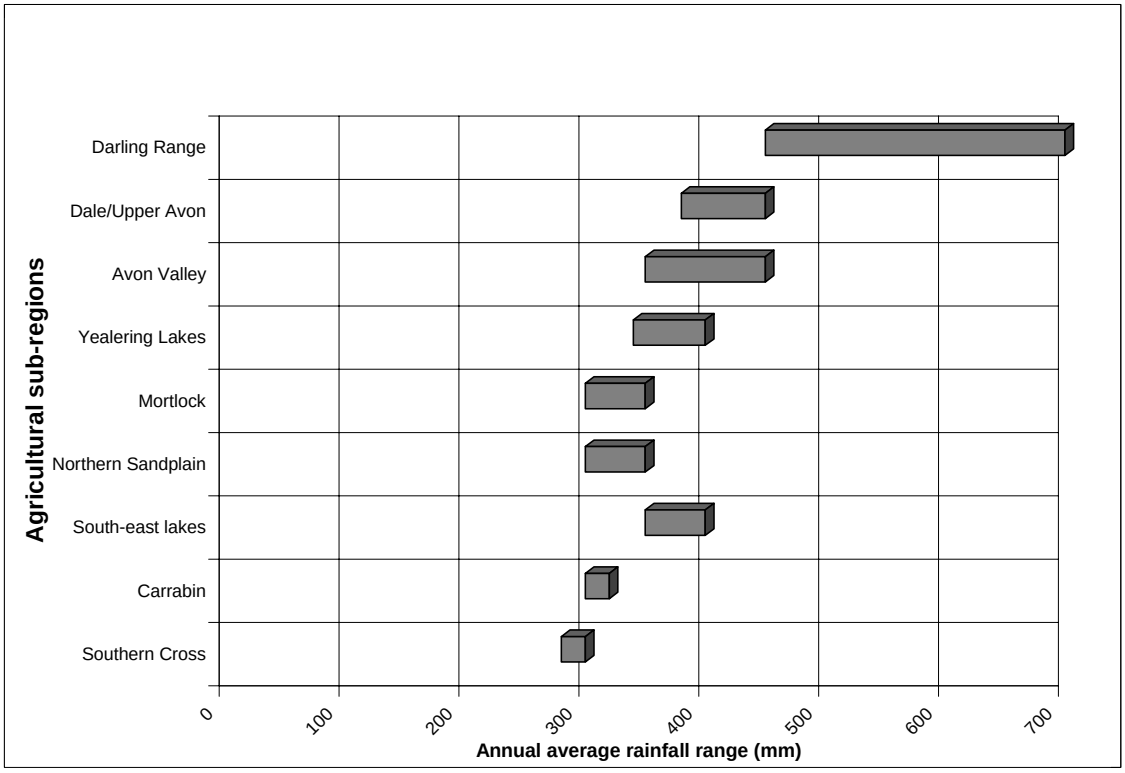

Figure 3: Annual rainfall range of agricultural sub-regions of the ARB

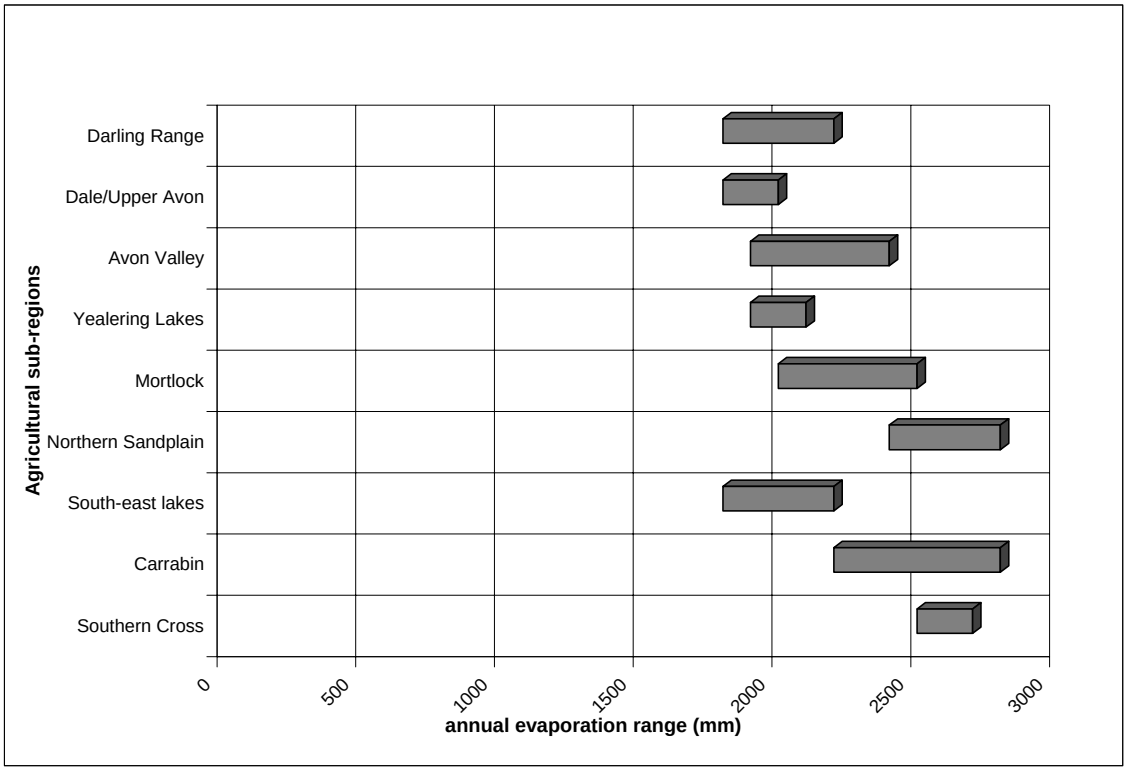

Figure 4: Annual evaporation range of agricultural sub-regions of the ARB

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5. Appendix

Main soils in the agricultural sub-regions of the Avon River Basin

Table A1: Areas and percentages of Soil Groups in the Darling Range sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Ironstone gravelly soils	58	39	Soils that have ironstone gravels or duricrust dominant within the top 15 cm
Deep sandy duplexes	23	16	Soils with a sandy surface and a texture or permeability contrast at 30-80 cm
Deep sands	12	8	Sands greater than 80 cm deep
Shallow loamy duplexes	9	6	Soils with a loamy surface and a texture contrast at 3-30 cm
Rocky or stony soils	7	5	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile.
Shallow sandy duplexes	6	4	Soils with a sandy surface and a texture or permeability contrast at 3-30 cm
Wet or waterlogged soils	6	4	Soils seasonally wet within 80 cm of the surface for a major part of the year
Deep loamy duplexes	5	4	Soils with a loamy surface and a texture contrast at 30-80 cm
Shallow sands	5	4	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Sandy earths	5	3	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Loamy earths	4	3	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Shallow loams	3	2	Loam 80 cm deep, over rock, hardpan or other cemented layer
Miscellaneous soils	2	1	Other minor soils
Non-cracking clays	1	<1	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Cracking clays	1	<1	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry

Table A2: Areas and percentages of Soil Groups in the Dale/Upper Avon sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Deep sandy duplexes	42	26	Soils with a sandy surface and a texture or permeability contrast at 30-80 cm
Deep sands	21	13	Sands greater than 80 cm deep
Ironstone gravelly soils	14	9	Soils that have ironstone gravel or duricrust dominant within the top 15 cm
Shallow sandy duplexes	13	8	Soils with a sandy surface and a texture or permeability contrast at 3-30 cm
Sandy earths	12	8	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Loamy earths	10	6	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Shallow loamy duplexes	10	6	Soils with a loamy surface and a texture contrast at 3-30 cm
Deep loamy duplexes	10	6	Soils with a loamy surface and a texture contrast at 30-80 cm
Rocky or stony soils	8	5	Rock outcrop and shallow soils with more than 50% gravel and stones (>20 mm) throughout the profile.
Shallow sands	6	4	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Non-cracking clays	6	3	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Shallow loams	5	3	Loam 80 cm deep, over rock, hardpan or other cemented layer
Wet or waterlogged soils	5	3	Soils seasonally wet within 80 cm of the surface for a major part of the year
Miscellaneous soils	1	<1	Other minor soils
Cracking clays	<1	<1	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry

Table A3: Areas and percentages of Soil Groups in the Avon Valley sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Deep sandy duplexes	193	24	Soils with a sandy surface and a texture or permeability contrast at 30-80 cm
Sandy earths	95	12	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth.
Deep sands	81	10	Sands greater than 80 cm deep
Shallow sandy duplexes	75	9	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Shallow sands	57	7	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Shallow loamy duplexes	55	7	Soils with a loamy surface and texture contrast at 3-30 cm
Deep loamy duplexes	52	6	Soils with a loamy surface and texture contrast at 30-80 cm
Ironstone gravelly soils	48	6	Soils that have ironstone gravels or duricrust dominant within the top 15 cm
Wet or waterlogged soils	40	5	Soils seasonally wet within 80 cm of the surface for a major part of the year
Loamy earths	30	4	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Non-cracking clays	28	3	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Rocky or stony soils	23	3	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile.
Cracking clays	17	2	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Shallow loams	17	2	Loam 80 cm deep, over rock, hardpan or other cemented layer
Miscellaneous soils	4	<1	Other minor soils

Table A4: Areas and percentages of Soil Groups in the Yealering Lakes sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Deep sandy duplexes	145	22	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Shallow sandy duplexes	124	19	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Ironstone gravelly soils	121	18	Soils that have dominant ironstone gravels or duricrust within the top 15 cm
Shallow loamy duplexes	63	10	Soils with a loamy surface and texture contrast at 3-30 cm
Deep sands	56	8	Sands greater than 80 cm deep
Loamy earths	53	8	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Sandy earths	31	5	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Wet or waterlogged soils	28	4	Soils seasonally wet within 80 cm of the surface for a major part of the year
Non-cracking clays	11	2	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Shallow sands	10	2	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Sandy duplexes	9	1	Soils with a sandy surface and texture or permeability contrast at 3-80 cm
Cracking clays	6	1	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Shallow loams	5	<1	Loam 80 cm deep, over rock, hardpan or other cemented layer
Deep loamy duplexes	3	<1	Soils with a loamy surface and texture contrast at 30-80 cm
Rocky or stony soils	3	<1	Rock outcrop and shallow soils with more than 50% gravel and stones (>20 mm) throughout the profile.
Miscellaneous soils	2	<1	Other minor soils

Table A5: Areas and percentages of Soil Groups in the Mortlock sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Sandy earths	241	35	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Loamy earths	143	21	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Shallow loamy duplexes	84	12	Soils with a loamy surface and texture contrast at 3-30 cm
Ironstone gravelly soils	64	9	Soils that have dominant ironstone gravels or duricrust within the top 15 cm
Deep sands	55	8	Sands greater than 80 cm deep
Shallow sandy duplexes	24	4	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Cracking clays	21	3	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Rocky or stony soils	19	3	Rock outcrop and shallow soils with more than 50% gravel and stones (>20 mm) throughout the profile.
Deep loamy duplexes	9	1	Soils with a loamy surface and texture contrast at 30-80 cm
Wet or waterlogged soils	8	1	Soils seasonally wet within 80 cm of the surface for a major part of the year
Shallow sands	7	1	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Shallow loams	5	<1	Loam 80 cm deep, over rock, hardpan or other cemented layer
Non-cracking clays	5	<1	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Deep sandy duplexes	2	<1	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Miscellaneous soils	1	<1	Other minor soils

Table A6: Areas and percentages of Soil Groups in Northern Sandplain sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Sandy earths	241	35	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Loamy earths	143	21	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Shallow loamy duplexes	84	12	Soils with a loamy surface and texture contrast at 3-30 cm
Ironstone gravelly soils	64	9	Soils that have dominant ironstone gravels or duricrust within the top 15 cm
Deep sands	55	8	Sands greater than 80 cm deep
Shallow sandy duplexes	24	4	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Cracking clays	21	3	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Rocky or stony soils	19	3	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile
Deep loamy duplexes	9	1	Soils with a loamy surface and texture contrast at 30-80 cm
Wet or waterlogged soils	8	1	Soils seasonally wet within 80 cm of the surface for a major part of the year
Shallow sands	7	1	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Non-cracking clays	5	<1	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Shallow loams	5	<1	Loam 80 cm deep, over rock, hardpan or other cemented layer
Deep sandy duplexes	2	<1	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Miscellaneous soils	1	<1	Other minor soils

Table A7: Areas and percentages of Soil Groups in the South-east Lakes sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Shallow sandy duplexes	368	23	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Deep sandy duplexes	243	15	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Loamy earths	183	11	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Wet or waterlogged soils	161	10	Soils seasonally wet within 80 cm of the surface for a major part of the year
Ironstone gravelly soils	152	10	Soils that have dominant ironstone gravels or duricrust within the top 15 cm
Shallow loamy duplexes	117	7	Soils with a loamy surface and texture contrast at 3-30 cm
Shallow sands	95	6	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Sandy earths	91	6	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Deep sands	59	4	Sands greater than 80 cm deep
Non-cracking clays	57	4	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Rocky or stony soils	24	2	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile
Miscellaneous soils	22	1	Other minor soils
Cracking clays	13	<1	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Shallow loams	7	<1	Loam 80 cm deep, over rock, hardpan or other cemented layer
Deep loamy duplexes	5	<1	Soils with a loamy surface and texture contrast at 30-80 cm

Table A8: Areas and percentages of Soil Groups in Carrabin sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Loamy earths	326	18	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Shallow loamy duplexes	312	18	Soils with a loamy surface and texture contrast at 3-30 cm
Sandy earths	276	15	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth.
Ironstone gravelly soils	214	12	Soils that have dominant ironstone gravel or duricrust within the top 15 cm
Deep sandy duplexes	159	9	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Shallow sandy duplexes	120	7	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Deep sands	107	6	Sands greater than 80 cm deep
Rocky or stony soils	64	4	Rock outcrop and shallow soils with more than 50% gravel and stones (>20 mm) throughout the profile
Shallow loams	62	3	Loam 80 cm deep, over rock, hardpan or other cemented layer
Wet or waterlogged soils	50	3	Soils seasonally wet within 80 cm of the surface for a major part of the year
Cracking clays	27	2	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Non-cracking clays	25	1	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Deep loamy duplexes	19	1	Soils with a loamy surface and texture contrast at 30-80 cm
Shallow sands	14	<1	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Miscellaneous soils	6	<1	Other minor soils

Table A9: Areas and percentages of Soil Groups in the Southern Cross sub-region

Soil type	Area		Brief description
	('000 ha)	(%)	
Loamy earths	55	29	Soils with a loamy surface and either loamy throughout or grading to clay loam or clay by 80 cm
Deep sands	25	13	Sands greater than 80 cm deep
Sandy earths	20	11	Soils with a sandy surface and grading to loam by 80 cm. May be clayey at depth
Shallow sandy duplexes	14	7	Soils with a sandy surface and texture or permeability contrast at 3-30 cm
Shallow loamy duplexes	14	7	Soils with a loamy surface and texture contrast at 3-30 cm
Cracking clays	14	7	Soils that have a clay surface at least 30 cm thick that does crack strongly when dry
Non-cracking clays	11	6	Soils that have a clay surface at least 30 cm thick that does not crack strongly when dry
Ironstone gravelly soils	11	6	Soils that have dominant ironstone gravel or duricrust within the top 15 cm
Deep sandy duplexes	8	4	Soils with a sandy surface and texture or permeability contrast at 30-80 cm
Shallow sands	8	4	Sands less than 80 cm deep over rock, hardpan or other cemented layer
Wet or waterlogged soils	6	3	Soils seasonally wet within 80 cm of the surface for a major part of the year
Shallow loams	3	2	Loam 80 cm deep, over rock, hardpan or other cemented layer
Rocky or stony soils	2	<1	Rock outcrop and shallow soils with more than 50% gravels and stones (>20 mm) throughout the profile
Deep loamy duplexes	<1	<1	Soils with a loamy surface and a texture contrast at 30-80 cm