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High rainfall rapid catchment appraisal South West Agricultural Region

Katie Bell

Department of Agriculture and Food
Government of Western Australia

High Rainfall
Rapid Catchment Appraisal
South West Agricultural Region

Compiled by Katie Bell

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for the

South West NRM Region
Catchment Appraisal Team

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CONTENTS

Acknowledgments

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Ned Stephenson	GIS support
Tim Mathwin	Hydrology
Katie Bell	Report compilation, soils, biodiversity, GIS
David Stapleton from the South West Catchments Council	Biodiversity

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Summary

- This appraisal encompasses a major portion of the South West Agricultural Region, with greater than 700 mm annual average rainfall. It covers over 2.4 million hectares, extending across major portions of 13 shires and includes the cities of Bunbury and Mandurah.
- The climate is Mediterranean with warm to hot dry summers and mild to cool wet winters. Long-term average annual rainfall ranges from 1,200 mm in the south to 700 mm in the east.
- Major rivers within the study area include the Murray, Blackwood and Warren. The Indian and Southern Oceans flank the western and southern coasts.
- Nine different soil-landscape zones are included. The most common soils are Wet or waterlogged soils, covering 24% of the study area, followed by the Ironstone gravelly soils (22%), Deep sands (21%) and Loamy earths (11%).
- Land management hazards assessed for the agricultural area within the study area include soil acidification, waterlogging, water and wind erosion and water repellence. Current estimates suggest that a quarter of subsurface soils are either presently acid or highly susceptible to acidification. Waterlogging, water and wind erosion and water repellence are high to very high hazards on approximately 22% of agricultural land.
- The primary land uses assessed were cropping and grazing within both dryland and irrigated systems. Horticulture and viticulture are important land uses.
- Remnant vegetation covers 68% of the study area, and 91% of this is located within Department of Environment and Conservation Estate. Threats to biodiversity include the loss and fragmentation of natural ecosystems, accumulation of sediments, nutrients and toxins, and pest plants and animals.
- The inland areas, where rainfall is lower, evaporation higher and drainage slower, are most susceptible to dryland salinity. The eastern margin of the study area is likely to experience the most rapid increase in the area of salt-affected land during the next few decades. Low-lying land, such as broad valley floors, is the most susceptible as it is often the first to be affected by rising watertables.
- Over much of the coastal plain, irrigation salinity is likely to be a compounding factor of equal or greater importance than dryland salinity.

1. Introduction

The objective of Rapid Catchment Appraisal (RCA) is to assess and provide information on relevant current and future risks and threats to agriculture, infrastructure and natural resources that result from land degradation. The RCA process attempts to determine the most suitable options for managing the risks. In addition, landholders are offered advice on where to access further information and support if needed.

The main land degradation issues identified for the High Rainfall RCA Area, defined as that part of the South West receiving more than 700 millimetres of average annual rainfall, are soil acidification, waterlogging, water erosion, wind erosion, water repellence, nutrient loss and eutrophication. Threats to natural resources including waterways and wetlands, remnant vegetation and biodiversity were examined.

1.1 Study area

The High Rainfall RCA extends from the WA coastline inland to the 700 mm rainfall isohyet and covers 2,436,300 ha. It is limited to the north and south-east by the boundaries of the South West Natural Resource Management (NRM) Region and by local government authorities elsewhere (i.e. to the north of the Shire of Serpentine-Jarrahdale and the Shire of Murray). Two cities, Bunbury and Mandurah, are within the study area, along with several major towns including Busselton, Collie and Manjimup. The Region covers 16 shires, or part thereof, and includes 727 km of highway. Figure 1 shows the location and major features.

The study area encompasses 923,280 ha of agricultural land (see Figure 2); which is approximately 38% of its total. The determination of land degradation hazards specific to non-intensive agriculture (predominantly grazing, broadacre cropping and fodder production) applies only to this agricultural land and does not include areas of State forest and reserves, and privately-owned remnant vegetation.

Native vegetation covers 1,671,600 ha (68%) of the study area. The Department of Environment and Conservation manages approximately 91% of this vegetation (Figure 2). The remainder occurs as remnant vegetation on privately-owned land.

Major rivers flowing through the study area include the Blackwood, Warren, Collie and Murray Rivers. Other significant hydrological features include the Peel-Harvey, Broke and Hardy Inlets, Leschenault Estuary, Lake Muir and the Vasse-Wonnerup Wetlands.

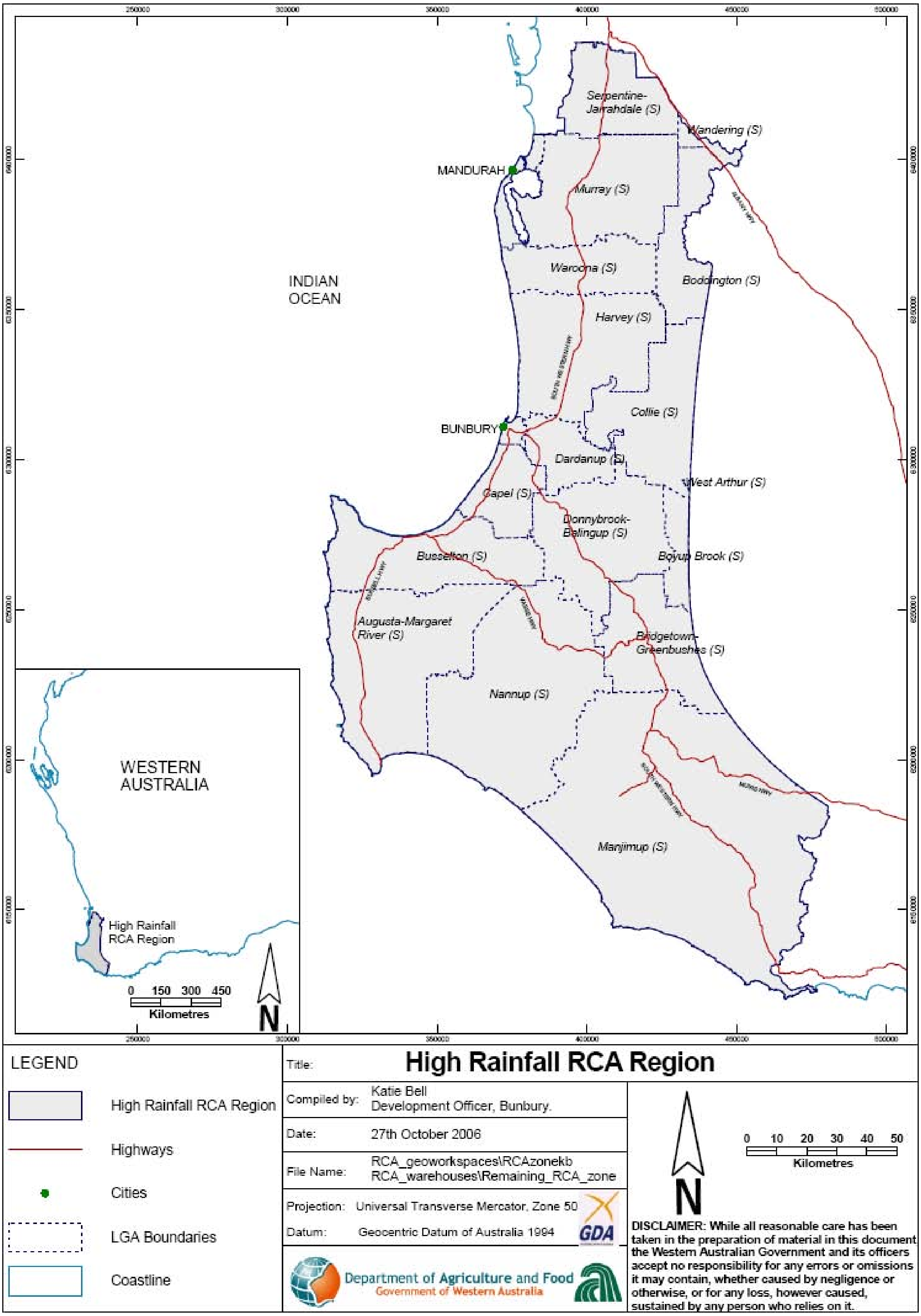

Figure 1. Location of High Rainfall RCA Region

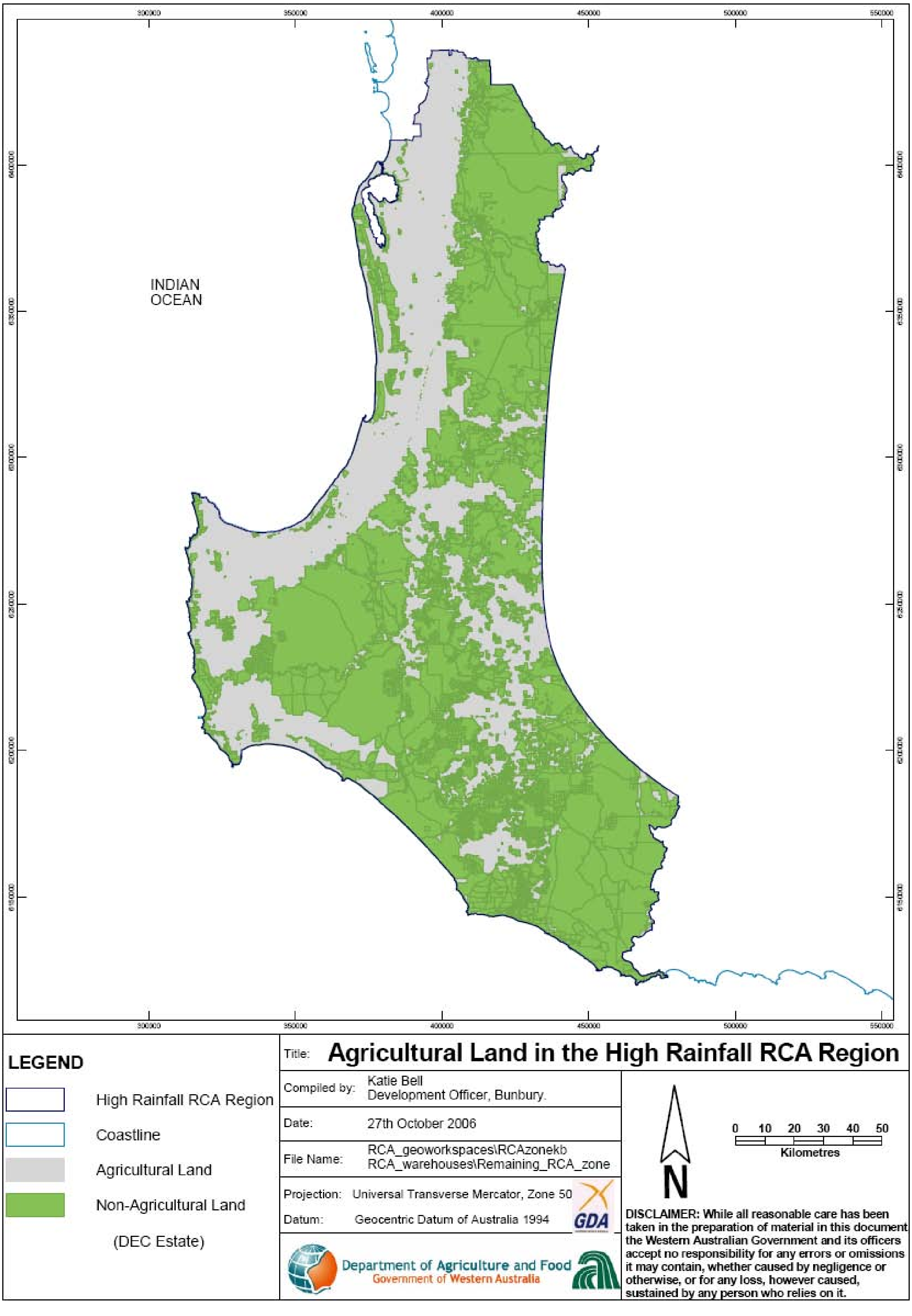

Figure 2. Agricultural land and DEC Estate in the High Rainfall RCA Region

2. Natural resource base

2.1 Climate

Henry Brockman and Katie Bell

The climate is Mediterranean, with warm to hot dry summers and cool wet winters. This climate is largely determined by two major global influences: the Southern Subtropical Ridge, and cold fronts generated in the Southern Ocean on the boundary between cold polar and warmer subtropical air (Tille *et al.* 2001). As this boundary moves north during winter, the frequency of fronts crossing the coast increases.

Maritime influence tends to keep variation in coastal temperatures relatively low. The highest minimums and lowest maximums tend to be found on the Leeuwin-Naturaliste peninsula, as it is surrounded by ocean on three sides, while variability increases further inland. Temperatures are generally milder in the south-west and become more extreme towards the north-east of the region. Mean maximum temperatures in the hottest month (usually February) range from the mid-20s°C at Margaret River to low 30s at Collie and Harvey. In July, the coolest month, mean minimum temperatures follow a similar pattern with 11°C around Augusta and Margaret River and 4°C at Collie. Frosts are rare on the coast but do occur (once to three times per year) further inland.

Rainfall ranges from 1,200 mm in the south to 700 mm in the east (see rainfall isohyets in Figure 3). The heaviest and most frequent rains generally fall between April and October (often beginning slightly earlier in areas such as Pemberton and Northcliffe). Although summer rainfall can occur, summer drought is common. Rainfall distribution is affected by the effect of the Darling Scarp on moist air coming off the Indian Ocean. Despite proximity to the ocean, the coastal plains receive less rain than adjoining areas further inland due to their flat terrain. Rainfall around Busselton is lower than in other areas of the Swan Coastal Plain due to the influence of Cape Naturaliste, which creates a moderate rain shadow ridge (Tille *et al.* 2001). Rainfall is highest around Northcliffe and Walpole which, being further south, receive fronts that miss the other areas.

Monthly rainfall averages over the past five, 10 and 30 years were compared for three major centres within the study area (Figure 12C-F). No significant variance was found between the three datasets for January to May and September to December. Both the five and ten year averages show an increase in August rainfall, but rainfall for the last five years has decreased for June and July.

Monthly average maximum and minimum temperatures were also compared (Appendix A; Figure 12a-f). An overall increase (up to 0.5ºC) in average maximum temperatures was found at all three centres, with a decrease in average minimum temperatures, particularly in June and July. The latter can probably be attributed to less cloud cover resulting in lower temperatures and a higher probability of frost.

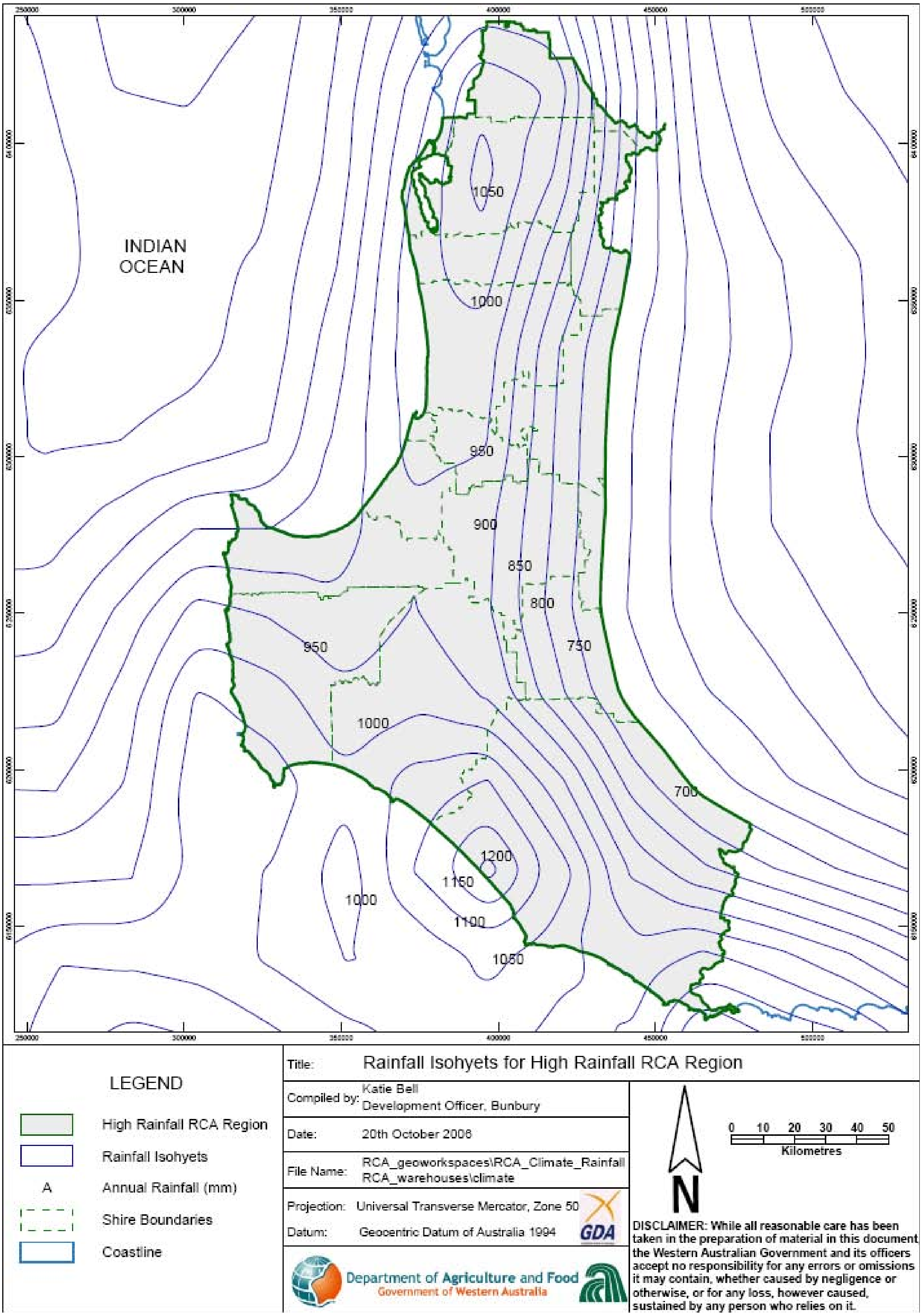

Figure 3. Rainfall within the High Rainfall RCA Region

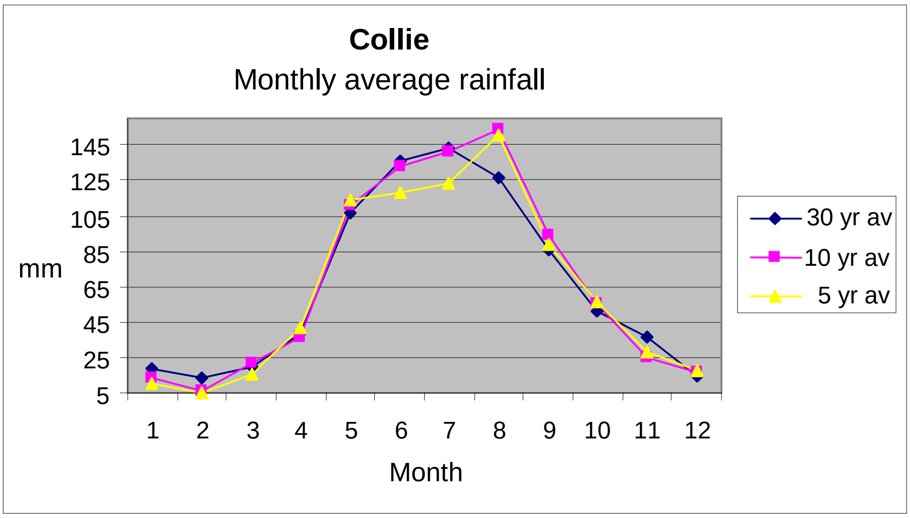

Figure 4. Average monthly rainfall comparisons for Collie

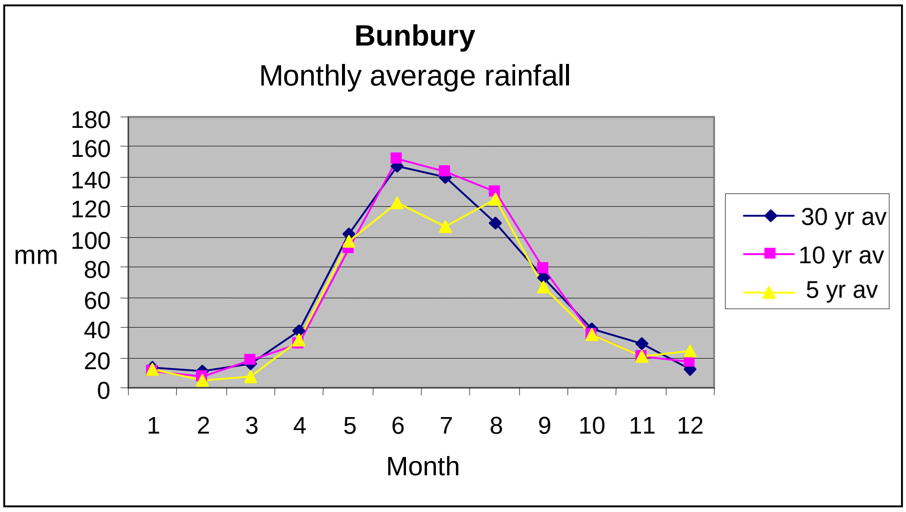

Figure 5. Average monthly rainfall comparisons for Bunbury

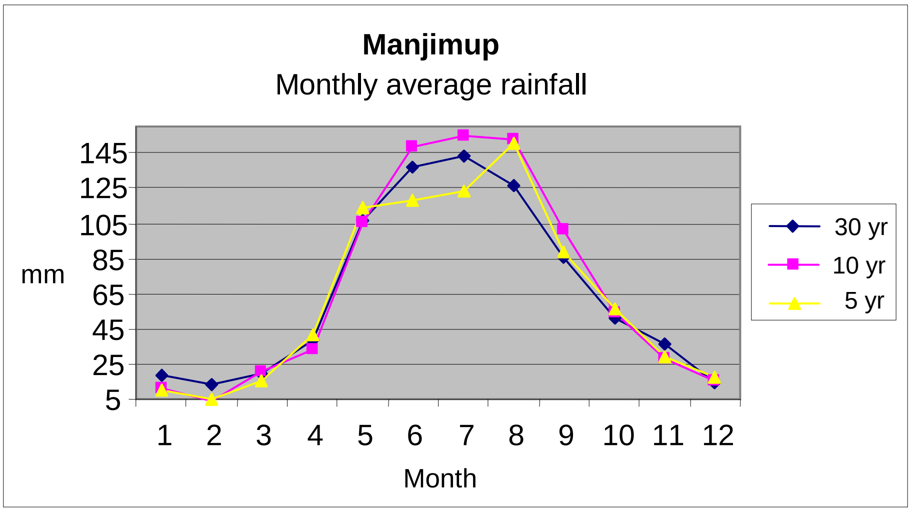

Figure 6. Average monthly rainfall comparisons for Manjimup

2.2 Geology

Katie Bell and Peter Tille

The study area overlies portions of five major geological areas: the Yilgarn Craton; the Leeuwin Complex; the Perth Basin; the Albany-Fraser Orogen; and the smaller Collie Basin (see Figure 7).

The Yilgarn Craton lies east of the Darling Fault and is the dominant feature of the South West of Western Australia. The portion in the study area is known as the Western Gneiss Terrane and comprises a variety of crystalline rocks. The oldest and the most prominent is the Balingup Gneiss Complex which is over 3.1 billion years old. It is dominated by metasedimentary rocks including gneiss, quartzite, schist and amphibolite, and a metagranite belt to the west.

Some sedimentary deposits overlie the crystalline rocks of the Yilgarn Craton. The most prominent of these is the Collie Basin. Basin rocks include sandstone, shale, siltstone and coal, which are overlain in places by surficial deposits of sand. Elsewhere, Eocene deposits overlie the granitic basement, typically sitting high in the landscape.

The Leeuwin Complex is a narrow strip of land lying between Cape Naturaliste and Cape Leeuwin. It comprises a range of metamorphic rocks including granite gneiss, porphyritic granite and anorthosite, which have been intensely deformed. The Darling Fault forms the eastern boundary of the Perth Basin while it extends to the edge of the continental shelf in the west. The Perth Basin is a deep linear trough of sedimentary rocks. Sediments vary from outwash derived from the Yilgarn Craton to marine sediments derived from incoming shallow seas. The sandstone, siltstone, shale, mudstone and coal of the basin are overlain by Quaternary alluvium and aeolian deposits.

The Albany-Fraser Orogen lies to the south of the Yilgarn Craton and is characterised by crystalline rocks, including high grade gneiss and granitic intrusions. In a belt along the northern and western boundaries lies the Biranup Complex. This consists mainly of gneiss inter-layered with small amounts of metasedimentary rocks. Within the appraisal area, the major portion of the Albany-Fraser Orogen is occupied by the Nornalup Complex, comprising gneiss and granite and less strongly deformed. Calcareous and non-calcareous sand dunes are also found along the coast.

The lateritic profile (as defined in Tille *et al.* 2001) is widespread. The typical lateritic profile consists of topsoil, duricrust, a mottled zone, a pallid zone and saprock overlying bedrock. The whole profile can be anywhere between 2 and 50 metres thick, and not all horizons are present in every profile. With the exception of the coastal plains, the lateritic profile probably once covered most of the South West with a considerable proportion of intact laterite currently found within the study area, the most prominent area being the Darling Plateau.

2.3 Soil-landscape Information

Katie Bell and Peter Tille

2.3.1 Soil-landscape zones

The regional soil-landscapes have been assessed on agricultural land (923,200 ha or 38% of the total) within the study area (Figure 2). Soil-landscape mapping covering the area includes Barnesby and Proulx-Nixon (2000); Churchward (1992); Churchward and McArthur (1980); Churchward *et al.* (1988); King and Wells (1990); McArthur *et al.* (1977); Smith and Smolinski (1997); Stuart-Street (2005); Tille (1996); Tille and Lantzke (1990); van Gool (1990); van Gool and Kipling (1992); and Wells (1989). Mapping for the northern and western parts of the study area is available on the Serpentine-Jarrahdale to Harvey and Capel to Augusta AGMAPS CD-ROMs (DAWA 2003, 2005)

Table 1. Soil-landscape zones in the High Rainfall RCA Region (Tille *et al*. 2001, Schoknecht *et al*. 2004), area and percentage of agricultural land covered by each zone

Soil-landscape zone (area, % of agric. area)	Code	Description
Western Darling Range (224,900 ha, 24%)	255	This zone is dominated by a gently undulating to undulating lateritic plateau. Deeply incised valleys occur as a result of dissection by major river systems. On the plateau surface duplex sandy gravels, loamy gravels and shallow gravels are found with pockets of pale deep sands and yellow deep sands. Friable red/brown loamy earths, brown loamy earths and brown deep loamy duplex soils have formed on freshly exposed gneiss and granite in the valleys.
Pinjarra Plain (201,500 ha, 22%)	213	Flat, often moderately saline and poorly drained alluvial plain with grey deep sandy duplex soils, grey shallow sandy duplex soils, brown shallow loamy duplex soils and wet soils. Cracking clays are found along the western margins and brown sandy earths and brown loamy earths have formed on recent alluvium.
Warren-Denmark Southland (134,000 ha, 15%)	254	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 plains are common. Loamy gravels, sandy gravels, and grey deep sandy duplex soils. Loamy gravels, friable red/brown loamy earths and brown deep loamy duplex soils are found in the dissected terrain.
Donnybrook Sunkland (77,600 ha, 8%)	214	The northern portion of the zone is dominated by a gently undulating lateritic plateau. Shallow valleys occur where the plateau has been dissected by major river systems. In the south, the plateau grades into a poorly drained sandy alluvial plain. Duplex sandy gravels, deep sandy gravels, shallow gravels, grey deep sandy duplex soils, pale deep sands and yellow deep sands.
Bassendean (83,000 ha, 9%)	212	Mid-Pleistocene Bassendean sands. A complex of low dunes, sandplains and swampy flats with pale deep sands and semi-wet and wet soils.
Leeuwin (76,400 ha, 8%)	216	Lateritic plateau moderately dissected in places to form a number of shallow valleys incised into the granite or gneiss bedrock, which contain colluvial soils. Yellow deep sands overlie a limestone ridge on the western margin, and calcareous deep sands are found on the coastal dunes.
Perth Coastal (61,200 ha, 7%)	211	Beach ridges and parabolic dunes of calcareous deep sands are backed by poorly drained estuarine deposits. Behind these lie low dunes of yellow deep sands overlying Tamala Limestone.
Scott Coastal Plain (54,500 ha, 6%)	215	Swampy coastal plain and coastal dunes with pale deep sands and semi-wet and wet soils. Calcareous deep sands and pale deep sands are found on dunes along the coast.

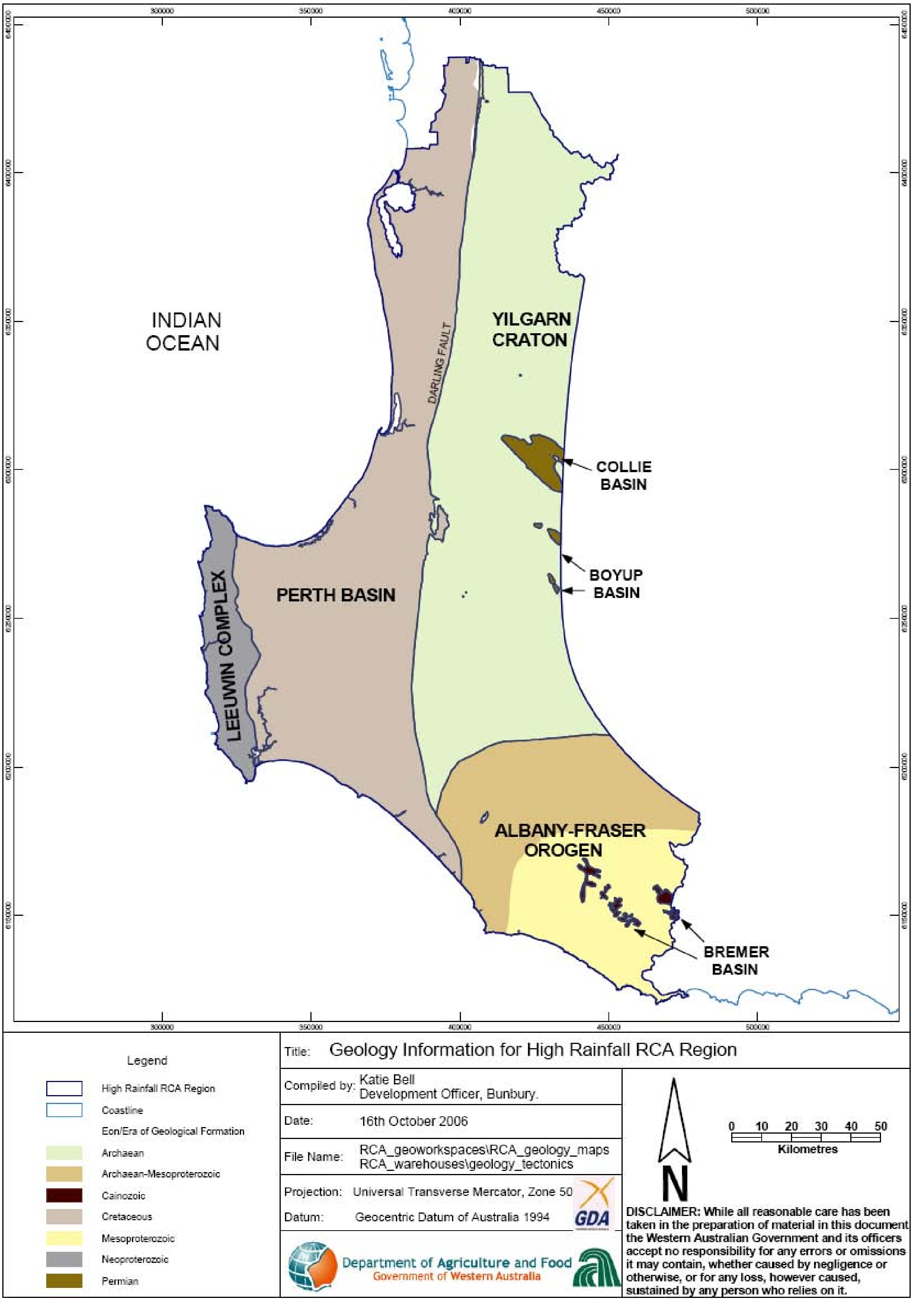

Figure 7. Geology of the High Rainfall RCA Region

Soil-landscape zones are regional units based on geomorphologic or geological criteria (Schoknecht *et al.* 2004). Nine different zones occur in the study area and are described in Table 1. The table includes the area and percentage of agricultural land covered by each soil-landscape zone.

More than 60% of the agricultural land is covered by three soil-landscape zones – the Western Darling Range, Pinjarra Plain and Warren-Denmark Southland (see Figure 8).

The Western Darling Range Zone and the Pinjarra Plain Zone lie to the east and west of the Darling Fault respectively, with the Pinjarra Plain Zone branching off in the south towards Cape Naturaliste. To the south of the Western Darling Range Zone and bordered on the west by the Darling Fault, the Warren-Denmark Southland Zone is flanked by the Southern Ocean and continues to the most eastern boundary of the study area.

2.3.2 Soils

The seven most common Soil Groups (Schoknecht 2002) are listed in Table 2. Three supergroups account for more than 65% of agricultural land. The Wet or waterlogged supergroup is the most common, covering 24% of agricultural land, mainly on the poorly drained flats of the Pinjarra Plain Zone and the swampy lowlands of the Warren-Denmark Southland Zone. The next most widespread supergroup at 22% is the Ironstone gravelly soils, prominent in the Western Darling Range Zone. Deep sands are widely distributed and cover 21% of the agricultural land.

The Loamy earths (11%), Sandy duplexes (7%) and Loamy duplexes (6%) account for another 25% of the agricultural area.

Table 2. Common soil groups of Western Australia on agricultural land in the High Rainfall RCA Region

WA soil group	WA soil supergroup	Area (ha)	Per cent
Semi-wet soil	*Waterlogged or wet soils*	149,100	16
Pale deep sand	*Deep sands*	129,400	14
Loamy gravel	*Ironstone gravelly soils*	87,400	10
Duplex sandy gravel	*Ironstone gravelly soils*	82,200	9
Wet soil	*Waterlogged or wet soils*	63,500	7
Brown loamy earth	*Loamy earths*	57,300	6
Friable red/brown loamy earth	*Loamy earths*	42,800	5

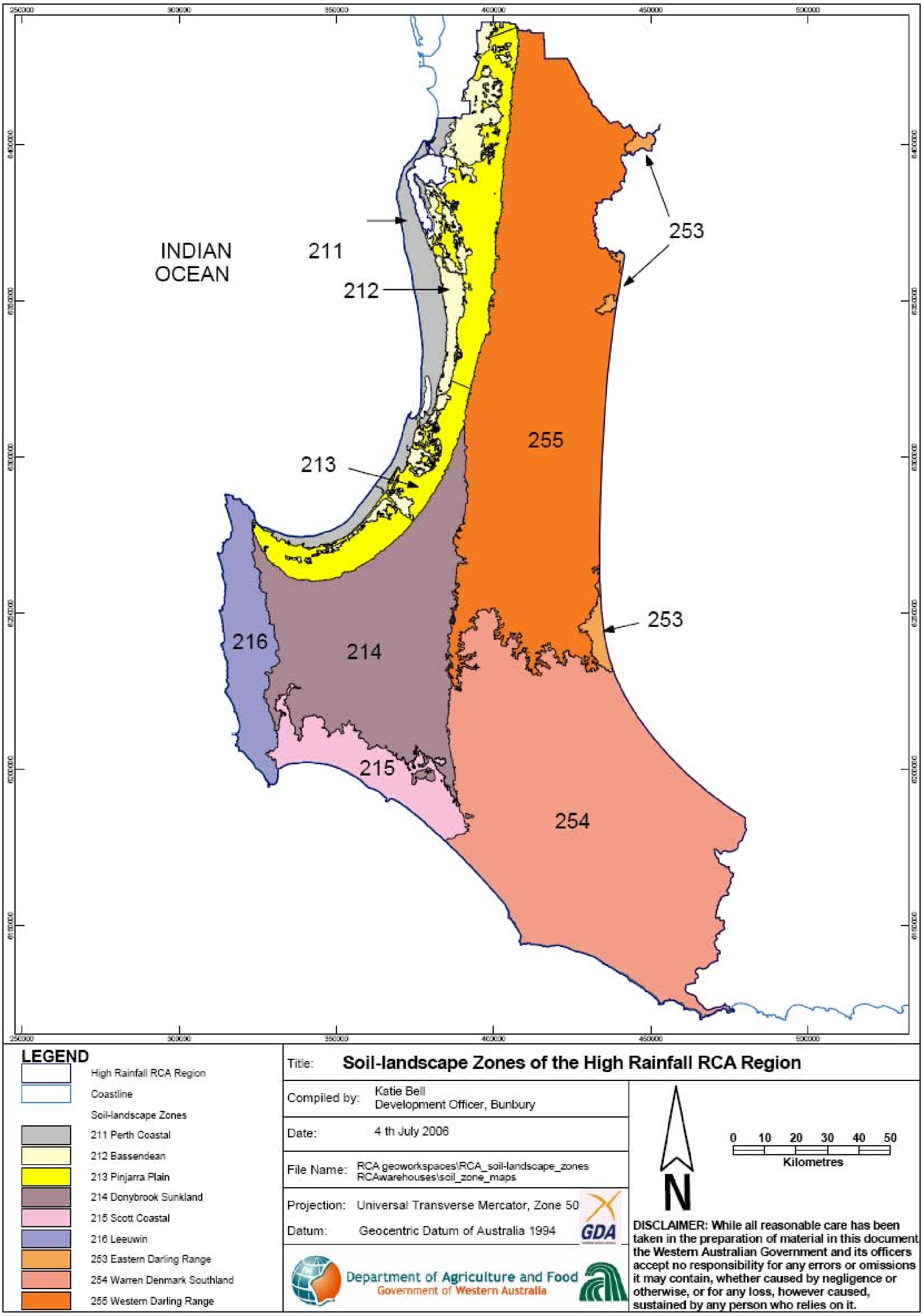

Figure 8. Soil-landscape zones within the High Rainfall RCA Region

2.4 Hydrology

Tim Mathwin

2.4.1 Hydrogeology

Darling Range, Warren-Denmark Southland and Donnybrook Sunkland

The hydrogeology of the elevated areas is influenced by the moderately high to high rainfall, large areas of uncleared land (68%) and undulating to rolling landscape (local relief and slope gradients can be up to 200 m and 30% respectively). Salt stores in the regolith are typically in the range 10 to 1,000 tonnes/hectare (t/ha).

Recharge occurs throughout the landscape, with major contributions coming from the gravelly plateau, poorly drained upland flats and swampy plains on the South Coast. Groundwater recharge rates are because where these zones remain forested. In cleared areas recharge rates of up to 200 mm/year can occur. Under forest, recharge is negligible in the lower rainfall districts on the eastern margin, but can be up to 30 mm/year in higher rainfall districts (Williamson *et al.* 1987).

Aquifers in consolidated sedimentary rocks contain the most significant amounts of groundwater. Under the Donnybrook Sunkland, the Leederville aquifer of the Perth Basin is typically 150 m thick and confined. The underlying Yarragadee aquifer is more than 1,200 m thick in places. Water salinity in these aquifers is typically fresh (< 500 mg/L). Water-bearing aquifers are found in the saprock and pallid zone of the lateritic profile, the Tertiary sediments on the plateau and Quaternary deposits of the Warren-Denmark Southland. Small amounts of water are contained in fractured rock aquifers below the lateritic profile. Centuries of water movement through fractures and faults, as well as groundwater flow in regolith on steep slopes, have limited the accumulation of salts.

As most of the land remains under native forest, rising watertables are less prevalent than further inland. Rates of groundwater rise under agricultural land are typically about 50 cm/year. The sandy Quaternary deposits on the South Coast contain permanent unconfined aquifers with fresh water (< 500 mg/L) which rises to the ground surface in winter. During winter, perched groundwater is common on low-lying flats on the plateau surfaces.

Groundwater movement in areas with crystalline geology is dominated by local flow systems due to the undulating landscape. Some intermediate flow systems may occur in the Tertiary aquifers. The south-eastern Donnybrook Sunkland is a major recharge area for a regional flow system in the Perth Basin Sediments. Thorpe and Baddock (1994) estimated recharge rates of 200 mm/year for the Yarragadee aquifer here.

Discharge from local flow systems is common and associated with dolerite dykes, bedrock highs and shear zones found exposed in valleys incised into crystalline rocks (including the Blackwood Valley upstream from Nannup, the Preston Valley, and hillslopes in the Pemberton District). Although this discharge is typically fresh (< 500 mg/L), there are some marginal to brackish seeps (to 3,000 mg/L), especially around Bridgetown. Break of slope seeps and capillary rise from valley aquifers occur in this terrain, but do not affect large areas because of the narrow valley floor. Seepage from sandy rises and deep gravels is minor but widespread.

Perth Coastal, Bassendean and Pinjarra

The hydrogeology of the Swan Coastal Plain is influenced by the moderately high rainfall, predominantly flat topography and discharge from the Perth Basin sediments. The average annual rainfall ranges from 820 mm at Busselton to 1,000 mm along the base of the Darling Scarp. Rainfall deposits more than 100 kg of chloride on each hectare each year (Hingston and Gailitis 1976). Most of the rain (90%) falls between April and October. Average annual pan evaporation ranges from 1,000 mm in the south to 1,700 mm in the north.

Annual surface runoff ranges from zero on the dunes to about 330 mm (30% of rainfall) on heavy clay flats. While major rivers such as the Serpentine, Murray, Collie, Preston and Capel cut across the plain, much streamflow now occurs in artificial drainage channels. Elsewhere, drainage is sluggish due to the low relief. Swampy depressions are common. Runoff ranges from fresh (200 mg/L) to marginal (to 1,000 mg/L) on the heavier soils of the irrigation area.

The most prominent surface water storages are the Peel-Harvey Estuary, Leschenault Estuary, Vasse-Wonnerup Estuary, Lake Clifton and Lake Preston. Swamps and pools in the rivers are other significant water stores.

Groundwater is stored in surficial aquifers in Quaternary sediments and the underlying confined aquifers of the Perth Basin. Some of the water in the lower aquifers may be 10,000 years old. Perched groundwater is widespread in the surface horizon of sandy and loamy duplex soils in winter when much of the Swan Coastal Plain is waterlogged or inundated.

The surficial aquifers, which include the Guildford Formation, are typically 5 to 50 m thick and storage fluctuates with seasonal conditions. Groundwater in the surficial aquifers south of Bunbury is generally brackish (900-1,000 mg/L) with some saline groundwater near the coast (WAWA 1995). North of Bunbury, fresh to marginal (< 1,000 mg/L) groundwater is found under sand dunes that cover much of the western half of the Plain. The groundwater under the Pinjarra Plain to the east of these dunes is often brackish (Deeney 1988) with some saline areas (up to 25,000 mg/L). The higher salinity in these surficial aquifers is often associated with salt water intruding from the coast, a concentration of salts following evaporation in groundwater discharge areas or heavier textured sediments. In the Perth Basin, the Leederville aquifer is typically 150 m thick while the underlying Yarragadee aquifer is more than 1,200 m thick in places. Groundwater in the Leederville and Yarragadee aquifers is fresh (mostly < 500 mg/L).

Groundwater movement is dominated by regional flow systems with discharge from the Leederville aquifer via surficial aquifers at locations such as Ambergate Road to the south of Busselton, Waterloo to the east of Bunbury and Hopelands Road to the west of Serpentine. Some of this discharge may have originated in the Yarragadee aquifer. Local flow systems are common in the sand dunes, with discharge from sandplain seeps found at the base of the dunes where they overlie clayey flats.

Scott Coastal

Most of the plain lies within the catchment of the Scott River. The hydrogeology is influenced by the high rainfall and predominantly flat topography. Rainfall is in the 1,100-1,300 mm/year range and deposits more than 100 kg/ha of chloride each year (Hingston and Gailitis 1976). The average annual pan evaporation is about 1,000-1,200 mm.

While little or no surface runoff originates on the dunes, the Scott River has a mean annual runoff of almost 180 mm, largely generated from waterlogged flats. The Scott River maintains some flow throughout the year. Drainage is sluggish due to the low relief, and swampy depressions are common. Runoff is usually fresh and the Scott River has an average salinity level of 210 mg/L. The most prominent surface water storages are the Hardy Inlet and Lake Jasper. Swamps and pools along the river are other significant surface stores.

Groundwater is stored in surficial aquifers in Quaternary sediments, which are typically 10 m thick and in the underlying confined aquifers of the Perth Basin. Storage in the surficial aquifers fluctuates with seasonal conditions, but watertables are close to the ground surface for much of the year (except under the sand dunes near the coast). The quality of this surface water is fresh (200-530 mg/L). In the Perth Basin, the Leederville aquifer is typically 150 m thick while the underlying Yarragadee aquifer is more than 1,200 m thick in places. Groundwater in the Leederville and Yarragadee aquifers is fresh (mostly < 500 mg/L).

Groundwater movement is dominated by regional flow systems in the Perth Basin aquifers. These aquifers discharge into the Southern Ocean. Local flow systems operate in the surficial aquifers that also recharge the underlying Perth Basin. Much of the Scott Coastal Plain is waterlogged or inundated in winter and early spring.

2.4.2 Surface water hydrology

The catchments of the Peel-Harvey Estuary, Leschenault Inlet, Geographe Bay, Margaret River, Blackwood River, Donnelly River, Warren River and Shannon River are all within the High Rainfall RCA Region (Figure 9). Table 3 presents the area of these catchments with the mean annual basin flows (the sum of the mean annual flows of all the major rivers and tributaries within the catchment).

Table 3. Area and mean annual flows of the catchments of the High Rainfall RCA Region

Catchment	Area of catchment (ha)	Mean annual basin flow (million m^3)
Blackwood	2,255,000	1,060
Peel-Harvey [1]	1,207,000	1,050
Leschenault [2]	478,000	560
Warren	436,000	640
Shannon	342,000	440
Geographe and Margaret [3]	299,500	470
Donnelly	169,000	350
Total	**5,186,500**	**4,570**

Adapted from Western Australian Water Resources Council (1984) and Schofield et al. (1988).

1. Includes the Murray, Serpentine and Harvey River catchments.
2. Includes the Collie, Brunswick and Preston River catchments.
3. Includes the Capel, Vasse, and Margaret River catchments.

The rivers of the study area combined (Figure 9) yield over 4.5 billion cubic metres of water per year (Western Australian Water Resources Council 1984). This represents approximately 75% of the mean annual basin flow of the total agricultural area (almost 335,000 km^2 from Geraldton to Esperance). The rivers contain approximately 9% of WA's divertible water supplies that are fresh or marginal (usually less than 1,070 mg/L total soluble salt in the South West).

The quality of the water in South West rivers ranges from fresh (< 500 mg/L) to saline (> 2,000 mg/L). Generally, salinity levels are lower close to the coast and increase inland where rainfall is lower and extensive clearing of native vegetation has occurred. The Blackwood, with headwaters over 300 km to the north-east of its mouth, is the longest river, and flows through its centre. It also has the largest catchment area and the greatest flow.

The average annual salinity level in the Blackwood remains above 2,000 mg/L for most of its course, but concentrations in most tributaries are as low as 600 mg/L (or less) on the western edge of the Darling Range. This difference is partly due to higher rainfall and partly because a significant portion of the Western Darling Range remains under forest. After crossing the Darling Scarp, the Blackwood passes through the Donnybrook Sunkland where valleys are shallower but drainage lines are still well defined. Here, average annual salinity levels are below 2,500 mg/L, while concentrations in most tributaries are below 300 mg/L. The Blackwood flows into the Hardy Inlet, where the Scott River, which drains the swampy flats of the Scott Coastal Plain before reaching the Southern Ocean, joins it.

To the north of the Blackwood River, most rivers flow in a general westerly direction to the Indian Ocean. The Murray River has its headwaters in the Southern Zone of Rejuvenated Drainage where its tributaries, the Hotham and Williams Rivers, rise and flow into broad valley floors. They cut through the Eastern Darling Range in well-defined courses and meet to form the Murray River on the edge of the Western Darling Range. From here, the Murray forms a deep valley until it crosses the Darling Scarp and meanders across the flats of the Swan Coastal Plain before entering the Peel-Harvey Estuary.

North of the Murray is the catchment of the Serpentine River, which rises on the surface of the Darling Plateau before cutting a deep valley into the edge of the Darling Range and flowing across the Coastal Plain to the Peel-Harvey Estuary.

To the south of the Murray, the Harvey River once followed a similar pattern to the Serpentine River. Now much of the Harvey's flow is carried directly though an artificial drain across the Coastal Plain to the Indian Ocean. Average annual salinity levels in the Murray River are about 3,000 mg/L because of clearing in the upper catchment. Salt concentrations in the Serpentine and Harvey Rivers, which have headwaters in forested areas, are considerably lower – about 200-300 mg/L.

Between the Peel-Harvey and Blackwood catchments, the Collie and Preston Rivers rise on the plateau surface before cutting deep valleys into the edge of the Darling Range and flowing across the Swan Coastal Plain to the Leschenault Inlet. Salinity levels in the Collie River are 6,000 mg/L in cleared portions of the upper catchment, but drop to 1,200 mg/L when tributaries from forested catchments join it. It then flows into Wellington Dam. A number of relatively short rivers flow into Geographe Bay to the west of the Leschenault Inlet.

The Capel River rises on the Western Darling Range, crosses through the Donnybrook Sunkland and Coastal Plain before flowing out to the bay through an artificial drain. Originally, it flowed into the Vasse-Wonerup Estuary, as did the Ludlow, Vasse and Carbunup Rivers, all of which rise in the Donnybrook Sunkland. Most of these now also flow through artificial drains into the bay, and a gate prevents tidal flushing of the estuary. A few rivers and creeks flow into the Indian Ocean on the coast of the Leeuwin Zone, the most significant of which is the Margaret River.

Most rivers from the Blackwood northwards have had to cut through or into the Western Darling Range that has been uplifted along the Darling Scarp. As a result they have formed deeply incised, steep-sided valleys. There is a high 'drainage density' of small subcatchments, and high velocity flows. In contrast, rivers south of the Blackwood generally flow in a southerly direction. Here the rivers have a gentler gradient and are less deeply incised, following the gradual fall of the land to the Southern Ocean. Many rivers rise in swampy plains on the Jarrahwood axis, a major catchment divide running approximately parallel to the coast.

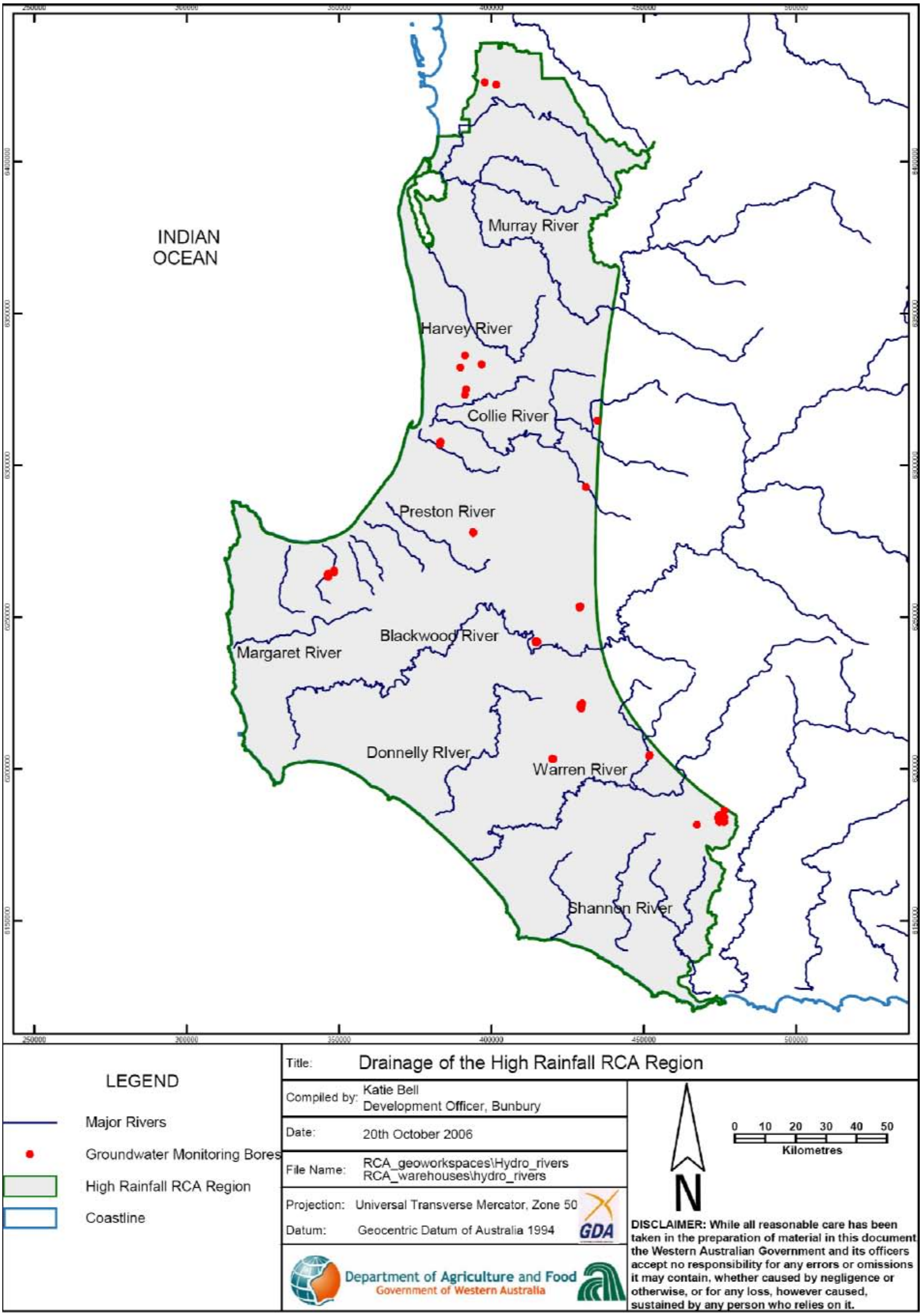

Figure 9. Major rivers within the High Rainfall RCA Region

2.5 Biodiversity

Katie Bell and Dave Stapleton

The importance of managing all areas of remaining vegetation for their conservation values is highlighted by the diversity of environments; the species richness and endemism; the high turnover of species across the landscape; and the large number of poorly known species, communities and ecosystems.

The biodiversity is described below under the headings of: Vegetation; Priority Species; and Important Ecological Communities. These are further categorised in three bioregions referred to as Interim Bio-geographical Regionalisation of Australia (IBRA): Swan Coastal Plain; Jarrah Forest; and Warren (see Figure 10).

The following descriptions are largely drawn from the 2005 South West Catchments Council 'Regional Strategy for Natural Resource Management' and accompanying technical reports (SWCC 2005).

2.5.1 Vegetation

Swan Coastal Plain

This bioregion contains a wide variety of vegetation, ranging from shrublands on ironstone soils and coastal limestone to *Banksia* and eucalypt woodlands on sands and loams and tall open forest on heavier alluvial soils (Seddon 1972). Heavier soils are predominantly cleared for agriculture with the largest areas of remnant vegetation comprising banksia low woodlands on deep sandy soils.

Coastal dunes with scrub-heath communities give way to banksia and tuart woodlands. Eucalypt woodlands dominated by marri and jarrah can be found on the sandy loams, loams, and heavy alluvial loams. Paperbark low woodland dominates swampy areas and small areas of species-rich scrubland occur on seasonally wet ironstone pavement soils.

The Swan Coastal Plain is 60% cleared of natural vegetation. Major reserves are Yalgorup National Park (tuart forest, coastal heath on limestone, saline lakes) and Leschenault Peninsula Conservation Park (tuart forest, southern white mangrove communities).

Jarrah Forest

Vegetation within this bioregion ranges from jarrah-marri forest in the west, bullich and blackbutt in the valleys to wandoo and marri woodlands in the east and powder bark wandoo on breakaways.

There are extensive but localised sand sheets with *Banksia* low woodlands. Heath is found around granite rocks and as a common understorey of forests and woodlands in the north and east. There are extensive areas of swamp vegetation in the south-east, dominated by paperbarks and swamp yate. The majority of the diversity in the communities occurs on the lower slopes or near granite soils where there are rapid changes in site conditions.

About 44% of natural vegetation of the entire Jarrah Forest Bioregion (including the portion not covered by the RCA) is cleared. Its largest reserve is Lane Pool (55,000 ha). Others include the Wellington National Park near Bunbury that has dense riverine forest and granite rock outcrops harbouring several threatened and restricted species, and the nature reserves of the Lake Muir area.

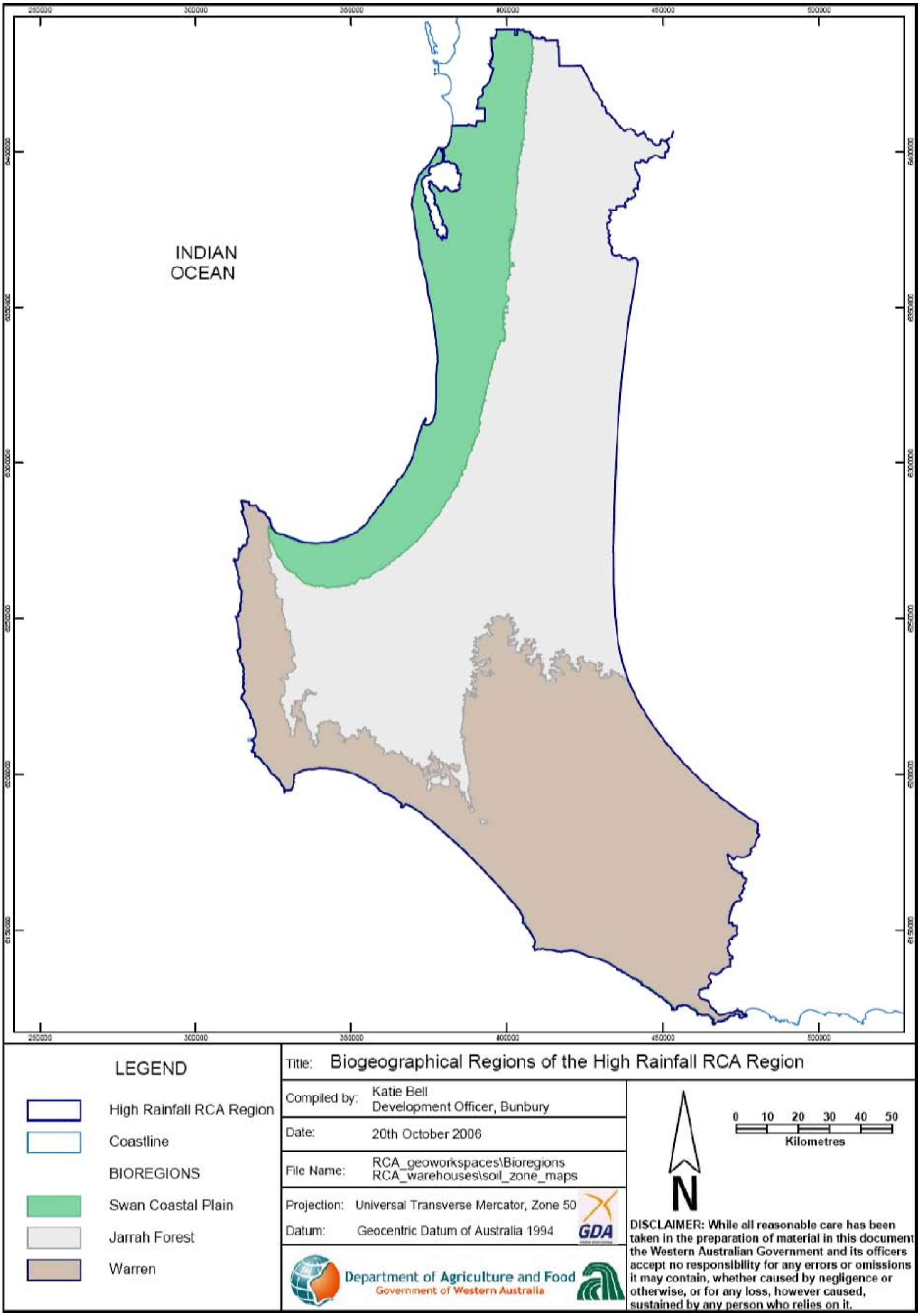

Figure 10. **Bioregions within the High Rainfall RCA Region**

Warren

Vegetation varies with geology and includes loamy soils supporting karri forest; laterites supporting jarrah-marri forest; leached sandy soils in depressions and plains supporting low jarrah woodlands and paperbark/sedge swamps; and Holocene marine dunes with *Agonis flexuosa* and banksia woodlands and heaths.

About 20% of natural vegetation is cleared. Significant remnant vegetation is on private property, some of which are in very good condition. There are three major national parks: D'Entrecasteaux, Shannon (which at 53,500 ha covers the entire basin of the Shannon River) and Leeuwin-Naturaliste which stretches 120 km along the Leeuwin-Naturaliste Ridge.

2.5.2 Priority species

Swan Coastal Plain

Fifteen plants, one reptile (western swamp tortoise) and one crustacean (Crystal Cave Crangonyctoid) species are declared as Critically Endangered. A further 19 plants and one bird (Carnaby’s cockatoo) are listed as Endangered under WA legislation.

Jarrah Forest

The State forests, reserves and national parks provide refuges for several Priority and Threatened species such as the noisy scrub-bird (*Atrichornis clamosus*), Australian bittern (*Botaurus poiciloptilus*), numbat (*Myrmecobius fasciatus*), woylie (*Bettongia penicillata ogilbyi*) and tammar (*Macropus eugenii derbianus*).

Warren

Threatened fauna include the chuditch (*Dasyurus geoffroii*), western ring-tailed possum (*Pseudocheirus occidentalis*), noisy scrub-bird (*Atrichornis clamosus*), Muir’s corella (*Cacatua pastinator pastinator*), white-bellied frog (*Geocrinia alba*) and the sunset frog (*Spicospina flammocaerulea*).

Threatened plants include the Critically Endangered bryophyte *Rhacocarpus webbianus* and the Endangered giant spider orchid (*Caladenia excelsa*), grand spider orchid (*Caladenia huegelii*), and majestic spider orchid (*Caladenia winfieldii*).

2.5.3 Important ecological communities

Swan Coastal Plain

Notable Critically Endangered Communities are the shrublands on the southern Swan Coastal Plain, ironstones in the Busselton area which have high species richness and a high number of threatened and restricted plant species (Gibson *et al*. 2000).

Jarrah Forest

The Reedia swamps (*Reedia spathacea, Empodisma gracillimum, Sporadanthus rivularis*) of the Blackwood Plateau are assessed as Critically Endangered primarily because of damage caused by feral pigs.

Warren

Threatened ecological communities include the aquatic root mat communities of caves of Leeuwin Naturaliste Ridge, the Scott River ironstone heaths, rimstone pools, algal nodules and cave structures formed by microbial activity on marine shorelines at Augusta and Black Point.

2.6 Land use

Henry Brockman

The study area covers major portions of 13 shires (Table 4) and 68% is covered by natural vegetation (mostly State reserves). In most shires, less than 20% of the workforce is employed in the agricultural sector. The exceptions are the shires of Donnybrook-Balingup, Manjimup and Nannup, though employment in agriculture is below 30% of the workforce.

Table 4. Land use statistics for shires

Shire	Area (ha)	Natural vegetation (ha)	Natural vegetation (%)	Agricultural land (ha)	Agricultural land (%)	Employed in agriculture (%)
Augusta-Margaret River	225,000	158,600	70	100,900	45	15
Bridgetown-Greenbushes*	134,000	87,500	65	58,700	44	16
Busselton	145,000	64,200	44	96,000	66	9
Capel	56,000	19,400	35	43,400	78	9
Collie*	170,000	152,700	90	25,500	15	4
Dardanup	53,000	27,300	52	26,800	51	7
Donnybrook-Balingup	156,000	108,300	69	68,000	44	28
Harvey	173,000	97,700	56	80,400	46	9
Manjimup*	702,000	592,100	84	111,000	16	26
Murray	177,000	94,300	53	78,100	44	10
Nannup	293,000	258,400	88	54,500	19	24
Serpentine-Jarrahdale	90,000	50,000	55	45,100	50	7
Waroona	83,000	51,000	60	37,200	45	11

* High Rainfall RCA Region does not encompass the whole shire. This figure is only representative of the portion that falls within the RCA Region. For exact areas in each shire see Table 9 in Appendix B.

The Gross Value of Agricultural Production (GVAP) in the South West increased by 18% between 1997-98 and 2001-02. The contribution of the GVAP to the total value of Gross Regional Production (GRP) was 9% in 2001-02, down 1% from 1997-98. Sheep and cattle numbers in Table 5 show that beef production has been the main animal enterprise (with the exclusion of Collie Shire) and that the largest dairy producers are the Augusta-Margaret River, Busselton and Harvey Shires.

Table 5. Sheep and cattle by shire (ABS 2001)

Shire	Sheep numbers	Dairy cattle numbers	Beef cattle numbers
Augusta-Margaret River	22,500	18,300	34,400
Bridgetown-Greenbushes	82,500	1,200	21,700
Busselton	54,700	18,400	35,200
Capel	700	10,000	20,500
Collie	34,500	30	6,600
Dardanup	9,300	10,600	14,600
Donnybrook-Balingup	33,100	100	27,800
Harvey	19,000	31,200	34,400
Manjimup	36,700	11,500	48,800
Murray	13,000	4,200	32,300
Nannup	5,000	1,000	21,800
Serpentine-Jarrahdale	25,700	5,100	12,600
Waroona	5,100	2,300	26,200

Viticulture is an important industry. In 2001, 32,000 tonnes of grapes were crushed, increasing to 44,000 tonnes in 2005. Vegetables and fruits contributed 38% and 40% respectively, of WA production. Gross value of vegetables produced was $74 million in 2001/02, decreasing to $73 million in 2003/04, whilst the gross value of fruit was $51 million, increasing to $59 million in 2003/04 (SWDC 2006).

Population growth in the South West was more than 3% between 2004 and 2005, and over 11% since 2000 (SWDC 2006). This trend has a big impact on agriculture due to the pressure to subdivide agricultural land for smaller lifestyle blocks and rezoning of agricultural land to other land uses. These issues are addressed via the determination of Priority Agricultural Areas through Rural Planning Strategies and by the Statement of Planning Policy SPP 2.5 (11) Agricultural and rural land use planning.

3. Resource condition and hazards

3.1 Land management hazards

Katie Bell

Land management hazards assessed for the agricultural portion of the study area included soil acidification, waterlogging, water and wind erosion, water repellence, nutrient loss and eutrophication. Hazards were derived using the methods outlined in van Gool *et al.* (2005) and assessments were based on regional soil-landscape mapping and updated attribution from the Department of Agriculture and Food's Map Unit Database.

These assessments do not measure the actual area affected by land degradation, but indicate the level of inherent hazard associated with soil and landscape features. For example, wind erosion hazard is greatest on pale deep sands. The likelihood of these soils degrading, or the risk, is determined by additional factors. On pale deep sands, the risk of wind erosion increases when ground cover is less than 50% due to overgrazing and when conditions are dry and windy.

3.1.1 Soil acidity

Current estimates suggest that 25% of subsurface soils (at depths of 10-20 cm) are either presently acid or highly susceptible to acidifying within the next 15 years. The most affected is the Bassendean Zone at 65%, followed by the Scott Coastal Zone at 39%. Another 41% (including large proportions of the Perth Coastal and Western Darling Range Zones) are moderately susceptible and may become acid within 15 to 30 years. Deep sands, which are inherently highly susceptible to acidification, are commonly affected. Fertiliser regimes and leguminous pastures contribute to increases.

3.1.2 Waterlogging

High levels of waterlogging are associated with very poor crop growth and root pruning of pastures. Under very high waterlogging, most annual pastures die. Around 22% of the overall agricultural area has high to very high waterlogging hazard, with the Pinjarra Plain, Scott Coastal and Bassendean Zones most affected. Another 11% has a moderate hazard.

Land with high waterlogging risk is widespread on the coastal plains where flat and low-lying areas are common. The prominence of Wet and waterlogged soils within the study area indicates this widespread problem on cleared land, though waterlogging within remnant vegetation indicates that many of these soils would have been subject to some degree of waterlogging prior to clearing.

3.1.3 Water erosion

Just over 22% of agricultural area has high to extreme water erosion hazard, with an additional 34% at moderate risk. The steeper valleys of the Western Darling Range Zone have the most extreme water erosion risk, with sheet and rill erosion evident in some areas. Other areas of risk are valleys in the Donnybrook Sunkland, Leeuwin and Warren-Denmark Southland Zones. Erosion in the Manjimup District is often associated with vegetable cropping (Stuart-Street 2003). Soil loss through sheet erosion on grazing land is usually less obvious but can be widespread.

The distribution of erosion is determined by the nature of the soils and landforms in conjunction with land management practices and seasonal climatic events. Sheet and rill erosion are more common on steeper land, but will occur on slopes of less than 1% if that soil has been heavily grazed or cultivated over spring and summer, leaving soils bare and vulnerable in the event of heavy summer or opening rains (Stuart-Street 2003).

3.1.4 Wind erosion

Wind erosion is most common on loose, dry soils (typically sandy soils) in landscape positions exposed to strong winds. It tends to happen in episodic events and is determined by a combination of wind speeds (> 28 km/hr), land management and inherent hazards associated with soil and landscape features. There can be a high risk of wind erosion on sandy soils, particularly when ground cover is less than 50% due to management practices such as overgrazing or cultivation.

About 27% of the agricultural area has a high to very high wind erosion hazard, with the highest risk in coastal areas. The Perth Coastal and Bassendean Zones are the most susceptible. More than 60% of their areas are at a high to very high risk. An additional 30% of the agricultural land has moderate wind erosion hazard.

3.1.5 Water repellence

Water repellence mainly affects deep sands and sandy duplex soils (Stuart-Street 2003). These soils are more vulnerable as their low surface area requires less hydrophobic organic material to coat the particles to render it repellent and susceptible to resulting runoff and uneven wetting patterns.

About 22% of agricultural land has soils that are highly susceptible to water repellence. The Bassendean Zone has the greatest susceptible area at almost 70%, indicative of the high proportion of sandy soils. The deep sands of the Perth and Scott Coastal Plains are also at significant risk.

3.1.6 Nutrient loss and eutrophication

Phosphorus and nitrogen are the main nutrients contributing to eutrophication of surface water and groundwater. These may leach through sandy soils and enter groundwater and surface water via groundwater discharge. Phosphorus, attached to clay particles, may also enter surface water directly via soil erosion.

High to very high risk of nutrient loss from agricultural land is 17% for phosphorus and 19% for nitrogen, while 1% is under extreme risk for phosphorus loss and 19% for nitrogen loss. Most susceptible areas occur in the Perth Coastal, Bassendean and Scott Coastal Zones.

3.1.7 Acid sulfate soils and acidic groundwater

Adam Lillicrap, Albany

Acid sulfate soils are naturally occurring soils that contain iron sulfides, mainly pyrite. Bacteria under waterlogged conditions form the sulfides on the coastal plains in saturated environments where there is a sulfate source. These areas include low-lying land near the sea, such as coastal wetlands (i.e. salt marshes), mangroves and estuaries or wetlands such as Benger Swamp which receives sulfate through groundwater or evaporative concentration of marine-derived salt. Figure 11 is an acid sulfate soil risk map produced by the Department of Environment and Conservation (2007) for the coastal plains from north of Perth to approximately Lake Jasper/Donnelly River.

High risk areas have a high probability of acid sulfate soils within 3 m of the ground surface. Moderate to low risk areas have a moderate to low probability of these soils within 3 m of the surface but have a high probability of acid sulfate soils at depths greater than 3 m. Low-lying areas (less than 10 m AHD) and waterlogged areas close to the coast to the east of the Donnelly River, though not mapped also have a high risk.

When acid sulfate soils are left undisturbed, they are harmless. When exposed to air, the pyrite oxidises to form sulfuric acid. Acid sulfate soils can be disturbed through drainage, digging soaks and groundwater abstraction from surface aquifers in high-risk areas. Local impacts on agriculture, infrastructure and the environment can occur.

Loss of pasture, horticultural production and gardens occurs when acidity kills plants and nutrients such as phosphorus become less available to plants under acid conditions. Pasture and horticultural products can increase in concentration of potentially toxic substances such as aluminium that become more available under acidic conditions.

Livestock production may be adversely affected through pasture loss and when stock consume toxic substances through pasture or drinking water. For example, high concentrations of sulfate can cause diarrhoea in young animals as well as weight loss. High concentrations of aluminium in stock water can react with phosphorus in intestines to form a non-absorbable complex leading to phosphorus deficiency.

Impacts on infrastructure caused by acid sulfate soils include corrosion of metals and concrete. Even if soils are neutralised, the sulfate generated can cause damage.

Acidic groundwater (see Figure 11) occurs around Donnybrook and Bridgetown, mainly in dissected valleys of the Lowden (255 Lv) and Darling Plateau (255 Dp) systems, often associated with saline seeps. It is caused when ferrous iron that is dissolved in groundwater is exposed to air, oxidises and generates acid.

It can be managed by recharge control but makes rehabilitating saline scalds more difficult as plants need to tolerate both acidity and salinity. Management practices such as using straw or other organic matter to mound and cover affected areas are the most effective options to rehabilitate sites. Engineering options developed by the mining industry to treat acid mine drainage could also be used to treat groundwater.

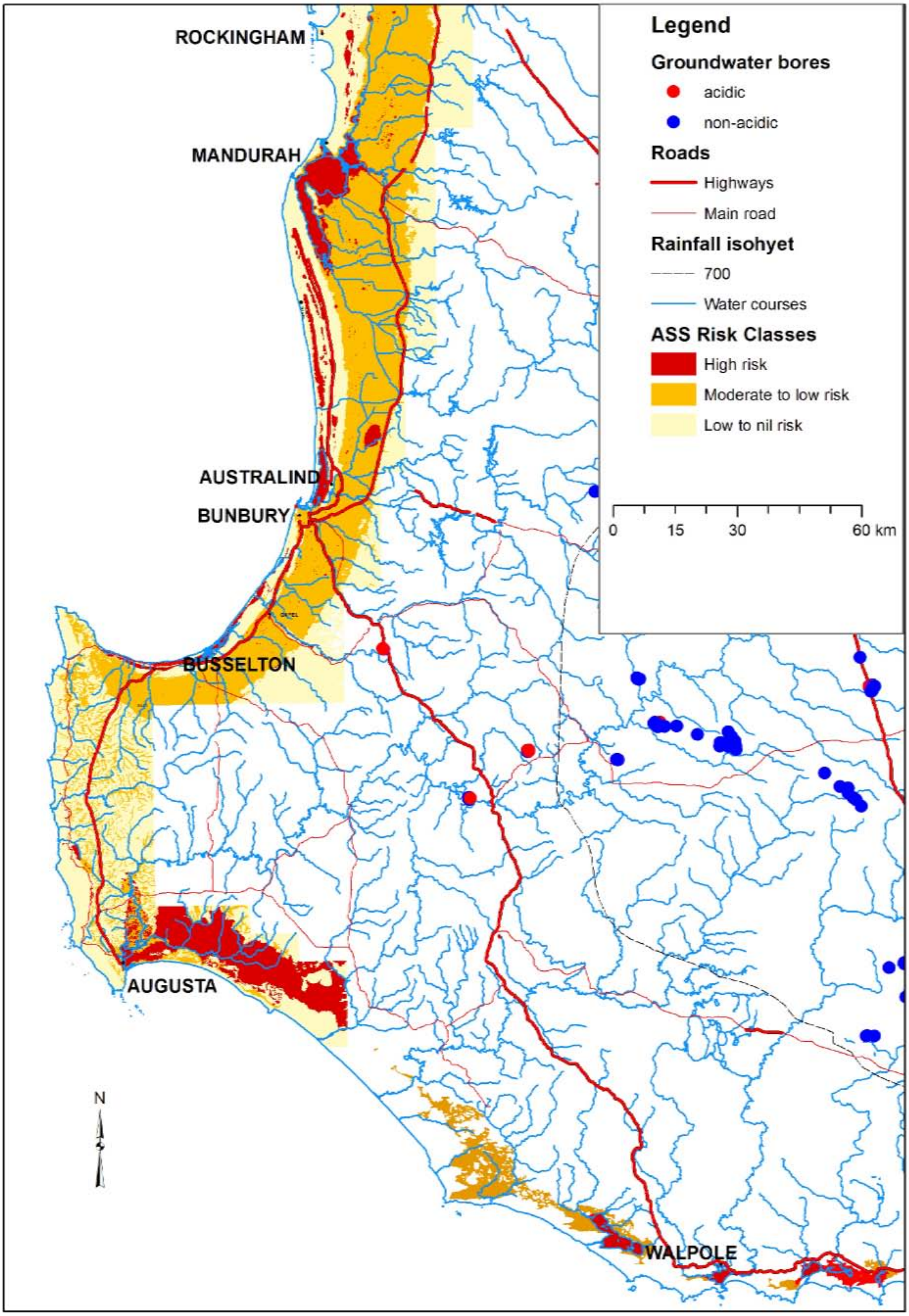

Figure 11. Risk areas for acid sulfate soils

3.2 Hydrological risk

3.2.1 Extent of dryland salinity

Dryland salinity is a major concern in the upper catchments of rivers to the east of the study area. These are largely in the < 500 mm rainfall zone with groundwater levels rising at 0.15-1.50 m/y (Anon. 1996). As noted in the Hydrology section (Section 2.4), groundwater rise is generally less than 0.5 m/y. The salinity risk is generally low due to factors including the higher precipitation and extensive vegetation cover. Current extent and future risks of salinity presented in Table 6 show that just 4% of the entire area is at risk. The hydrological risk for this area is discussed below, summarised from Tille *et al.* (2001).

Table 6. Estimates of land currently saline or at risk (Map Unit Database extracted 2007)

Zone	Area (ha)	Currently saline		At risk	
		(ha)	%	(ha)	%
211	61,173	4,000	6	8,000	13
212	82,992	0	0	0	0
213	201,490	9,000	5	23,000	12
214	77,607	0	0	0	0
215	54,495	200	0	200	0
216	76,448	0	0	0	0
253	10,037	200	2	900	9
254	134,049	100	0	1,400	1
255	224,984	2,000	1	4,000	2
Total	**923,275**	**15,500**	**2**	**37,500**	**4**

On the eastern fringe (Zone 253 and east of 254 and 255), rapid rise of watertables has been recorded in cleared areas, largely due to the higher rainfall and relatively recent history of land clearing. The average salinity of seeps here is often lower than to the east, however, partly because of the extent of leaching and salt removal from higher rainfall, and partly because of better defined drainage systems. Some areas of extensive salinity still occur, such as the broad valley floor of the upper Collie River catchment, associated with Eocene sediments. Additionally, deep incision has confined groundwater discharge to the narrow valley floors of the parts of the Blackwood and Murray River catchments.

Salinity decreases toward the coast as rainfall and leaching increase. Apart from the Swan Coastal Plain, much land remains under native forest and as a result, rising watertables are also less prevalent (Zones 214, 216 and western parts of 254 and 255). Small saline seeps do occur sporadically across this upland area, and some isolated seeps were saline prior to clearing. Salinity has affected water quality in the upper Preston valley, and around Bridgetown and north-east of Manjimup. This water is still suitable for stock but is becoming marginal for irrigation.

Dryland salinity on the Swan Coastal Plain (Zones 211, 212 and 213) is associated with areas of both local and regional discharge. Groundwater discharge from local flow systems occurs along the edge of the Whicher and Darling Scarps, as well as at the base of large sand dunes (e.g. Bassendean Dunes). Regional groundwater systems may discharge into surface sediments from deeper, semi-confined aquifers of the Perth Basin. Between Dardanup and Waroona, dryland salinity is compounded by irrigation salinity, and it can be difficult to distinguish between the two.

On the Scott River Plain (Zone 215) to the south, only limited salinity has been identified to date. This appears to be mostly the result of surface salt concentration by evaporation rather than discharge from saline aquifers.

3.2.2 Areas most susceptible to dryland salinity

It is the inland areas where rainfall is lower, more land is cleared, evaporation is higher and drainage slower, that are most susceptible to dryland salinity. If current trends in groundwater movement do not change, the cleared areas on the eastern margin of the study area are likely to experience the most rapid increase in salt-affected land during the next few decades. Based on information currently available, predictions on the Swan Coastal Plain are less certain. Table 7 is an excerpt from George *et al*. (2005) showing an estimation of urgency for each zone with regard to the future impact of salinity.

Table 7. Estimation of salinity urgency rating for each soil-landscape zone

Zone	Area (ha)	Salinity urgency rating*
211	61,173	5
212	82,992	5
213	201,490	5
214	77,607	0
215	54,495	0
216	76,448	0
253	10,037	3
254	134,049	5
255	224,984	4

* The rating scale developed by the expert panel for timing of salinity or Urgency Factor was:
- 0 No significant problems from salinity.
- 1 Most potential salinity after 2075.
- 2 Most potential salinity after 2030 and before 2075.
- 3 Most potential salinity after 2020 and before 2030.
- 4 Most potential salinity after 2010 and before 2020.
- 5 Most potential salinity at or before 2010.

The areas most susceptible to dryland salinity are associated with discharge from intermediate flow systems. Low-lying land, such as broad valley floors, tends to be the most susceptible as it is the first to be affected by rising watertables. Extensive areas of flat poorly drained land, even in elevated positions, can also be highly susceptible.

Discharge from local flow systems tends to affect smaller areas on sloping land, and can have significant impacts on water resources and land use.

Across the study area, groundwater levels are generally stable with rising trends in the cleared land along the eastern margins. No soil-landscape systems have significant falling trends. Areas with stable groundwater levels have watertables that have reached the near surface, oscillate on a seasonal basis, or are deeper and show no trend. No trend was recorded for several soil-landscape zones, in particular the Western Darling Range Zone where the major land use is natural forest, as well as some coastal systems.

One of the biggest impacts of salinity is the reduction in the water quality of major rivers which have headwaters rising in lower rainfall regions to the east. This includes the Collie River (which impacts on the water quality of Wellington Dam), and the Blackwood, Murray and Warren Rivers. This issue is further examined in Section 2.4.2.

3.3 Threats to biodiversity

Katie Bell and David Stapleton

3.3.1 Fragmentation and loss of natural ecosystems

A substantial portion (68%) of the study area is covered by remnant vegetation; the bulk in the east and south (Figure 2) across the Western Darling Range, Donnybrook Sunkland and Warren-Denmark Southland soil-landscape zones. However, extensive clearing over the last century has changed the landscape of the coastal plains, particularly the Swan Coastal Plain, from one dominated by a mosaic of woody perennial vegetation communities to mixed annual crops and pastures with scattered islands of remnant vegetation (Hobbs *et al*. 1993). Land clearing is still occurring, but the rate has fallen substantially over the last two decades and is mainly associated with urban development rather than agriculture.

Excluding the absolute loss of habitat and species associated with large-scale clearing, fragmentation processes have been shown to cause major changes to ecosystem function of remnant native vegetation and fauna through isolation and edge effects by exposure to environmental weeds, domestic grazing and extreme fluxes such as wind, water and fire. Reduced resilience of remnant vegetation complexes continues to cause biodiversity loss.

3.3.2 Sediment, nutrient and toxin accumulation

These threats affect rivers, wetlands and estuaries and encompass the loss or degradation of biodiversity caused by accumulation of soil, nutrient or toxins (including acid sulfates) to levels that exceed the capacity of natural ecosystems to absorb them.

Coastal inlets and estuaries are particularly susceptible to eutrophication (nutrient accumulation) because of the intensive agricultural and urban development on the predominantly sandy soils of the western portion of the Swan Coastal Plain. As a result, widespread waterlogging and artificial drainage systems rapidly move water and nutrients into waterways. Phosphorus is the major nutrient which accumulates, resulting in periodic algal blooms in waterways such as the Peel-Harvey Inlet.

3.3.3 Pest plants, animals and disease

Exotic plants frequently out-compete native species, especially in the modified environment of remnant vegetation. Foxes and feral cats are widespread throughout the South West, with the cats most concentrated around human settlements. Feral pigs are also a problem over wide areas of State forest. Weeds are a problem on small reserves, in parts of State forests, national parks, local government reserves and in most unfenced, and some fenced, bush remnants on farms. Key weeds of concern include bridal creeper, blackberry, arum lily, cottonbush, veldt and love grass, invasive pasture species and various woody species.

Phytophthora dieback *(P. cinnamomi)* is a chronic biodiversity threat, which can also affect some orchard crops, commercial wood production, and nature-based tourism in the study area. There are no eradication methods therefore preventing the spread and managing impacts on priority Important Ecological Communities are the best current responses.

Management bodies set up to facilitate its management are the Dieback Consultative Council, the Dieback Working Group and the Dieback Response Group.

3.3.4 Salinity

Though most concerns for loss of biodiversity are focused on the wheatbelt, affected areas are in the east of the study area, where some vegetation on lower slopes and valley floors is at risk. Parts of the coastal plain are under threat as a result of irrigation salinity.

4. Management options

This section sets out options for managing hazards. Factors such as soil type, topography, annual rainfall, enterprise mix and financial structure will influence the most appropriate approach for an individual farm business.

4.1 Land management

Implementation of the options listed below is often site-specific. It will also depend on the goals of the land manager and the economic benefits versus the costs.

4.1.1 Soil acidity management options

Adding alkaline reagents: Lime as topdressing (to increase surface pH) and banding or incorporating at depth (to increase subsoil pH) is the main recommendation. This has proven effective and economically viable for surface acidity, and also effective at ameliorating the subsurface with time (Tang and Rengel 2001).

Surface liming is effective at maintaining pH in the subsurface if a program is started before significant acidity has developed. Treatment for subsurface acidity is generally more expensive, technically challenging and variable, depending on method of incorporation and topsoil conditions (such as topsoil pH).

Reduce rate of acidification: Part of an integrated solution in conjunction with adding alkaline reagents. Reducing the rate of product removal from paddocks will reduce acidification by reducing export of cations (that are replaced by acid hydrogen ions in the soil). An example is to limit hay cutting to alkaline soils and to distribute the hay as feed on acid paddocks.

Reducing or removing the input of acidifying fertilisers will decrease acidification. Reducing or stopping nitrate leaching will also help. This can be achieved by reducing or splitting nitrogen applications to what the crops can use.

Acid tolerant species: Plants that can tolerate lower pH can help to maintain profitability over the short term and can be used in conjunction with an amelioration strategy. However, this measure is ineffective at reversing acidification as it allows processes to continue.

4.1.2 Waterlogging management options

Waterlogging needs to be addressed from both agricultural and hydrological viewpoints, and a combination can be very effective. Recommended changes in agricultural practices are:

High water use farming systems: Establishment of high water use pasture, crops and trees upslope helps to reduce recharge and waterlogging (Tille *et al*. 2001, pp. 111-121). These methods can be effective in managing waterlogging caused by rising watertables in intermediate or local flow systems, but are best used with other management options.

Tolerant crops and pastures: Although this practice is primarily an adaptation rather than control, increased water use on affected areas can lead to reduced waterlogging (Tille *et al*. 2001, pp. 159-161).

Soil management: Waterlogging due to surface ponding on dispersive but otherwise well drained soils can be mitigated by minimum tillage practices and gypsum application, increasing water infiltration.

Engineering options: Surface drains, subsurface drainage, banks, raised beds and pumping are options that may be considered (Tille *et al*. 2001, pp. 162-166).

4.1.3 Water erosion

Water erosion tends to happen in episodic events and is determined by a combination of rainfall and land management, as well as inherent hazards associated with soil and landscape features. It occurs in natural ecosystems, but accelerated rates are common because of land clearance, cultivation and overgrazing (Tille *et al*. 2001).

Farm layout: Realigning fences, tracks and laneways to avoid channelling runoff and isolate areas of high erosion (Tille *et al*. 2001, pp. 186-187). This is essential for effective management of water erosion.

Maintaining vegetative cover: Establishing perennial vegetative cover, maximising productivity of annual crops, retention of stubble and trash in broadscale crops and use of cover crops and inter-row ground cover can be considered (Tille *et al*. 2001, pp. 187-188).

Stock control: Waterlogging or erosion susceptibility can be mitigated by managing grazing pressure to prevent overgrazing and hence denuding soils (Tille *et al*. 2001, pp. 187-188).

Cross-slope cultivation: Cropping along the contour or at a slight gradient to slow runoff (Tille *et al*. 2001, p. 188).

Reduced tillage: Minimum tillage or no-tillage cropping systems maintain soil stability (Tille *et al*. 2001, p. 188 & Moore 1998, p. 239). This can be very effective in reducing (but not eliminating) erosion in broadscale cropping areas.

4.1.4 Wind erosion

Land management and ground cover play an important role in determining the erosion that occurs during strong winds. Without prevention and minimisation, the impacts of wind erosion can include sand blasting damage to crops, loss of soil, loss of macro- and micro-nutrients, long-term loss of productivity and loss of the pasture seed bank.

Windbreaks: Tree belts have been demonstrated to reduce wind erosion risk. They are generally used in conjunction with other management options.

Isolating problem areas: If the susceptibility of a paddock varies widely, fence to soil type so that susceptible areas can be managed separately. Another option is the claying of the soil to reduce the wind erosion risk.

Land use: Adjusting land use practices to maintain more than 50% ground cover on all soils is very effective (e.g. destocking and stubble retention).

4.1.5 Water repellence

Water repellence can lead to uneven wetting patterns in susceptible soils, which result in the poor and patchy germination of crops and pasture (Moore 1998). Susceptible soils generally have less than 5% clay in the topsoil. Management options include:

Claying: Addition of clay to topsoil to increase surface area and reduce repellence (Moore 1998 p. 63). Claying is currently the best long-term solution (Blackwell 1996), it can be highly effective on light topsoils containing less than 3% clay, but not very effective on heavier topsoils. A suitable source of clay (dispersible kaolinite) is required close to the area to be treated due to high transport costs.

Furrow sowing: This sowing method can be employed when cropping for harvesting water and ensuring even wetting around the seed (Moore 1998, pp. 60-62), however, it can increase risks of erosion, herbicide concentration, leaching and waterlogging.

Perennial vegetation: This can reduce germination problems as the requirement for annual germination is removed, although it can lead to higher water repellence of infiltrating water (Stuart-Street 2003).

4.1.6 Nutrient loss and eutrophication

Fertiliser management: Match applications to plant requirements by soil testing, tissue testing or rapid sap tests, and manage the timing and method of application of fertiliser to avoid runoff and leaching.

Alternative fertilisers: Use low soluble phosphorus fertiliser or rock phosphate if phosphorus required on sandy soils especially in coastal areas close to waterways. If sulphur is lacking, use gypsum rather than superphosphate as a sulphur source.

Soil amendments: e.g. Alkaloam can improve nutrient retention (Tille *et al.* 2001, p. 226).

Streamlining and filter strips: Fence off and establish buffer strips to filter nutrients and protect waterways. The recommended width of buffer strips varies with land use and soil type and should also consider topographical and hydrological attributes. For more information, see Tille *et al.* 2001, p. 227.

Perennial pastures: Can minimise losses from leaching, as they are able to access nutrients longer and deeper than annual species.

4.1.7 Acid sulfate soils and acid groundwater

Learn to recognise acid sulfate soils and minimise their disturbance. Use agricultural lime to increase the pH of affected soils.

Use straw or mulch to mound and cover affected areas to encourage revegetation.

Cover soils with fresh water (requires careful design to avoid waterlogging and other problems). Use wide, shallow drains (designed to prevent erosion) that allow surface water to flow away quickly without exposing pyrites.

Further information is available from:

- DEC website http://portal.environment.wa.gov.au/portal/page?_pageid=53,34347&_dad=portal&_schema=PORTAL
- NSW DPI www.dpi.nsw.gov.au/agriculture/resources/soils/ass
- www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality

4.2 Groundwater management

Drainage, pumping, siphons and relief wells can be used to manage groundwater. Thorough investigation and planning are essential for success and will ultimately save money. A 'Notification of Intent' must be lodged with the Commissioner of Soil Conservation (*Soil and Land Conservation Act 1945*) prior to the commencement of works.

4.2.1 Groundwater

At a number of sites, drains have been dug to lower the surrounding groundwater levels. These have been constructed where the groundwater level is within 2 m of the surface and are mostly on lower slopes or valley floors. The effectiveness varies due to the hydraulic conductivity of the soils. It is advisable to dig 'test pits' along the path of a proposed drain to assess its potential to increase discharge.

Proper design to allow for controlled surface water entry, prevention of wall collapse and stock access reduces maintenance costs. Bligh (1989) and Keen (1998) provide some good guidelines for construction.

Pumps perform the same function as a drain although the area of influence where groundwater levels have dropped is generally circular around the bore. Bore depth and the hydraulic properties of the aquifer influence the magnitude of drawdown. Pumping is expensive, and while some farmers had some success with a subsidised initial capital outlay in the late 1980s, the main expense comes through running costs and maintenance. Unless the aquifer has high hydraulic conductivity and the zone of influence measures tens of hectares, this option should only be used where protecting high value infrastructure such as dams, buildings and roads.

Siphons and relief wells lower the watertable and soil salinity levels within the root zone of plants and may be used to manage small saline seeps in relatively dissected landscapes. Siphons use gravity to maintain the flow, resulting in lower running costs. The main limitations of the siphoning systems are the aquifer hydraulic conductivity and the gradient of the surrounding land. Seymour (2003) noted that the gradient needs to be at least 1.5%.

Significant maintenance problems and loss of siphon occur due to the presence of iron bacteria and high levels of dissolved gas in the groundwater. Relief wells are used in specific situations where the groundwater level is above the natural surface. This happens when a bore penetrates an aquifer with enough hydraulic pressure to push the water to the surface (artesian aquifer). They are normally more effective in areas with slopes greater than 5%. The wells are usually cut off, at or below ground level, and the water is discharged to an appropriate receiving body. Drawdown in the well remains at or near ground level. Numerous piezometers in the lower slopes have suitable conditions, which indicate that the use of relief wells may be possible.

4.3 Surface water management

Table 8 summarises suitable surface water management practices for the main slope classes.

Table 8. Suitable earthworks for slope classes and landform elements

Slope class	Landform element	Suitable earthworks
0-1%	Valley floors, lower footslopes	Levee and Levied waterways W-drains or spoon drains Raised beds Deep drains and pumping depending on site
	Crests	None recommended
1-3%	Long slopes, footslopes Lower to upper slopes	Seepage interceptor drains Reverse bank seepage interceptor drains Levee and levied waterways Diversion banks Broad-based banks (not less than 2%)
3-5%	Mid-slopes to upper slopes	Grade banks Seepage interceptor drains Reverse bank seepage interceptor drains Levee and levied waterways Diversion banks Broad-based banks
5-10%	Mid-slopes to upper slopes	Grade banks Levee and levied waterways Diversion banks
>10%	Steep slopes and rock outcrop	No earthworks recommended – site specific solutions required

4.4 Biodiversity management

Katie Bell and Dave Stapleton

Maintaining biodiversity is important for ecosystem processes, ethics, aesthetics and culture, economics and recreation.

4.4.1 Management of fragmentation or loss of natural ecosystems

Programs and practices that manage the loss or fragmentation of natural ecosystems in Western Australia focus on restricting where and how much clearing can occur, and on improving the conservation status and management of remnants, natural ecosystems and their components. Fencing remnant vegetation and revegetating farmland to create ecological linkages is one way to mitigate the impact of fragmentation.

The Department of Environment and Conservation (DEC) is responsible for the management, primarily for conservation, of reserves that covers over 1.5 million hectares (62%) in the study area, including national parks, conservation parks, regional parks, nature reserves, State and timber reserves. There are also many reserves vested in local government authorities, some of which are managed for biodiversity conservation purposes.

4.4.2 Management of sediment, nutrient and toxin accumulation

The Wetlands Conservation Policy for Western Australia (1997, as cited in SWCC 2005) has principal objectives relating to prevention of further loss or degradation of valuable wetlands, conserving viable representations of major wetland types and viable wild populations and diversity of wetland biota; conserving the abundance of water birds, particularly migratory species, and to greatly increase community awareness of wetland values.

Management plans and strategies which address the issue of sediment, nutrient and toxin accumulation in wetlands on the Swan Coastal Plain have been developed for most of the catchments in the region. Typically these plans address the issue of eutrophication of waterways through a combination of revegetation of streamlines and better management of soils and fertiliser use and controls on point sources of pollution, such as intensive piggeries (CGC 2000) (also see Section 4.1.6).

4.4.3 Management of pest plants, animals and disease

The State Weed Plan (DAWA 2001) guides the identification, priority ranking and management of environmental weeds in the study area.

DEC's reserve management plans also include weed management activities, placing highest priority for the control of environmental weeds on those impacting on rare flora, fauna and threatened ecological communities; impeding management operations; or adjacent to private property and likely to affect it. Local government authorities also carry out considerable weed control activities on land vested with them.

Increasing numbers of private land managers are targeting environmental as well as declared weeds on their properties. Some catchment groups and local governments have undertaken surveys and mapping of priority weeds to determine extent and locations of infestations and to guide coordinated and strategic control of weed species on roadsides reserves and private land.

The Western Shield Program has benefited some mammal populations such as southern brown bandicoot (*Isoodon obesulus fusciventer*), chuditch (*Dasyurus geoffroii*), woylie (*Bettongia penicillata ogilbyi*) and brush-tailed phascogale (*Phascogale tapoatafa*) which have increased throughout some State forest following the establishment of fox baiting.

The management of Phytophthora dieback is done at several response levels. At the local level, emphasis is on action-oriented activities such as phosphate tree injections and spraying. At the wider regional and State level, a Phytophthora dieback atlas is being developed as part of a cross-NRM regional project funded under State and Australian Government programs.

4.4.4 Salinity mitigation

DEC and DAFWA are developing new deep-rooted native perennial crops suitable for strategic revegetation that aim to achieve both biodiversity and commercial goals. Greatly increasing their use is seen as the main measure by which landholders can minimise watertable rises and reduce impacts of salinisation on the productivity of their land and both on- and off-farm natural ecosystems. The Forest Products Commission’s *Infinitree* program also assists greatly with eucalypt, *Pinus pinaster* and *P. radiata* establishment.

5. Publications – DAFWA

Available at www.agric.wa.gov.au in the Farmnotes section of DAFWA publications.

Number	Title
Climate	
6/2005	ENSO and how it affects south Western Australian rainfall
56/2005	What are rainfall deciles?
111/2006	Sources of climate data
204/2007	Climate risk outlook 2007
Farm forestry	
10/2003	Selecting tree varieties for small land holdings
62/2004	Farmer experiences in farm forestry: Peter and Jan Coffey, Boyup Brook
Farm planning and environmental management	
63/1996	Farming with environmental benefits
112/1999	Farm laneways: Design and construction
38/2000	Vegetation buffer zones
Irrigated agriculture	
26/1990	Soil moisture monitoring equipment
198/2007	Calculating readily available water
234/2007	Water salinity and plant irrigation
Managing salinity	
25/1994	Managing saline, high rainfall valleys and flats
39/2001	Recharge management for salinity control
42/2001	Relief wells in south Western Australia
59/2002	Monitoring groundwater levels
52/2003	Subsurface drainage and surface water management for salinity control
76/2003	Shallow relief drains
36/2004	Groundwater pumping for salinity control
53/2004	Evaporation basins for salinity management
Pastures and grazing management	
43/2001	Native perennial grass based pastures for livestock
84/2001	Lucerne – a high water use production package
7/2004	Grazing management
Surface water management and water supply	
79/1993	Managing waterlogging and inundation in pastures
72/2002	Using windbreaks to reduce evaporation from farm dams
75/2003	Grade banks to manage water erosion
79/2003	Grassed waterways
80/2003	Broad-based banks
81/2003	Seepage interceptor drains
64/2004	Rainwater tanks
249/2007	Livestock and water salinity
256/2007	Reducing and maintaining low salt levels in marginal farm dams

Soil and land management	
109/1996	Managing water repellent soils
65/1996	Soil management options to control land degradation
66/1996	Stubble management to control land degradation
68/2000	Looking at liming: Test strips
70/2000	Looking at liming: Consider the rate
80/2000	Management of soil acidity in agricultural land
73/2001	Sulphur for high rainfall pastures
74/2001	Potassium for high rainfall pastures
75/2001	Soil test and phosphorous rate for high rainfall pastures
67/2002	Amount of stubble needed to reduce wind erosion
215/2007	Effectiveness of rock phosphates
217/2007	Soil testing for phosphorus

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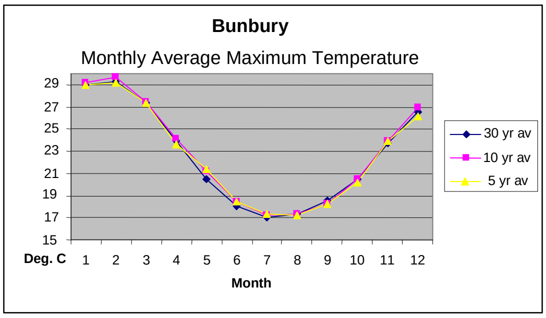
7. Appendices

7.1 Appendix A



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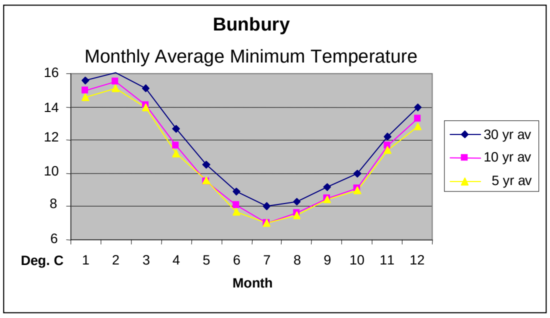

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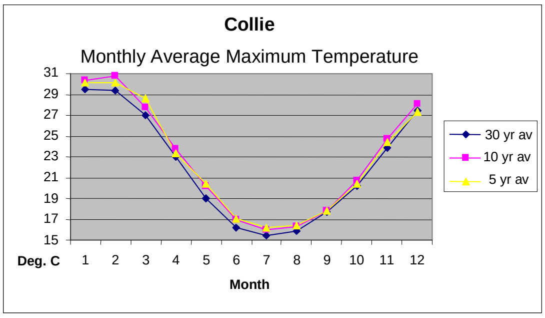

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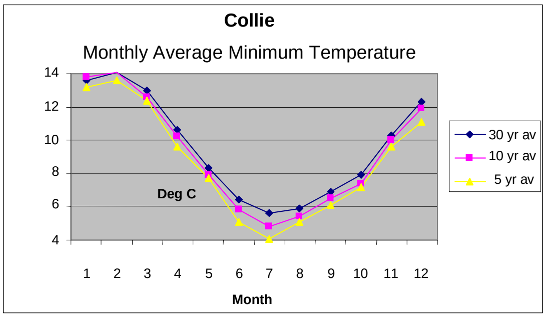

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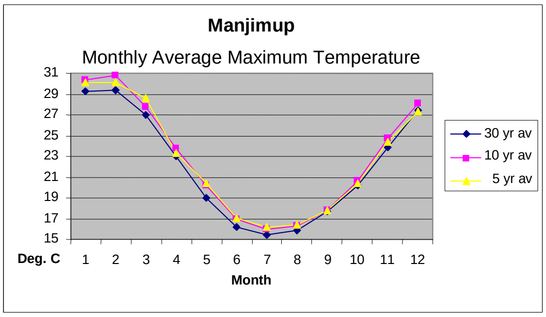

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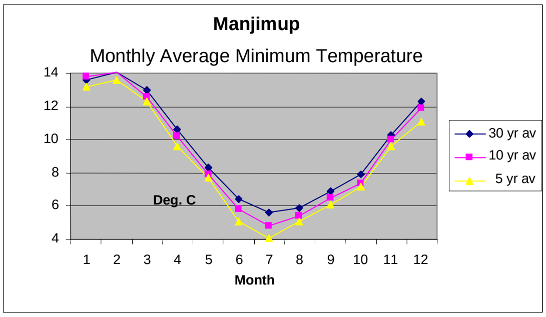

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Figure 12A-F. Graphical representation of comparisons between monthly average maximum and minimum temperatures for Bunbury, Collie and Manjimup

7.2 Appendix B

Table 9. High Rainfall RCA Region coverage of shires

Shire	Shire area (ha)	RCA coverage (ha)	RCA coverage (%)	Overall agric. area (%)	RCA agric. area (%)
Augusta-Margaret River	225,100	225,100	100	47	47
Nannup	293,500	293,500	100	21	21
Waroona	83,200	83,200	100	50	50
Dardanup	52,900	52,900	100	56	56
Harvey	173,400	173,400	100	55	55
Donnybrook-Balingup	156,000	156,000	100	44	44
Serpentine-Jarrahdale	90,000	90,000	100	53	53
Capel	55,800	55,800	100	83	83
Busselton	145,500	144,500	99	68	69
Murray	177,600	169,000	95	48	51
Manjimup	702,800	608,800	87	17	20
Bridgetown-Greenbushes	133,800	114,500	86	44	52
Collie	170,200	129,800	76	17	22
Boddington	191,900	71,800	37	3	9
Boyup Brook	282,600	29,200	10	4	43
Wandering	190,500	10,500	5	1	13

Shire area (ha) – Area of whole shire.

RCA coverage (ha) – Area of that shire contained within the RCA Region.

RCA coverage (%) – Percentage of that shire contained within the RCA Region.

Overall agric. area (%) – Percentage of the whole shire covered by agricultural area.

RCA agric. area (%) – Percentage of the RCA portion of the shire covered by agricultural area. This demonstrates the agricultural significance of the portion of the shire included in the RCA Region.