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Wilson Inlet catchment appraisal 2007

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WILSON INLET
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WILSON INLET
CATCHMENT APPRAISAL 2007

Compiled by

Ronald Master

for the South Coast Agricultural Region RCA Team

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Disclaimer:

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Contents

Summary

The objective of Rapid Catchment Appraisal (RCA) is to assess the condition of, and future risks to, agricultural and natural resources within regional geographic catchments. The process also attempts to identify the most suitable options to manage the risk.

This report describes the Wilson Inlet study area which covers about 263 000 ha in an area to the west of Albany. It includes the Wilson Inlet and all of its tributaries.

The geological area is covered mainly by the Ravensthorpe Ramp comprising of benches, separated by ridges that run in an east-west direction. The rivers draining to the south coast are relatively short and are incised into the tilted surface of this ramp.

Ironstone gravelly soil and Wet or waterlogged soil are the dominant soil supergroups. The most common soil groups are Duplex sandy gravel, Pale deep sand, Wet soil, Grey deep sandy duplex and Semi-wet soils, which together cover 60 per cent of the study area.

The hydrology is influenced by two types of groundwater flows. Local groundwater flow systems which are responsive to land use changes with on-site issues of rising groundwater and salinity. The intermediate groundwater systems may experience shallow groundwater levels and soil salinity.

The primary land use is agriculture with predominantly sheep and cattle grazing, forestry, viticulture and some cropping. There are also considerable, scattered areas of state forest and increasing areas of semi-rural land developments.

There are two main rivers systems and three minor systems. The main threats for the Hay and Denmark Rivers are nutrients, salinity and sedimentation. The minor systems — Sleeman, Little and Lake Saide–Cuppup — are at most risk from nutrients and sedimentation. The Denmark River is earmarked as a potential future water supply for Albany and Denmark and has been proclaimed under the *Country Areas Water Supplies Act*. It has also been identified as a Water Recovery Catchment under the Salinity Action Plan.

The degradation risks and their extent in the study area are:

- subsurface soil compaction – 85 per cent
- subsurface soil acidity – 70 per cent
- wind erosion – 70 per cent
- water repellence – 60 per cent
- water erosion – 55 per cent
- nitrogen loss – 35 per cent
- current salinity (year 2000) – 2 per cent.

1 Introduction

While dryland salinity, waterlogging and soil erosion cause serious environmental problems in Australia, several other forms of soil degradation are of concern such as water repellence, wind erosion and soil acidity. Dryland salinity will increase as groundwater levels continue rising, decreasing the value of agricultural land and reducing agricultural production.

The objective of Rapid Catchment Appraisal (RCA) is to assess the condition of, and future risks to, agricultural and natural resources within regional geographic catchments. The process also attempts to identify the most suitable options to manage the risk.

This report describes the condition of, and the risk to, the resources found in the Wilson Inlet study area including soils, geomorphology, and groundwater and surface water hydrology.

1.1 Study area

The Wilson Inlet study area is located in the south-western portion of the southern agricultural region (Figure 1). It contains the river catchments of the Wilson Inlet including the Denmark, which is earmarked as a potential water source for Albany and Denmark. The study area covers the Plantagenet, Denmark and Albany Shires and includes the major rural centres of Albany, Denmark and some of Mount Barker.

The important assets within the study area are:

- Wilson Inlet, an internationally recognised estuary of significance
- Hay River and its tributaries such as Sheep Wash Creek
- Lake Kwornicup Nature Reserve
- Sheep Wash and Mitchell National Parks
- Named wetlands within the Eyrie and Kwornicup groups
  - the Eyrie, Fern, Kokokup, Don, Nyandyeetup, Mowilyilip and Barnes Lakes
  - Pardelup and Owingup Lagoons
  - Noogunillup, Nyoongarup, Kwornicup and Quichenup Swamps
  - Old Barrack Spring and Moolagup Water Hole
- High value grazing, horticultural and viticulture land.

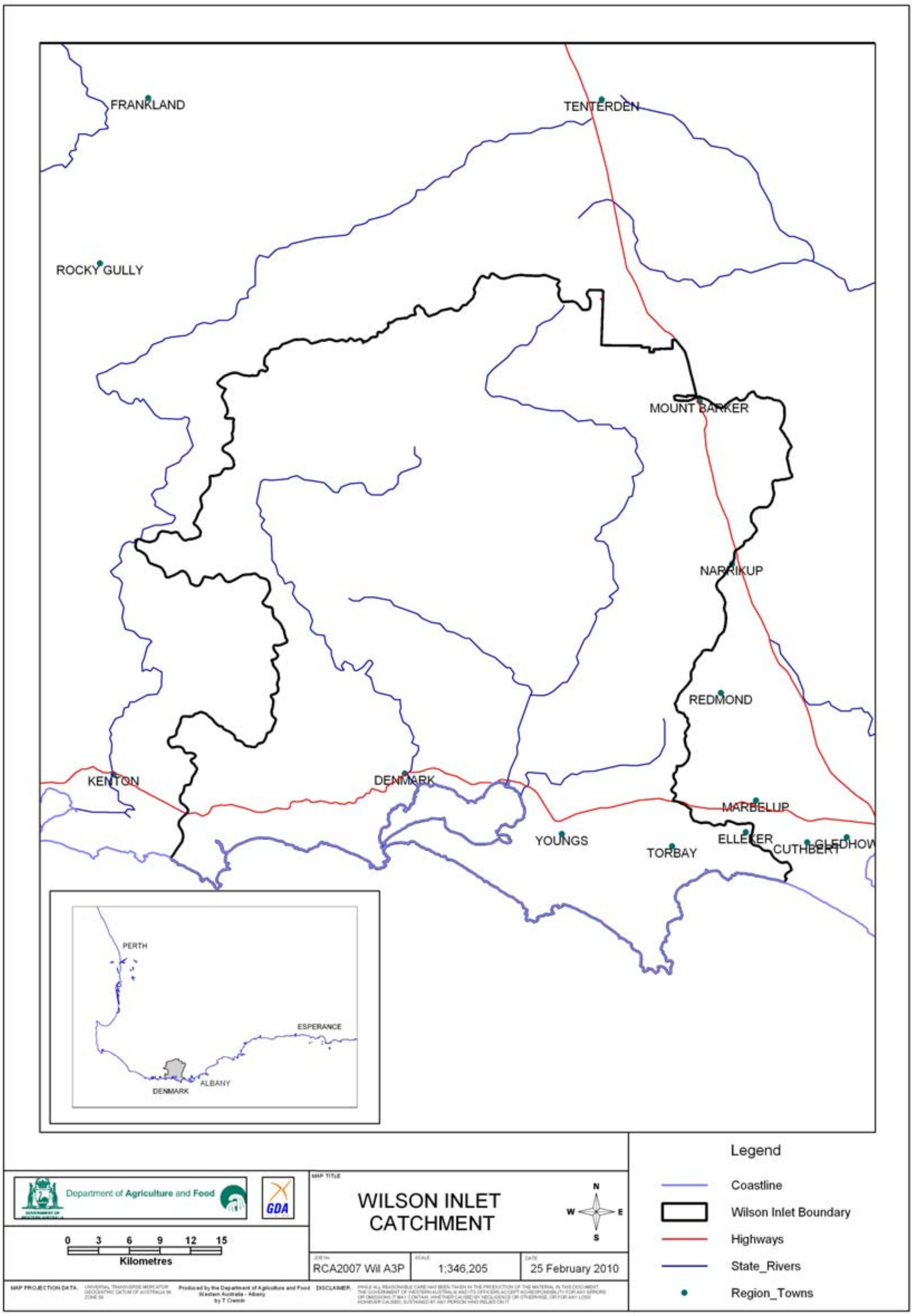


Figure 1: Wilson Inlet study area

2 Natural resource base

2.1 Climate

Jill Lisson, Land Conservation Officer

The climate of the Wilson Inlet study area is temperate with cool wet winters and dry warm summers.

2.1.1 Rainfall

The mean annual rainfall varies from 1050 mm in the south-west of the study area to 600 mm in the north, and nearly three-quarters of the rain falls during the growing season of May to October. Described below is interpolated data from 30 years (1975–2005) from Young's siding in the south and Pardelup in the central north.

In the south, the average annual rainfall is 940 mm, with the driest year, 1987, receiving 710 mm, and the highest annual rainfall of 1200 mm in 1992. There is a 20 per cent chance that the area will receive more than 1010 mm (wet year) and a 20 per cent chance of receiving less than 820 mm (dry year). The area averages 150 mm during the wettest month of July and 20 mm in February.

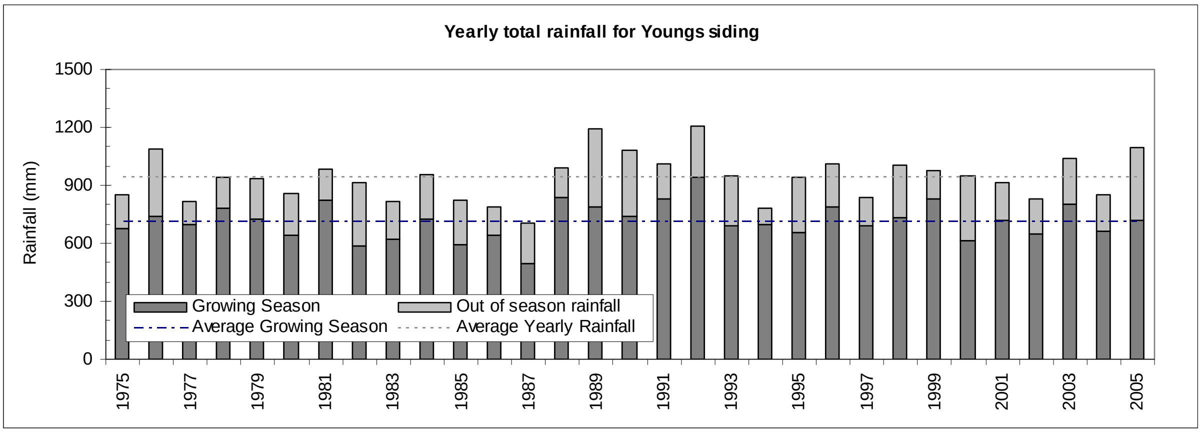
In the north, the average annual rainfall is 720 mm, with the driest year, 1994, receiving 520 mm, and the highest annual rainfall of 960 mm in 2005. There is a 20 per cent chance of receiving more than 810 mm (wet year) and a 20 per cent chance of receiving less than 610 mm (dry year). The area averages 100 mm during the wettest month of July and 20 mm in January (Figures 2 and 3).

2.1.2 Temperature

The mean summer maximum temperature at Young's siding is 24.5 °C and there are occasional heat waves, during which the maximum temperature exceeds 40 °C. The average summer minimum temperature is 14 °C. The average winter temperature is 17 °C with an average minimum of 8 °C. The highest recorded temperature for the period 1975–2005 is 45 °C and the lowest is 1 °C (Figure 4).

At the Pardelup weather station, the mean summer maximum temperature is 25.5 °C, with the occasional heat wave exceeding 40 °C. The average summer minimum temperature is 13 °C. The average winter temperature is 15 °C with an average minimum of 7 °C. The highest recorded temperature for the period 1975–2005 is 44 °C and the lowest is 0.5 °C.

a)



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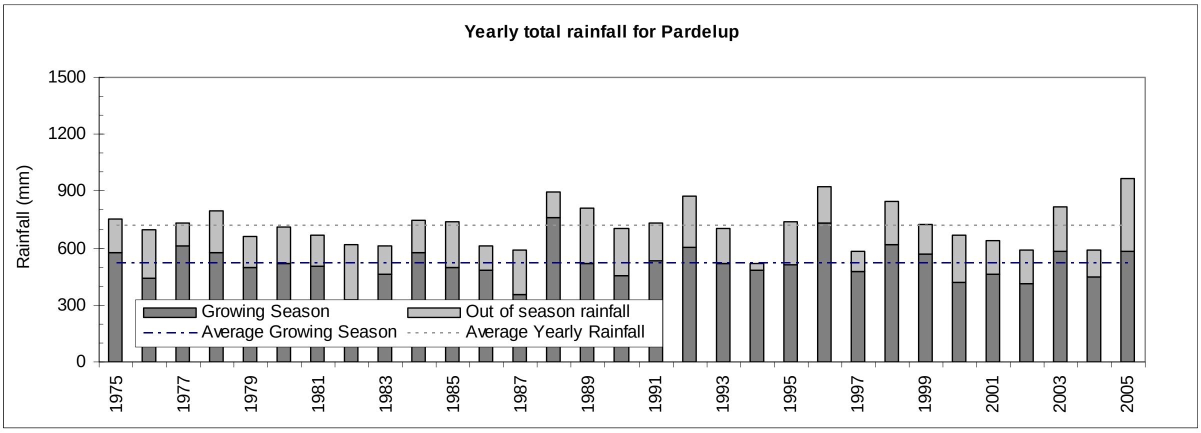
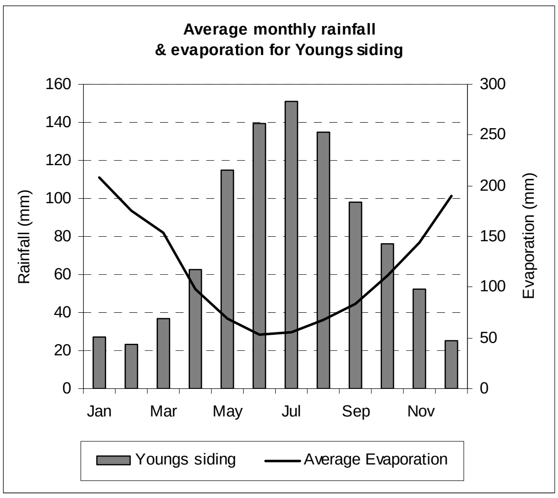


Figure 2: Annual rainfall for a) Young's siding and b) Pardelup

a) **b)**



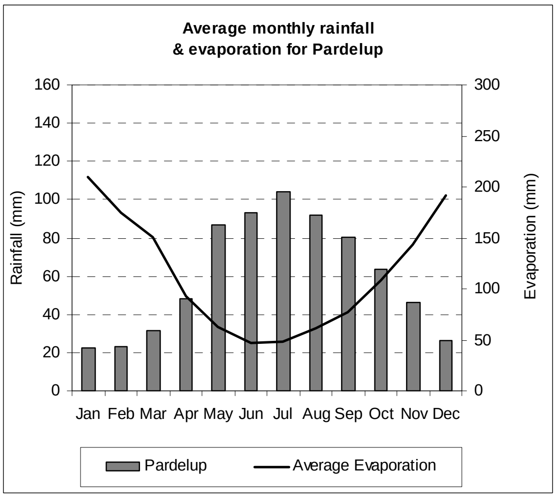
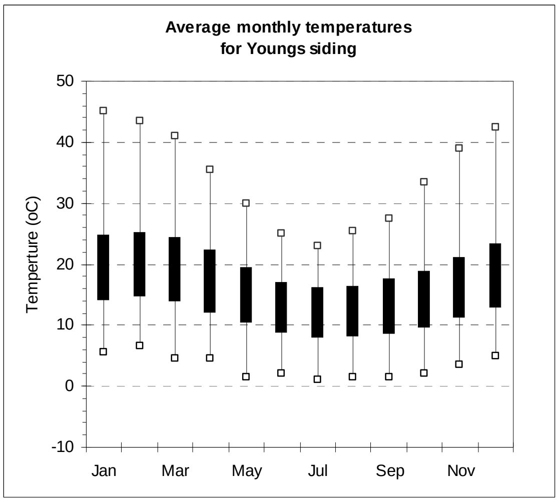


Figure 3: Average monthly rainfall and evaporation 1975–2005, for a) Young's siding and b) Pardelup

a) b)



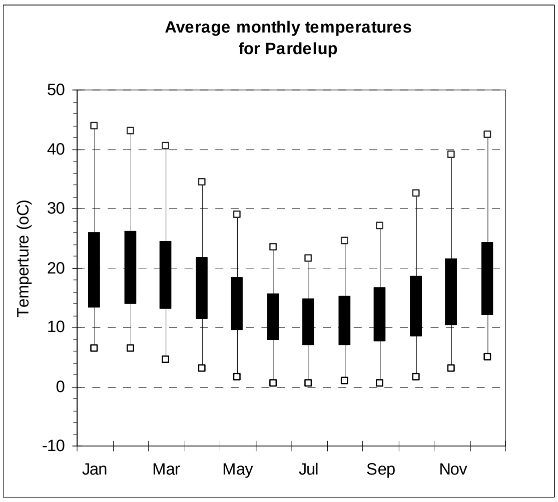
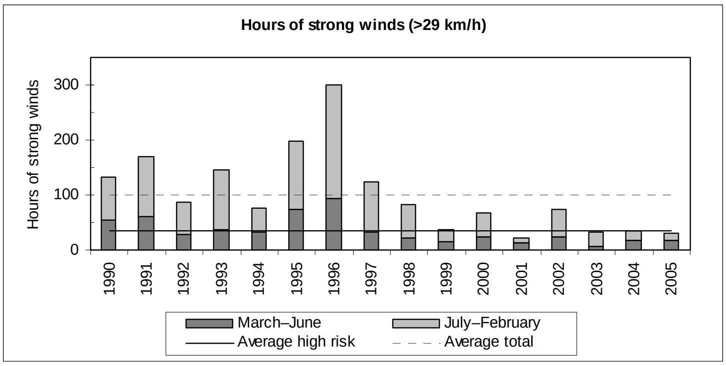


Figure 4: Average monthly temperatures for a) Young's siding and b) Pardelup. The graphs show the highest and lowest recorded temperatures, and average minimum and maximum daily temperatures (1975–2005).

2.1.3 Wind

When wind reaches speeds of 29 km/h it can move exposed particles of soil up to sand grain size. The hours of strong winds (greater than 29 kph) for 1990–2005, have been recorded by the department's climate station in Mount Barker. About one-third of these strong winds blow from March to June, which are the months where there is high risk of wind erosion. The predominant direction of strong winds is north-west (Figure 5).

a) b)



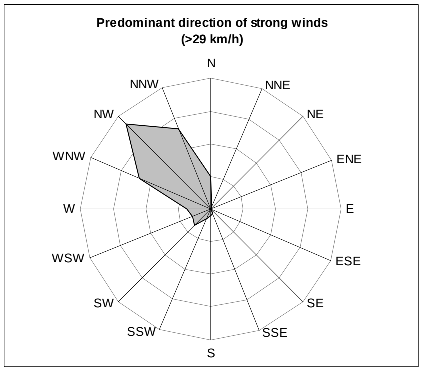


Figure 5: a) Hours of strong winds and b) predominant wind direction at Mount Barker

2.2 Geology

Ruhi Ferdowsian, Senior Hydrologist

2.2.1 Physiography

The study area lies within the Albany–Fraser Orogen, a tectonic unit bordering the southern margin of the Yilgarn Craton. It is covered almost entirely by the Ravensthorpe Ramp (Cope 1975).

The Ravensthorpe Ramp comprises of benches, separated by ridges that run in an east-west direction. The Ramp has a gradual southerly slope from around 350 m elevation near the southern edge of the Darling Plateau to sea level. The rivers draining to the south coast are relatively short and are incised into the tilted surface of this ramp.

The Denmark and Hay Rivers are two of these rejuvenated rivers that, through active headwater erosion and river capture, have dissected a series of east-west benches (with ancillary swampy flats) and formed new landform patterns. These swampy flats are probably remnants of ancient river courses that flowed westward. Good indications of this are the topography of the area, remnants of ancient lakes, the occurrence of alluvial and colluvial deposits, rounded pebbles, and lateritised deposits in old flat-bottomed valleys. Three of these ancient river courses which had very poor drainage can be traced within the study area.

2.2.2 Basement rocks

Precambrian basement rocks (> 600 million years old) underlie the entire area and they consist of Proterozoic granite, gneiss and migmatite from the Albany–Fraser Orogen (Morgan & Peers 1973). These rocks are generally igneous and metamorphic. Numerous shear zones and faults occur in the basement rocks. These features have dictated the position of the creeks and affect surface and groundwater flows in the study area (Ferdowsian & Greenham 1992).

In swampy areas, Tertiary sediments (marine deposits) cover the basement rocks. These sedimentary rocks are known as the 'Werillup Formation' and the overlying 'Pallinup Siltstone'. The Werillup Formation consists of a dark grey siltstone, sandstone, claystone and lignite (brown coal) deposited in swampland environments (Cockbain 1968). The Pallinup Siltstone consists of siltstone and sponge-like materials deposited in a marine environment.

2.2.3 Regolith

In hilly areas, the regolith (the incoherent material that rests upon solid rock) is shallow to moderately shallow (< 20 m) and is mostly composed of in-situ weathered material over basement rocks. This weathered profile contains a considerable quantity of salt (up to or even more than 2,000 t/ha) and consists of sandy clay that may change to gritty sandy clay. A thin layer of coarser material usually exists just above bedrock, through which most of the groundwater flows.

Regolith in the very gently undulating areas and in flat landscapes is moderately deep (10-30 m). In most of this area, the basement rocks or the in-situ weathered profiles are covered by sediments of Tertiary age (Pallinup Siltstone) which may be overlain by Quaternary alluvium.

The hydrology of most of the areas is strongly influenced by the broad and often stagnant flats and depressions that are found mostly around the main drainage channels and in very gently undulating areas. The regolith in these flats consists mainly of a heavy clay profile that hinders the movement of groundwater because of low hydraulic conductivity and low hydraulic gradient.

2.3 Soil-landscape information

Sharon Hu, Soil Research Officer

2.3.1 Soil groups

Ironstone gravelly soils and Wet or waterlogged soils are the most common soil supergroups covering half of the study area, followed by Deep sands and Deep sandy duplex soils which cover nearly another third (Table 1).

Table 1: Soil supergroups

Soil supergroup	Area (ha)	Area (%)
Ironstone gravelly soils	73 000	28
Wet or waterlogged soils	60 000	23
Deep sands	43 000	16
Deep sandy duplexes	38 000	14
Shallow sandy duplexes	14 000	5
Rocky or stony soils	14 000	5
Other soil supergroups	21 000	8
Total	**263 000**	**100**

Soil groups are defined within soil supergroups and are used to identify the soil component of the land resource data sets maintained by DAFWA. The most common soil groups are Duplex sandy gravel, Pale deep sand, Wet soil, Grey deep sandy duplex and Semi-wet soils, which together represent 60 per cent of the study area (Schoknecht 2005) (Table 2).

Table 2: Soil groups

Soil group	Area (ha)	Area (%)
Duplex sandy gravel	43 000	16
Pale deep sand	31 000	12
Wet soil	30 000	11
Grey deep sandy duplex	29 000	11
Semi-wet soil	26 000	10
Loamy gravel	13 000	5
Grey shallow sandy duplex	11 000	4
Shallow gravel	10 000	4
Stony soil	9 000	3
Yellow/brown deep sandy duplex	7 000	3
Deep sandy gravel	7 000	3
Bare rock	5 000	2
Gravelly pale deep sand	5 000	2
Pale shallow sand	4 000	2
Brown deep loamy duplex	4 000	2
Other soil groups	29 000	11
Total	**263 000**	**100**

2.3.2 Soil-landscape systems and subsystems

Soil-landscape systems are areas that consist of repeating patterns of landforms and slopes with associated soils. There are 18 systems and the Kent and Kentdale Systems cover half of the study. Ten subsystems have been identified within these two systems and the four most extensive are described in Table 3. The large number of systems and subsystems of small area covering the rest of the study area is a reflection of the high landscape variability. Appendix 1 describes the minor systems and subsystems that individually cover at least 1 per cent (2600 ha) of the study area, which excludes 27 subsystems that together cover about 8 per cent (20 000 ha).

Table 3: Most common soil-landscape systems and subsystems

Subsystem	Description
Kent System	
KeMW (43 000 ha, 16%)	Undulating rises with broad flat swampy depressions. Soils are formed in colluvium and weathered granite. Gravelly soils are common.
KePP (19 000 ha, 7%)	Gently undulating plain with some swamps. Duplex sandy gravels, Grey deep sandy duplexes with Wet and Semi-wet soils.
KeNYd (12 000 ha, 5%)	Low relief (< 20 m) valleys. Saline in some areas. Soils are formed in weathered colluvium from gneiss.
Kentdale System	
KdMI (13 000 ha, 5%)	Broadly undulating uplands. Gravelly yellow duplex soils and laterite on crests; jarrah–marri forest. Leached sands in depressions; jarrah–sheoak woodland.

2.4 Hydrology

Ruhi Ferdowsian, Senior Hydrologist

2.4.1 Groundwater flow systems

Groundwater processes causing salinity can be categorised according to their flow systems. This is because the type (local, intermediate or regional) of system reflects the ease with which salinisation can be managed. Two of these groundwater flow systems exist in the area — local and intermediate.

Local groundwater flow systems

These are where recharge and discharge of groundwater are in close proximity to each other — usually within 1–3 km (hillside scale). In these areas, the hydraulic head surfaces (in most cases it is the same as groundwater levels) conform to local topography. This kind of aquifer has a reasonable hydraulic gradient and is responsive to land use changes. Shortly after recharge is controlled, groundwater will drain away allowing levels to drop. More than 60 per cent of the study area has local groundwater flow systems including the dissected landscape in the north-east and along Sheepwash Creek, Mitchell and Hay Rivers. In these areas, salinity and rising groundwater are on-site issues. Therefore, management practices outside the influence of these areas will have little or no effect on the extent of their salinity.

Intermediate groundwater flow systems

These have a horizontal extent of 5–10 km and generally occur across several properties. Intermediate groundwater flow systems have low hydraulic gradient and in some cases low hydraulic conductivity. The low gradient results in little lateral groundwater flow out of the area. Consequently large areas may experience shallow groundwater levels and soil salinity. The surface of the landscape may be gently undulating or flat. The gently undulating swampy areas in the north-west of the study area, the flats to the east of Albany Highway and the stagnant flats in the south have intermediate groundwater flow systems. Groundwater levels in the flat landscapes will not have a rapid decline after recharge is controlled. However, the treatments in gently undulating areas may result in an initial rapid decline in groundwater levels.

2.4.2 Hydrological landscapes

Three types of hydrological landscapes exist in the study area.

2.4.2.1 Dissected landscape with low hills

More than 60 per cent of the study area is composed of dissected landscapes called Low Hills (30–90 m relief). These areas have moderate to gently undulating plains with well-defined creeklines. The valleys are v-shaped and have erosional stream channels (Figure 6). Some of the valleys have been infilled by alluvial sediments. In these cases the valley floors have changed to elongated narrow flats with defined creeks cut into their floors. The hillsides have shallow basement rocks that may surface on the landscape. Numerous shear zones and faults occur in the study area and often dictate the position of the creeks and affect surface and groundwater flows.

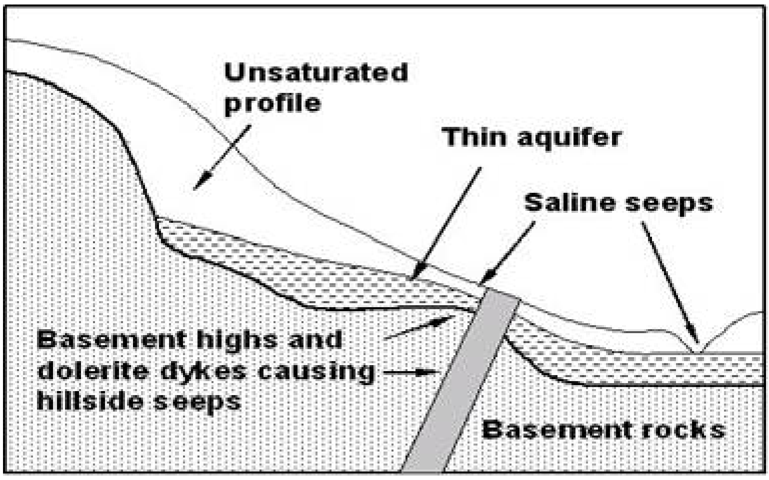


Figure 6: Typical cross-section of a dissected landscape and low hills

Groundwater flow systems

Groundwater flow systems in these landscapes are local and roughly align with the direction of surface drainage. In the more dissected areas, aquifers have a higher gradient, which allows groundwater to move towards low-lying discharge areas, such as creeks and valley floors. Shallow basement rocks can partially obstruct groundwater flow and cause hillside seeps. Most of the discharge sites are in the lower parts of landscape and form the creekline seeps and valley floor salinity that have an impact on streams and rivers.

2.4.2.2 Moderately dissected undulating areas

This landscape covers almost all of the north-west of the study area. The valleys and lower slopes are depositional zones and may be in the shape of stagnant flats with or without a defined creekline. The regolith is usually deep although a few rock outcrops may be seen on hilltops and upper slopes. Figure 7 depicts a typical cross-section.

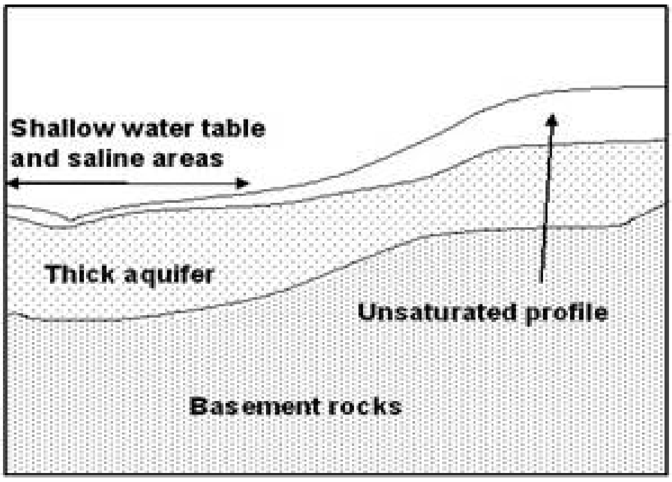


Figure 7: Typical cross-section of a moderately dissected undulating landscape

Groundwater flow systems

Groundwater flow systems along the slopes are local but may change to intermediate in the valley floors. The aquifers are usually thicker than those in the dissected landscape and have very low hydraulic gradients.

2.4.2.3 Very gently undulating areas with stagnant flats and swampy floors

These areas have broad stagnant flats and ancient drainage flats with salt lakes and swamps (Figure 8). A few broad sand dunes may also be present.

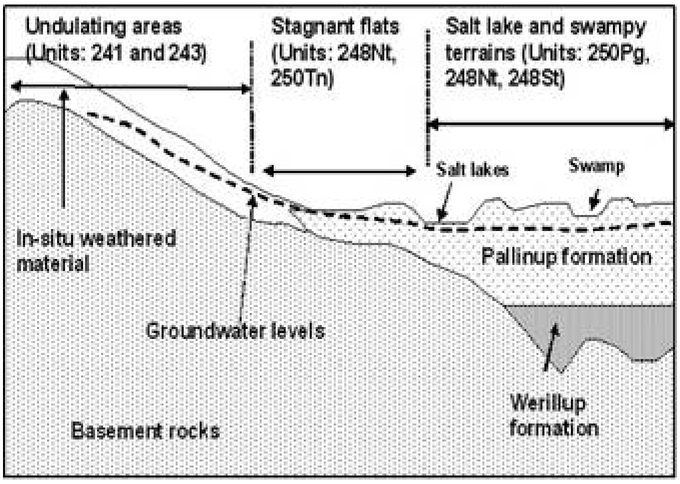


Figure 8: Sequential change of hydrological landscapes in very gently undulating areas with stagnant flats and swampy floors

Groundwater flow systems

Groundwater flow systems are mainly intermediate and have very low groundwater gradients which results in very little lateral groundwater flow into or out of the area. It is also the recipient of some groundwater flow and larger volumes of surface runoff from the gently undulating landscapes. The lakes and swamps have become windows to groundwater. Groundwater discharges through the floors of the lakes and changes them to salt lakes and saline swamps.

2.5 Waterways

This information is taken from Mercer (1999) unless otherwise stated

The Wilson Inlet study area contains two major river systems and three minor systems (Table 4). These systems have a number of issues, with the main threats for the major systems, the Hay and Denmark Rivers, being nutrients, salinity and sedimentation. The Hay River is at most risk from salinity, and the minor systems — Sleeman, Little, and Lake Saide – Cuppup --- are at most risk from nutrients and siltation.

All of these systems drain in a southerly direction and discharge directly into the Wilson Inlet and have varying levels of salinity ranging from fresh to brackish (table 4). The Denmark River is of particular significance with fresh to marginal salinity and a significant flow from a mainly vegetated catchment which has resulted in it being earmarked as a potential future water supply.

Table 4: Main waterways (west to east)

Waterway	Catchment size (km^2)	Area of catchment cleared (%)	Main channel length (km)	Average annual flow (ML)	Water quality
Lake Saide	30	20	8	3,800	Fresh
Cuppup	60	80	10	13,000	Fresh
Sleeman	90	80	22	15,000	Fresh
Hay	1280	60	80	78,000	Marg/brak
Denmark	690	15	60	45,000	Fresh/marg
Little	30	40	10	6,600	Fresh

Source: Pen (1999)

2.5.1 Riparian fringing vegetation

Riverine fringing vegetation of the Denmark and Hay Rivers is predominantly forest with a wide range of forms and diversity of species. Karri forest occurs in the hilly country, usually on loamy soils derived from granite outcrops or along incised valleys. Jarrah formations characterise much of the area. Broad swampy drainage lines carry paperbark or banksia woodlands and reed swamps, with sandy, seasonally inundated flats bearing low woodland of jarrah, marri, wandoo (*E. wandoo subsp. wandoo*) or swamp yate.

2.5.2 Wilson Inlet fringing vegetation

The Wilson Inlet, channels, and for a short distance up the rivers are fringed by the rush *Juncus kraussi* and the salt-tolerant paperbark *Melaleuca cuticularis*. Juncus forms single species stands near the mouth of the inlet, or mixed with samphire (*Sarcocornia quinqueflora*), *Samolus repens* and occasional *M. cuticularis* in salt marshes. In disturbed areas of salt marshes there are introduced grasses including salt water couch (*Sporobolus virginicus*), *Polypogon monspeliensis* and buffalo grass (*Stenotaphrum secundatum*). A second community dominated by the sedges *Isolepis nodosa* and *Baumea juncea,* and the herb *S. repens,* occurs in flatter areas behind the juncus–melaleuca community.

These areas provide important feeding and roosting areas for waterbirds including migratory waders which feed in these areas during the summer months to prepare for their long journey to their breeding grounds in the northern hemisphere. Groups of migratory waders observed in these areas include sandpipers, plovers, stilts and stints. Many of these birds are protected by international agreements.

2.6 Native vegetation

Jack Mercer, Marlak PTY LTD

2.6.1 Vegetation communities

The Wilson Inlet study area lies within the South-west Botanical Province. It occupies parts of the Menzies and Warren Sub-districts of the Darling Botanical District in the south of this province. The vegetation of the area is relatively diverse and there are four main vegetation communities (Beard 1979):

- Kent System overlies gently undulating and poorly drained terrain, with numerous large swamps. Soils are shallow leached sands over rock or laterite. Jarrah (*Eucalyptus marginata*) low forest predominates with little karri (*E. diversicolor*) present. Patches of jarrah and marri (*Corymbia calophylla*) are on the better soils with some karri on alluvial soil along the Denmark River. Mount Lindesay occurs within the system surrounded by kingia, heath, and jarrah and marri forest. Swampy drainage lines support reeds and scrub heath.

- Hay System contains most of the Hay River catchment. The landform is more dissected than the Kent System with jarrah–marri forest on upper slopes and ridges, jarrah and sheoak (*Allocasuarina fraseriana*) low forest on lower slopes and swamps consisting of reeds and scattered shrubs in the valley floor.
- Denmark System includes forest with patches of karri on high slopes. Jarrah or jarrah–sheoak occurs on mid to lower slopes on sand or laterite. East of Denmark, wide belts of swampland occupy flat valley floors, with karri occurring on the hilltops. The swamps feature dense sedges with woody plants in various communities.
- Torndirrup System extends along the coastal strip of the sub-region. The coastal dunes and slopes support mixed heath and scrub heath with peppermint (*Agonis flexuosa*) low woodland in the sheltered swales and areas further away from the coast. Stabilised inland dunes support jarrah forest with some karri on older sands.

The broad vegetation classification system by Beard can be further divided into nine vegetation formations for the coast and adjacent areas near Denmark. These are: high open forest; open forest; woodland; low woodland; closed scrub; open scrub; sedgelands; granite outcrops; and waterways and wetlands. Open forest predominates in the uncleared areas of the study area's lower rainfall zone. Except for near the coast, high open forest predominates in the catchment east and north of the inlet. Other plant associations are represented to a lesser degree although sedgeland communities are relatively widespread between the Hay and Denmark Rivers.

2.6.2 Declared flora

Declared flora in the study area are few, compared to the eastern sector of the South Coast Region. Proteaceous genera and endemism are not as prevalent in this area which has relatively less diverse vegetation communities particularly in the karri and jarrah forests. Recorded declared rare flora are *Banksia goodii*, *Lambertia orbifolia*, *Laxmannia jamsii* and possibly *Isopogon uncinatus* in the south-western extremities (Robinson & Coates 1995).

2.7 Land use

Ronald Master, Development Officer

The dominant land use in the upper part of the study area is sheep production, viticulture, and blue gum forestry. There is some cropping, mainly canola, barley and oats, though there are issues associated with grain quality because of high rainfall and moist conditions during harvest, as well as waterlogging.

The medium to high rainfall and long growing seasons make the central and southern portions of the study area ideal for cattle production and intensification. Viticulture is the largest single intensive land use. There was 1200 ha planted to vines up to 2001 and the industry has continued to expand since then, mainly to the west and south-west of Mount Barker, with pockets of development to the north of Denmark. Other horticultural crops like apricots, avocadoes and olives have been established for some time and cover 1500 ha in the Plantagenet Shire with much of this production within the study area. Additional intensive land uses, such as strawberries, vegetables and seed potatoes, supply mainly local markets, although some produce (e.g. seed potatoes) makes its way to Perth domestic markets (ABS 2001).

Blue gums have become a large and permanent part of the agricultural landscape in the higher rainfall areas. Expansion was very rapid in the 1990s but this has slowed partly because of the substantial increase in land values and competition for suitable land. However, the industry is still seeking to expand and it is likely that more land will be planted to blue gums.

The study area also has significant areas of state forest and there are increasing areas of semi-rural land developments in the southern areas.

2.7.1 Land management initiatives

The Denmark River is earmarked as a potential future water supply for Albany and Denmark, which has prompted the Department of Water to proclaim the Denmark River catchment under the *Country Areas Water Supplies Act*, which could involve land water management advice and regulation. The Denmark River has also been identified as a Water Recovery Catchment under the Salinity Action Plan which has led to substantial investment by the federal and state governments through the South Coast NRM Inc to implement on-ground works.

Landholders have also made substantial commitments towards addressing land management issues in the medium to long term. In partnership with the state and federal governments, state departments and the South Coast NRM Inc, a large project was initiated that implemented a range of works including 3500 ha of perennial pastures, 50 km of earthworks, 20 stock crossings, 100 km of biodiversity and riparian fencing and 80 ha of riparian and biodiversity revegetation.

2.7.2 Demographics

The population of the coastal Albany and Denmark Shires, which encompasses a large proportion of the study area (Figure 1), has shown a gradual increase in the period 2001–06 of 1.3 and 2 per cent respectively. This increase seems to buck the decreasing population trend evident in many smaller rural centres, although the majority of the population lives within and around the towns of Albany and Denmark. Issues of rural decline associated with decreasing farm numbers and increasing farm size are evident in the study area however, with the population of the inland Plantagenet Shire growing only 0.1 per cent for the same period (ABS 2007).

3 Catchment condition and future risk

3.1 Climate change impacts

Miriam Lang, Senior Project Officer

For the purposes of showing indicative climatic patterns, patch point data from Carmendale which is roughly in the middle of the catchment will be used to show seasonal patterns and possible changes. The current long term average rainfall for Carmendale is 671mm (Figure 9).

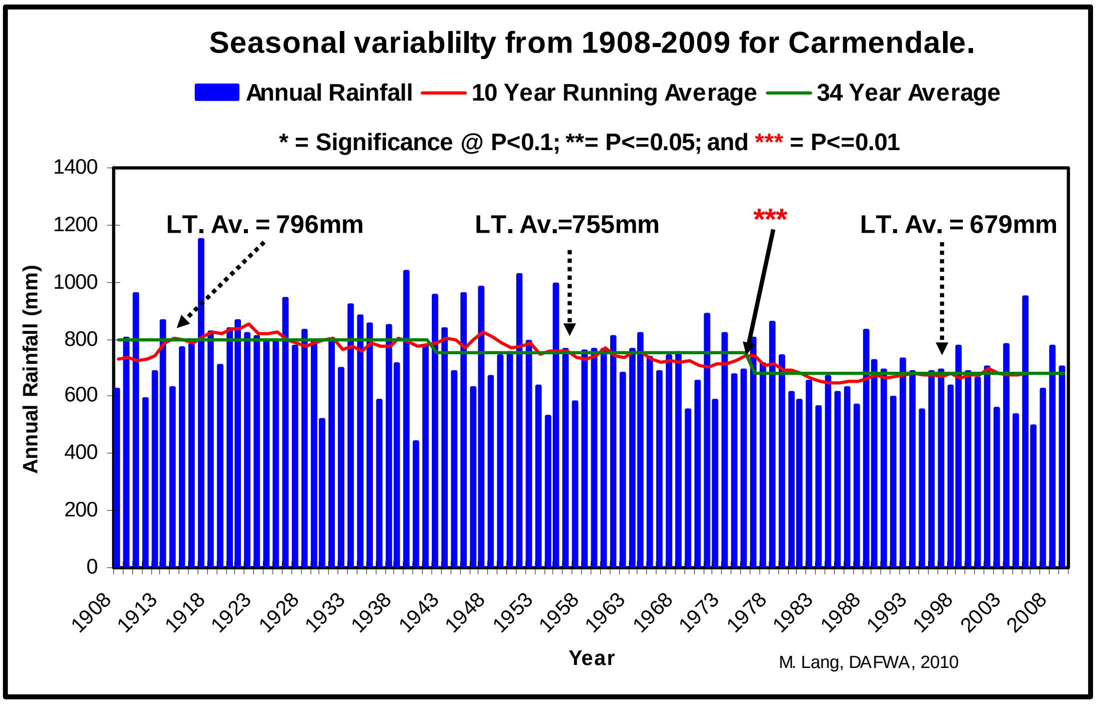


Figure 9. Seasonal variability in rainfall from 1889 to 2008 for Carmendale.

For Carmendale, there has been a gradual decline in average rainfall as evident by both the 33 year average trend and the 10 year running average. The step down in rainfall between the averages for the 33 year period 1943 to 1975 relative to the 33 year period 1976 to 2009 is significant (*** =99% probability). This decline of 78mm represents a 12% reduction in long term rainfall.

A comparison of the average monthly rainfall between the time periods 1908-1941, 1942-1975 and 1976 -2009 (Figure 10) highlights the significant decline in winter rainfall. Of recent the most significant decline in rainfall has been for the month of July. In line with this it is clear that rainfall has declined for the months April to October inclusive, as such driving the overall decline in winter growing season rainfall.

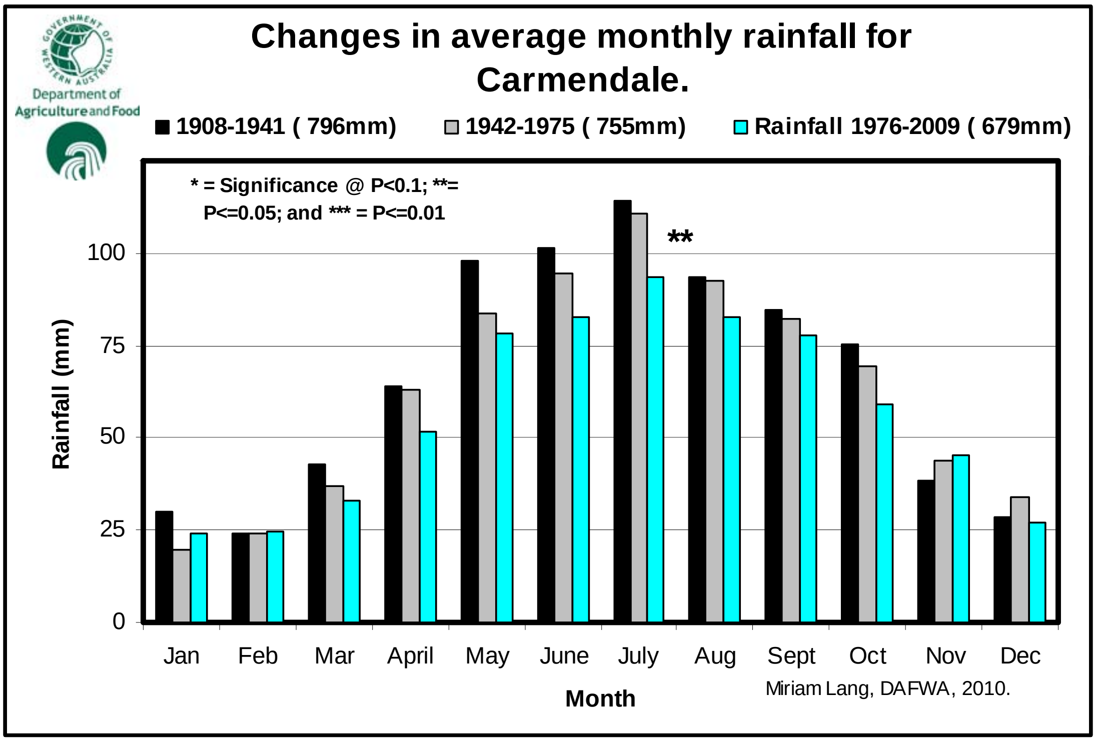


Figure 10 Change in average monthly rainfall between three time periods for Carmendale.

Maximum temperatures for Carmendale indicate mild conditions with average summer temperatures just above 25°C and winter temperatures attaining just over 15°C. Night time average minimum temperatures range between 7°C in winter and 14°C in summer months.

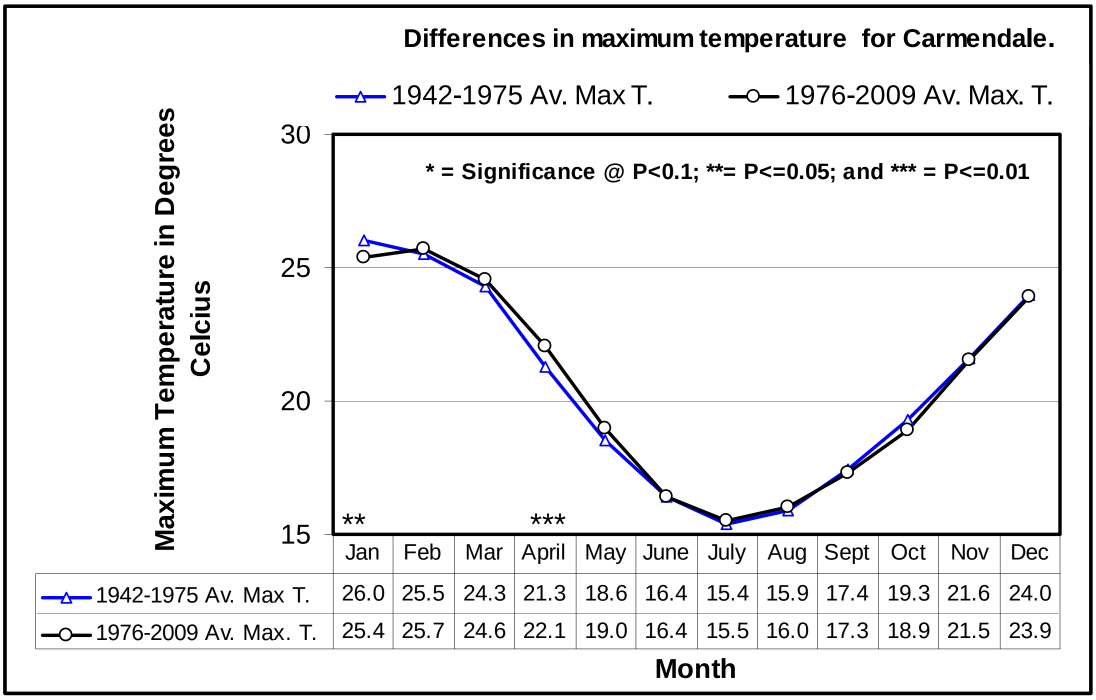
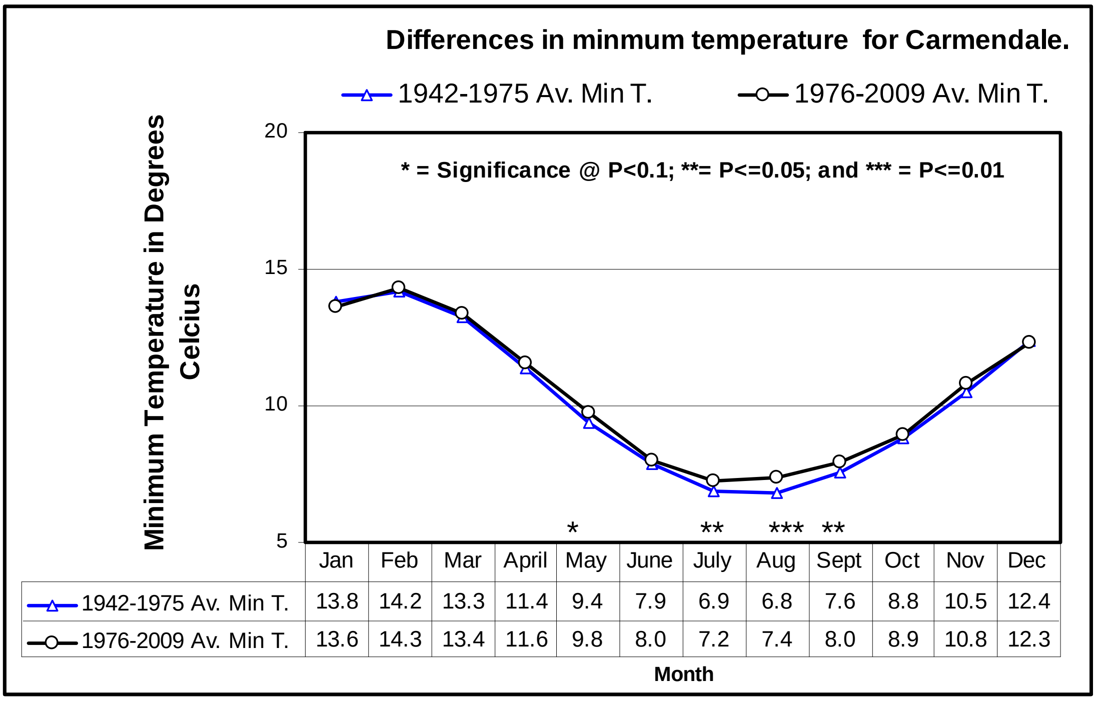


Figure 11 Change in max temperature based on 33yr running averages.

An analysis of long term temperature records indicates a significant shift in temperatures for the months of Jan and April. (fig 11) The 33 year running average of 1942-1975 when compared to 1976-2009 has shown a significant decrease in maximum temperatures of 0.6

Celsius in January and an increase in Aril of 0.8 Celsius. The minimum temperature has also shown some trends with significant differences in the months of May, July, August and September (fig 12), all of which have shown an increase.



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1942-1975 Av. Min T.	13.8	14.2	13.3	11.4	9.4	7.9	6.9	6.8	7.6	8.8	10.5	12.4
1976-2009 Av. Min T.	13.6	14.3	13.4	11.6	9.8	8.0	7.2	7.4	8.0	8.9	10.8	12.3

Figure 12 Change in min temperature based on 33yr running averages.

3.1.1 Climate trends

Not only is it evident from the historical rainfall records of Carmendale that there is a change in the amount and distribution of rainfall throughout the season, but there is also international recognition that climate patterns appear to be changing globally. Figure 13 is a scenario based on CSIRO modelling of the possible changes in rainfall that might be experienced in the future for Carmendale. In particular it reflects the potential for a continued decrease in annual rainfall. The modelling indicates that rainfall may decline by 30mm by 2010, 49mm by 2020 and 68mm by 2030 relative to the average rainfall of 682mm for the period 1971-2000.

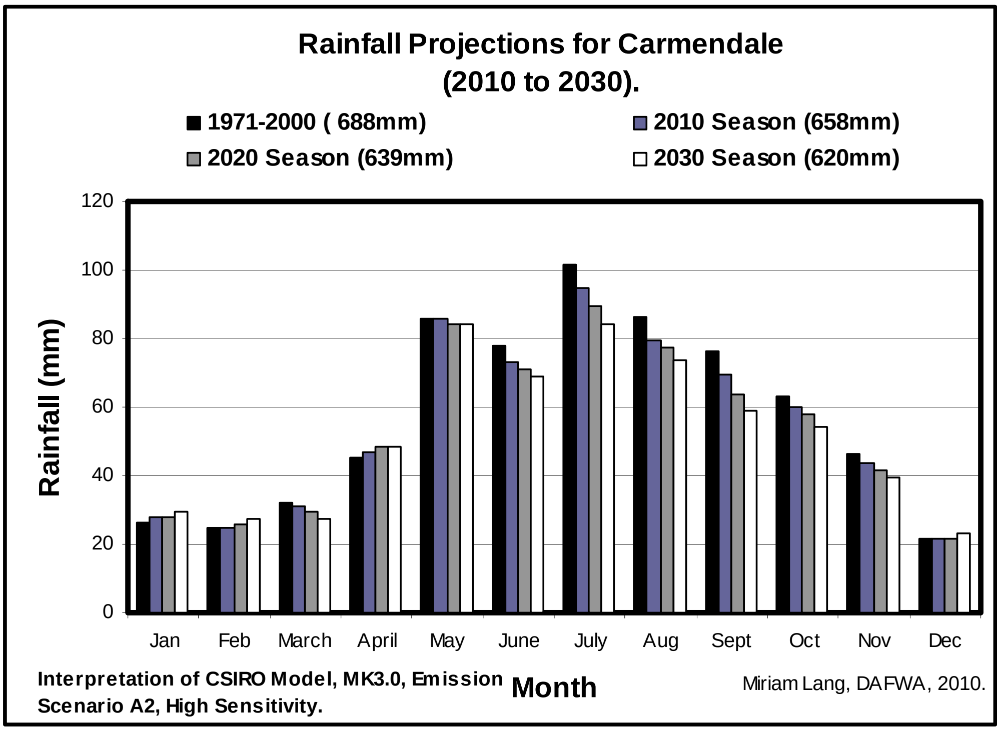
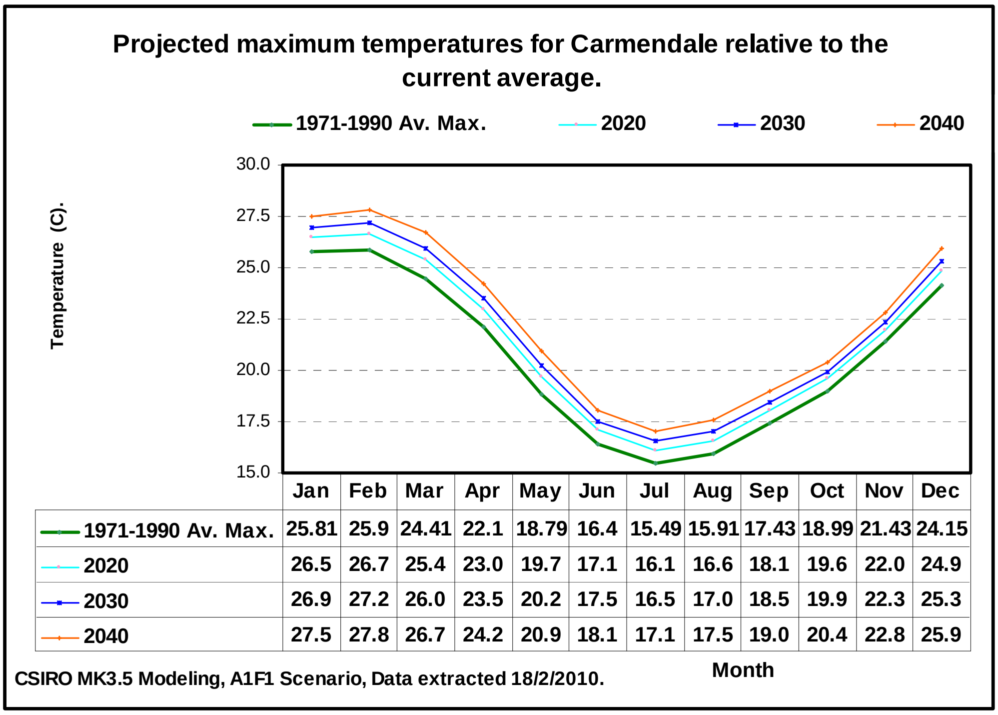


Figure 13 Scenario for future decadal averages in rainfall for Carmendale.

It is possible that temperatures will also change into the future given that there is evidence of recent changes in minimum and maximum temperatures. Modelling of temperature into the future indicates it is possible that by 2030, the average daily temperature will increase by between 0.7 to 0.8°C (fig 14). This trend is evident in both the maximum and minimum temperatures.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971-1990 Av. Max.	25.81	25.9	24.41	22.1	18.79	16.4	15.49	15.91	17.43	18.99	21.43	24.15
2020	26.5	26.7	25.4	23.0	19.7	17.1	16.1	16.6	18.1	19.6	22.0	24.9
2030	26.9	27.2	26.0	23.5	20.2	17.5	16.5	17.0	18.5	19.9	22.3	25.3
2040	27.5	27.8	26.7	24.2	20.9	18.1	17.1	17.5	19.0	20.4	22.8	25.9

Figure 14: Scenario for future decadal average changes in max temperature for Carmendale

3.2 Land degradation risks

Sharon Hu, Soil Research Officer

The major soil degradation hazards at risk in the study area are subsurface soil compaction (85 per cent), subsurface soil acidity (70 per cent) and wind erosion (70 per cent) (Table 5).

An assessment of land qualities land degradation hazards for land management units is found in the Land Evaluation Standards for Land Resource Mapping (van Gool et al. 2005). The land management unit areas are derived from occurrences of WA soil groups across the zone. This mapping has been done at a course scale and the figures for the various soil degradation risks could be either under- or over-estimated. For instance, the risk of waterlogging is very likely higher then that stated in Table 5.

Table 5: Summary of degradation hazards

Hazard	Description and risk factors for affected subsystems
Subsurface soil compaction 224 000 ha (85%) at moderate to high risk	Soils with a wide range of particle size, low organic matter and no secondary structure are particularly at risk. Risk factors are sandy duplex units and yellow and brown deep sands. Main subsystems and/or phases affected are KeMW, KdMI and KeCM.
Subsurface soil acidity 185 000 ha (70%) at moderate to high risk and areas presently acidic (< 5%)	This land quality is only a general indicator because management, productivity and crop rotation all affect the rate of subsurface acidification, which refers to acidification below the depth of normal cultivation (10–20 cm). Risk factors are sandy, highly leached soils with low organic carbon content that have little resistance (or buffering capacity) to pH change. Soil groups most at risk are the sandy duplex soils and pale deep sands. Main subsystems and/or phases affected are KeMW, KeCM and KePP.
Wind erosion 182 000 ha (70%) at moderate to very high risk	Wind erosion is largely a function of wind speed and duration, soil erodibility, ground cover, aspect, soil moisture and nutrient availability. Strong winds are common in the area causing erosion, particularly in dry years. Most susceptible are the sandy duplex soils and pale deep sands and yellow and brown sands, particularly on exposed crests and upper slopes. Main subsystems and/or phases affected are KeMW, KdMI and KeCM.
Nutrient loss (N and P) 166 000 ha (65%) high to extreme risk	Susceptibility to nutrient export assesses the likelihood of nutrient run-off and the likelihood of it contributing to eutrophication of surface water. In the case of nitrogen the risk of leaching and run-off is considered, whereas for phosphorous, only potential losses through run-off and the associated risk of particulate and dissolved P is considered. Susceptibility to nutrient export risk is primarily a concern of the coastal plain, which is characterised by sandy soils and intensive drainage. Main subsystems and/or phases affected are KeMW, KeCM, NkMRp, BrBWo, KdMI. and NkMRp. Note: The risk of phosphorous leaching is not considered in the nutrient risk data in this table; however, it is an important component of nutrient loss given the prevalence of low PRI soils (< 7).
Water repellence 155 000 ha (60%) at moderate to high risk	Pale deep sand, yellow and brown deep sand and poorly drained sandy duplex land management units are susceptible. Main subsystems and/or phases affected are KeMW, KdMI and KdS8.
Water erosion 146 000 ha (55%) at moderate to extreme risk	Water erosion involves complex processes of run-off and soil detachment and is influenced by rainfall erosivity, soil erodibility, slope angle, management practices and the amount and type of groundcover. Soils most at risk are those with low permeability because of the proportionately greater surface run-off. However, there are also many sands which are susceptible as a result of their non-wetting condition, particularly during rainfall immediately following the dry summer period. Main subsystems and/or phases affected are KeMW, KeCM and KdS8.
Waterlogging 74 000 ha (30%) moderate to very high risk	Risk factors include soils with low permeability subsoils that develop perched watertables during the winter growing season. Soils most at risk are poorly drained sandy duplex and grey/greyish brown loams and clays (particularly on lower slopes), wet soils and salt-affected land. Main subsystems and/or phases affected are KeMW, KeCM and CaCA.

Table 5: (continued)

Hazard	Description and risk factors for affected subsystems
Surface soil structure decline 50 000 ha (20%) moderate to high risk	Soil structure decline is caused primarily by excessive tillage. Soil texture, soil chemistry (e.g. organic matter content, exchangeable sodium percentage, electrical conductivity, clay mineralogy and calcium to magnesium ratio) and management practices all play an important part. Soils at highest risk of soil structure decline are usually fine textured loamy and clayey soils, such as the alkaline grey shallow loamy duplexes and the grey non-cracking clays. Main subsystems and/or phases affected are KeMW, KeCM, CaCA and BrBWo.
Salinity risk 22 000 ha (10%) moderate to high risk and presently saline (< 5%)	Salinity risk refers to the likelihood of the soil becoming saline given current land use patterns and land management practices. The primary cause of secondary salinity has been the clearing of perennial native vegetation and its replacement with annual pasture and crops which has caused a rise in the groundwater level and subsequent mobilisation of salt deposits stored within the soil profile. Secondary salinity is most prominent on valley floors. Main subsystems and/or phases affected are KeMW, KeCM and CaCA.

3.2.1 Acid sulphate soils

Adam Lillicrap, Hydrologist

Acid sulphate soils (ASS) contain sulphide minerals, predominantly iron pyrite, and are formed by bacteria under waterlogged conditions. They are generally found in low-lying areas near the sea, such as coastal wetlands and estuaries, and wetlands that maintain their water and obtain sulphate from groundwater flow or coastal saline lakes (Appendix 2). The soil-landscape systems that have the highest probability of having ASS are the Owingup Subsystem's plains with swamps, lunettes and dunes and the Blackwater Subsystem's flat, poorly drained plain with some linear dunes and granite domes.

Undisturbed, these soils are harmless, but when they are exposed to air through practices such as drainage, soaks, groundwater extraction, and by stock pugging the soil, the sulphides oxidise to form sulphuric acid. Soils with high levels of carbonate are better able to neutralise the acidity compared to sands which have a low acid neutralising capacity.

The potential impacts on agriculture caused by the exposure of ASS include production losses and animal health issues. Under acidic conditions nutrients become less available to plants and potentially toxic substances, such as aluminium and iron, become more available. Stock may also consume toxic substances through pasture or drinking acidic water.

Disturbed ASS may also corrode concrete, iron, steel and certain aluminium alloys which results in damage to infrastructure. Impacts on the environment include fish kills, fish disease, loss of macroinvertebrates, reduced growth of molluscs such as oysters, loss of habitat, and dominance of acid-tolerant water plants.

3.3 Hydrological risk

3.3.1 Shallow watertables and salinity

3.3.1.1 Dissected landscape with low hills

Groundwater depth, quality and trends

Depth to groundwater ranges from 1 m to deeper than 8 m, depending on the position in landscape and the depth to basement rocks. Groundwater is brackish to saline and generally ranges from 600 mS/m (milliSiemens per metre) in upper slopes to 1,500 mS/m near creeklines and within salt-affected areas.

Short-term monitoring of groundwater levels indicates that these landscapes are highly responsive to rainfall. Bores in the various parts of the dissected landscape have varied trends. The ones with small upslope catchments are possibly in hydrological equilibrium because of the small recharge areas and high groundwater gradient. Bores which are in the mid-slope have a steady rate of rise. Groundwater levels in these bores will acquire a downward trend after commercial trees are planted (Figure 14). Areas in lower slopes and close to creeklines have become discharge sites. Evaporation from salt-affected land prevents further rise in groundwater levels and consequently groundwater levels seasonally fluctuate within 1.5 m of the soil surface.

Risk of shallow watertables

The dissected areas have a low to moderate risk of shallow watertables*. Creeklines, low-lying areas and some upland seepage zones are already saline and the extent of these will increase until a new hydrological equilibrium is reached.

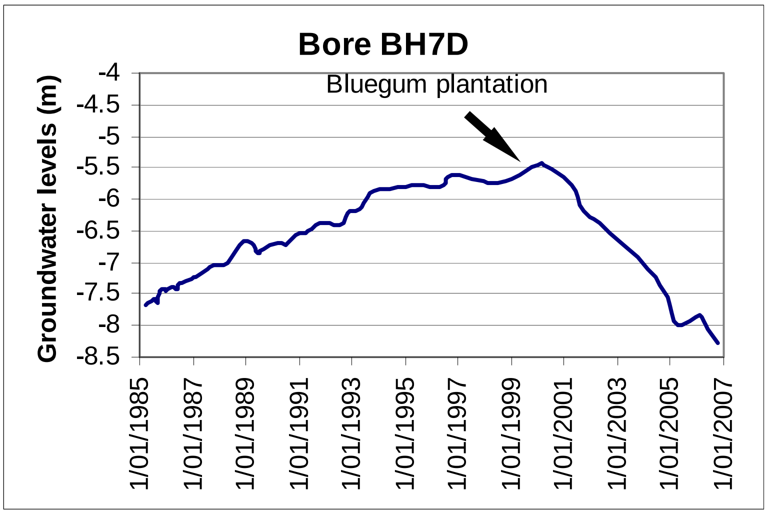


Figure 14: Typical hydrograph of a bore located mid-slope in a dissected landscape, with a rising groundwater level trend before commercial plantation, and a falling trend after

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* NLWRA risk categories (NLWRA 2001):

High – depth to groundwater < 2 m, or 2–5 m and rising

Moderate – depth to groundwater 2–5 m and static, or > 5 m and rising

Low – depth to groundwater > 5 m and static

3.3.1.2 Moderately dissected undulating areas

Groundwater depth, quality and trends

Groundwater levels in the flats and valley floors are at or close to the soil surface and fluctuate seasonally. The depth to groundwater increases on the hillside. Groundwater salinities are similar or slightly higher than in the dissected landscapes.

Groundwater moves very slowly and consequently large areas, including the very gently undulating slopes and broad hilltops, may experience shallow watertables. Groundwater levels have risen after the land was cleared in 1985 (Figure 15) and this trend will continue until groundwater levels become close to the soil surface (Figure 16) and discharge areas develop in nearby areas. Groundwater levels will acquire a downward trend after commercial trees are planted.

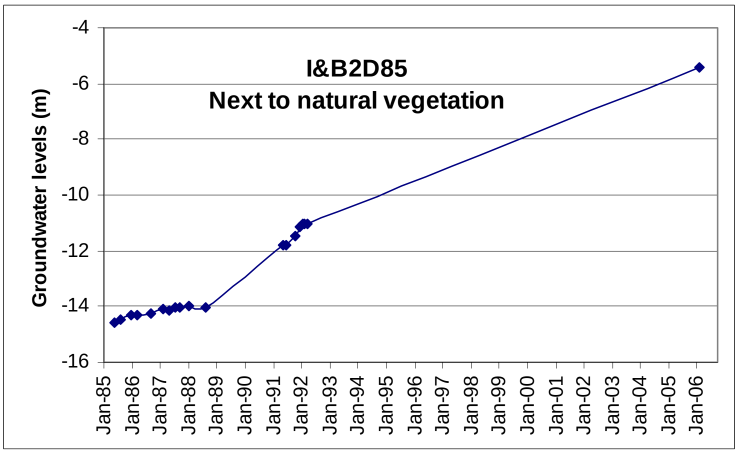

Figure 15: Groundwater level rise after the broad hilltops in moderately dissected landscapes are cleared

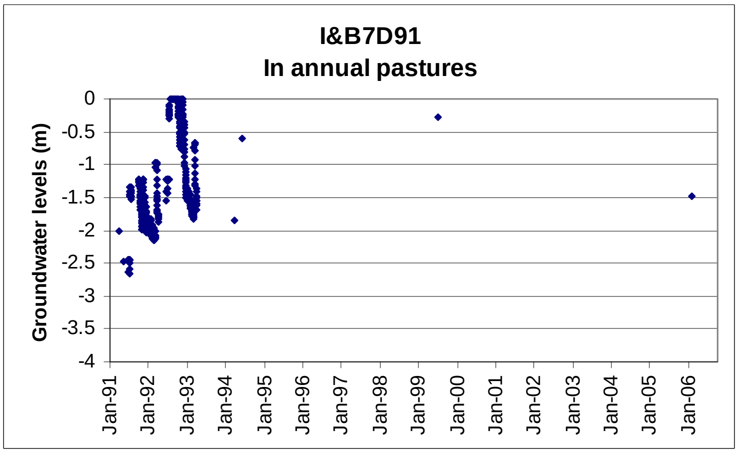

Figure 16: Seasonal fluctuation and groundwater level rise in broad hilltops

Risk of shallow watertables

Groundwater cannot drain easily because of the low (1–2 per cent) hydraulic gradient. Consequently, groundwater levels will continue to rise for a long period until significant areas become salt-affected. Therefore, this landscape has a high risk of shallow watertables. Creeklines, flats and low-lying areas are already saline. It is likely that the extent of salinity will increase until a new hydrological equilibrium is reached.

3.3.1.3 Very gently undulating areas with stagnant flats and swampy floors

Groundwater depth, quality and trends

Groundwater is saline and close to the soil surface. Shallow groundwater is likely to be acidic. Draining such acidic groundwater may cause environmental damage. Groundwater levels are no longer rising. Near discharge sites (saline flats, swamps and lakes), the depth to groundwater is less than 2 m. In these areas, groundwater levels fluctuate in response to rainfall and evaporation interactions. Areas with deeper groundwater (2–5 m) have rates of rise between 0.05 and 0.15 m/yr. The rate of rise increases with depth to groundwater level and distance from discharge sites.

Risk of shallow watertables

The high salt storage and shallow groundwater levels mean that these zones have a high risk of salinity. The area has always had some salinity (in subsoil); however, salinity expression has increased considerably since clearing. Groundwater levels will continue to slowly rise until discharge through evaporation equals the recharge. Even with shallow groundwater levels, areas with a moderately deep, sandy A horizon can continue to be productive because seasonal rainfall flushes accumulated salt from the root zone.

3.3.2 Nutrient loss

David Weaver, Research Officer

3.3.2.1 Nutrient loss by land use

The loss of nitrogen and phosphorus has long been recognised as one of the greatest threats to the Wilson Inlet and its tributaries. Based on modelled nutrient exports, grazing is the highest nutrient exporter with about 60 per cent of both P and N losses (Table 6). Plantations are the second most significant, although in most cases these have replaced grazing at a lower rate of loss per hectare (Weaver et al. 2005).

The modelling in the Wilson Inlet indicates high nutrient reductions through assimilation in the river system, which reflects the much larger catchments of the Denmark and Hay Rivers. Two notes can be made regarding this assimilation:

- The level of assimilation would likely be much less in high rainfall years, when high river flow would lead to much shorter residence times, and may also see the re-mobilisation of previously retained in-stream sediments.
- The assimilation figures are based on research from the eastern States and may not be as appropriate here. WA streams are recognised to have a relatively impoverished fauna compared to their eastern States' counterparts, and much of the upper reaches of the Hay River in particular may be expected to lack their normal functioning because of degradation of riparian vegetation and loss of stream form. However, the effect of this degradation on nutrient assimilation may be offset by higher levels of algae growth

because of the more open and therefore sunnier conditions (higher temperatures) in the river systems.

Table 6: Top six land uses contributing the highest nutrient loads

Land use	*At source**		*Routed & assimilated (at Inlet)*	
	P%	*N%*	*P%*	*N%*
Grazing	***63***	***64***	***60***	***62***
Plantation	***16***	***20***	***12***	***14***
Dairying	***8***	***4***	***11***	***6***
Annual horticulture	***6***	***5***	***9***	***8***
Remnant vegetation	***3***	***4***	***3***	***4***
Peri-urban	***2***	***2***	***3***	***2***

3.3.2.2 Nutrient loss by sub-catchment

The loss of nutrients across the catchment does not occur evenly. Modelling carried out by Weaver et al (2005) showed that nutrient loads entering the estuary varied according to a number of factors including landuse, soil type, slope, history of fertiliser use and distance from the estuary. The three catchments identified in table seven were chosen from the lower, middle and upper regions of the catchment and demonstrate that as you move further away from the receiving body the effect of assimilation within the water bodies fixes the available nutrients, preventing them from entering the estuary. These figures are the product of a modelling exercise by Weaver et al however they were also reinforced by stream monitoring at the time. It is also important to note that these figures are relevant to a 50^{th} percentile rainfall year. Assimilation processes will be affected to some degree by the rainfall intensity and amount.

Table 7: Nutrient generation by sub-catchment

Sub-catchment	*At source*		*Routed & assimilated*	
	P%	*N%*	*P%*	*N%*
Cuppup Creek (lower catchment)	***4.4***	***4.5***	***8.2***	***8.7***
Sheepwash (mid catchment)	***2.8***	***3.0***	***3.3***	***3.7***
Pardelup (upper catchment)	***1.6***	***1.9***	***0.4***	***0.5***

3.3.3 Waterway condition

Information taken from Mercer (1999)

The fringing vegetation of the river valleys forms a significant ecological corridor connecting patches of remnant bush along the banks of the river. In the freshwater areas of the rivers the fringing vegetation is mostly healthy, but where fences have not been maintained or are absent, livestock have grazed and trampled out native species which, along with frequent fires, has encouraged the growth of introduced grasses. The loss of deep-rooted native vegetation has led to the erosion and subsidence of river embankments in places.

In 1995, the main channel of the Hay River was surveyed and about 40 per cent of the riparian zone was pristine, 20 per cent degraded, just over one-third is erosion prone, and a small section was categorised as weed infested. Only 40 per cent of the foreshores that bordered agricultural land were fenced, leaving 85 km unprotected from stock, and 170 ha of river valley embankment and foreshore was identified as needing revegetation (Pen & Apace 1995).

The middle and lower sections of the Hay River are very scenic and contain foreshores generally of a high quality. However, points of erosion and subsidence and sections of extensive degradation do occur. The increasingly saline upper half of the Hay River is degraded, exhibiting erosion along fire breaks located within the floodplain of the river valley, siltation, and some vegetation death as a result of salinisation.

3.4 Vegetation condition and risks

Jack Mercer, Marlak PTY LTD

The proportion of cleared land in the catchments of the study area is nearly 30 per cent of the Denmark River, half of the Little River, 70 per cent of the Hay River, and three-quarters of the Sleeman River. There are still significant areas of state forest in the west of the study area.

Patterns of vegetation decline are usually evident where tree crowns have protruding dead branches, understorey is damaged or missing and there is little or no regeneration. Protruding dead branches may also be a legacy of fire. Overall, vegetation decline is more pronounced in the upper catchment where main decline factors have had a synergistic impact on less vegetation.

The main factors implicated in past, present and future vegetation decline are salinity and waterlogging, dieback fungi, and stock grazing. An increasingly plausible threat is a rainfall deficit as a characteristic of climate change. Other factors are rabbits, pigs, and parrots of pest status.

Salinity and waterlogging threatens remaining vegetation occupying stagnant flats, gently inclined v-shaped valleys, u-shaped valleys, undulating plains and rises with swampy flats. Archetypal species, such as *E. wandoo*, *E. occidentalis* and even *M. raphiophylla* are being replaced by more salt-tolerant species, such as *M. cuticularis*. Dieback fungi, most commonly *Phytophthora cinnamomi,* affect jarrah, banksias and blackboy while marri, karri and rushes remain healthy. Stock grazing impacts upon unfenced vegetation and paddock trees, leaving exposed roots and dead trees around stock camps, bare compacted soil, no understorey and weed incursion, and stripped bark.

Rainfall deficit has been implicated in the loss of usually mature trees as evident by stand thinning that has been recorded across agricultural areas. Wandoo, jarrah and marri may have been affected in the lower rainfall areas in the study area. Prolonged dry periods can cause water stress and consequent fungal and insect attack. Swamplands and, possibly, stands of karri may succumb to extended dry periods predicted for the south-west of WA. Rabbits cause loss of native plants, including regeneration, and the undermining of heath stands, causing serious moisture loss in dry months. Weed seeds are also imported in rabbit faeces into bushland. Parrots of pest status damage trees and blackboys as well as blue gums, fruit trees, olives and grapes.

4 Management options and impacts

4.1 Land management

Sharon Hu, Soil Research Officer

Table 8 presents a summary of best practice land management options suitable to manage the common natural resource management risks in the study area.

Table 8: Options for managing common NRM risks

Natural resource risk	Principal management options
Water repellence	Principal management options include claying (100 t/ha), furrow sowing and use of wetting agents. The effectiveness of claying is dependent on using the right type of clay and the economic benefit is dependent on finding a suitable source close by. Note that regular passes to incorporate the clay may cause soil compaction.
Subsurface acidity	The principal management option is liming. Add dry lime at 1–2.5 t/ha either by surface spreading (or preferably placed into acid layer at about 10–20 cm) to improve soil pH and displace aluminium. Liming will be necessary to achieve crop and pasture production potential and assist in the establishment of lucerne.
Soil compaction	Minimum tillage (and/ or direct drilling on the heavier soils in the catchment soils) is encouraged Where the topsoil is sodic (i.e. exchangeable sodium percentage is greater than 14%), susceptible soils can be ameliorated through topdressing with gypsum together with practices to increase the organic carbon content of the soil, such as stubble retention. Green manuring of a high legume percentage pasture or a legume crop such as lentils or peas may improve organic matter content and soil structure and aid in improving yields. Activities that result in rapid loss of organic matter, deep tillage of the soil, long fallowing in a crop rotation and stubble burning among others, should be avoided.
Wind erosion	Critical to maintain ground cover at adequate levels. On soils at risk, practice stubble retention or aim to maintain at least 50% ground cover to control risk Minimum tillage and stubble retention, or revegetation with trees (various suitable species available) for shelterbelts or alley farming together with management of summer grazing on risk soils (including de-stocking during dry seasonal conditions). Planting of susceptible sites to long season annuals (serradellas) or preferable deep rooted perennial pastures like kikuyu, rhodes or veldt grass.
Waterlogging	Land that is prone to waterlogging for 6–10 weeks in an average season cropping with oats, barley and wheat is the best option, though earthworks would be required to achieve reasonable yields. Plant waterlogging tolerant perennial pastures such as kikuyu, tall fescue and phalaris or annual pastures like balansa and persian clovers where waterlogging is persistent in an average season for more than 10 weeks. In saline waterlogged conditions, fence these areas (where practical) and establish tall wheat grass and puccinellia. Engineering options: Raised beds and shallow relief drains such as w banks and spoon drains should be used in areas with < 0.2% slope. Alternatively use contour and interceptor banks to divert surface and subsurface flows away from areas prone to waterlogging.

Table 8: (continued)

Natural resource risk	Principal management options
Acid sulphate soils	The best way to manage ASS is to avoid disturbing or draining them because they are harmless when covered by water. If soils have been exposed, agricultural lime can be used to increase the pH of affected soils. If the soils have been exposed through drainage, the soils could be recovered with water. This practice requires careful design to avoid waterlogging and other problems. If drainage is to be installed, wide, shallow drains that allow surface water to drain away while not exposing pyrites should be used rather than deep drains.

4.2 Water management

4.2.1 Salinity management

The cause of salinity is excessive recharge under common agricultural practices (non-irrigated or irrigated), leading to rising levels of naturally saline groundwater. As water levels come close to the soil surface, saline groundwater discharges causing soil salinity and contamination of water resources. The impact of salinity increases where it is combined with waterlogging. A waterlogged landscape has a higher rate of recharge than the non-waterlogged areas. Thus salinity control measures may be combined with appropriate earthworks to reduce waterlogging.

The best management option for recovery or containment of salinity is to grow deep-rooted perennials, such as lucerne and kikuyu, to reduce recharge and lower groundwater levels. The effectiveness of salinity control measures is dependant on hydrological attributes of the landscape.

4.2.1.1 Technical feasibility of salinity management in dissected landscape

Since the groundwater gradient is high, groundwater moves towards discharge areas. Under these conditions there is a good chance of recovering some saline land and an excellent technical feasibility of preventing further spread of soil salinity. Deep-rooted perennials, such as kikuyu and lucerne, that mimic the temporal and spatial distribution of leaf area that existed prior to clearing, can effectively reduce land and water salinity.

4.2.1.2 Technical feasibility of salinity management in moderately dissected undulating areas

In the moderately dissected areas, it is possible to contain the salt-affected areas or even recover some areas. The best management option for recovery or containment is to grow deep-rooted perennials, such as kikuyu and lucerne, and although research has shown that lucerne is not as effective in these landscapes as in the dissected landscapes, it will still reverse (in hilly areas) or halt (in lower slopes) the rising trend of groundwater levels. Commercial plantations have a positive contribution and are a good means for controlling salinity in the study area. The target areas may be lower slopes and foothills but not the stagnant flats.

4.2.1.3 Technical feasibility of salinity management in very gently undulating areas with stagnant flats and swampy floors

Leakage of excess rainfall followed by evaporation from the soil surface causes the saline watertable to fluctuate and occasionally inundate the root zone of plants. Under these conditions there is a moderate chance of containing salinity by reducing recharge with perennials and a low chance of recovering saline land.

4.2.2 Surface water management

Ben Whitfield and Austin Rogerson, Land Conservation Officers

There are many land management options that can be used for surface water control before it contributes to erosion, eutrophication, sedimentation, waterlogging, flooding, and salinity. Conservation land management options are employed to provide the best conditions for plants to use water so as to minimise run-off and then manage the excess run-off into dams and waterways. Earthworks alone will not prevent land degradation but they are effective when properly designed and used in conjunction with other conservation farming strategies.

The main conservation land management options which may be used to reduce degradation risks and improve production and sustainability are:

- increase and maintain vegetative cover to use the water and protect the soil from direct raindrop impact and to slow down surface water flow. This cover can be achieved by incorporating perennial vegetation, controlled grazing of pastures to maintain good coverage, and maximising stubble retention
- working land along the contour to contain surface water in the furrows
- adopting minimum-tillage or no-tillage cropping techniques to reduce soil structure decline.
- soil improvement techniques, such as liming, to maximise vegetative cover
- appropriately designed conservation earthworks including permanently grassed waterways to slow water speed while providing maximum drainage of all areas.

Where the slope and soil characteristics encourage water to run-off the land (shedding landscape), earthworks can reduce the speed and volume (peak flow) of surface water flows by diverting or retaining. Conservation earthworks in the shedding landscape, such as grade banks, minimise the risk of soil erosion and associated loss of nutrients, provide water resources, and help to manage excess water entering the lower slope areas.

Water flows from a shedding landscape and accumulates in a receiving landscape, which has low slope (< 1 per cent) and is therefore prone to waterlogging, ponding and flooding. Excess water in receiving landscapes is a major contributor to groundwater recharge and the development of salinity. Earthworks, such as shallow relief drains, in receiving parts of the landscape are designed to improve flat land drainage by moving surface and shallow subsurface water, at a safe speed, to defined waterways.

Receiving landscapes occur in the upper (peneplains) and lower (stagnant flats) portions of the landscape throughout the study area, particularly in the Upper Hay sub-catchment. Much of the natural surface water drainage is limited, as it was prior to clearing. Peneplains shed only a small proportion of the surface water that has fallen as in-situ rainfall. Stagnant flats tend to collect water as in-situ rainfall and as run-off from other parts of the landscape. Earthworks considered for these low relief areas are those typical of a receiving environment. The remainder of the study area consists of a variably dissected landscape and earthworks should be designed accordingly.

It is important to note that earthworks require careful planning because inappropriate and poor designs can cause more degradation than what the structure was intended to alleviate. Suitably qualified people need to be consulted for the legal aspects, design and construction of earthworks.

4.2.3 Management of nutrient loss

David Weaver, Research Officer

Modelled level of impact of some best management practices (BMP) at both a sub-catchment and catchment scale is dependent on the nutrient considered. For instance, perennial pastures have the largest impact on phosphorous loss at both a sub-catchment and whole of catchment scale. The impact on nitrogen however, is less than the riparian buffers, with the modelled impact of the riparian buffers dependent on a number of assumptions. It is assumed that by revegetating the creeks, the assimilative capacity of the waterway itself is also increased, through both slowing the water column and creating localised anaerobic conditions associated with the breakdown of organic matter, which leads to an increased demand for nitrogen and increased gaseous losses.

The level of impact of any one treatment is likely to vary considerably; however, to achieve any meaningful impact, the adoption of a range of BMP's is necessary. Even with the maximum level of adoption, the highest modelled reduction possible in the Upper Hay sub-catchment would be one-third for P and half for N (Weaver et al. 2005). Although these figures are estimates, it demonstrates the difficulty associated with reducing the loss of P and N from agricultural landscapes. Of course it is not necessary to reduce the losses to zero because the environment has some assimilative capacity. Also it is interesting to note that for P losses at a sub-catchment level, 20 per cent of the modelled one-third reduction can be attributed to the adoption of perennial pastures and soil fertility management (at a high level), both of which are likely to have positive economic implications for the landholder.

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Appendix 1: Soil-landscape systems descriptions

Table A1: Minor soil-landscape subsystems description (alphabetical order)[†]

Subsystem	Description
Broke System	
BrBWo (11 000 ha, 4%)	Shallow gleyed duplex soils; paperbark woodland. Podzols on dunes; banksia–sheoak woodland.
Caldyanup System	
CaCA (9500 ha, 4%)	Plains with drainage floors and low rises. Yellow solonetzic soils; hakea scrub, paperbark woodland. Humus podzols; kangaroo grass sedgelands.
Chillinup System	
Ch4 (4000 ha, 1%)	Salt lakes and associated lunettes.
Ch6 (3500 ha, 1%)	Large lunettes associated with Ch4.
Jaffa System	
Jf2 (5000 ha, 1%)	Footslopes, gently undulating rises and undulating plains. Grey deep sandy duplex is widespread with Grey shallow sandy duplex and Semi-wet soil.
Jf3 (3000 ha, 1%)	Mid to upper slopes and hillcrest areas dominated by rock outcrop. Grey deep sandy duplex, Grey shallow loamy duplex, Bare rock and Shallow gravel are common.
Kent System	
KeCM (9000 ha, 3%)	Swampy plains with some broad drainage lines, lakes and low rises, including areas of permanent and ephemeral lakes and swamps with lunettes.
Kentdale System	
KdFE (8000 ha, 3%)	Gently undulating sandy terrain. Sandy or gravelly yellow duplex soils on rises; jarrah–bullich woodland. Humus podzols in broad depressions; kangaroo grass sedgeland; teatree heath.
KdS8 (8000 ha, 3%)	Broad, shallow, gently sloping valleys and alcoves. Deep sands and gravelly sands on slopes; jarrah–sheoak low forest. Humus podzols on floors; kangaroo grass sedgeland, paperbark woodland.
KdS7 (8000 ha, 3%)	Swampy U-shaped minor valleys with broadly concave to flat swampy floor deposits on sedimentary basement. They are seldom > 30 m deep and small erosional alcoves occur. Some siltstone outcrops occur on the valley floors and slopes.
KdV8h (4500 ha, 2%)	Slopes of broad, shallow, gently sloping valleys and alcoves. Deep sands and gravelly sands on slopes; jarrah–sheoak low forest. Humus podzols on floors; kangaroo grass sedgeland, paperbark woodland.
KdDMc (4000 ha, 2%)	Sands and laterite on elongate crests; jarrah–Albany blackbutt–marri forest.
King System	
KgS7f (5000 ha, 2%)	Footslopes and swampy valley floors of minor valleys.

[†] Subsystems that are < 1 per cent (2600 ha) in area are not included

Nullakai Dunes System	
NkMRp (7000 ha, 3%)	Podzols over calcareous sand; banksia–bullich–yate woodland.
Porongurup Range System	
PrBAg (5000 ha, 2%)	Granite outcrop.
PrPN (4000 ha, 2%)	Hills of granite with a fringe of sedimentary rocks; < 60 m relief; rounded crests and smooth gentle slopes; some granite. Gravelly yellow duplex soils, sands and laterite; jarrah–marri–yate low forest.
Redmond System	
ReBO (5000 ha, 2%)	Broad, shallow poorly drained depressions in plateau surface; complex of swamps, lakes, low lateritic rises, lunettes and hummocks. Yellow solonetzic soils in swamps, podzols in sands.
ReS6 (3000 ha, 1%)	Narrow V-shaped valleys, in sedimentary rocks; <10 m relief. Sandy yellow duplex soils on slopes; jarrah–marri low forest. Deep sands on narrow swampy floor; sedges and reeds.
Roe Hills System	
RhMTp (8000 ha, 3%)	Shallow gritty yellow duplex soils; jarrah woodland.
RhCOp (4000 ha, 2%)	Shallow gritty yellow duplex soils; jarrah–bullich woodland.
Stirling Range System	
St1 (4000 ha, 2%)	Crests, peaks and upper slopes of the Stirling Ranges, soils formed in weathered sandstone and shale.
Upper Kalgan System	
UkPN (4000 ha, 2%)	Hills of granite with a fringe of sedimentary rocks; < 60 m relief; rounded crests and smooth gentle slopes; some granite. Gravelly yellow duplex soils, sands and laterite; jarrah–marri–yate low forest.
UkWP (4000 ha, 2%)	Flat saline floor of valleys.
Walpole Hills System	
WhKYb (9000 ha, 3%)	Brown gravelly duplex soils and red or yellow earths; much laterite. Marri–karri–red tingle–yellow tingle forest.
Wilgarup Valleys System	
WvHYd (6000 ha, 2%)	Valleys in granitic areas; 20–40 m relief; smooth, moderate slopes; narrow terrace.

Appendix 2: Acid sulphate soils

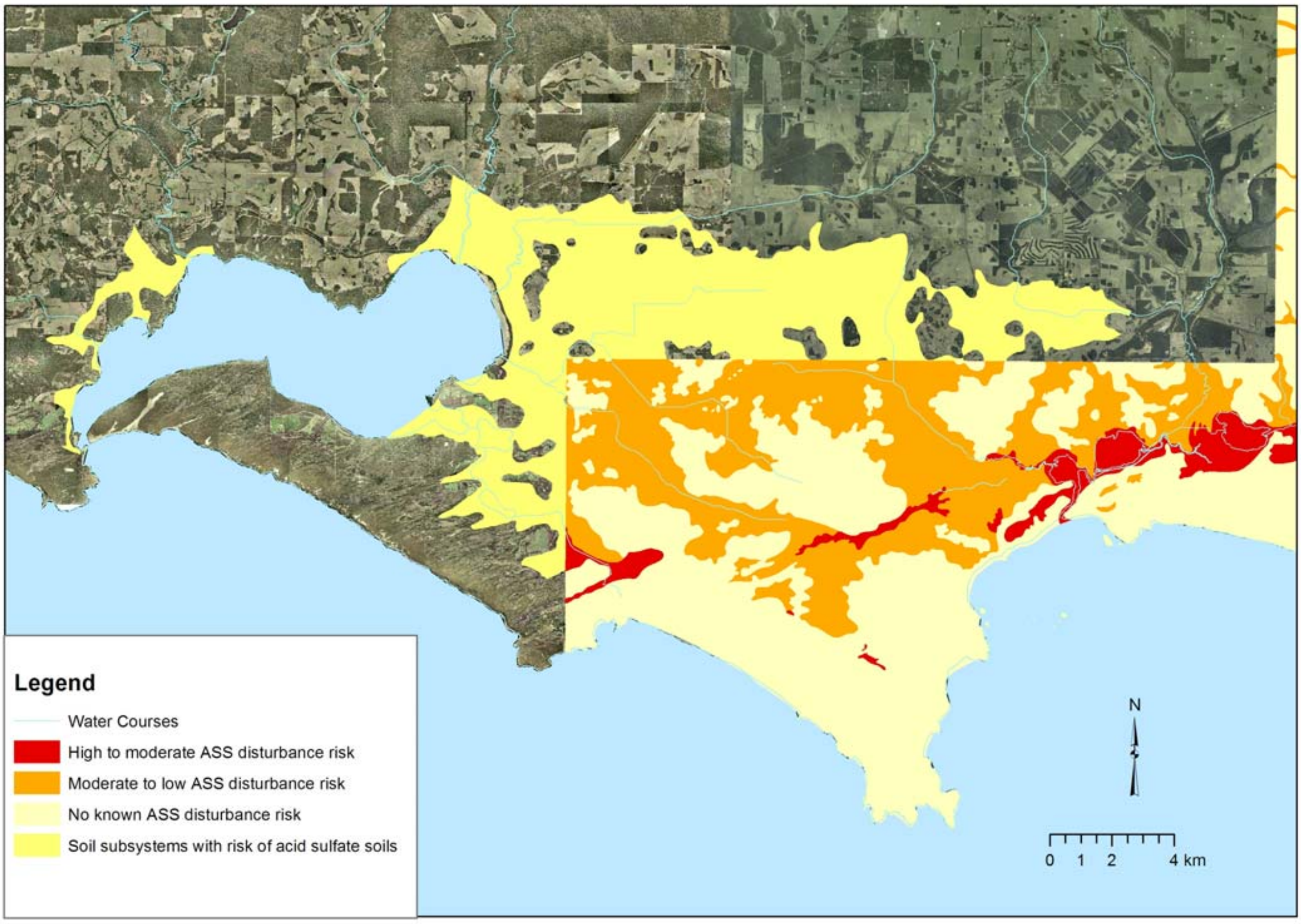

Figure A2: Moderate to high acid sulphate soil risk map