Department of Agriculture
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Blackwood Catchment
Beaufort Zone
(Zone 4)

CATCHMENT APPRAISAL 2002

Compiled by the Blackwood Catchment Appraisal Team led by Henry Brockman

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Department of Agriculture

Natural Heritage Trust

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CONTENTS

		Page
SUMMARY		iii
1.	**INTRODUCTION**	1
	1.1 Study area	1
2.	**NATURAL RESOURCE BASE**	2
	2.1 Climate	2
	2.2 Geology	4
	2.3 Soil-landscape information	5
	2.4 Hydrology	10
	2.5 Native vegetation	14
	2.6 Agricultural production	14
	2.7 Demographics	20
3.	**RESOURCE CONDITION AND FUTURE RISK**	21
	3.1 Soil degradation risk	21
	3.2 Hydrological risk	23
	3.3 Biodiversity condition and risks	27
	3.4 Agricultural production	30
	3.5 Infrastructure	33
4.	**MANAGEMENT OPTIONS AND IMPACTS**	34
	4.1 Land management	34
	4.2 Water management	49
	4.3 Economic analysis of management options	52
5.	**BENCHMARKS**	54
6.	**REFERENCES**	55
ACKNOWLEDGMENTS		59
7.	**APPENDICES - MAPS**	60
	Map 1 Location of Beaufort Zone	
	Map 2 Beaufort paleochannel and soil landscape systems	
	Map 3 Salinity extent in 1999	
	Map 4 Valley floors and low-lying areas	

SUMMARY

The Beaufort Zone covers 339,000 ha in the South-Western agricultural area of Western Australia, and Kojonup is the only town in it. It has a Mediterranean climate, and lies between the 500 mm and 600 mm rainfall isohyets.

Soils are predominantly grey, deep sandy duplexes with ironstone gravel increasing from east to west. Half of the catchment is susceptible to wind erosion, 20 per cent is susceptible to water erosion, 20 per cent to waterlogging, and 72 per cent to soil acidity.

The groundwater level in 65 per cent of measured bores (mostly situated low in the landscape) was less than two metres below the surface, indicating high salinity risk. Currently the saline/waterlogged area covers three per cent of the Zone, but this will increase if watertables continue rising. The resulting loss to industry could be $4.5 million per year with additional damage to infrastructure estimated at $70,000 per year.

Remnant vegetation covers only 11 per cent of the catchment, mainly on privately owned land. Another 19 per cent of the remnants are situated in low-lying areas and under threat from salinity and a rising watertable. At risk are thirteen species of declared endangered flora and 15 rare and priority fauna species.

The gross value of agricultural production (GVAP) is $55.5 million. The average farm covers 790 ha and has a debt of $245 per hectare (the equity is 85 per cent of the total farm value).

Social indicators show that more than half the people in the zone are employed in agriculture, 80 per cent of farmers do not have tertiary or vocational qualifications and the median age for farmers is 45 years.

The strategies outlined for the main land management units may be useful for farmers when they assess the extent of land degradation on their own properties and consider options to manage them.

Most of the information reported here is at a scale too large for use by land managers at the farm or paddock level, but can be used as a guide in planning the allocation of resources into the area.

1. INTRODUCTION

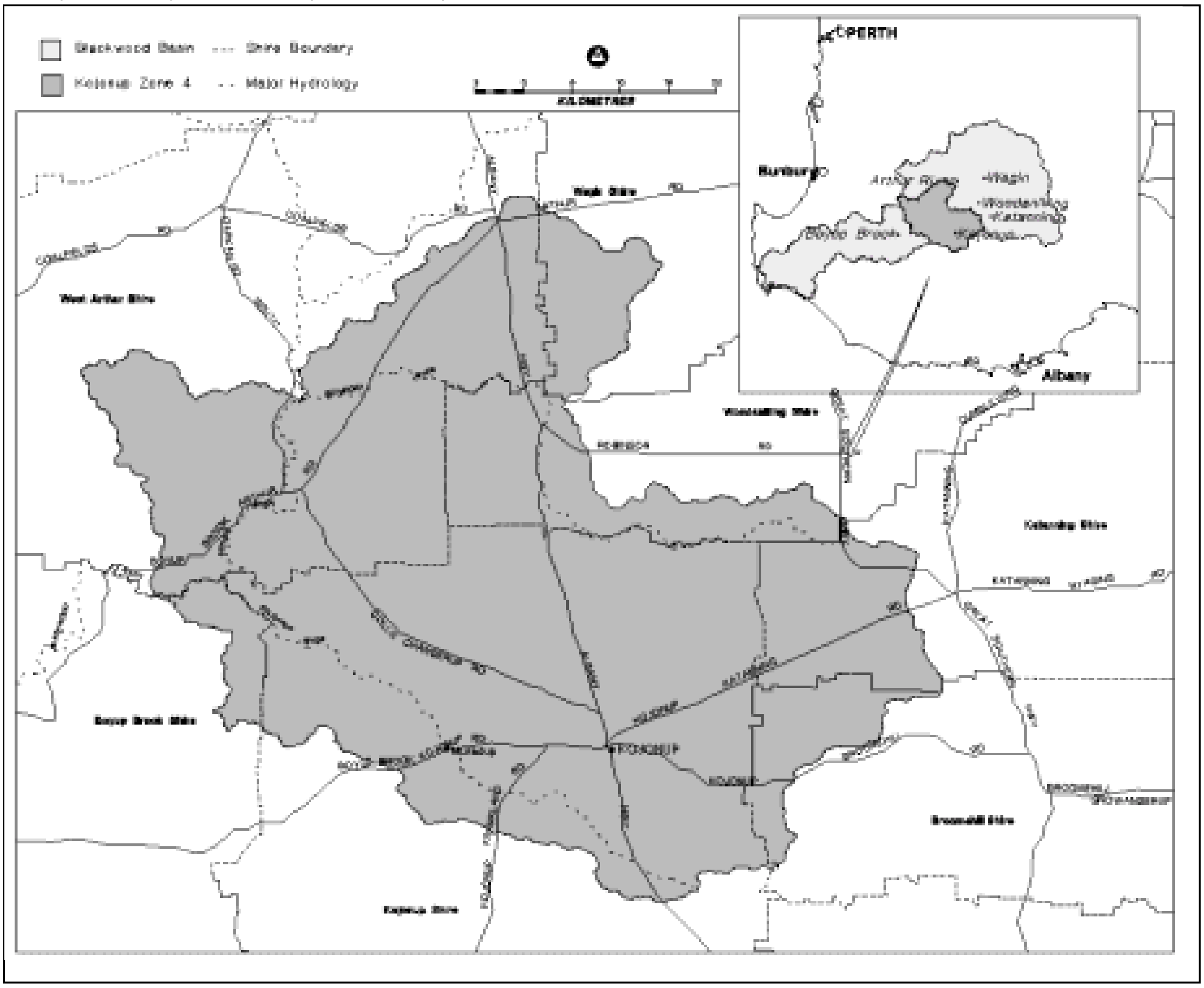
Soil degradation on farmland reduces agricultural production and damages infrastructure and natural resources such as remnant vegetation, waterways and wetlands.

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 watertables 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, and provide information for reducing those risks within regional geographic catchments. The process also attempts to identify the most suitable options to manage the risk. As part of the process, landholders are given direction on where to access further information and support if necessary.

1.1 Study area

The Beaufort zone is within the mid to southern part of the Blackwood Basin (Map 1), covers 339,000 ha, including parts of the shires of Kojonup (44 per cent), West Arthur (29 per cent), Woodanilling (10 per cent), Katanning (7 per cent), Broomehill (4 per cent), Wagin (4 per cent) and Boyup Brook (2 per cent).



Map 1. Location of Beaufort Zone within the Blackwood Basin.

2. NATURAL RESOURCE BASE

2.1 Climate

The climate is Mediterranean with hot, dry summers and cool, wet winters. Most rain is caused by the passage of cold fronts between May and November with summer thunderstorms rarely occurring. The mean maximum and minimum temperatures in January are 29.5°C and 13.2°C, respectively, and in July are 14.4°C and 5.9°C (Bureau of Meteorology, 2002). There is a likelihood that frosts will occur from May to November.

Beaufort Zone lies between isohyets of rainfall of 500 mm and 600 mm and isopleths of evaporation of 1200 mm and 1400 mm, the mean monthly rainfall in winter months from May to August generally exceeds evaporation.

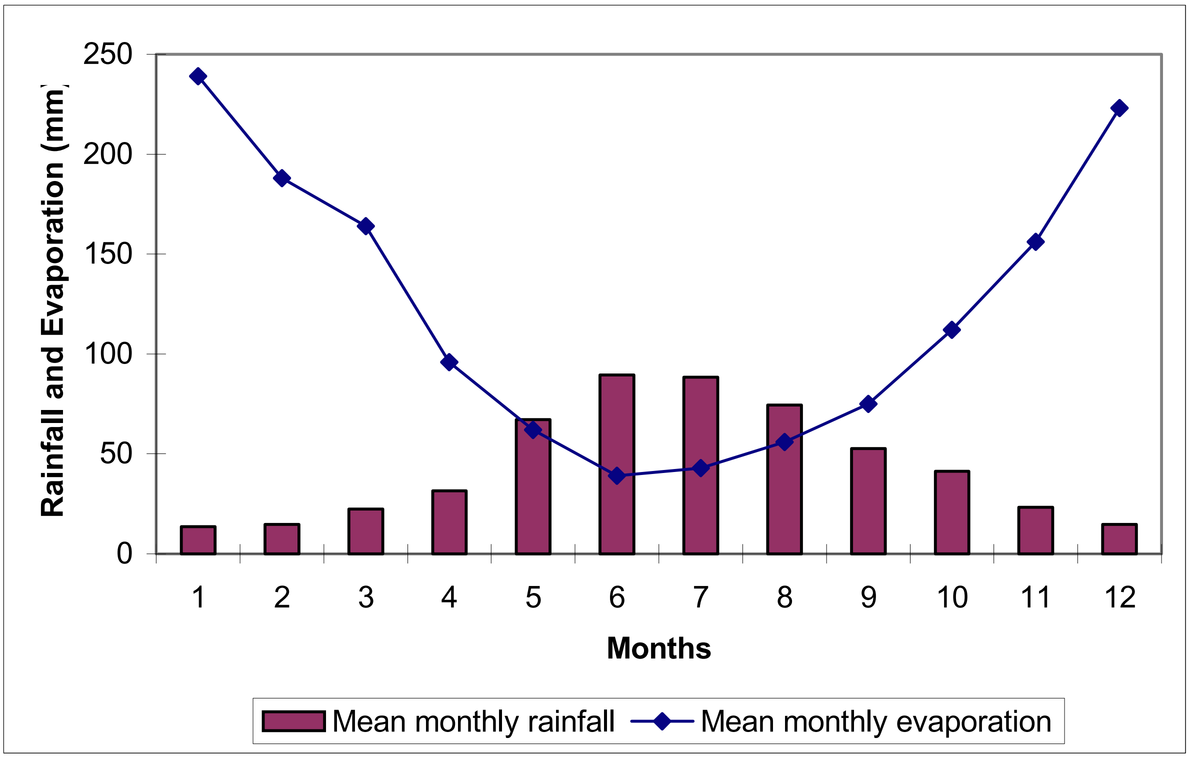


Figure 2.1. Average rainfall and evaporation for Beaufort Zone (Bureau of Meteorology, 2002).

2.1.1 Climatic events

There was a major drought in 1914 and flood events were recorded in 1955, 1964 and 1982. According to Butterworth and Carr (1996), during the 1955 flood Lake Dumbleyung overflowed and the water in the Blackwood River became saltier. Prior to the 1955 flood there were mussels in the Blackwood, livestock were watered on the river, water was used for irrigating orchards and build up of algae did not occur.

The 1955 flood permanently decreased the water level in Lake Dumbleyung, local residents recall erosion on the western side of the lake.

2.1.2 Seasonal rainfall trends

Winter rainfall records for Kojonup townsite from 1951 to 2000 indicate great variation between years (Figure 2.2). Average winter rainfall is 378 mm. with a slight downward trend, while summer averages 122 mm with a slight upward trend (Figure 2.3).

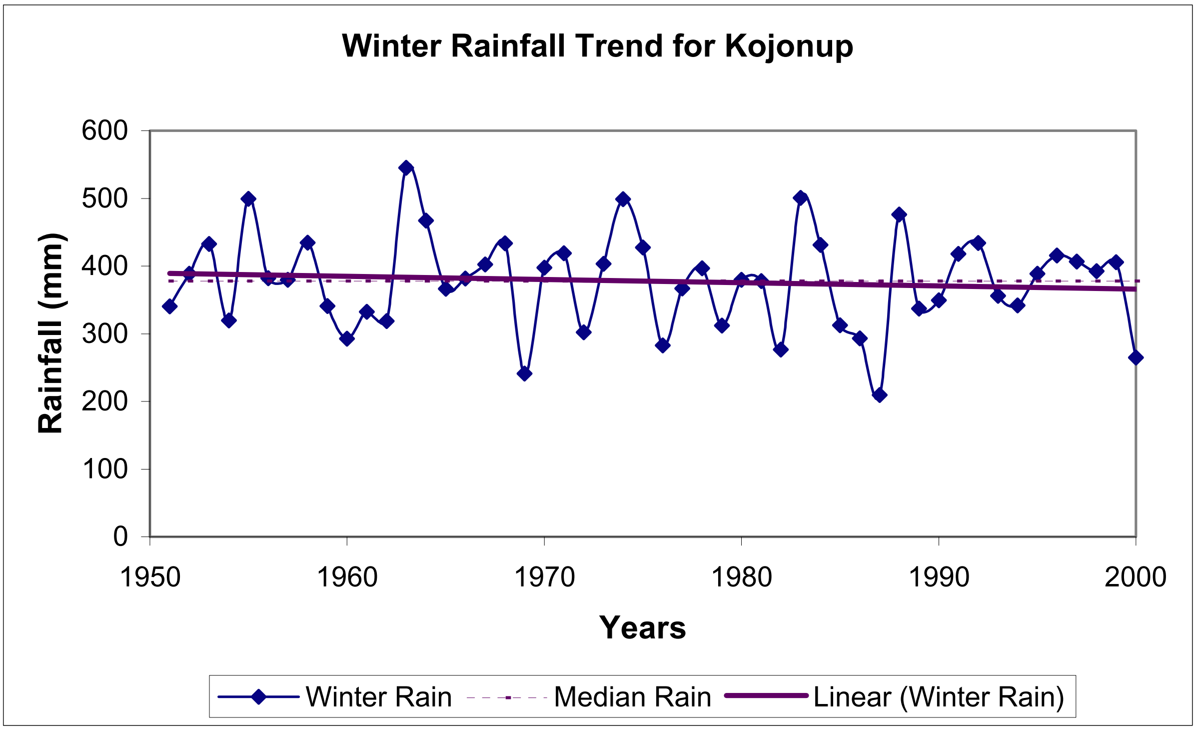


Figure 2.2. Winter rainfall (Bureau of Meteorology, 2002).

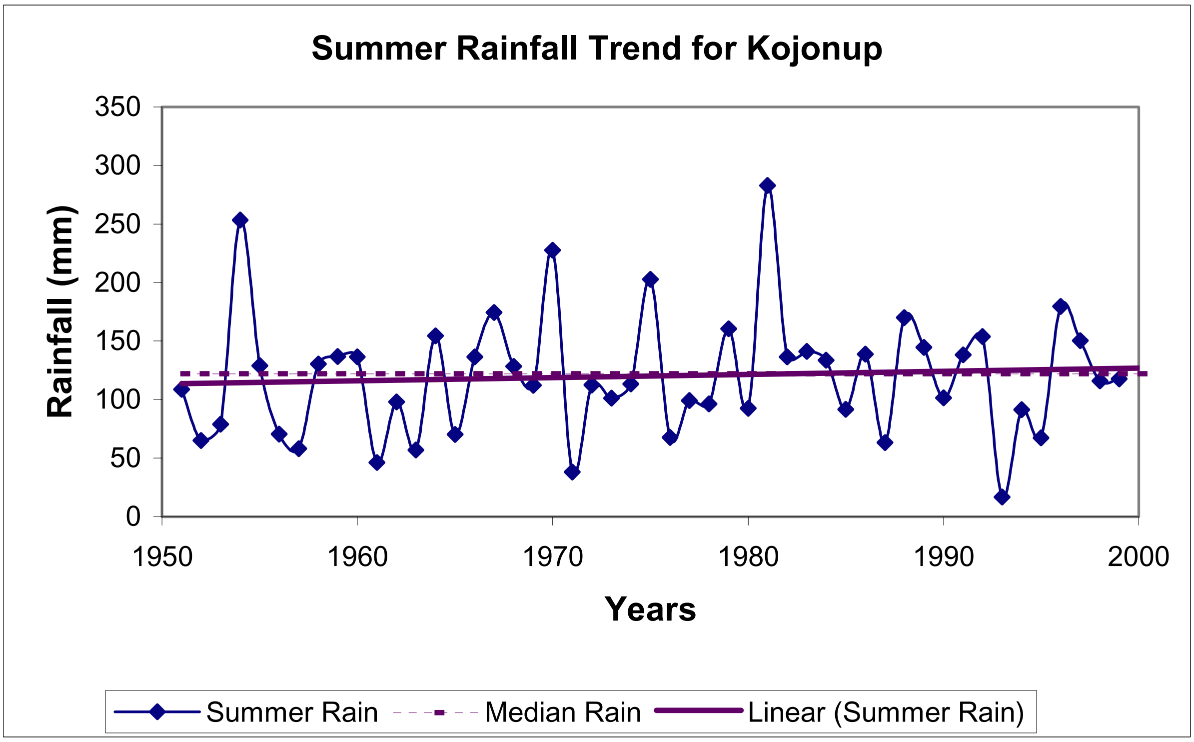


Figure 2.3. Summer rainfall (Bureau of Meteorology, 2002).

2.2 Geology

Geology has been described in relation to the main soil-landscape systems in section 2.3.1.

2.2.1 Beaufort System

Occupies low-lying areas around the Beaufort River and consists of Cainozoic alluvial deposits of sand, silt and clay with small areas of Quaternary dunes and lacustrine deposits. Archaean granite and adamellite comprise underlying bedrock (Wilde and Walker, 1982; Chin and Brakel, 1986). Hawkes (1993) and Prangley (1994a,b, 1995a,b) identified the Beaufort Palaeochannel system across 60 km, seven km of which underlies this landscape system (Map 2).

2.2.2 Boscabel System

Comprises surficial Quaternary deposits of colluvium, alluvium and reworked sand and areas of Cainozoic laterite and reworked sandplain. Underlying bedrock is Archaean biotite granite, adamellite and quartz monzonite, with Proterozoic north-west trending dolerite dykes and north-west and west trending quartz veins. Small areas of alluvium were mapped on the crests of present rises (Wilde and Walker, 1982; Chin and Brakel, 1986). Approximately 40 km of the Beaufort Palaeochannel underlies this landscape system (Map 2).

2.2.3 Carrolup System

Quaternary colluvium dominates with minor areas of alluvium. Archaean granite, adamellite, granodiorite and gneiss crop-out and are the dominant underlying rock types. Proterozoic dolerite and gabbro dykes trend west and north-west. Quaternary and Cainozoic alluvial deposits cover the valley flats and alluvial plains. Small areas of Cainozoic laterite and reworked sandplain occur (Chin and Brakel, 1986).

2.2.4 Darkan System

Archaean granite, adamellite and quartz monzonite underlie the Darkan system. The Kojonup and Darkan Faults trend north-west through this landscape system. Cainozoic laterite and Quaternary colluvial deposits are common. Small areas of Eocene alluvial deposits occur south of Capercup (Wilde and Walker, 1982). Approximately 12 km of the Beaufort Palaeochannel underlies this landscape system (Map 2).

2.2.5 Dellyanine System

Underlying Archaean basement comprises adamellite granite and granodiorite. Proterozoic dolerite and gabbro dykes trend west and north-west. Slopes are covered with Quaternary colluvium and minor alluvial deposits and small areas of Cainozoic laterite cap the rises (Wilde and Walker, 1982; Chin and Brakel, 1986).

2.2.6 Farrar System

Archaean biotite granite and adamellite underlie this system. The system has many Proterozoic dolerite and gabbro dykes and quartz veins. Small areas of Cainozoic laterite and Quaternary colluvium and alluvium also occur. Tertiary Kojonup sandstone often containing fossils is found in the Muradup area in elevated positions (Wilde and Walker, 1982; Chin and Brakel, 1986).

2.3 Soil-landscape information

The zone lies within the Avon soil-landscape province, and sits largely within the Southern Zone of Rejuvenated Drainage and the Eastern Darling Range Zone. A small area of land on the western fringe lies within the Western Darling Range Zone.

2.3.1 Soil-landscapes

The three main soil-landscape systems (Map 2) are:

- Broadly undulating rises, low hills and narrow alluvial plains of the Carrolup soil-landscape system (23 per cent of the area) in the south-east of the zone.
- Undulating rises and hills of the Farrar soil-landscape system (23 per cent) in the southern region of the zone.
- Gently undulating rises and hills with valley flats and plains of the Boscabel System (23 per cent) in the central part of the zone.

Remaining systems include the Dellyanine System (13 per cent) in the north-eastern sector of undulating rises and low hills with rock outcrops and narrow drainage lines and the Darkan System (8 per cent) in the north western region which is dissected lateritic terrain with rock outcrops and narrow drainage lines. The Beaufort System (6 per cent) occurs in the central part of the zone featuring broad valley floors of the Beaufort River with minor dunes and lakes. The Eulin Uplands (3 per cent), which are lateritic plateau remnants with lakes and poorly drained flats occur on the western edge. The remaining systems, the Darling Plateau and Jingalup, make up less than 1 per cent.

2.3.2 Soil groups

The most common soil groups (Schoknecht, 2000) are listed in Table 2.1. They are predominantly grey deep sandy duplex, and a large proportion of subsoils are neutral and sodic. Duplex sandy gravels, deep sandy gravels and shallow duplex soils are also common and ironstone gravelly soils increase in prominence from east to west.

Table 2.1. Soil groups

WA soil group*	Approximate area (ha)	% of zone
Grey deep sandy duplex	110,220	32
Duplex sandy gravel	33,175	10
Deep sandy gravel	32,590	10
Grey shallow sandy duplex	30,075	9
Brown deep sand	20,990	6
Saline wet soil	13,200	4
Shallow gravel	12,170	4
Loamy gravel	9,935	3
Bare rock	9,295	3
Red shallow loamy duplex	8,620	3
Other soils (< 3% of zone)	58,995	17

2.3.3 Land Management Units

Land management units are defined as "parcels of land, with common soils and landforms, which should be managed similarly in order to maximise their production and minimise land degradation" (Lloyd, 1992). Twelve land management units have been identified in the study area and are shown in Table 2.2.

Figure 2.4 is a cross sectional diagram showing where each land management unit is situated in the landscape.

Table 2.2. Land Management Units in the Beaufort Zone

Land Management Unit	Approx. area (ha)	Landscape position	Associated vegetation	Main soils and landscape position
Moderately Drained Sandy Duplex	121,830	Crests, upper and lower slopes	Wandoo(white gum); marri (red gum); York gum	Sand or sandy loam over clay at 10-60 cm, seasonally perched watertable common
Gravel Ridges and Slopes	87,870	Hillcrests and upper slopes, to the north and east of Kojonup may extend down to lower slopes	Jarrah; marri (red gum); wandoo (white gum)	Ironstone gravel > 60% overlying clay or hard ironstone at varying depths - usually > 30 cm and often > 60 cm
Poorly Drained Sandy Duplex	37,560	Lower slopes, drainage lines and broad valley floors	Flooded gum; flat topped yate; York gum	Sand or sandy loam over clay at 10-60 cm - clay may be blue/grey in colour or very mottled, very wet in winter months
Red Soils	27,820	Upper to lower slopes (often associated with dolerite dykes)	Jam; wandoo (white gum); Flooded gum; marri (red gum)	Reddish brown sandy loams over clay or grading to clay at 10-20 cm (red loams); red or reddish brown clay loam over red clay at < 10 cm or grading to red clay at depth (red clay)
Salt-Affected Land	13,200	Valley floors, drainage lines and saline seeps on hillslopes	Salt-tolerant vegetation - samphire; barley grass	Various soil types
Yellow and Brown Deep Sand	11,490	Valley floors, often as low dunes and lunettes and slopes	Banksia; Christmas tree; paper barks; sheoaks	Yellow or brown sands deeper than 80 cm
Pale Deep Sands	11,110	Crests and slopes	Christmas tree	Pale grey or white sands deeper than 80 cm
Rock Outcrops and Quartz Veins	9,390	Outcrops of granite, dolerite, quartz and hard ironstone	Wandoo (white gum); York gum	Includes outcrops of granite; dolerite quartz and hard ironstone
Grey/greyish brown loams and clays	9,080	Lower slopes or valley floors	Flat topped yate, flooded gum	Hard setting grey clay loam and clay including cracking clays and crabhole clays

Table 2.2 continued …

Land Management Unit	Approx. area (ha)	Landscape position	Associated vegetation	Main soils and landscape position
Mallet Hills	6,540	Breakaways or upper slopes and ridges	Blue and brown mallet	Pink or reddish water repellent soils, maybe gravelly, often acid
Wet Soil	2,080	Swamps, lakes, non-saline hillside seeps	Flooded gum; flat topped yate; York gum, swamp sheoaks	Various soils which are waterlogged from 30 to 80 cm or less for a major part of the year
Salt Lakes	1,280	Salt lakes	Swamp sheoak, Melaleuca thickets	Variable soils, seasonally waterlogged salt lakes

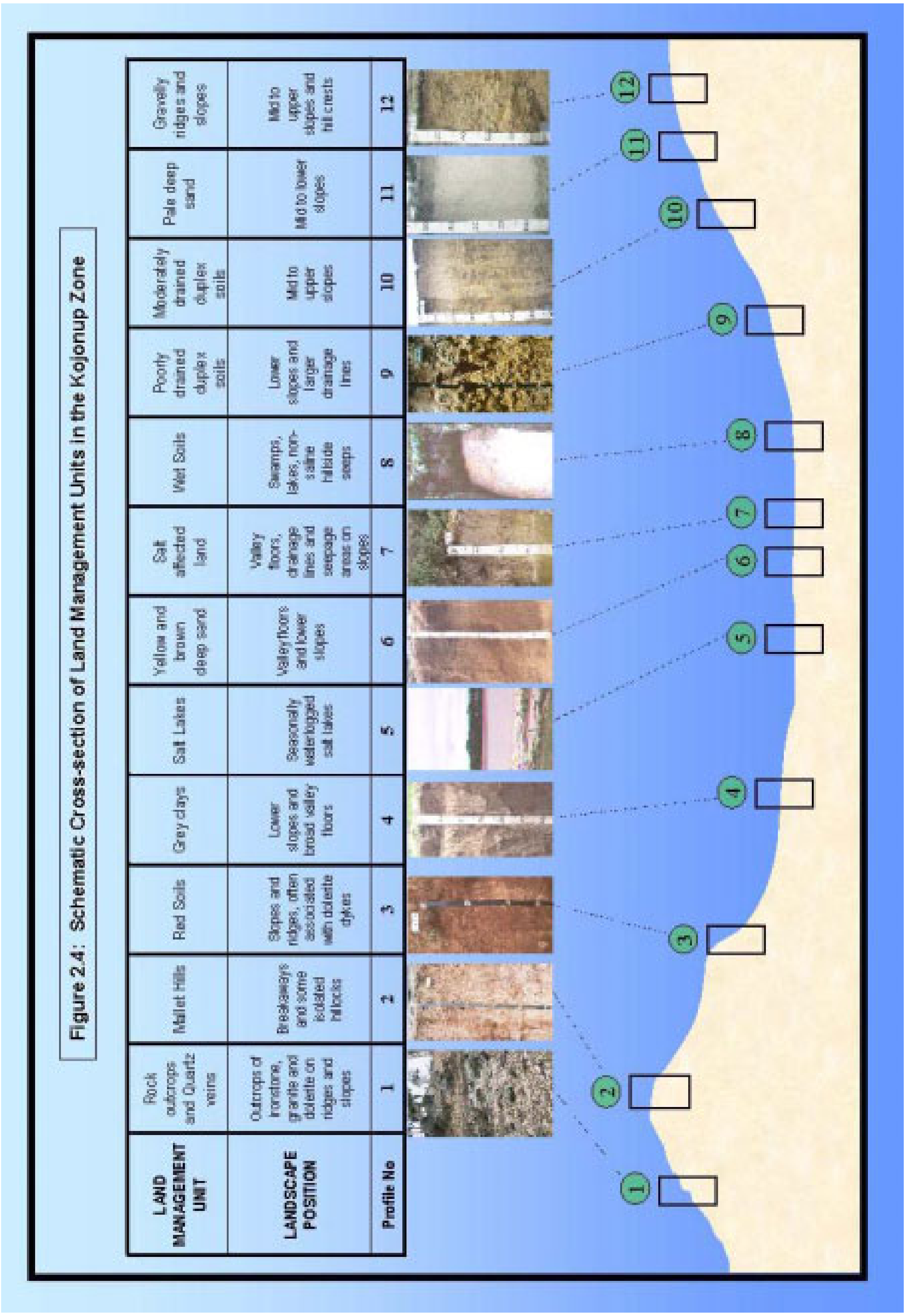


Figure 2.4. Schematic cross-section of Land Management Units in the Kojonup Zone.

Soil-landscape subsystems in the Beaufort Zone

Boscabel System: Gently undulating rises and narrow valley floors, in the south of the Eastern Darling Range. Sandy gravel mainly pale coloured, grey deep sandy duplex and pale deep sand. Wandoo-marri-jarrah woodland.

Bo1	Sandy gravels, usually pale coloured, on broad hill crests and upper slopes, small swamps and lunettes scattered on this unit.
Bo1s	Extensive areas of pale deep sands associated with sandy gravel uplands.
Bo1w	Small swamps and wet lands located on gravelly uplands with associated dunes with yellowish brown deep sands.
Bo2	Slopes of rises in the Boscabel system with grey deep sandy duplex soils and significant areas of moderately deep to deep sandy gravels.
Bo3	Small areas of the Boscabel system with shallow bedrock and soils formed on weathered granite.
Bo4	Broad valley flats and alluvial plains (150 - 2500m wide) with very minor areas of swamps and lunettes. Grey deep sandy duplex soils and significant salty soils.
Bo4s	Dunes and lunettes on broad valley flats with brown and pale deep sands.
Bo4w	Small areas of salt affected swamps and lakes with wet saline soils and brown deep sands.

Darkan System: Undulating rises and rolling low hills, in the south of the Eastern Darling Range (Blackwood Catchment). Gravels (mostly sandy) and grey sandy duplex (mostly deep). Wandoo-jarrah-marri woodland

Dk1	Gravelly hill crests and upper slopes with mainly yellowish brown sandy and loamy gravels.
Dk1p	Steeper slopes of the gravelly uplands (Darkan 1) with mainly deep sandy gravels and large areas of shallow to moderately deep sandy gravels.
Dk2	Slopes of the Darkan System with mainly moderately deep sandy gravels and grey deep sandy duplex soils.
Dk2i	Slopes of the Darkan System with moderately deep to deep sandy gravels, shallow gravels and pale deep sands.
Dk3	Slopes with red deep and shallow loamy and sandy duplex soils and grey deep sandy and loamy duplex soils associated with rock outcrops.
Dk4	Foot slopes with grey deep sandy duplex and moderately deep sandy gravels.
Dk5	Valley flats and narrow alluvial plans (300 - 1000m wide) with mainly grey deep sandy duplex soils.
Dk5w	Swamps and lakes in the Darkan system, including Lake Towerinning.
Dk6	Footslopes and very low rises adjacent to alluvial plains. Soils are sandy and loamy gravels and pale sands formed in Eocene sediments.
Dk6f	Foot slopes with mainly sandy and loamy gravels formed on Eocene sediments.
Dk6i	Very low rises adjacent to alluvial plains with pale sandy gravels and pale sands, formed on Eocene sediments.
Dk7	Dunes with yellowish brown deep sands along the Hillman River and its tributaries including dunes and lunettes on the east and south east of swamps and lakes.

Eulin Uplands System: Plateau remnants, in the south of the Eastern Darling Range (Blackwood Catchment). Gravel, sandy duplex soil and wet soil. Jarrah-marri-wandoo forest and woodland.

DM	Undulating ridges and hill crests on laterite and granite. Relief 5-20 m, slopes 5-15%. Soils are gravels, loamy duplex and sandy duplex soils.
DMi	Soil parent material is laterite. Soils are gravels, and sands.
DMs	Soil parent material is Kirup Conglomerate. Soils are sandy gravels, and sands.
KU	Poorly drained flats and gently undulating terrain with circular lakes and swampy depressions. Soils are sandy and loamy gravels with some sandy earths and deep sands.
KUi	Moderately well drained to poorly drained gravels.
KUw	Poorly drained depressions and swamps.
LK	Shallow (5-40 m) minor valleys with swampy floors incised in to lateritic terrain. Soils are sandy and loamy gravels, loamy duplex soils and deep sands.
LKd	Relief 20-40 m, slopes 5-20%. Soils are loamy earths and loamy duplex soils with some gravels and sands.
LKk	Shallow valleys with gentle slopes incised in to Eocene sedimentary deposits. Relief 5-20 m, slopes 3-10%. Soils are gravels and sands.
LKu	Relief 5-20 m, slopes 3-10%.
QU	Broad poorly drained flats between low hills, circular lakes and swampy depressions are common. Soils are sandy gravels, deep sands and non-saline wet soils.
QUs	Broad poorly drained flats between low hills, circular lakes and swampy depressions are common. Soils are deep sands and non-saline wet soils.
QUw	Very poorly drained depressions and swamps. Soils are non-saline wet soils and saline wet soils.
SD	Low hills (40-80 m) rising above the general landscape, slopes 5-20%. Soils are loamy and sandy gravels.

Beaufort System: Broad valley floors, in the southern Zone of Rejuvenated Drainage (Blackwood Catchment). Grey sandy duplex soils and saline wet soils. Wandoo-sheoak-jam woodland. Located along the Beaufort, Carlecatup and Hillman Rivers.

Be1	Broad flats (1.5-6km wide) along the Beaufort and Hillman Rivers with grey deep and shallow duplex soils (mainly with mottled, grey sodic subsoils) and areas of saline wet soils and alkaline grey shallow sandy duplex common.
Be2	Saline broad flats along Beaufort River with mainly saline grey sandy duplex soils and areas of non-saline grey deep sandy duplex soils.
Be3	Sand dunes along the Beaufort River with aeolian brown deep sands.
Be4	Small swamp and lakes on Beaufort River flood plain with small areas of sandy dunes and lunettes on their eastern margins.

Carrolup System: Undulating rises and low hills, in the southern Zone of Rejuvenated Drainage. Grey sandy duplex (deep and shallow) and shallow loamy duplex. Wandoo-sheoak-jam woodland.

Ca1	Gravelly soils capping hill crests and upper slopes in the Carrolup system.
Ca2	Grey sandy duplex soils on slopes, hill crests and less commonly minor drainage lines, within the Carrolup system.
Ca2s	Areas of wind blown brown deep sands covering the lower and mid slopes of the Carrolup 2 subsystem. Located east of brown sand in dunes along the Carlecatup and Gordon Rivers and their tributaries.
Ca3	Low hills and rises in the Carrolup system with sandy and loamy soils formed on shallow weathered granite and dolerite and small areas of rock outcrop.
Ca4	Grey sandy duplex soils and some sandy gravels located on footslopes and lower slopes within the Carrolup system.
Ca5	Drainage lines and valley flats which are 100 - 300 m wide with mainly saline wet soils. Also includes some lower slopes.
Ca6	Broad valley flats and narrow alluvial plains, Carlecatup and Gordon Rivers. The flats are 300 to 1500m wide. Soils are mainly grey deep and shallow sandy duplex soils. Brown deep sands occur in small dunes along the river.
Ca7	Dunes along the Carlecatup and Gordon Rivers with mainly brown deep sands derived from wind blown river deposits.

Dellyanine System: Undulating rises and low hills on granite, in the southern Zone of Rejuvenated Drainage. Grey sandy duplex (shallow and deep), sandy gravel and red deep sandy duplex. Wandoo-sheoak woodland.

De1	Gravelly crests and upper slopes usually bounded by breakaways with mainly deep and moderately deep sandy gravels and significant areas of shallow gravels.
De1s	Small areas of pale deep sands associated with sandy gravels on mid to upper slopes.
De2	Hillslopes and hillcrests with mainly grey deep sandy duplex soils and significant areas of grey shallow sandy duplex and moderately deep sandy gravels.
De3	Grey deep sandy duplex, gritty brown deep sands and red deep loamy and sandy duplex soils associated with outcrops of granite, adamellite and dolerite on hillslopes and less commonly hillcrests.
De4	Grey deep sandy duplex soils on foot slopes and lower slopes.
De5	Narrow valley flats (100 -300m wide) with mainly saline soils and grey deep and shallow sandy duplex soils.
De6	Broad valley flats and narrow alluvial plains (300-1500m wide) along the Arthur River (down stream of Buchanan River) with grey deep sandy duplex, deep sands and alkaline grey shallow sandy duplex soils.
De8	Rocky rises and low hills, with deep sandy duplex soils capped with duplex sandy gravels

Farrar System: Undulating rises and low hills on granite, in the southern Zone of Rejuvenated Drainage. Grey sandy duplex (mostly deep), sandy gravel, bare rock and red shallow loamy duplex. Wandoo-jarrah-marri woodland.

Fa1	Gravelly hill crests and upper slopes with mainly yellowish brown moderately deep to deep sandy gravels.
Fa2	Undulating rises and low hills with mainly grey deep sandy duplex soils.
Fa3	Rocky undulating rises and low hills with mainly grey deep sandy duplex, red sandy and loamy duplex formed on weathered bedrock.
Fa4	Foot slopes and concave lower slopes adjacent to drainage lines with grey deep sandy duplex soils and some areas of loamy gravels.
Fa5	Valley flats (200-700m wide) with grey deep sandy duplex soils with sodic, mottled grey and brown clay subsoils, and significant areas of saline wet soils.

Jingalup System: Gently undulating rises, on the southern edge of the Zone of Rejuvenated Drainage. Sandy gravel, grey sandy duplex (mostly deep) and shallow loamy duplex. Marri-wandoo-jarrah woodland.

Jp1	Moderately deep sandy gravels capping rises and low hills often forming broad hill crests with pockets of shallow gravels and deep sandy gravels.
Jp1s	Very small areas of pale deep sands associated with gravelly hill crests and upper slopes.
Jp2	Hill slopes of gently undulating rises with mainly grey deep sandy duplex soils and areas of deep sandy gravels and grey shallow sand duplex.

2.4 Hydrology

2.4.1 Groundwater

Five types of aquifers have been identified in the area (Figure 2.5). Local flow systems are groundwater systems where recharge and discharge occur within two kilometres. Intermediate flow systems are those where recharge and discharge takes place two to 10 km apart.

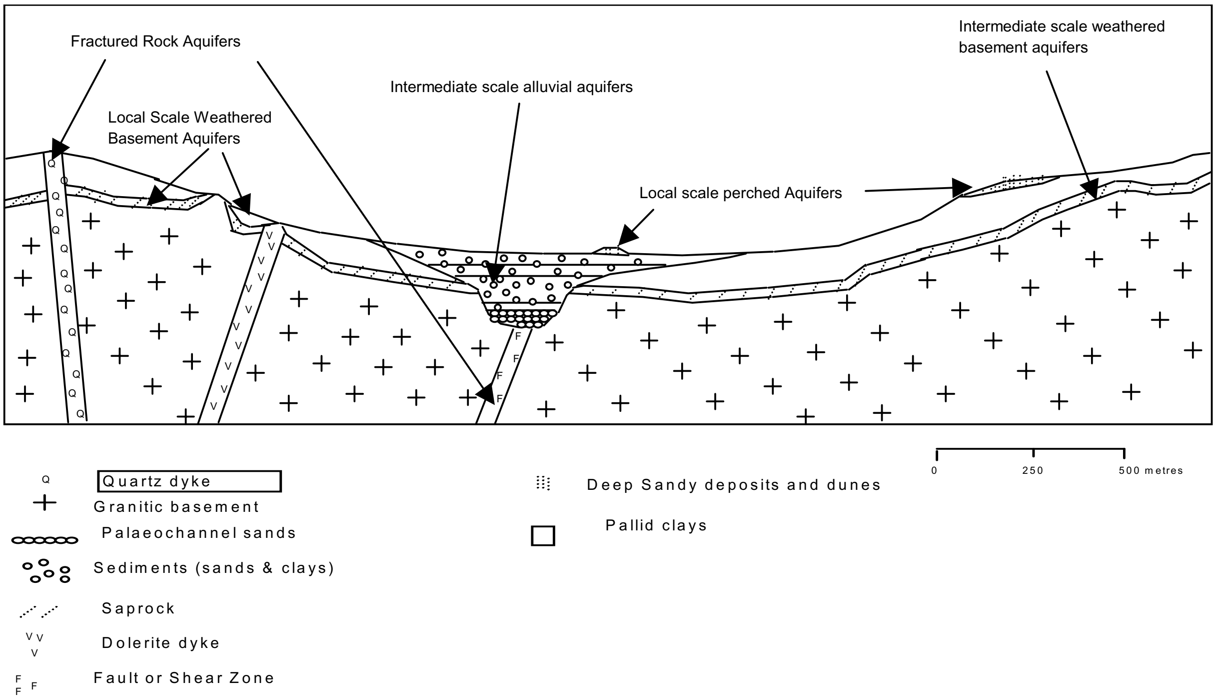


Figure 2.5. Representative cross section of main aquifers in Beaufort Zone.

2.4.1.1 Intermediate scale weathered basement aquifers

Intermediate scale weathered basement aquifers refer to the saprock aquifer at the base of the lateritic profile. Aquifers are typically 0.5-5.0 m thick, are semi-confined or unconfined by overlying pallid clays, and occur where most of the lateritic profile is preserved. Excluding areas with shallow rock, seeps, palaeochannels and rock outcrop, approximately 92 per cent of the Zone is underlain by this aquifer-type.

Mean horizontal saturated hydraulic conductivities measured in the weathered basement aquifers are in the range 0.21 to 3.08 m/day (Clark, George, Bennett & Bell, 2000). Values above 1.0 m/day are associated with faulting in the underlying basement.

2.4.1.2 Intermediate scale alluvial aquifers

Intermediate scale aquifers in alluvial deposits on valley floors may be surficial, semi-confined or confined. Sand rich sediments act as aquifers, while clay rich sediments act as confining layers. These aquifers commonly discharge into the broad valley floors such as the Beaufort1 soil-landscape subsystem, which covers approximately five per cent of the Zone, and is prone to waterlogging or inundation throughout winter. Other soil-landscape subsystems that define alluvial deposits in broad valley floors include Boscabel4, Carrolup6, Carrolup7, Darkan5 and Darkan6, covering a further nine per cent of the Zone.

Discharge is typically saline (> 2000 mS/m) and leads to dryland salinity in large areas left bare and eroded, or covered by barley grass and occasionally samphire during summer - for example, the Beaufort River flats. Capillary rise from valley floor aquifers is the most common form of discharge along with discharge from semi-confined aquifers.

Palaeochannels are intermediate scale alluvial aquifers where ancient river systems eroded deeply into the landscape and were filled with more recent alluvial sediments (Figure 2.5). The Beaufort Palaeochannel underlies the Boscabel, Darkan and Beaufort soil-landscape systems. Currently, the identified boundaries cover an area of 6280 ha (5 per cent of Zone) with up to 50 m of sediments (Commander, 1995). Groundwater quality varied from 1500 mg/L to 10,000 mg/L with drought relief bores yielding between 276 and 319 m^3/day (Commander, 1995). Local businesses that currently extract potable water from this palaeochannel include numerous broadacre farms, Duranillan townsite, two piggeries, an abattoir, a native floriculture export business and a roadhouse.

2.4.1.3 Local scale perched aquifers

Local unconfined (perched) aquifers occur in deep sandy deposits and dunes such as those in the Boscabel and Carlecatup areas, particularly within Bo1s, Bo4s, Ca2s and Ca7 soil-landscape subsystems. Minor deep sands are found in the Dellyanine System (De1s) south-east of the Arthur River townsite. The Jingalup System on the southern zone boundary south-west of Kojonup, contains a deep sandy aquifer on the watershed divide. It is used by local farmers during periods of low surface run-off and was the major source of water for a stock pellet mill. Perched aquifers occur as grey, white and brown sands, more than 80 cm deep. Duplex soils may act as a temporary aquifer (four or five years in 10) when recharge through rainfall exceeds the lateral conductivity of the sand layer, which is about 1.8 m/day (Cox, 1988).

2.4.1.4 Local scale weathered basement aquifers

Local semi-confined to confined aquifers in weathered basement rocks exist in the same conditions as those at intermediate scale. Geological structures and conditions cause discharge close to the recharge point. Local scale aquifers include break of slope discharge, discharge over dolerite dykes, shear zones or bedrock highs and are most common in higher relief areas. They occur as a subset of intermediate scale, weathered basement aquifers beneath 60 to 70 per cent of the landscape and are usually associated with undulating to hilly terrain of the Carrolup, Dellyanine, Darkan and Farrar soil-landscape systems. Flows may be permanent or temporary. Water is typically transported down a hill slope through thin (< 20 m), unconfined aquifers close to the surface.

2.4.1.5 Fractured rock aquifers

Fractured rock aquifers are formed when structures such as dykes, faults and shear zones create fractures within unweathered bedrock. They occur at both local and intermediate scales, extending from tens of metres to tens of kilometres in length. They have high conductivities (above 1.0 m/s) but lower porosity (0-10 per cent) than saprock (25 to 50 per cent - Kruseman and de Ridder, 1994); their low porosity and small aerial extent (< 1 per cent of the zone) limits their yield of groundwater. Sometimes, fabric of the fractured zone is retained in the lateritic profile and can cause preferential discharge over shear zones and faults, as in the Towerrinning area. Clark *et al.* (1998) identified preferential discharge causing saline seeps in the Towerinning-Duranillin area overlying the Kojonup and Darkan regional faults. Groundwater was also found to move through topographic divides within shear zones.

2.4.2 Groundwater levels and quality

Sixty five per cent of monitoring bores indicated a watertable less than two metres from ground surface. These bores were located low in the landscape in areas considered to have the highest salinity risk. The watertable was deeper than five metres (least salinity risk) in 15 per cent of bores.

Groundwater in 45 per cent of bores was saline (> 1000 mS/m) and was fresh (< 250 mS/m) in 25 per cent. Fresh, brackish and saline groundwater was observed in most sub-catchments.

Groundwater pH ranged from slightly acid (5.4) to slightly alkaline (8) with an average close to neutral at 6.7. Average pH of Beaufort palaeochannel bores was neutral (7) and of Byenup Hill bores was slightly acid (6.4).

Groundwater data was analysed for 770 bores from the Department's AgBores database, Shire of West Arthur's ComBores database, Water and Rivers Commission Water Resources Information Catalogue and CSIRO.

2.4.3 Waterways and wetlands

Rivers are ephemeral, with flows following winter rains and pools remaining in dry summers, including:

- Carrolup River;
- Carlecatup Creek draining south-east into the Beaufort River;
- Arthur River from the north-east joins the Balgarup River, to become the Blackwood River;
- Fifty-Two Creek and Kojonup Brook originate near Kojonup Town, join then flow into the Blackwood River near Moodiarup;
- Balgarup River drains the south-west of the zone and joins the Blackwood River before Boyup Brook town; and
- Carrolup River (severely affected by salinity and waterlogging - Grein, 1995), joins the Beaufort River and runs into the Blackwood.

Wetlands include: Towerrinning Lake (the major water body), Qualeup Lake, Intermittents Lake, Clear Lake, Rushy Lake and Koolbooking Swamp.

According to Water and Rivers Commission (2002a, 2002b), all rivers in the zone are highly saline (more than 5000 mg/L), with low concentrations of nitrogen (0.76-1.2 mg/L) and the pH is neutral. High phosphorus concentrations (0.09-0.2 mg/L) were found in the Beaufort river and in Mardelup Pool (part of the Balgarup River).

2.4.4 Water resources

Northern areas are prone to droughts, dry spells and water deficiencies. Severe droughts occurred in 1944-45 and 1969 and farm water deficiencies were declared in 1980, 1986 and 1987.

Around 10 per cent of groundwater is suitable for livestock. About 30 per cent of farms in West Arthur Shire, 17 per cent of Boyup Brook Shire farms and 85 per cent of Kojonup Shire farms have bores, but many are saline. Dunal areas along banks of the Carlecatup Creek provide water supplies: perched fresh water can be accessed by building dams or soaks into the clay/sand interface.

Great Southern Towns Water Supply Scheme provides reticulated water to parts of the Wagin, Woodanilling, Katanning and Kojonup Shires. Standpipes provide for those farmers without access to the reticulated water.

Four standpipes exist between Katanning and Wagin and four between Katanning and Muradup. Two bores north of Kojonup in the Beaufort River area are equipped with tanks to supplement farm supplies.

2.5 Native vegetation

The study area is situated within the South-west Botanical Province, across the Avon Botanical District and Irwin Botanical District (Beard, 1981). Avon Botanical District contains two vegetation systems - Wagin (north-eastern region) and Tambellup (south-eastern region). The Irwin Botanical District has four systems: Beaufort (north-western region), Bridgetown (western region), and Jingalup (central southern region) systems are part of Menzies sub district, and the Williams system (central northern region), in the Dale sub-district. The distribution of these original native vegetation systems was determined by soil type, topography and rainfall (Table 2.3).

Table 2.3. Native Vegetation Systems of the Beaufort Zone

Vegetation system	Area (ha)	Area %	Vegetation associations
Beaufort	215,910	64	Wandoo on laterite residuals; woodlands of York gum and wandoo on undulating country and woodland of York gum and flat-topped yate on sand patches.
Jingalup	41,110	12	Mosaic of jarrah, marri and wandoo woodland on ironstone gravels; woodland of marri and wandoo on slopes. Brown mallet and jarrah occur on breakaways; flooded gum occurs along minor creeks. Woodlands of marri and wandoo.
Wagin	37,940	11	Brown mallet and wandoo on laterite mesas and breakaways; low woodland of York gum and wandoo on the slopes of undulating country. Woodland of wandoo, flat-topped yate and tea-tree on flats and drainage lines.
Williams	31,220	9	Jarrah on gravelly soils, which merge with wandoo woodland. An open forest of brown mallet occurs on breakaways, while marri and flooded gum woodland occupy granitic hills and slopes. On lower slopes of hills and valleys, York gum forms woodland with an understorey of jam.
Tambellup	7,190	2	Woodland of wandoo and flat-topped yate; scattered laterite capped hills carry brown and blue mallet.
Bridgetown	5,880	2	Jarrah-marri forest dominates; marri wandoo woodlands in valleys at the eastern boundary. Flooded gum and paperbark dominate in wet areas.

2.6 Agricultural production

2.6.1 Farming systems

The main agricultural enterprises are cropping (wheat, canola, oats, lupins and barley) integrated with livestock production.

Sheep production used to be the main enterprise, with oats and barley grown for feed. As wool and meat prices declined, bigger areas were planted with lupins, canola, wheat and barley, particularly over the last five years. Recent price-rises, however, have caused a shift back to sheep production.

2.6.1.1 Cropping systems

Until recently, it was advocated that cropping paddocks should stay in a short pasture/crop rotation such as legume pasture/cereal or pasture/cereal/cereal/pasture, depending on soil type. However, with improved crop varieties and the recent introduction of high yielding, disease resistant canola varieties, cropping in the area has become more intensive and paddocks are cropped more often. For example, rotations of canola/cereal/cereal/cereal/ pasture or canola/cereal/lupins/cereal/canola are commonly practiced.

Canola is used to 'break out' of the pasture phase and into the cereal phase. Benefits include the use of canola to control weeds, particularly grasses that harbour cereal diseases. Innovative crop sowing techniques, used by some farmers, are minimum till, and in a few cases, no-till. Raised beds are being used by a small number of farmers in the higher rainfall area where waterlogging is a problem.

Some farmers have sown balansa clover or medics in areas prone to waterlogging.

2.6.1.2 Livestock systems in Beaufort Zone

Sheep and cattle were the main enterprises in this region until wool prices dramatically dropped in 1991 (Figure 2.9). Since then, sheep numbers have followed wool prices, only increasing in the last 18 months.

Grazing management practices in the area include feedlotting, strip grazing, deferred grazing and/or rotational grazing. Paddock feed is often limited through the dry months (December to April) with supplementary feeding required. There are some very successful sheep breeding enterprises (studs) in this Zone, particularly in and around the Kojonup area.

2.6.1.3 Other systems in Beaufort Zone

Intensive and alternative farming systems within the Zone include:

- Summer cropping - most common crops grown are sorghum and millet.
- Aquaculture - species include marron, yabbies, barramundi, saltwater trout and perch.
- Flower production.
- Organic farming methods - some farmers use a biodynamic farming system.
- Agroforestry - bluegums, oil mallees, tea trees, sandalwood, Acacia species, pine trees and other Eucalypt species (only 3 per cent of the 250,000 trees planted are for timber production*).
- Vineyards.
- Vegetable production - mainly potatoes.
- Other livestock - chickens, pigs, alpacas, emus, deer and oxen.
- Olive groves.

(* Australian Bureau of Statistics, 1997.)

2.6.2 Land values

Over the last twenty years land values have remained relatively constant, apart from some volatility in the late 1980s and early 1990s (Figure 2.6). The 1980s downturn was due to high debt levels and interest rates, but the trend was reversed at the end of the decade as wool prices rose. Land values then followed wool prices down in 1990. Figure 2.7 shows the capital gain for farmers in the Kojonup Shire in nominal terms (no adjustment for inflation), with values at 2001 as the base year. Gains were as high as 13 per cent (2000), and averaged 5.3 per cent for the last 20 years.

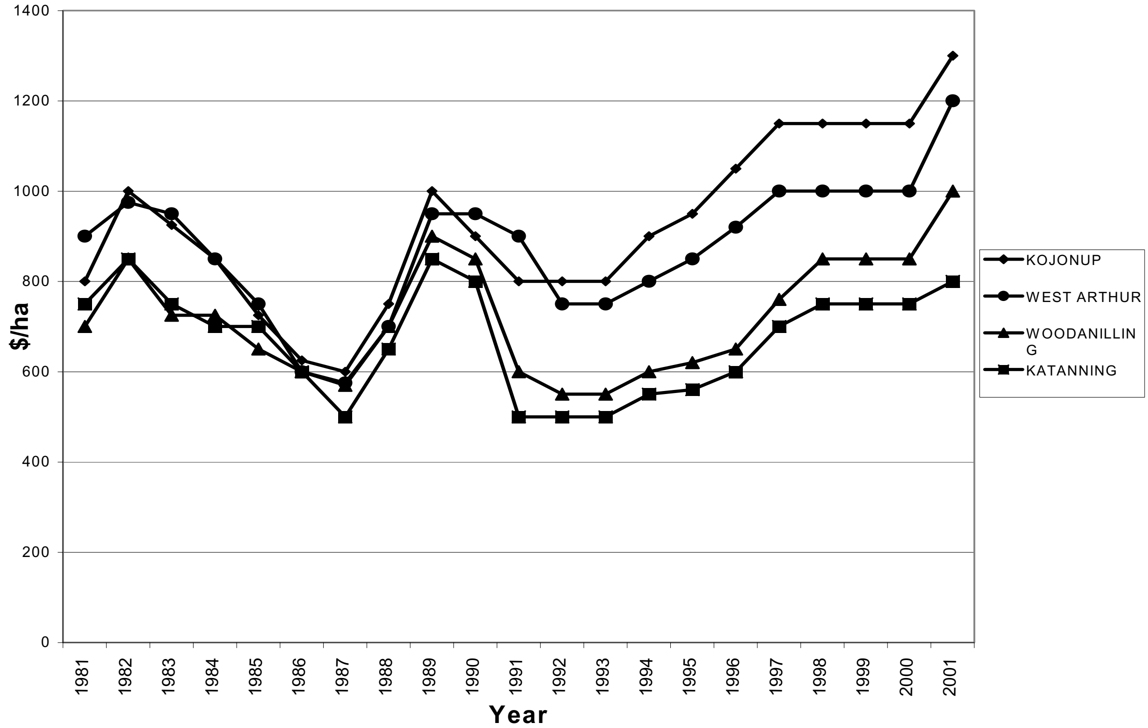


Figure 2.6. Nominal value of land in zone (Gusto, 2001).

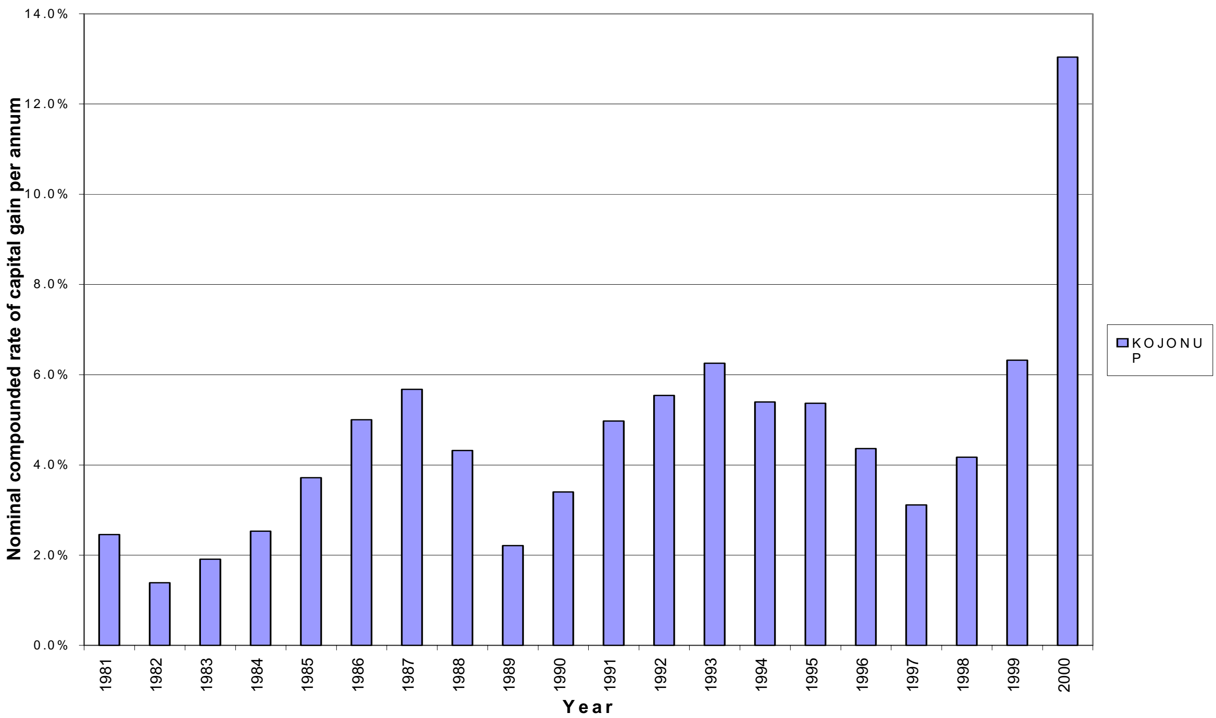


Figure 2.7. Nominal capital gains for farms (Gusto, 2001).

According to Figure 2.8, farmers who purchased in the early 1990s after the wool collapse have realised considerable capital gain in the last decade.

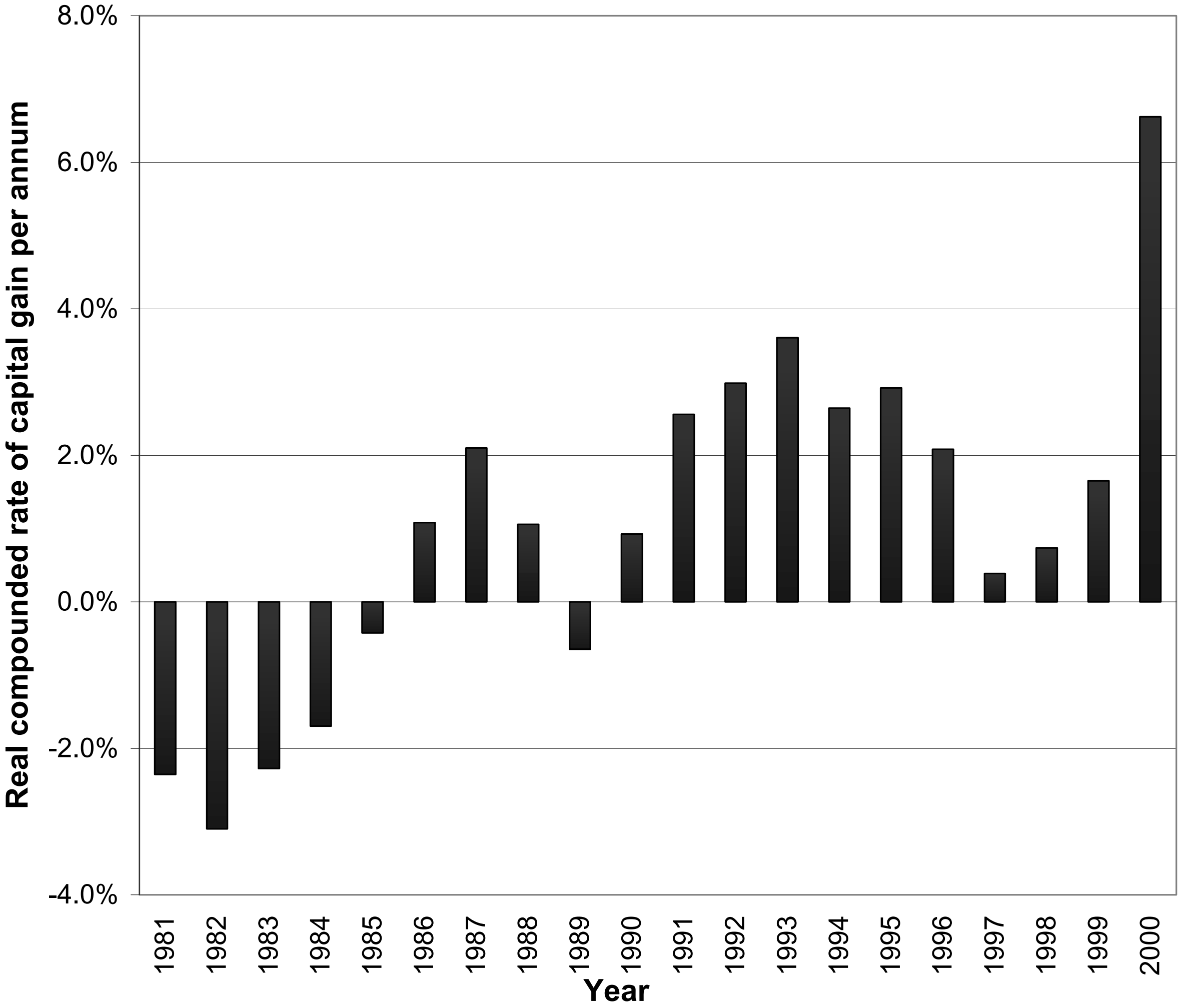


Figure 2.8. Real Capital gains for farmers in the Beaufort Zone (Gusto, 2001).

2.6.3 Value of agricultural production

Gross value of agriculture production (GVAP) in 1996 was $55.5 million - 1.24 per cent of the State's total GVAP[1]. Production rose to $62.2 million in 1999 (1.46 per cent of the State's GVAP), and has averaged $45.8 million since 1983.

Cereal grains have contributed almost 80 per cent of the value of agricultural production since 1983, while livestock (wool and meat) contributed 18 per cent.

1 The statistics (Agstats) used for analysis are based on Shires and they are collected by Australian Bureau of Statistics. This data was collected annually until 1997, it is now collected every five years. The data subsequent to 1997 is estimated, based on historical data, there may be some errors.

Production trends

The Beaufort zone has 490 mixed farming enterprises. The average farm size is 790 ha, and the largest is 5,500 ha.

Figure 2.9 shows the inverse relation between wool value and the number of ha of crop planted.

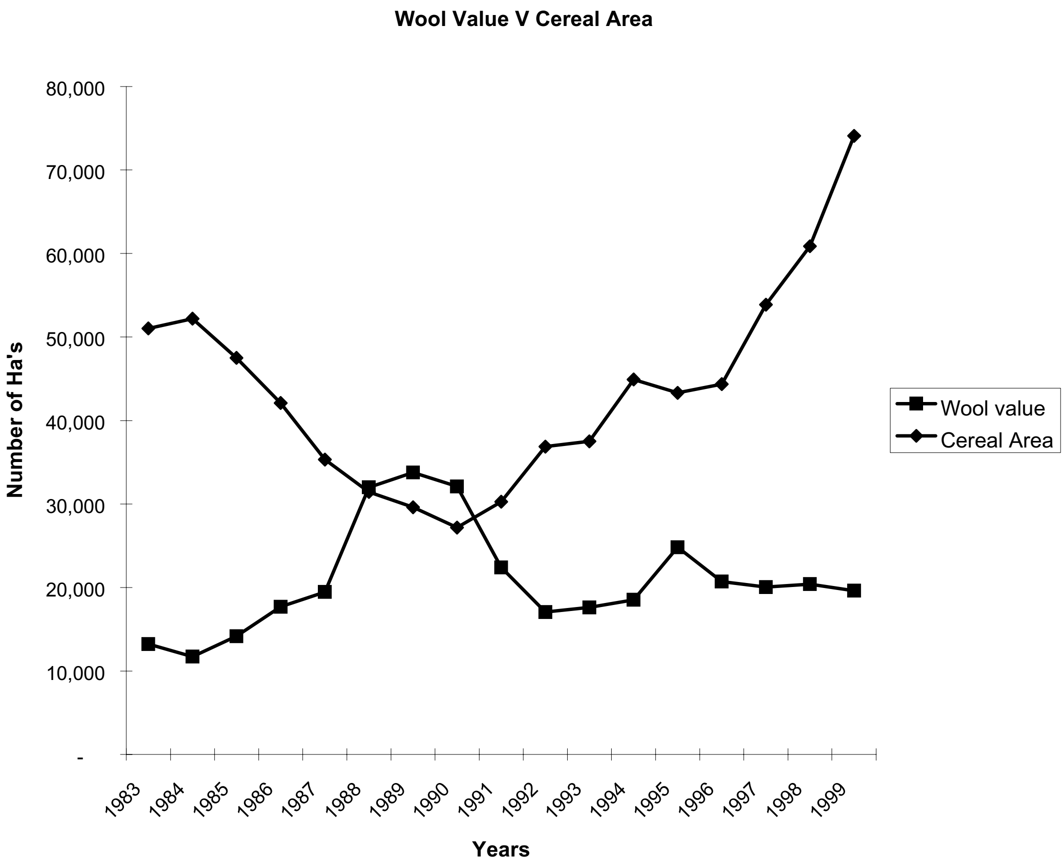


Figure 2.9. Cereal Area V Wool Value 1983 to 1999. Source: ABS Agstats.

Sheep numbers have gradually declined from a peak of 972,000 in 1992, to a low of 508,000 in 1990 Since 1999, numbers have increased due to improved prices of wool and prime lambs.

2.6.4 Farm performance

Farms in the region are generally small and carry high debt per hectare; however, income per hectare, asset values, equity levels and land values are all relatively high (Table 2.5 - BankWest benchmarks 2000/01). Compared with other farms in WA, debt to income ratio is 13 per cent higher, but more gross income is generated per dollar of debt (95 vs 84 cents).

The variation in profitability of farms in the region is shown in Table 2.4.

Table 2.4. Retained profit for farms in the Kojonup shire 1997 to 2000 (BankWest Benchmarks, 2001)

Retained profit/ha	1997/98 $	1998/99 $	1999/00 $	2000/01 $
Top 25%	67	59	69	63
Other 75%	- 9	10	11	37
Low 25%	- 38	- 30	- 28	28

Table 2.5. BankWest benchmarks - four-year average data 1997 to 2000/2001

Capital analysis	Great Southern	Western Australia	Kojonup Shire
Effective area (ha)	1645	2653	1304
Assets ($/Eff ha)	1514	1089	1707
Debt ($/Eff ha)	215	162	245
Long term debt ($/Eff ha)	151	104	213
Equity (%)	86	84	85
Long term debt to income (%)	60	48	0
Return to capital (%)	0.8	0.1	2.8
Machinery value ($/Eff ha)	211	193	144
Farm income ($/Eff ha)	226	193	223
Operating costs ($/Eff ha)	155	136	142
Operating cost/farm income (%)	70	74	65
Grain % of farm income	45	68	25
Sheep and wool % of farm income	38	20	61
Crop % of effective area (%)	47	60	25
Machinery value ($/crop ha)	414	360	706
Total sheep income ($/winter grazed ha)	159	116	166
Sheep costs ($/winter grazed ha)	105	n/a	82
Wool price ($/kg)	3.59	3.38	2.9
Average sheep sale price ($/hd)	23	24	22

2.7 Demographics

Demographic data for Beaufort zone are displayed in Table 2.6.

Table 2.6. 1996 demographics on a shire basis (ABS, 2000 and Patterson Market Research, 1999)

Demographics		Kojonup	West Arthur	Woodanilling
Employment in agriculture as % of labour force	Farmers	36	60	52
	People employed in agriculture	48	73	65
Farmer education (%)	No award	80	81	83
	Vocational	5	7	4
	Tertiary education	15	12	13
Average taxable income ($)	1995/1996	24,600	25,800	29,400
	1997/1998 ($32,444 in regional WA)	24,800	28,600	26,800
Unemployment (%)	As at 12/1996	3.7	2.7	3.7
	As at 12/2000 (5.2% in regional WA)	2.6	1.5	1.2
Total population (% change in 2000)		2,404 (- 4.5)	1,003 (- 6.0)	364 (6.6)
Median age of farmers		45	45	41

Negative trends in agriculture will be detrimental to the town communities as more than half of the total current workforce is employed in agriculture. This impact will have a flow-on effect in declining incomes, increased unemployment and a further decline in total population.

3. RESOURCE CONDITION AND FUTURE RISK

3.1 Soil degradation risk

The main land degradation hazards are soil acidity, wind erosion, water erosion and waterlogging. The risks from these and other hazards for each land management unit are presented in Table 3.1.

3.1.1 Soil acidity

Soil most susceptible to subsoil acidification is sandy, highly leached, has low organic carbon content and little resistance (or buffering capacity) to pH change. The land management units most at risk are poorly drained sandy duplex, moderately drained sandy duplex and pale deep sands. Approximately 245,000 ha (72 per cent of the zone) are moderately to highly susceptible.

3.1.2 Wind erosion

Wind erosion is uncommon but can have a major impact on the landscape. Areas of unprotected, loose, dry soil, in higher landscape positions are most at risk (Moore and McFarlane, 1998). The most susceptible LMU's (particularly on crests and upper slopes) are sandy duplexes, pale deep sands and yellow and brown deep sands. Approximately 166,000 ha (49 per cent) are moderately to extremely susceptible.

3.1.3 Water erosion

Water erosion following intense rainfall is influenced by soil erodibility, slope angle, slope length, management practices and the amount and type of groundcover (Coles and Moore, 1998). Approximately 69,000 ha (20 per cent) are moderately too extremely susceptible.

3.1.4 Waterlogging

Waterlogging enhances the effect of salinity on plant growth (Moore and McFarlane, 1998). These areas are often saline or at high risk of soil salinity. The LMU's most at risk from waterlogging are Poorly Drained Sandy Duplex and Grey/greyish Brown Loams and Clays (particularly on lower slopes), and Salt-affected Land. Approximately 67,000 ha (20 per cent of the Zone) are moderately to very highly susceptible.

Table 3.1. Assessment of land degradation hazards[1] for land management units[2]

Land Management Unit	Approx. area (ha)	Salinity risk	Waterlogging/ inundation risk	Susceptibility to phosphorus export	Susceptibility to water erosion	Susceptibility to wind erosion	Susceptibility to subsurface acidification (10-20 cm)	Susceptibility to water repellence	Susceptibility to topsoil structure decline	Susceptibility to subsurface compaction (10-30 cm)
Moderately Drained Sandy duplex	122,000	Low risk*	Low	Moderate	Moderate	Moderate to High **	High	Moderate	Low	Moderate
Gravelly ridges and slopes	88,000	No risk	Nil	Moderate	Moderate	Low	Moderate	Moderate	Low	Low
Poorly drained sandy duplex	38,000	High	Moderate to High for lower slopes	Moderate, low on valley flats	Moderate, low on valley flats	Low	High	Moderate	Low	Moderate
Red soils	28,000	Low risk*	Low	Moderate	Moderate	Low	Low	Low	Moderate	Low
Salt-affected land	13,000	Presently saline	Very high	High	High	Low	Variable ***	Low	Not rated	Not rated
Grey/greyish brown loams and clays	11,000	Low risk	Moderate to high on valley flats	Moderate	Moderate (on slopes)	Generally low	Low	Low	Moderate to High	Low to Moderate
Yellow and Brown deep sands	11,000	Moderate	Very Low	Moderate	Moderate	Moderate to High**	Moderate to High	High	Low	Low to Moderate
Pale Deep sand	9,000	No risk	Nil	Low	Moderate	High	High	High	Low	Low to Moderate
Rock outcrops and quartz veins	9,000	Variable	Nil	Low	Low	Low	Low	Low	Low	Not rated
Mallet hills	6,500	No risk****	Nil	Moderate	High	Low	Presently acid	High	High	Low
Wet Soils	2,000	High	Not rated	Moderate	Low	Low to moderate	Moderate to High	Not rated	Low	Low
Salt Lakes	1,000	Presently Saline	Not rated	Moderate	Low	Low	Not rated	Not rated	Not rated	Not rated

* Low risk, salinity likely to develop as hillside seeps on the units where shallow bedrock forces saline groundwater close to the surface.
** Highly susceptible to wind erosion on crests and upper slopes.
*** Soil pH on saline soils is highly variable but they may not be economic to lime.
**** Many Mallet Hills have acid clay subsoils that are often saline.

1 Risk assessments based on guidelines in Van Gool, Tille and Moore, 2000.
2 Land management units derived from Schoknecht, 2000, Soil Groups of WA.

3.2 Hydrological risk

3.2.1 Salinity

The Land Monitor project estimated the current extent of salinity in the zone at 11,500 ha or three per cent (Map 3).

3.2.1.1 Watertable trends

Bores high in the landscape on ridges had the highest rate of watertable rise, averaging one metre per year. On mid- to upper-slopes, in both gravelly and sandy duplex soils, the watertables have risen 0.1 to 0.3 m per year, and low in the landscape the average annual rise was 0.2 m in gravelly soils and 0.1 m in sandy duplex soils. The watertable on salt-affected land was stable (Table 3.2).

Estimates were obtained from 43 bores located at Byenup Hill, Fifty-Two Mile Creek, northwest of Lake Towerrinning, and north of Cherry Tree Pool Road. Hydrographs and watertable trends for representative bores in each Land Management Unit across different landscape positions are illustrated in Figure 3.1.

Table 3.2. Watertable trends* for Land Management Units

Land Management Unit	Landscape position	Watertable trend range (m/year)	Watertable trend average (m/year)	Number of bores
Gravelly Ridges and Slopes	Lower slope Mid slope Upper slope Ridge	0.1 - 0.4 0.1 - 0.3 0.1 - 0.5 0.7 - 1.5	0.2 0.2 0.3 1.0	5 7 4 3
Moderately Drained Sandy Duplex	Mid slope Upper slope	0.1 - 0.2 No trend - 0.2	0.2 0.1	2 3
Poorly Drained Sandy Duplex	Valley floor Lower slope	No trend - 0.3 No trend - 0.2	0.1 0.1	13 4
Salt Affected Land	Lower slope	No trend	No trend	2

* Watertable trends estimated using HARTT (Hydrograph Analysis Rainfall and Time Trend) analysis (Ferdowsian, Pannel, McCarron, Ryder and Crossing, 2001).

3.2.1.2 Potential salinity risk (land monitor and flowtube)

The valley floor maps produced by the Land Monitor project show the area of land within two metres (vertical height) above the flowpaths through the landscape, but do not show potential groundwater levels or salinity. They are simply topographical maps indicating the low-lying areas at risk of becoming saline/waterlogged *if the watertables rise sufficiently.*

About 27 per cent of the landscape (90,000 ha) is mapped as low-lying (Map 4), and most of that is at risk of becoming waterlogged and/or saline because borehole data indicate generally rising watertables.

LAND MANAGEMENT UNIT	Salt affected land	Poorly drained duplex soils	Moderately drained duplex soils	Gravelly ridges and slopes
Hydrograph No	1	2	3	4

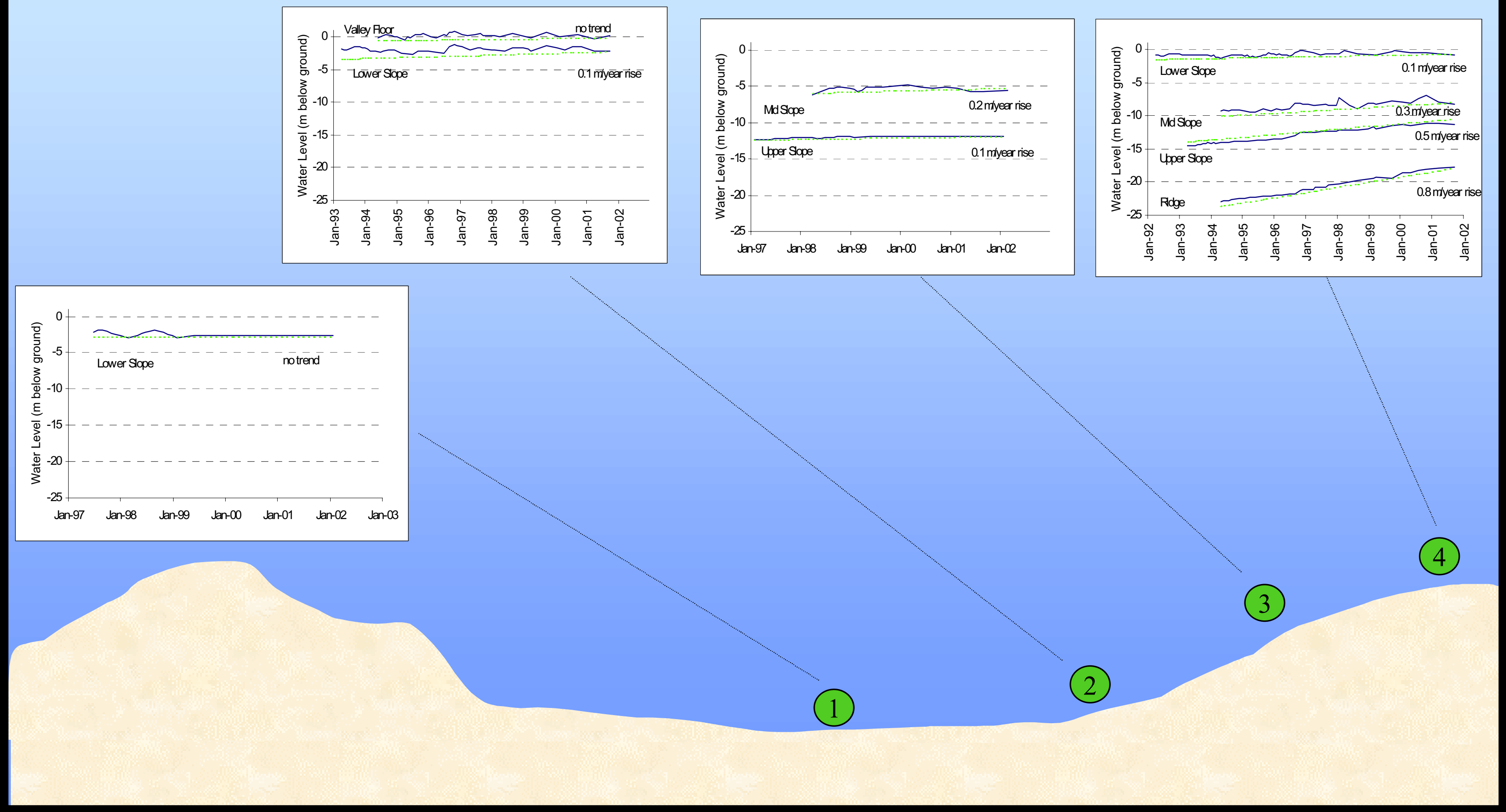


Figure 3.1. Hydrographs for representative bores in four Land Management Units.

Flowtube is a two-dimensional model that simulates groundwater levels while changing variables such as recharge, evapotranspiration, hydraulic conductivity and geology. A transect was constructed in a Byenup Hill catchment using existing data. Assumptions on which the model is based include:

- main aquifer is saprock overlying unweathered granite basement;
- hydraulic conductivity of the main aquifer is 0.1 m/day, which is less than that measured in the west of the Blackwood Catchment at Duranillan (Clarke *et al*. 2000);
- lower hydraulic conductivity is based on three dykes mapped by Raper and Guppy (2002) that intersect the transect and lower the average conductivity;
- porosity and conductivity of overlying clays is 35 per cent and 0.02 respectively;
- current recharge is seven per cent of the average annual rainfall which is 500 mm/yr; and
- length of the flowtube with a shallow watertable (two-dimensional) is linearly related only to high relief areas of the zone with a shallow watertable.

The model showed significant changes in groundwater levels only when values assigned to recharge and hydraulic conductivity were changed. In the '100 per cent' scenario, allowing all seven per cent of the rainfall to recharge, after 50 years, approximately 61 per cent of the flowtube will have a watertable within 2 m of ground surface (Figure 3.2). This equates to 28 per cent of the Zone when extrapolating the two-dimensional model to the whole Zone.

Modelled rates of groundwater level rise under 100 per cent recharge are similar to those observed and projected by the HARTT analysis for moderately drained duplex soils and are for the upper slope. The rates are 0.1 to 0.2 m/year for upper slopes; mid-slope - 0.05 to 0.1 m/year; and lower slope - 0.01 to 0.05 m/year.

If recharge is reduced to 50 per cent (for example, lucerne over the whole landscape) approximately 47 per cent of the flowtube will have a shallow watertable after 50 years. If recharge is reduced to 25 per cent the Flowtube length affected falls to 19 per cent. Reduction of recharge to zero results in only 9.5 per cent being affected by a shallow watertable after 50 years.

Table 3.4 illustrates the relationship between percentage of the flowtube transect with a shallow watertable to percentage of the Beaufort Zone with a shallow watertable. Numbers produced by the flowtube model are much higher than the Zone average because the transect has been modelled down a part of the landscape in a small catchment of approximately 1800 ha near the zone boundary. Percentage of the transect with a shallow watertable extrapolated to the entire catchment indicates that 32 per cent will have groundwater levels within two metres with 100 per cent recharge.

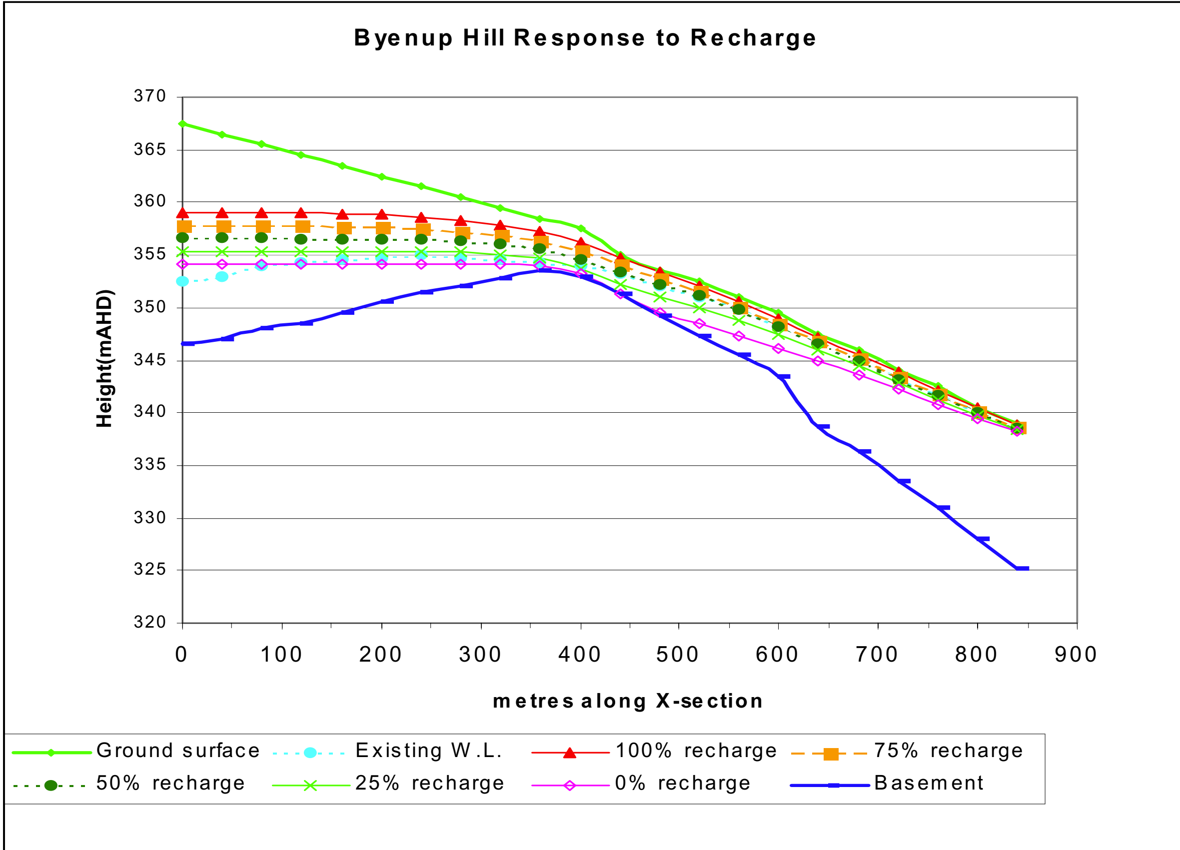


Figure 3.2. Groundwater levels calculated for varying percentages of present recharge estimate.

Table 3.4. Relationship of recharge rates to the percentage of transect and whole zone with potential for shallow watertables (< 2.0 m) after 50 years

Recharge (% of current rate)	Flowtube result (% of transect)	Extrapolation of transect to % of catchment
100	61	32
75	52	26
50	47	24
25	19	9.5
0	9.5	5

3.2.2 Surface water

The Blackwood catchment has flooded twice since streamflow monitoring began in 1955: July/August 1964 and January 1982. The 1982 flood is considered the largest in this catchment, since European settlement.

Annual peak flows from four gauging stations were measured from 1977 to 1996 and probability distributions were fitted to the data (Table 3.4 - Bowman and Ruprecht, 2000). The table shows how the flows range from fairly common events (once in two years or ARI = 2) to extreme floods (once in fifty years or ARI = 50).

Table 3.5. Peak flows (m^3/s) in four waterways in the Blackwood catchment for various average recurrence intervals

Waterways	Catchment area (sq. km)	Average recurrence interval (years)				
		2	5	10	20	50
Arthur River	3110	27	82	145	230	387
Beaufort River	9354	23	64	104	150	221
Weenup Creek Mandelup Pool	82.4	3.5	15	38	92	279
Weenup Creek, Balgarup	13.24	0.9	3.3	6.4	11.3	22.0

Floods have become a problem because of agricultural development and settlement in floodprone areas along rivers and waterways. Land clearing has caused high groundwater levels and saturated soil, leading to increased flooding. Floods damage both bitumen and gravel roads, destroy fences and conservation earthworks, erode paddocks and foul farm dams and other surface water supplies with mud, organic material and saline groundwater.

3.3 Biodiversity condition and risks

3.3.1 Remnant vegetation

There are 38,610 ha (11 per cent) of remnant vegetation in the zone, of which only 1,180 ha are protected within CALM estate. The remainder is largely held on privately owned land. The soil-landscape units with the biggest areas of remnant vegetation are shown in Table 3.6.

Table 3.6. Soil-landscape map units, which have greater than 5% cover with remnant vegetation

Soil-landscape map unit	Main soil and landscape position	Area of remaining remnant vegetation (ha)	Percentage of map unit with remnant vegetation cover	Proportion of vegetation in map unit relative to the zone (%)
Boscabel 1 (Bo1)	Gravelly hillcrests and summit surfaces and mid to upper slopes	6603	16	17
Beaufort 1 (Be1)	Broad valley flats and alluvial plains, with sandy duplex soils	4293	27	11
Farrar 1 (Fa1)	Gravelly crests, mid to upper slopes and breakaways	3199	33	8
Farrar 3 (Fa3)	Lower to upper slopes and crests with rock outcropping	3183	8	8
Carrolup 2 (Ca2)	Drainage lines, lower to upper slopes and crests with shallow and deep duplex soil	2574	4	7

Vegetation on privately managed land is often unfenced, unprotected and vulnerable to land management practices. Hazards include introduced animals and plants, disease, competition, altered fire regimes, altered hydrology, pollutants (including fertilisers and chemicals) and hunting.

Altered hydrology, including increased waterlogging and a rising saline watertable is threatening some remnants (Table 3.7). Most at risk are those in lower parts of the landscape - including river valleys, flood plains and lower slopes where 39 per cent of the remnant native vegetation in the zone is located - and areas adjacent to hillside seeps.

Table 3.7. Proportion of vegetation in low-lying areas (at 'future risk' from waterlogging/ salinity) and currently affected by salinity

Map unit	Current proportion of vegetation for Zone %	Current risk (%)	Future risk (%)
Boscabel 1	17	1	20
Beaufort 1	11	18	86
Farrar 1	8	< 1	1
Farrar 3	8	< 1	9
Carrolup 2	7	1	14

A further potential risk to the remaining vegetation comes from mining. Isolated remnants of the ancient lateritic plateau remain in the highest parts of the landscape. These areas are targeted as gravel reserves by local shires. Because these soils are generally regarded as having low agricultural value, many have been left uncleared, and contain 35 per cent of the zone's remnant vegetation.

3.3.2 Fauna and flora

There are 26 species of declared endangered and priority flora in the zone, of which 15 are found within three CALM reserves - Reserve No. 38731, Reserve No. 1736 and Reserve No. 28471.

The major species of mammals commonly seen in the Beaufort Zone include the western grey kangaroo (*Macropus fuliginosus*); the western brush wallaby (*Macropus irma*); echidna (*Tachyglossus aculeatus*). Reptiles include the bobtail (*Tiliqua ragosa*); the blue tongued lizard (*Tiliqua occipitalis*); the dugite (*Pseudonaja affinif*); the mulga snake (*Notechis australis*); and a variety of geckos (Grein, 1994).

Fifteen species of mammals, considered to be under threat of extinction, are being monitored. Many of these are under threat because of introduced predators, loss of habitat and loss of their preferred food.

The zone has a number of prominent lakes and wetlands within its boundaries, including Lake Towerinning, Rushy Lake and Clear Lake. Lake Towerinning is a brackish lake 179 ha in size with a vegetated area of 21 ha. Many of the vertebrate animals, such as the water rat (*Hydromys chrysogaster)*, water birds, such as the clamorous reed-warbler (*Acrocephalus stentoreus*), reptiles and frogs that were once common to these wetlands and surrounding areas have now disappeared.

The health of the wetlands is declining because of salinity, saltation (worsened by run-off from agricultural drainage earthworks), groundwater pumping, eutrophication and algal blooms (caused by agricultural fertilisers) and direct damage from recreational activities (Grein, 1994).

In 1994 a series of reports called Native Vegetation Handbooks were produced by the Department of Agriculture, in conjunction with Greening Australia and the Australian Nature Conservation Agency. These handbooks were produced for all shires covering the South-West Agricultural Region and contain a complete list of flora and fauna found within each shire, including locations of all public and private land and wetlands and lakes. These handbooks are a valuable source of information, further to that presented in this section.

3.3.3 Biodiversity risk

About 20 per cent (7200 ha) of native remnant vegetation stands, including 14 per cent of CALM reserves, are situated in low-lying areas of the landscape. Flora and fauna communities in these areas are at a high risk of habitat destruction from rising watertables, including some rare species.

The decline of flooded gums (*Eucalyptus rudis*), discussed in the Middle Balgarup Focus Catchment Action Plan (Department of Agriculture, 2000, p. 10), is of particular concern.

The lack of revegetation corridors linking remnant vegetation stands is an added threat to biodiversity. If fauna habitats were destroyed by a rising watertable there would be little opportunity for smaller species of fauna to migrate to different remnant vegetation stands.

Furthermore, remnant vegetation on farmlands is in poor condition due to grazing from sheep and cattle, colonisation of weeds and removal of dead logs for firewood.

Given the majority of remnant vegetation is on private land, it may be necessary to provide landholders with incentives to actively manage the remaining remnant vegetation for conservation and preservation. The 'Bush-broker Scheme' is one incentive to achieve this goal. Other incentives such as the removal of land rates on remnant vegetation and financial assistance associated with fencing and protection of remnant vegetation will help as well.

3.3.4 Weeds

The most important environmental weeds are listed in Table 3.8, with Bridal Creeper being of most concern to the community. There are also nine Declared Plants within the zone. Declared Plants are considered to be of significant threat to agriculture and the environment and are listed under the Agriculture and Related Resources Protection Act 1976; the most common of these are Cape Tulip and Paterson's Curse.

Table 3.8. Important weeds in the Beaufort Zone (Blacklock, 2002)

Declared agricultural weeds	Environmental weeds
Cape Tulip one leaf (*Homeria flaccida*)	Afghan thistle (*Solanum hoplopetalum*)
Common Heliotrope (*Heliotropium europaeum*)	Bridal creeper (*Asparagus asparagoides*)
Cotton Bush (*Gomphocarpus fruticosus*)	Caltrop (*Tribulus terrestris*)
Doublegee (*Emex australis*)	Tagasaste (*Chamaecytisus palmensis*)
Paterson's Curse (*Echium plantagineum*)	Victorian tea-tree (*Leptospermum laevigatum*)
	Watsonia (*Watsonia* spp.)

3.4 Agricultural production

3.4.1 Farming systems

Figures 3.4 to 3.8 are results generated from AgET (a water balance calculator). AgET calculates the yearly amount of unused water that moves below the rooting zone from a particular farming system. These results are a guide to the relative amounts of water used by different farming systems. A number of generalisations and assumptions have been used to run the model and the results, therefore, show general trends, but do not accurately predict the deep flow on individual paddocks. Specific site investigations are needed when considering options for individual paddocks.

Each graph shows a variety of farming systems including oil mallees, tagasaste trees and various annual crop/pasture rotations.

Current crop rotations within the Zone have been applied to the model. Oil mallees, tagasaste and lucerne are all deep-rooted perennials and use significantly more water than a shallow rooted annual crop. Clover pasture and volunteer pastures use less water than an annual crop. Deep sands and ironstone gravels contribute more water to the groundwater compared with loamy earth soils, loamy duplex soils and sandy duplex soils, when under a rotation of annual crops. All of these soil types however, have the potential to contribute significantly to ground water, where waterlogging and a perched watertable exist.

Figure 3.4 to 3.8 indicate which farming system or crop rotation will be most effective when choosing a crop rotation to reduce recharge and slow the advance of salinity (for a complete list of recommended cropping/annual pasture options, refer to Section 4.1).

The Ag ET model does not account for lateral movement of water, waterlogging, perched watertables, preferred pathway recharge (which may lead to higher rates of recharge) or year-to-year variation. Also, there is limited data across Western Australia to calibrate the model, leading to reduced accuracy of predictions; however, trends will remain fairly constant and comparisons can be made.

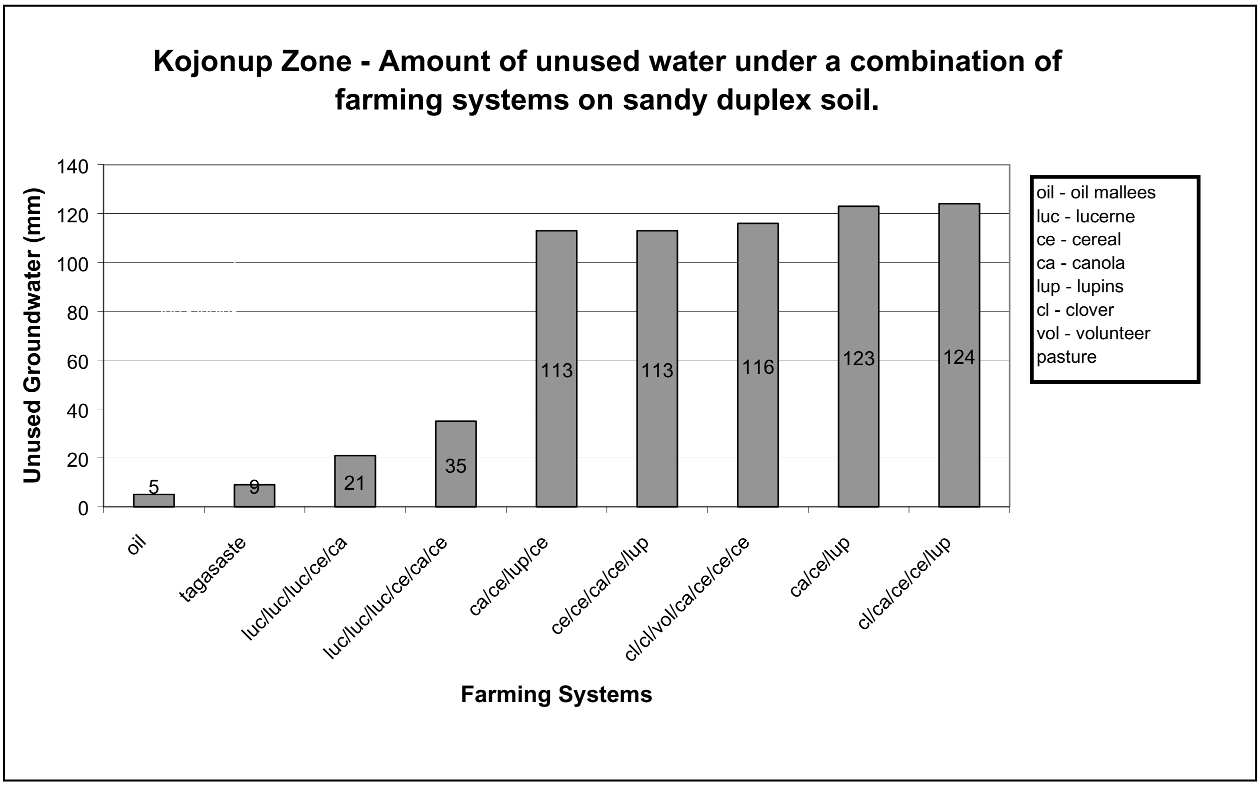


Figure 3.4. Farming systems on sandy duplex soil.

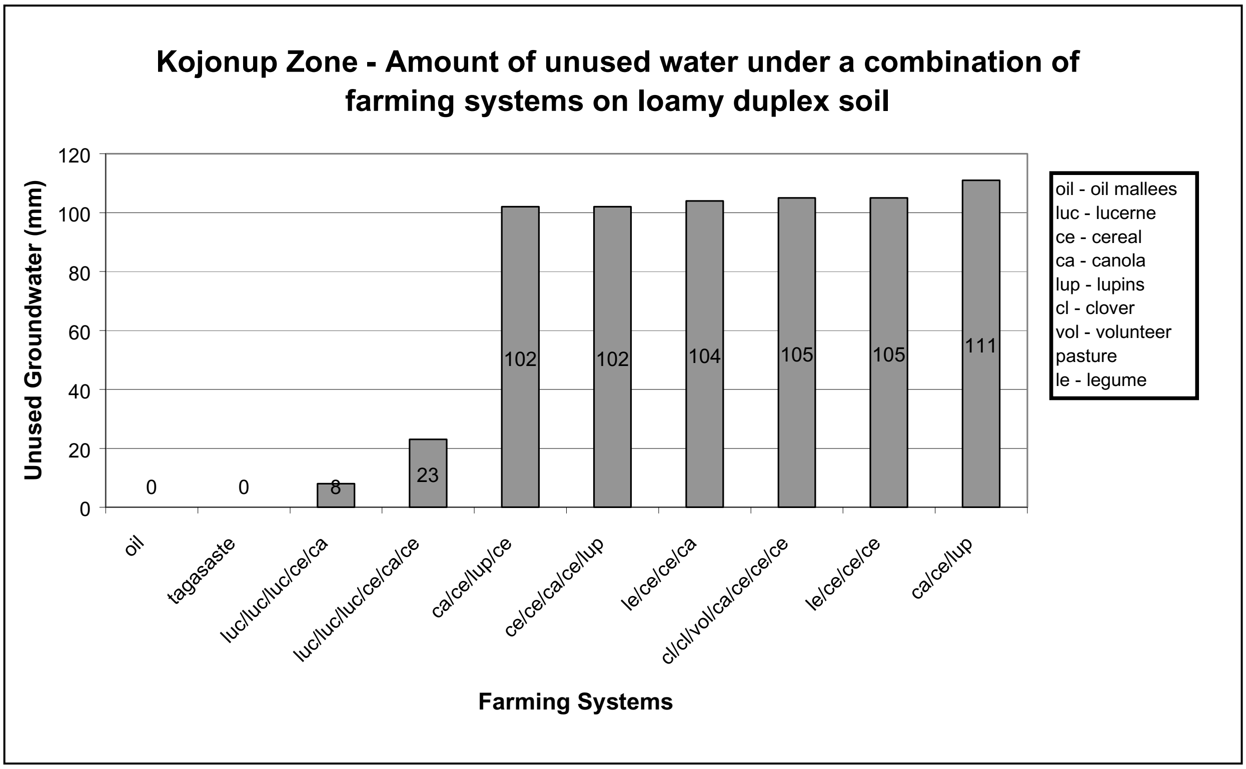


Figure 3.5. Farming systems on loamy duplex soil.

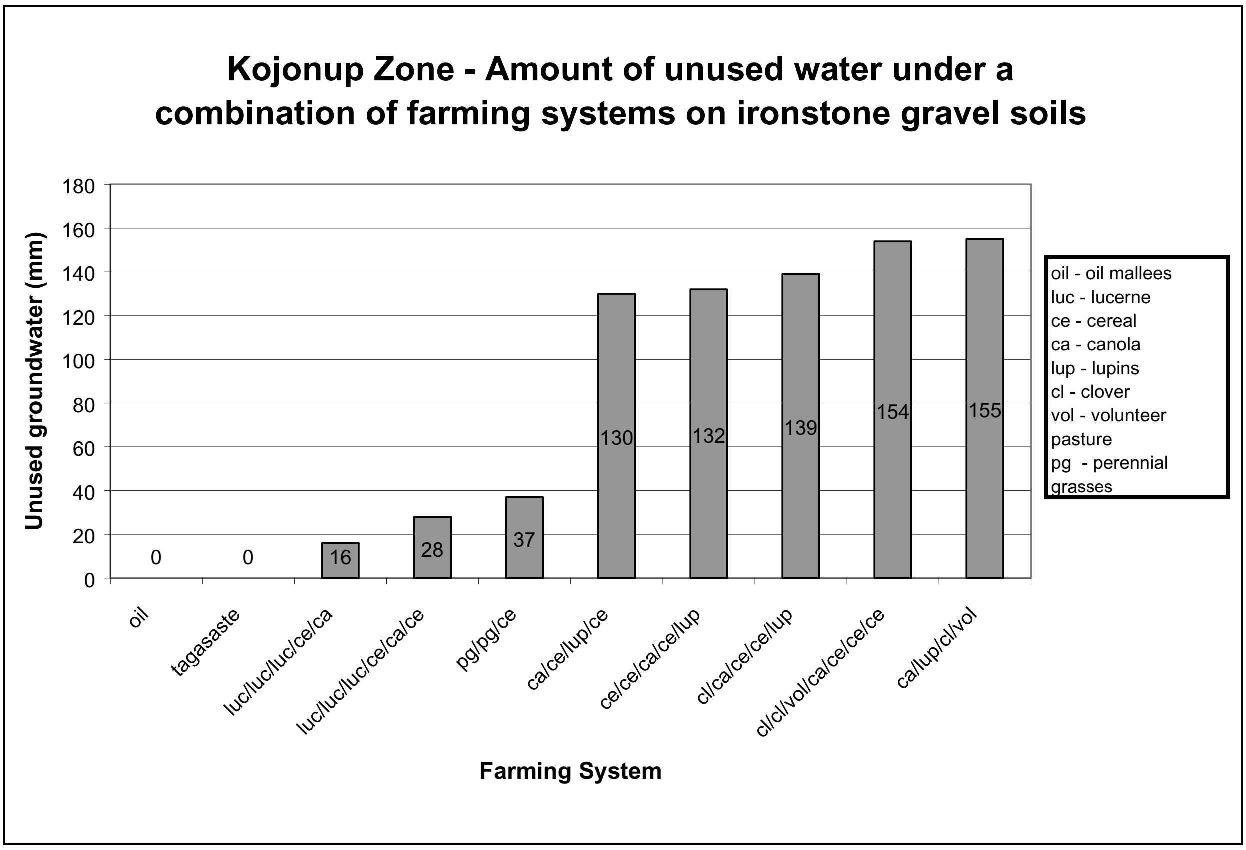


Figure 3.6. Farming systems on ironstone gravel soil.

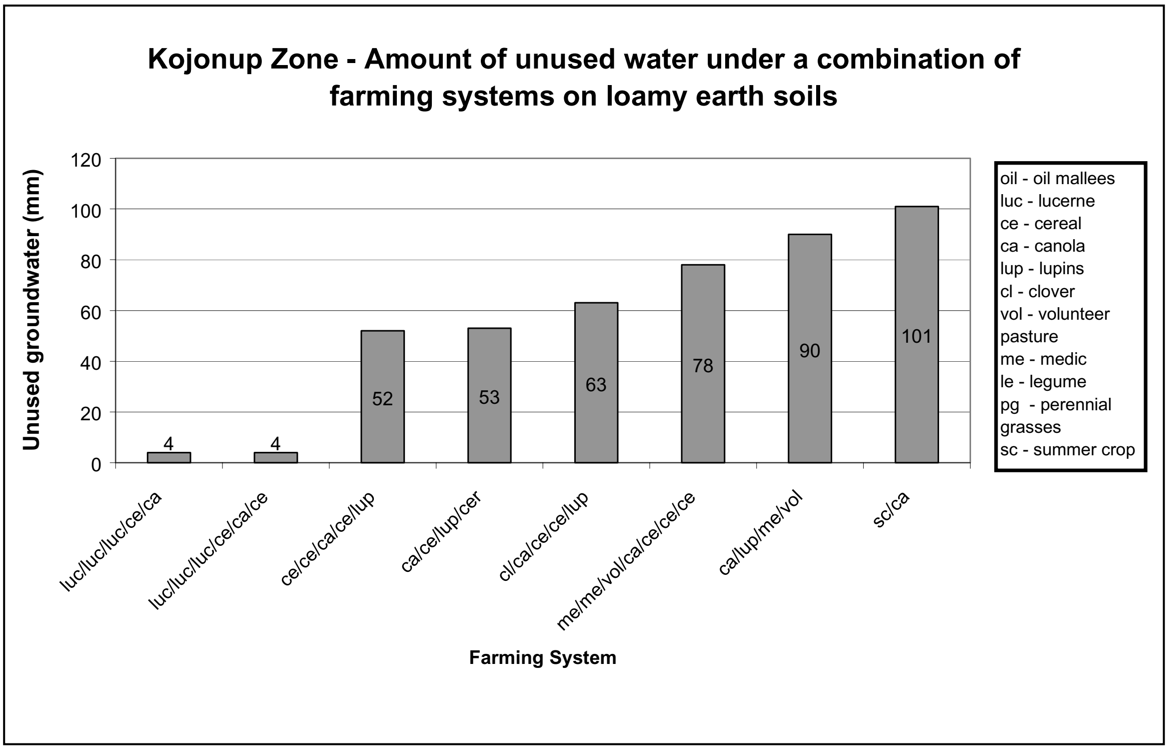


Figure 3.7. Farming systems on loamy earth soil.

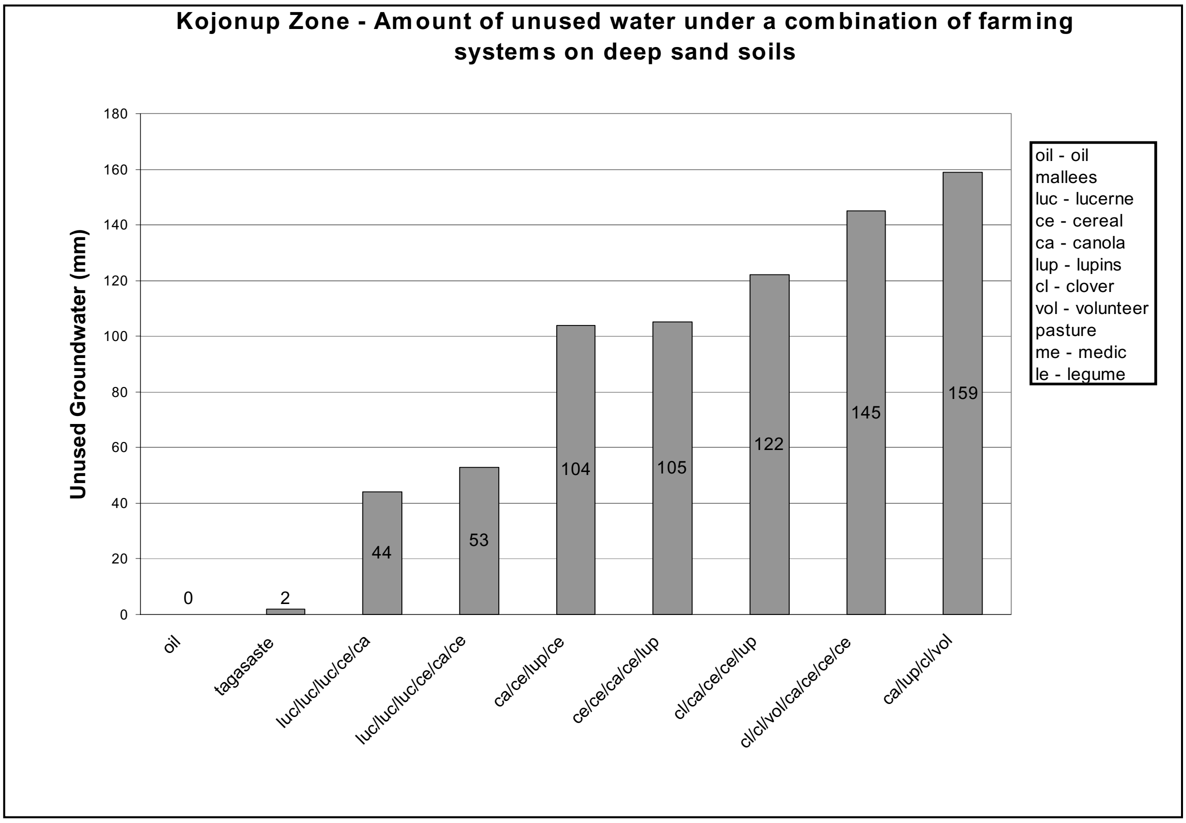


Figure 3.8. Farming systems on deep sand.

3.5 Infrastructure

3.5.1 Roads

Beaufort Zone has 2,104 km of gazetted roads. This is made up of 397 km sealed, 258 km are local roads, 1,021 km unsealed roads and 689 km tracks.

According to Land Monitor data, 15 km sealed roads and 50 km unsealed roads are currently affected by salinity and a further 13 km are located in low-lying areas which could be affected by salinity or waterlogging in future if groundwater continues rising. Additional costs will be incurred as shallow watertables affect road construction costs, increase maintenance costs and reduce the life expectancy of the roads - Dames and Moore (2001) these additional costs to be between $300 and $400/km for sealed country roads and $20/km for gravel roads, possibly amounting to $53,000 to $70,000 per year.

3.5.2 Kojonup town

The Kojonup townsite covers 1,807 ha of which 44 ha (or 2.5 per cent) are currently affected by a shallow watertable. Dames and Moore (2001), estimated the cost for a shallow watertable per hectare for town infrastructure to be $1,176/ha - the cost to Kojonup town infrastructure could be $52,000.

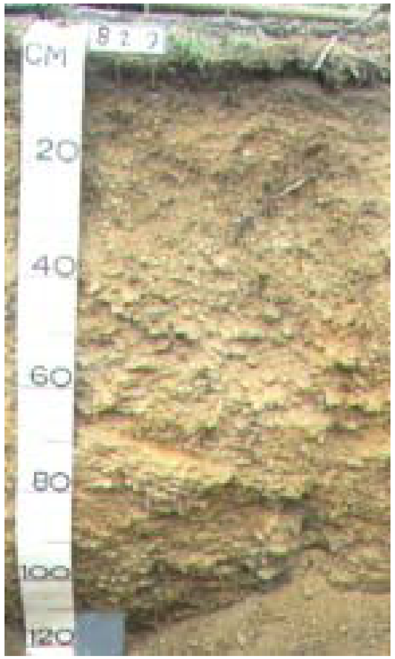
4. MANAGEMENT OPTIONS AND IMPACTS

4.1 Land management

Management options for reducing groundwater recharge and land degradation for each of the 12 land management units, described in Section 2.3, are presented in the following tables.

4.1.1 Farm forestry tables

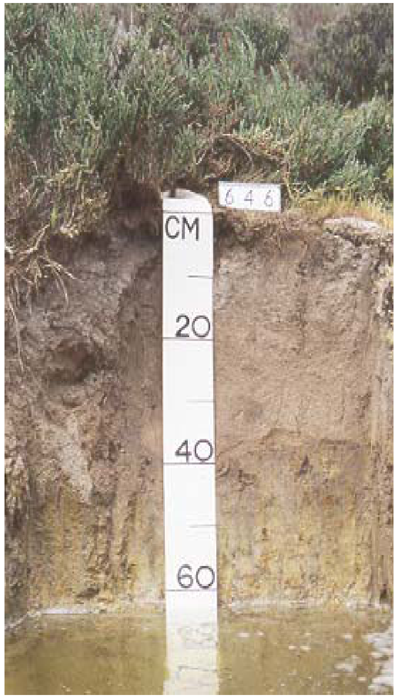
Potential farm forestry options and a comprehensive list of suitable farm forestry species are in Table 4.1.

Land Management Unit	Water and soil problems	Management options
GRAVELLY RIDGES AND SLOPES (WELL DRAINED): *Approx. 88,000 ha* Ironstone gravel > 60% overlying clay or hard ironstone at varying depths - usually > 30 cm and often > 60 cm. Found on hill crests and upper to lower slopes.  	• High groundwater recharge if cleared. • Moderately susceptible to water erosion. • Mild wind erosion on exposed sites on upper slopes. • Low soil water storage. • May be susceptible to water repellence. • A seasonal perched watertable may overlie the texture or permeability contrast layer. • Highly susceptible to soil acidification.	**SOIL MANAGEMENT** • Liming may be necessary and cultivation should be carried out on the contour to reduce erosion risks and improve water conservation for crops. • Minimum tillage or no-till should be practiced to reduce the incidence of traffic and plough pans and improve soil structure and maintain soil organic matter. • Practice stubble retention or aim to maintain > 50% ground cover to control risk of erosion. **CROPPING/PASTURE OPTIONS** • Phase farming between alleys of oil mallees or other trees is highly desirable. • Cereals, narrow-leafed lupins and canola can be included in rotations with lucerne (pH > 4.8) mixed with serradella. Lucerne is the most desirable species to use to increase water use and to reduce recharge. Other perennial options include cocksfoot, phalaris, and tall fescue. • Alley farming with mixed fodder shrubs (such as tagasaste) can improve productivity and minimise recharge, especially where gravelly topsoils are sandy. **SURFACE WATER CONTROL** • Soil profile and depth to clay or ironstone needs to be checked prior to commencing earthworks. Care should be taken when constructing banks earthworks here as banks striking ironstone may lead to poorly constructed shallow channels and increased recharge. • Grade banks to a protected waterway don't have to be into clay if constructed for water erosion control only, but these may increase recharge. An alternative is 3-4 rows of trees on the contour or a combination of both. • Plant 3-4 rows of trees below any existing absorption banks to compensate for extra recharge. **REVEGETATION AND TREE PLANTING OPTIONS** • Fence off remnant vegetation. • Revegetate area with commercial or native species (see Farm Forestry Options Table). Plant in small blocks or belts 3-10 rows wide. Distance between belts should be no greater than 150 m. • Maintenance of perennials is important here to reduce or prevent drainage of soil water below the root zone.

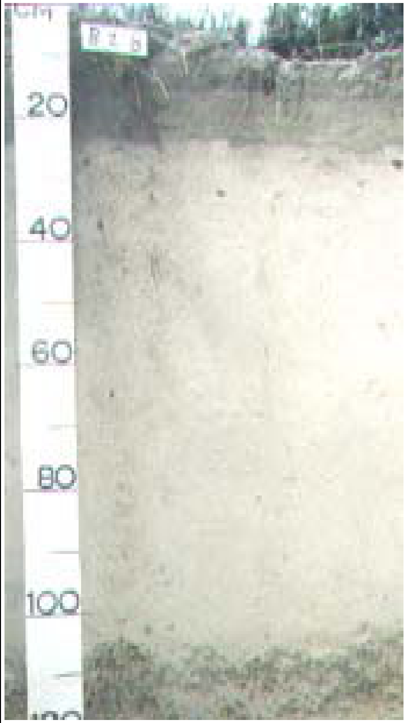
Land Management Unit	Water and soil problems	Management options
MODERATELY DRAINED SANDY DUPLEX SOILS: *Approx. 122,000 ha* Sand or sandy loam over clay at 10-80 cm, seasonally perched watertables common. Occurs mainly on crests, upper and lower slopes. 	• Groundwater recharge hazard may be high in winter months, associated with perched watertables. • Generally non-saline but may develop hillside seeps or saline drainage lines. • Highly susceptible to wind erosion on exposed crests and upper slopes, otherwise moderately susceptible. • Highly susceptible to soil acidification. • Water erosion, traffic and plough pans can be a risk. • Waterlogging risk mainly occurs on lower slopes, drainage lines and flatter areas. • Sandy topsoils may display water repellence. • Soil water storage in sandy topsoils may be low.	**SOIL MANAGEMENT** • Minimum tillage or no-till operations will aid in reducing soil erosion and compaction problems, improving soil structure and maintaining levels of organic matter. • Practice stubble retention or maintain approximately 50% ground cover to control wind erosion and maintain soil organic matter. • Any cultivation should be carried out on the contour. This is generally economically beneficial and should be standard best practice to improve water conservation for pasture and crops and to minimise erosion. • Liming may be necessary to achieve potential crop production and assist in the establishment of lucerne. **CROPPING/PASTURE OPTIONS** • Lupin, cereal and canola rotations are suitable on this soil and should be combined with a perennial pasture such as lucerne (pH > 4.8), and serradella or sub. clover, in a phase farming system to reduce recharge. Other perennial options include cocksfoot, phalaris, and tall fescue. Lupins are not suitable on shallower soils. **SURFACE WATER CONTROL** • Grade banks are effective in controlling water erosion and waterlogging. Soil profile and depth to clay needs to be checked prior to commencing earthworks. • Grade banks for water erosion control don't have to be into clay, but there is a risk of increasing recharge. An alternative is 3-4 rows of trees on the contour or a combination of both. • Conventional or reverse interceptor banks on a grade are effective on duplex soils to control waterlogging. As there is more water being transferred to waterways, they should not be cultivated or overgrazed and may have to be fenced. **REVEGETATION AND TREE PLANTING OPTIONS** • Fence off remnant vegetation. • Plant commercial or native species (see Farm Forestry Options Table) below grade banks to increase water use. Oil mallees, eucalypt sawlogs, or other stock resistant trees/shrubs can be planted without fencing if there is limited grazing in the establishment years. • 3-10 row belts or strategic blocks of commercial timber trees (see Farm Forestry Options Table) particularly when there is fresh water at depth. Distance between belts should be no greater than 150 m. • Mounding is recommended on waterlogged sites.

Land Management Unit	Water and soil problems	Management options
POORLY DRAINED SANDY DUPLEX SOILS: *Approx. 38,000 ha* Sand or sandy loam over clay at 10-80 cm - clay may be blue/grey in colour or very mottled and generally very wet in winter months. Seen on lower slopes, drainage lines and broad valley floors. 	• Groundwater recharge hazard is high in winter months, associated with perched watertables. • High risk of salinity developing as usually along drainage lines and ponded areas. • Moderate waterlogging risk. Waterlogging is the major limitation in this LMU. • Highly susceptible to acidification. • Moderately susceptible to water erosion, traffic and plough pans. • Soil water storage in sandy topsoils can be low.	**SOIL MANAGEMENT** • Liming may be necessary to ensure good establishment of lucerne, and to enable good growth of pastures. • Reduction of traffic in paddocks and avoidance of traffic movement when soil is wet minimises soil compaction. • Practice stubble retention or maintain approximately 50% ground cover to control wind erosion and maintain soil organic manner. • Minimum tillage or no-till practices, and stubble retention in cropping areas, should be considered to maintain organic matter and improve soil structure. **CROPPING/PASTURE OPTIONS** • Perennial pastures of lucerne (in areas not subject to a high incidence of waterlogging) and/or tall wheat grass mixed with balansa clover are productive options. In summer moist areas the perennial legume, strawberry clover, may be an option. • These soils are often wet and so are not reliable producers of good yielding crops. Oats or triticale may be suitable cropping options. • Summer cropping options such as sorghum, sunflowers or millet may be a consideration in summer moist areas. **SURFACE WATER CONTROL** • Grade banks are effective in alleviating water erosion and waterlogging. Soil profile and depth to clay needs to be checked prior to commencing earthworks. • Grade banks for water erosion control don't have to be into clay, but there is a risk of increasing recharge. This risk can be reduced by planting 3-4 rows of trees below the bank. • Conventional or reverse interceptor banks on a grade are effective on duplex soils to control waterlogging. As there is more water being transferred to waterways, they should be revegetated and fenced. • Well-designed and placed earthworks may alter this LMU to a moderately drained sandy duplex. **REVEGETATION AND TREE PLANTING OPTIONS** • Mounding is highly recommended on this LMU. • Fence off remnant vegetation. • Plant commercial or native species (see Farm Forestry Options Table) below grade banks. Oil mallees, eucalypt sawlogs, or other stock resistant trees/shrubs can be planted without fencing if there is limited grazing in the establishment years. • 3-10 row belts or strategic blocks of commercial timber trees particularly when there is fresh water at depth. Distance between belts should be no greater than 150 m.

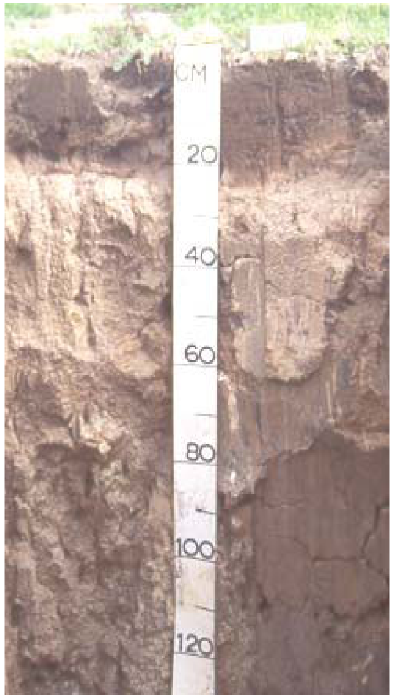
Land Management Unit	Water and soil problems	Management options
RED SOILS: *Approx. 28,000 ha* Reddish brown sandy loam over clay or grading to clay at 10-20 cm (red loam); red or reddish brown clay loam over red clay at < 10 cm or grading to red clay at depth (red clay). Some gravel may be present in profile. Seen mainly on slopes and ridges, often associated with dolerite dykes. 	• Low to moderate groundwater recharge. • Hillside seeps may occur on or near these soils as they are formed on dolerite dykes. • Low risk of waterlogging. Lighter soils upslope from this LMU may exhibit waterlogging due to the heavier red soils acting as a textural barrier to lateral water movement.	**SOIL MANAGEMENT** • Cropping operations should occur on the contour and minimum tillage or no-till practices and stubble retention should be considered to aid in improvement of soil structure. • Reduction of traffic in paddocks and avoidance of traffic movement when soil is wet minimises soil compaction. **CROPPING/PASTURE OPTIONS** • Cereals in rotation with field peas, faba beans, vetches or good quality pastures are most profitable, and canola will grow well where waterlogging is limited. • Phase cropping incorporating lucerne will provide a useful option for areas where waterlogging is not a problem and should be considered as a method to reduce groundwater recharge. • In areas where waterlogging is a problem, tall wheat grass and balansa should be considered. **SURFACE WATER CONTROL** • Grade banks and seepage interceptors will alleviate water erosion and waterlogging. • Care should be taken when constructing earthworks on this LMU as banks striking rock may lead to poorly constructed shallow channels and increased recharge. **REVEGETATION AND TREE PLANTING OPTIONS** • Plant commercial or native species (see Farm Forestry Options Table) below grade banks to increase water use. Oil mallees, eucalypt sawlogs, or other stock resistant trees/shrubs can be planted without fencing. • Mounding is highly recommended on this LMU. • Plant 3-10 row belts or strategic blocks of commercial timber trees. Distance between belts should be no greater than 150 m.

Land Management Unit	Water and soil problems	Management options
SALT AFFECTED LAND *Approx. 13,000 ha* A range of soils is affected by salt. They are usually waterlogged and may be subject to flooding. It is usually seen on valley floors and drainage lines, and on hillsides as saline hillside seeps. 	• Mainly groundwater discharge but recharge may occur during winter. • Presently saline. • Very high risk of waterlogging and inundation. • Highly susceptible to serious water erosion problems (gully and rill), particularly along saline drainage lines.	**SOIL MANAGEMENT** • Where possible, fence affected area to protect from compaction and erosion by stock and traffic. • Maintenance of ground cover to reduce risk of water erosion is recommended. **CROPPING/PASTURE OPTIONS** • Salt tolerant pastures such as saltbush, puccinellia, or tall wheat grass and annuals such as balansa clover for mildly saline areas, are recommended to stabilise saline areas. **RECHARGE REDUCTION AND SURFACE WATER CONTROL** • Appropriate shallow surface drainage is recommended (e.g. W-drains, grade banks). Notification of intent to drain may be required. Grader built intercepting banks to clay installed above the salt affected area may aid in alleviating perched water aggravating the saline areas. • Increase water use off-site as well as on-site. **GROUND WATER OPTIONS** • Drains to relieve groundwater and groundwater pumping are expensive options. Good design is essential and should be site specific. • Drainage effluent should be disposed of without on or off site degradation. • A Notice of Intent to Drain will be required. • Use of saline groundwater in aquaculture for production of trout, bream, brine shrimp and/or algae. • Desalinate saline groundwater for human or livestock consumption. • Extraction of minerals from saline water for use by industry and for animal nutrition. • Produce energy using saline water in a salt gradient solar pond. **REVEGETATION AND TREE PLANTING OPTIONS** • All revegetation areas should be mounded at 0.5 to 1% slope to reduce waterlogging - mounds with a distinct 'V' work best. • Belts or rows of trees should complement surface water control and be planned once surface drains have been marked. • Mild saline areas - 4 row belts of salt-tolerant oil mallees or 3-10 row belts of salt tolerant commercial trees, with tolerant pasture species (balansa, etc.) sown between - maintain grazing. Distance between belts should be no greater than 50-100 m. • Single rows of saltbush species (direct seeded or seedlings), separated by alleys of saltland pastures - managed for fodder. • Fence off creeks, waterways and adjacent bare/eroded areas. Allow regeneration of rushes, samphires, paperbarks and/or revegetate with tolerant native species/saltbushes - not grazed.

Land Management Unit	Water and soil problems	Management options
YELLOW AND BROWN DEEP SAND: *Approx. 11,000 ha* Yellow or brown sand deeper than 80 cm. Generally seen on mid to lower slopes and valley floors, and as dunes and lunettes. 	• High groundwater recharge. • High risk of wind erosion on exposed crests and upper slopes, otherwise the risk is moderate. • These soils are very highly leached, do not retain nutrients, and are highly prone to sub-surface acidification. • Moderately susceptible to water erosion, inundation on flats, traffic and plough pans. • Water erosion is a high risk on exposed upper slopes. • Sandy soils may display water repellence. • Soil water storage is generally low.	**SOIL MANAGEMENT** • Practice stubble retention, brown manuring or maintain approximately 50% ground cover to control wind and water erosion and maintain soil organic matter. • Liming may be necessary to achieve crop and pasture production potentials and assist in the establishment of lucerne; regular monitoring of soil pH levels is advised. • Claying water repellent soils may be an option to consider where the problem is widespread. **CROPPING/PASTURE OPTIONS** • Long season annual legume pastures that are suites include Cadiz French serradella, Santorini and Charano yellow serradella and casbah biserrula. Perennial pastures of lucerne (pH > 4.8) or of Rhodes grass and veldt grass mixed with serradella in between alleys of trees is recommended. • Phase farming with the above mentioned pasture species or between alleys of fodder shrubs such as tagasate and golden wreath wattle, or suitable native species with narrowed leafed lupins and cereals. **RECHARGE REDUCTION AND SURFACE WATER CONTROL** • Generally not suitable for surface water control earthworks due to slumping of the structures. • Revegetate area with commercial or native species (see Farm Forestry Options Table). Plant in small blocks or belts 3-10 rows wide. Distance between belts should be no greater than 150 m. • Maximise water retention with good soil management practices such as working to the contour and maintaining a good pasture cover. • See also pale deep sands. • Ripping is recommended, mounding is not. Scalping a narrow area may remove non-wetting layer.

Land Management Unit	Water and soil problems	Management options
PALE DEEP SANDS: *Approx. 11,000 ha* Pale grey or white sands deeper than 80 cm. Gravel (< 20%) may be present through profile. Generally seen on crests and upper to lower slopes. 	• High groundwater recharge. • High risk of wind erosion on exposed crests and upper slopes, otherwise the risk is moderate. • These soils are very highly leached, do not retain nutrients, and are highly prone to sub-surface acidification. • Moderately susceptible to water erosion, inundation on flats, traffic and plough pans. • Water erosion is a high risk on exposed upper slopes. • Sandy soils may display water repellence. • Soil water storage is generally low.	**SOIL MANAGEMENT** • Practice stubble retention or maintain approximately 50% ground cover to control wind and water erosion, and maintain soil organic matter. • Liming is likely to be uneconomical due to the characteristically low productivity of this soil. **CROPPING/PASTURE OPTIONS** • Long season annual legume pastures suited include Cadiz French serradella, Santorini and Charano yellow serradella and Casbah biserrula in between alleys of trees. • Perennial pastures of lucerne (pH > 4.8) or of Rhodes grass mixed with serradella in between alleys of trees. • Phase farming with narrow-leafed lupins and cereals can be carried out in between alleys of fodder shrubs such as tagasaste and golden wreath wattle, or with native tree species. Yields are still likely to be relatively low due to infertility of the soil and low pH. **RECHARGE REDUCTION AND SURFACE WATER CONTROL** • Grader built earthworks may alleviate soil erosion on slopes or inundation on flats, but have a high maintenance requirement. Unless the clay layer is reached, banks will be ineffective for waterlogging control. **REVEGETATION AND TREE PLANTING OPTIONS** • Maritime Pine plantation over entire area. • Plots of tagasaste planted in rows 3-6 m apart - manage as fodder for cattle (will need to be cut for sheep) Tagasaste/Acacia saligna mix can be planted. • Fence off low production areas and remnant vegetation, allow regeneration or plant suitable banksia, acacia species. • Seedlings usually grow best on deep sands, plant as early as possible. • Ripping is recommended, mounding is not. Scalping a narrow area may remove non-wetting layer.

Land Management Unit	Water and soil problems	Management options
ROCK OUTCROPS AND QUARTZ VEINS: *Approx. 9,000 ha* Includes outcrops of granite, dolerite and hard ironstone, quartz sand, gravels and stones. Generally seen on ridges and upper slopes. 	• Very high recharge through soil at the edge of outcrops. • Variable recharge can occur through fractures in the rock. • Hillside seeps can develop where outcrop forces saline groundwater to the surface. • Outcrops may shed water resulting in water erosion downslope.	**SURFACE WATER CONTROL** • Grade banks below water shedding areas can alleviate erosion problems. • Absorption banks can be used where no safe disposal point can be located, as a last resort due to the increased recharge risk. • Larger granite rocks can be a good run-off source for dams. **REVEGETATION AND TREE PLANTING OPTIONS** • Fence off and allow any existing vegetation to regenerate. • Sandalwood plantation - hosts required. • Revegetate with a mixture of native species around the rock areas - direct seed sandalwood after hosts are established. • Use direct seeding or seedlings as a method of establishing a buffer zone and extra habitat around these important nature conservation areas.

Land Management Unit	Water and soil problems	Management options
GREY/GREYISH BROWN LOAMS AND CLAYS: *Approx. 9,000 ha* Hardsetting grey clay loam and clay. Grey/greyish brown loamy surface layers over clay at < 30 cm, or clay at surface. These soils mainly occur on mid to lower slopes, flats and valley floors. 	• Moderate groundwater recharge, highest where water ponds. • Salinity may develop on valley floors and drainage lines with shallow watertables, or on ponded areas, or as hillside seeps. • Moderate to high risk of waterlogging and inundation, highest on flats and low-lying areas. • Moderately susceptible to topsoil structure decline.	**SOIL MANAGEMENT** • 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. • Minimum tillage or no-till practices are preferred to maintain soil structure. • Adding gypsum may help improve soil structure and increase productivity. Investigate with a gypsum test and test strips first. • Avoid working the soil when excessively wet. • Activities which result in rapid loss of organic matter, such as long fallowing in a crop rotation and stubble burning, should also be avoided. **CROPPING/PASTURE OPTIONS** • Lucerne (where incidence of waterlogging is low and pH > 4.8) or phalaris mixed with annual medics; Persian clover (pH > 5.5) or balansa clover are suitable annual pastures that can be rotated with cereals. • Phase farming between alleys of oil mallees or native species is highly desired. • Pulse crops such as field peas, chickpeas or fababeans can be included to extend the rotation. **RECHARGE REDUCTION AND SURFACE WATER CONTROL** • Appropriate shallow surface drains (W drains) can effectively reduce ponding and the associated risks. • Hard setting grey clays on slopes can be a good reliable run-off source for dams. **REVEGETATION AND TREE PLANTING OPTIONS** • Belts of oil mallees (4 or 8 rows) below banks, separated by crop pasture areas (suitable machinery width). • Fence off remnant vegetation/swamps and allow to regenerate, plant a buffer of suitable native or commercial species.

Land Management Unit	Water and soil problems	Management options
MALLET HILLS: *Approx. 7,000 ha* Pink or reddish water repellent soils, maybe gravelly, often acidic. Isolated hillcrests and breakaways. 	• Generally low recharge because water runs off. • Highly susceptible to water erosion, particularly on breakaways with slopes > 10%. • Highly susceptible to water repellence and topsoil structure decline. • Subsoils are often acid and saline, and if exposed remain bare and unproductive.	**SOIL MANAGEMENT** • Maintenance of ground cover is important to reduce water erosion risk **SURFACE WATER CONTROL** • Grade banks below a water shedding area can alleviate erosion problems and may be a good water source for dams situated nearby. • Dams should not be constructed on this LMU due to the poor water holding capability of the subsoil. **REVEGETATION AND TREE PLANTING OPTIONS** • Fence off and revegetate with species native to the catchment.

Land Management Unit	Water and soil problems	Management options
WET SOILS: *Approx. 2000 ha* Semi-wet soil and wet soil. Waterlogged for a major part of the year. Appear as low-lying waterlogged depressions and as non-saline hillside seeps, swamps, plains and dune swales. 	• Seasonal waterlogging, inundation and flooding often render this area unsuitable for agricultural production. • High salinity risk. • Recharge is likely to be high, especially if water use by pasture and crops is low owing to poor growth. • Surface and sub-surface acidity may be a problem. • Poor soil workability. • Rooting depth may be reduced.	**SOIL MANAGEMENT** • Where possible, fence affected area to protect from compaction and erosion by stock and traffic. • Maintenance of ground cover to reduce risk of water erosion is recommended. **CROPPING/PASTURE OPTIONS** • Tall wheat grass and annuals such as balansa clover for waterlogged or mildly saline areas are recommended to stabilise wet areas. **RECHARGE REDUCTION AND SURFACE WATER CONTROL** • Appropriate shallow surface drainage is recommended (e.g. W-drains, grade banks). Notification of intent to drain may be required. Grader built intercepting banks to clay installed above the salt affected area may aid in alleviating perched water aggravating the saline areas. • Increase water use off-site as well as on-site. **GROUND WATER OPTIONS** • Drains to relieve groundwater and groundwater pumping are expensive options. Good design is essential and should be site specific. • Drainage effluent should be disposed of without on or off site degradation. • A Notice of Intent to Drain will be required. **REVEGETATION AND TREE PLANTING OPTIONS** • All revegetation areas should be mounded at 0.5 to 1 % slope to reduce waterlogging - mounds with a distinct 'V' work best. • Belts or rows of trees should complement surface water control and be planned once surface drains have been marked. • Mild saline areas - 4 row belts of tolerant oil mallees, or 3-10 row belts of commercial trees, with tolerant pasture species (balansa, etc.) sown between - maintain grazing. Distance between rows should be no greater than 50-100 m. • Single rows of saltbush species (direct seeded or seedlings), separated by alleys of saltland pastures - managed for fodder. • Fence off creeks, waterways and adjacent bare/eroded areas. Allow regeneration of rushes, samphires, paperbarks and/or revegetate with tolerant native species/saltbushes - not grazed.

Land Management Unit	Water and soil problems	Management options
SALT LAKES *Approx. 1,000 ha* Salt lake soil. Associated with salt lakes, swamps, plains and minor lunettes. 	• High salinity and seasonal waterlogging and inundation render this soil unsuitable for the growth of most plants, except halophytes (e.g. saltbush) in fringing areas. • There may be degradation by sheet, rill and wind erosion and be devoid of vegetation in many areas.	**SOIL MANAGEMENT** • Much of this area is non-agricultural land, but where possible, should be fenced off and managed separately, with emphasis on maintaining ground cover on surrounding associated areas to reduce risk of erosion. **REVEGETATION AND TREE PLANTING OPTIONS** • Fence off and revegetate with salt tolerant species such as *Atriplex*. • Mounding is recommended on this LMU.

Table 4.1 Farm forestry options

PLANT GENUS AND SPECIES	COMMON NAME	USE	GROWTH RATE	MIN. RAIN FALL	LAND MANAGEMENT UNIT									
					Gravel ridges and slopes	Mode-rately drained sandy duplex	Poorly drained sandy duplex	Red soils	Grey/ greyish brown loams and clays	Salt-affected soils	Wet soils	Rock outcrops and quartz veins	Yellow and brown deep sands	Pale deep sands
Acacia acuminata var. *acuminata*	Jam	Timber & posts	Med	250 mm		♦		♦		2		♦	♦	
Allocasuarina huegeliana	Rock Sheok	Timber	Med	300 mm	♦	♦		♦				♦		
Casuarina cunninghamiana	River Sheok	Timber	Fast	450 mm		♦				2	♦		♦	♦
Casuarina glauca	Swamp Sheok	Timber	Fast	350 mm		♦	♦			3	♦		♦	♦
Casuarina obesa	Swamp Sheok	Timber	Med	275 mm			♦		♦	3	♦			
Eucalyptus accedens	Powderbark Wandoo	Timber & firewood	Med	350 mm	♦	♦		♦				♦		
Eucalyptus angustissma	Narrow Leafed Mallee	Biomass & oil	N/A	250 mm						3			♦	♦
Eucalyptus astringens	Brown Mallet	Timber	Med	350 mm	♦					1				
Eucalyptus botryoides	Southern Mahogany	Timber & firewood	Fast	450 mm		♦	♦	♦		1	♦			
Eucalyptus citriodora	Lemon Scented Gum	Timber	Med	400 mm	♦	♦		♦						
Eucalyptus cladocalyx	Sugar Gum	Timber, firewood & posts	Fast	400 mm		♦		♦		1			♦	
Eucalyptus camaldulensis	River Red Gum	Timber, firewood & posts	Med	400 mm		♦		♦		2	♦		♦	
Eucalyptus horistes	Ningan Mallee	Biomass & oil	N/A	250 mm		♦		♦					♦	
Eucalyptus kochii subsp. *Plenissima*	Oil Mallee	Biomass & oil	N/A	250 mm		♦		♦						
Eucalyptus loxophleba subsp. *Gratiae*	Smooth Barked York Gum	Biomass & oil	N/A	300 mm		♦	♦		♦	2	♦			
Eucalyptus loxophleba subsp. *Lissophloia*	Smooth Barked York Gum	Biomass & oil	N/A	300 mm		♦	♦		♦	2	♦			
Eucalyptus maculata	Spotted Gum	Timber & firewood	Fast	450 mm	♦	♦		♦						
Eucalyptus occidentalis	Flat Topped Yate	Timber & firewood	Med	350 mm		♦	♦	♦	♦	3	♦			

Table 4.1 continued …

PLANT GENUS AND SPECIES	COMMON NAME	USE	GROWTH RATE	MIN. RAIN-FALL	LAND MANAGEMENT UNIT									
					Gravel ridges and slopes	Mode-rately drained sandy duplex	Poorly drained sandy duplex	Red soils	Grey/ greyish brown loams and clays	Salt-affected soils	Wet soils	Rock outcrops and quartz veins	Yellow and brown deep sands	Pale deep sands
Eucalyptus polybractea	Blue Leaved Mallee	Biomass & oil	N/A	300 mm				♦		1			♦	
Eucalyptus tricarpa	Red Ironbark	Timber, firewood & posts	Med	450 mm	♦	♦		♦						
Eucalyptus saligna	Sydney Blue Gum	Timber	Fast	500 mm	♦	♦		♦						
Eucalyptus vegrandis	Swamp Mallee	Biomass & oil	N/A	250 mm		♦	♦		♦	2	♦			
Eucalyptus wandoo	Wandoo	Timber, firewood & posts	Med	400 mm	♦	♦		♦		1				
Melaleuca acuminata	Creamy Honey Myrtle	Oil	N/A	250 mm		♦	♦	♦		2	♦		♦	
Melaleuca lateriflora	Oblong Leaf Honey Myrtle	Oil	N/A	250 mm		♦		♦	♦	3	♦			
Melaleuca uncinata	Broombush	Oil & brush fencing	N/A	250 mm	♦					2			♦	
Pinus pinaster	Maritime Pine	Timber	Med	400 mm	♦								♦	♦
Santalum spicatum	Sandalwood	Timber & oil	Med	300 mm		♦		♦				♦	♦	

Growth rate:	
Fast	Harvest in 20-25 years
Medium	Harvest in 25-30 years
Slow	Harvest after 30 years
Salinity tolerance (vertical reading with an EM38):	1 = 50 - 100 mS/m 2 = 100 - 150 mS/m 3 = 150 - 200 mS/m

4.2 Water management

4.2.1 Groundwater management

Groundwater drainage has limited application in this area because of the local and intermediate groundwater flow systems with low permeabilities and gradients. Drains or bores that intercept groundwater require ‘notification of the intent’ to the Commissioner of Soil Conservation at least 90 days before the commencement of any earthworks (*Soil and Land Conservation Act 1945*).

Open deep drains

Open deep drains are used to lower the groundwater table, preventing accumulation of salts while allowing rainfall to leach salt from the upper profile. Open deep drains may be levied, unleveed or closed. Closed drains are constructed by laying pipe or recycled tyres in a trench and backfilling with aggregate and/or excavated soil and only carry groundwater. Leveed drains have the spoil placed along both sides of the drain to prevent surface water entering the drain and so remove only sub-surface water. Unleveed deep drains have the spoil placed on one side or alternating from side to side and remove both surface and subsurface water. Careful planning and application of engineering principles is essential so that drain specifications will cope with large run-off events without damage to the spoil or channel.

Groundwater pumping

Pumping is most effective in deep sands and gravels. Pumping systems can lower the watertable and soil salinity levels within the root-zone of plants and improve production from previously salt-affected areas. Groundwater pumping is most effective in permeable aquifer systems and where pumped groundwater is used for some productive purpose such as water supply, aquaculture, or salt harvesting.

Relief wells (Artesian bores)

A relief well is a ‘free flowing’ groundwater bore driven by artesian pressure. That is, a bore that allows groundwater to continuously flow up to the surface by a steady release of confined pressure stored within the aquifer at depth. This ‘confined’ artesian pressure at depth is constantly renewed by rainfall that infiltrates into the soil profile (at higher elevation) and recharges the deeper aquifers.

Relief wells are a means of reducing the impact of salinisation and waterlogging around specific groundwater seepage areas and a way of developing water supplies for aquaculture and livestock.

Relief wells are most effective in reducing the impact of dryland salinity when placed on localised hillside seeps.

4.2.2 Surface water management

Land management options can be used to manage surface water before it contributes to erosion, eutrophication, sedimentation, waterlogging, flooding, groundwater recharge and salinity. Reducing the velocity (speed) and amount of surface water is possible by firstly implementing appropriate land management and soil improvement practices and secondly by managing excess surface water (run-off) with earthworks.

Surface water run-off occurs when rainfall intensity exceeds the capability of the soil to absorb the rainfall. The aim of surface water management is to control and transport run-off to reduce the frequency, volume and velocity of flowing water by constructing earthworks that intercept, retain and spread surface water. This conserves the soil resource, reduces land degradation hazards (including erosion and waterlogging) and utilises water as a resource.

4.2.3 Land management principles

Conservation land management options include:

- vegetative cover to protect the soil from raindrop impact and reduce surface water;
- working land along the contour to hold surface water in the furrows;
- grass strips and permanently grassed waterways to slow surface water concentrated by natural landforms and earthworks;
- managing the farm according to land management units.

4.2.4 Surface water earthworks

Earthworks require careful planning as inappropriate and poor designs can cause more degradation than what the structure was intended to alleviate. Suitably qualified people should be consulted for the legal aspects, design and construction of earthworks. The following points need to be addressed when planning earthworks:

- **Land assessment -** Information on soil condition, vegetation cover, catchment area, annual average rainfall and slope is used to calculate maximum flows, safe grades and safe velocity. For more information visit the Department of Agriculture Website: (http://www.agric.wa.gov.au/progserv/natural/assess/index.htm).
- **Annual Recurrence Interval (ARI) -** Describes the average period in years between the occurrence of a rainfall event of specified magnitude (duration and intensity) and an equal or greater event. Earthworks should be designed and constructed to fill or safely fail when subjected to a specified ARI. Important earthworks, such as dams, waterways and absorption banks are designed for at least a 20 year ARI. Minimum design of most surface drains and banks is a 10-year ARI (Bligh,1989).
- **Legal aspects -** Legal aspects that must be considered before earthworks are constructed. Diversion of flows, increasing flow velocities or increasing quantity of flow, could cause damage to neighbouring properties for which the drainage proponent may be responsible (Drainwise, 2001). Catchment planning and discussing planned earthworks with potentially affected neighbours is essential.

After earthwork planning is completed, the type and design of earthwork to construct is selected. Design criterion for earthworks commonly used in Western Australia are listed in Table 4.2. For more information refer to Resource Management Technical Report 185, “Common Conservation Works used in Western Australia’ or visit the Department of Agriculture web site:
(http://www.agric.wa.gov.au/environment/land/drainwise/options/index.htm).

Table 4.2. Design criteria for earthworks and groundwater management

Structure	Soil type	Grade (%)	Landscape position
Shallow relief drains	C, SD	Up to 0.2	VF
Levee and levied waterways	C, S, DD, SD	Up to 10	Variable
Diversion banks	C, SD, L, DD	Up to 10	LS
Seepage interceptor drains	SD	Up to 5	LS, MS
Reverse bank seepage interceptor drains	SD	5 - 8	LS, MS
Broad based bank	SD, L	2 - 6	US, MS
Grade banks	SD, L	Up to 10	US, MS
Absorption or level banks	SD, L	Up to 10	US, MS
Dams	C, SD, DD, L	Up to 10	Not watercourses
Roaded catchments	C, SD	Up to 6	Any
Raised bed	C, SD	0.1 - 2	VF
Deep drains	SD, DD, S, L	Up to 1	VF
Evaporation basin/pond	C, SD	Up to 0.2	VF, LS
Groundwater pumping	Transmissive profiles	Any	VF, LS
Relief well, syphons	Transmissive profiles	> 2	MS, US

Key			
C = clay	VF = valley floor	S = sand	L = loam
MS = mid slopes	LS = lower slopes	G = gravel	US = upper slopes
SD = shallow duplex	R = ridge	DD = deep duplex	B = breakaway

Table 4.3. Slope suitable for types of earthworks

Slope class (%)	Landscape element	Suitable earthworks
0-1 55,000 ha (16% of catchment)	Valley floors, lower footslopes	Shallow relief drains Levee and levied waterways Deep drains and pumping depending on site-specific details
1-3 114,000 ha (34% of catchment)	Long slopes, footslopes	Seepage interceptor drains Reverse bank seepage interceptor drains Levee and levied waterways Diversion bank Broad-based bank (not less than 2%)
3-5 106,000 ha (31% of catchment)	Mid-slopes, minor upperslopes	Grade bank Seepage interceptor drains Reverse bank seepage interceptor drains Levee and levied waterways Diversion bank Broad-based bank

Table 4.2 continued …

Slope class (%)	Landscape element	Suitable earthworks
5-10 60,000 ha (18% of catchment)	Upperslopes	Grade bank Level/adsorption banks directly below steep slopes of Mallet Hills Levee and levied waterways Diversion bank
> 10 4,000 ha (1% of catchment)	Steep slopes, Mallet Hills and rock outcrop	No earthworks recommended - utilise conservation land management practices

4.3 Economic analysis of management options

Options for managing salinity are assessed in economic terms. The costs of changing traditional farming practices to implement high water-use systems are analysed in terms of 'net present value' of rotational gross margins. The options discussed include: surface water control, e.g. grade banks and shallow relief drains; groundwater control, e.g. deep drains and syphons/relief wells; fencing areas and revegetation.

4.3.1 Rotational gross margins

Table 4.4 shows that rotation 2 (prime lamb and cropping) is more profitable than the high water-use system (rotation 4) where lucerne is in the rotation. The high establishment costs of lucerne reduce profitability; however, the added benefits of lowering the watertable and improved soil structure have not been accounted for in this analysis.

Table 4.4. Rotations for crop/stock (Dept. of Agriculture, 2002)

Rotation 1 **Crop and Merino self replacing flock**	**$/ha**	**Rotation 2** **Crop and Prime lamb production**	**$/ha**
Canola, Wheat, Pasture, Pasture		Pasture, Pasture, Pasture, Canola, Wheat, Barley, Oats	
Equivalent Annual value	171	Equivalent Annual Value	188
Rotation 3 **Merino self replacing ewe flock**	**$/ha**	**Rotation 4** **High water use, prime lambs**	**$/ha**
Pasture, Pasture, Pasture, Canola, Wheat, Barley, Oats		Lucerne/Barley mix, Lucerne, Lucerne Wheat, Canola, Wheat	
Equivalent Annual Value	184	Equivalent Annual Value	163

4.3.2 Water management options

Grade banks

Grade banks are flat channels that retain overland flows of water and are usually part of a system of banks within a farmland catchment (Drainwise, 2002). Cost of banks is about $550 per km but varies with different soil type, machinery used, size of banks and contractors used. Maintenance of banks is required every five years ($150/km). Benefits would be a reduction in waterlogging between 50 and 100 m downslope.

Shallow relief drains

Shallow relief drains are channels constructed to remove water from areas that may be affected by waterlogging, inundation or flooding (Drainwise, 2002). Cost of drains varies from $350 to $550 per km. depending on soil types, contractors used, machinery used and size of drains.

Deep drains

Deep drains, or groundwater drains, are used to lower the watertable, preventing the accumulation of salts while allowing rainfall to leach salt from the upper profile. The cost ranges from $2.50 per metre to $3.50.

Relief wells and siphons

A relief well is a 'free flowing' groundwater bore driven by artesian pressure (Drainwise, 2002). A typical relief well with a drilling diameter of 100 mm, installed using 50 mm diameter casing, to a depth of 20 to 30 m, is estimated to cost $2000 and the area reclaimed can be up to 20 ha (Allan Seymour, pers. comm. 2002).

4.3.3 Revegetation

Two constraints to setting aside land to protect or enhance biodiversity are the establishment cost and subsequent loss of income from the land taken out of production.

This economic analysis is based on the minimum desirable area for biodiversity conservation, which is 20 ha (Stapleton, 2002), with the initial establishment cost for revegetation at $500/ha and fencing at $1450/ha. Ongoing costs for repairs and maintenance to fencing are minimal.

Figure 4.1 shows cost to the farmer over a thirty-year period, comparing land producing different Gross Margins per ha per year. For example, assuming the discount rate is eight per cent, low production land such as poor quality pasture is generating $40/ha per year. Including initial establishment cost it will cost the farmer $33,000 to allocate 20 ha to nature conservation over thirty years. The cost would be about $55,000 for highly productive land.

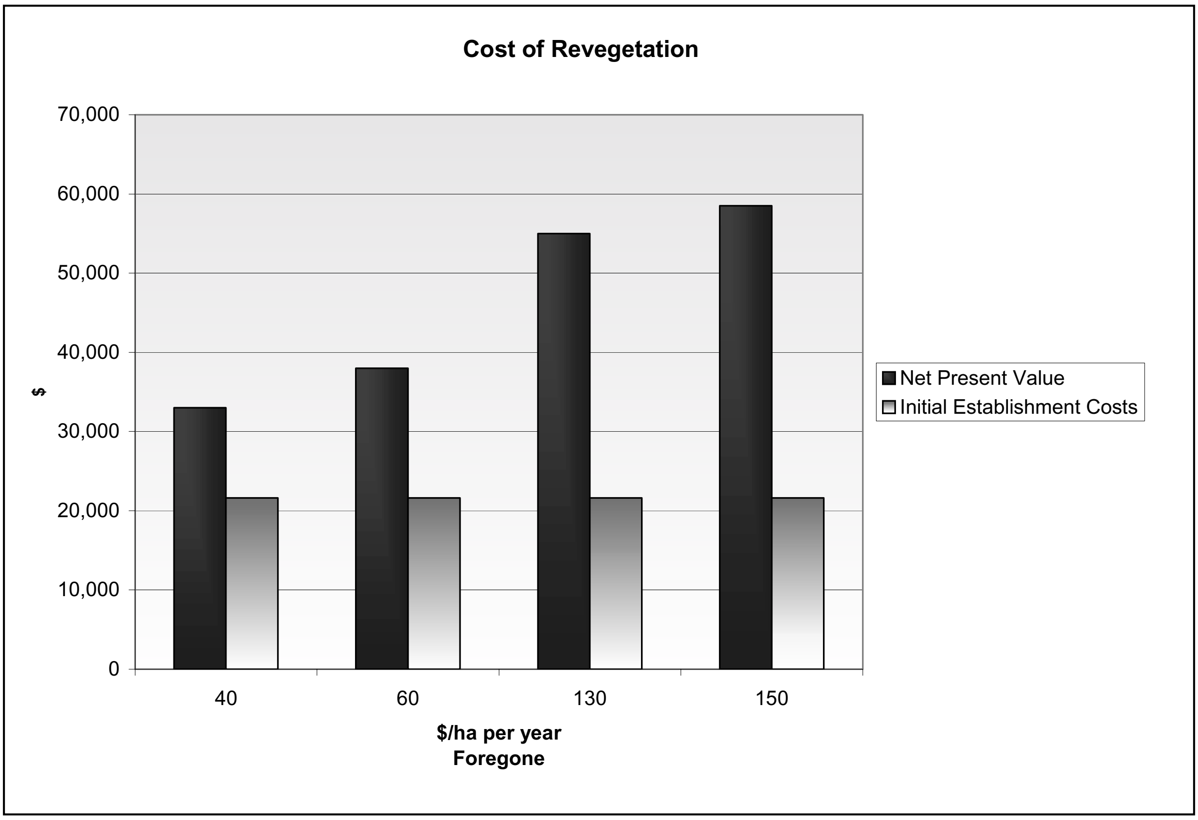


Figure 4.1. Cost of revegetation.

5. Benchmarking

This report provides baseline data on the environmental, economic and social status of the Beaufort Zone. These can be used as a benchmark against which change can be evaluated at set periods in the future, thereby assessing the sustainability of the farming systems. The three measures of sustainability (environmental, economic and social) have been discussed in previous sections, but have been summarised here for convenience - Tables 5.1, 5.2 and 5.3.

Table 5.1. Indicators showing the impact of agriculture on the environment

Environmental baseline data, 1996 unless indicated otherwise			
Area of salinity/waterlogging (ha)	15,837 (4.67%)		
Remnant vegetation (ha)	38,616 (11.38%)		
Perennial pasture 1997-2000*	Kojonup	West Arthur	Woodanilling
Number of farmers	40	12	4
Area (ha)	4,000	1,200	400
Soil acidity - Lime use (tonnes)**			
Estimated requirements/year	23,946	19,380	9,709
Lime use/yr as % of requirement (95/96-99)	39%	6%	14%

* Personal communication S. Dawson (2002).
** Porter and Miler (1998).

Table 5.2. Benchmarks* for economical sustainability,1996 unless indicated otherwise

Indicator			
GVAP for Zone	$ 55.5 million (1.24% of State GDP)		
Change in farming systems (per farm) Cropping (% of effective ha) Pastures (ha) Sheep	331 ha (25%) 994 6,790		
Average farm size (ha)	790		
Retained profit ($)	**Top 25%**	**Other 75%**	**Low 25%**
1997/1998	67.00	9.00	38.00
2000/2001	63.00	37.00	28.00
Equity (4 yr average: 1997-2000)	85%		
Debt (4 yr average: 1997-2000)	$245/effective ha		
Infrastructure at risk (km)**	**Sealed roads**	**Unsealed roads**	**Tracks**
	50	26	19
Estimated additional cost/year ($)	45,500-62,700	7,103	474

* Benchmarks per farm unless otherwise indicated.
** Land monitor (2001).

Table 5.3. Social data by shire, 1996 unless indicated otherwise

Indicator	Kojonup	West Arthur	Woodanilling
People employed in agriculture (%)	48	73	65
Farmer education (%)			
No award	80	81	83
Vocational	5	7	4
Tertiary	15	12	13
Average taxable income	24,600	25,800	29,400
Total population	2,404	1,003	364
Median age of farmers	45	45	41

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- Tim Mathwin, *Hydrogeologist*
- Belinda O'Brien, *Farming Systems Development Officer/Editor*
- Jaki Richardson, *GIS Support*
- Chrissy Rob, *Farm Forestry Development Officer, CALM*
- Muhammed Siddiqi, *Surface Water Hydrologist*
- Angela Stuart-Street, *Soils Resource Officer*
- Sylvia Tetlow, *Landcare Support Officer*