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MOORE RIVER

CATCHMENT APPRAISAL 2002

Compiled by Angela Alderman and
Mike Clarke

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Compiled by Angela Alderman and Mike Clarke
for the Northern Agricultural Region
Rapid Catchment Appraisal Team

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Government of Western Australia Department of Agriculture

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Contents

Summary

- The Moore River catchment begins about 75 km north of Perth on the west coast of Western Australia. The catchment covers 1.38 million hectares and contains three hydrological zones. The climate is typically Mediterranean with cool wet winters and dry warm summers.
- The Moore River is fed by nine subcatchments and has a number of tributaries and lakes along its length. Surface salinity levels in the Moore River estuary and lower catchment range from brackish to saline whereas the Gingin Brook—a major tributary—remains fresh throughout the year.
- The dominant soil supergroups are Deep sands, Sandy earths and Ironstone gravelly soils.
- One-third of bores in the catchment have groundwater levels at less than 2 m and the majority of these contain moderately to highly saline groundwater.
- One-quarter of the catchment east of the Darling Fault is low-lying with potential for developing shallow watertables. Nearly 20 per cent (1,550 km) of roads could be affected by salinity or waterlogging if the groundwater continues to rise.
- Two-thirds of the catchment has a moderate to high risk of water repellence and 60 per cent has a moderate to high risk of subsurface compaction and acidity.
- Approximately one-quarter of the original vegetation has been retained. This vegetation contains more than 80 species of priority flora and nearly 40 species of rare flora. Over 10 per cent of the remnant vegetation occurs in low-lying areas.
- In 1999, the gross value of agricultural production (GVAP) in the catchment was $200 million—nearly 5 per cent of the total GVAP of WA. Crops include wheat, lupins and barley, and the livestock enterprises are wool, sheepmeat and weaner and steer production.
- A range of options for reducing land degradation is discussed. Factors such as soil type, annual rainfall, enterprise mix and financial structure will determine the most suitable approach for each farm business.

Acknowledgments

The members of the Moore River Rapid Catchment Appraisal Team responsible for this report are:

Mike Clarke	Team Leader and revegetation
John Bonnardeaux	Soils
Stuart Delphin	Groundwater hydrology
Kari-Lee Falconer	Farming systems
Jason Kelly	Economic impacts of salinity
Frank Rickwood	Surface water hydrology
David Rogers	Farming systems
Damian Shepherd	GIS mapping support and data interrogation
Ross Upchurch	GIS mapping support
Peter Whale	Surface water hydrology

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Special thanks to Angela Alderman, Brendan Nicholas, John Simons and Nick Middleton from the Esperance Catchment Support Team who assisted in analysis, review and map production.

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.

This report has been prepared by the Northern Agricultural Region RCA Team. The report summarises current information for the Moore River catchment. Land managers are urged to use it as a starting point and to gather further information from the sources listed.

1.1 Study area

The Moore River catchment covers 1.38 million hectares and 80 per cent of that is farmland. It is located in the southern portion of the Northern Agricultural Region of Western Australia and extends across eight shires. The catchment contains a number of National Parks and nature reserves.

For this report, the catchment has been divided into three hydrological zones: Moore River North, Moore River South and Moore River West (Figure 1). Moore River North and South zones are east of the Darling Fault on the Yilgarn Craton. Moore River West zone is west of the Darling Fault on the Perth Basin.

The headwaters of the Moore River commence in the Perenjori, Carnamah and Dalwallinu Shires and drain southwards through Moora. The River is eventually met by the Gingin Brook about 19 km in from the coast and then meets the Indian Ocean at Guilderton, 75 km north of Perth.

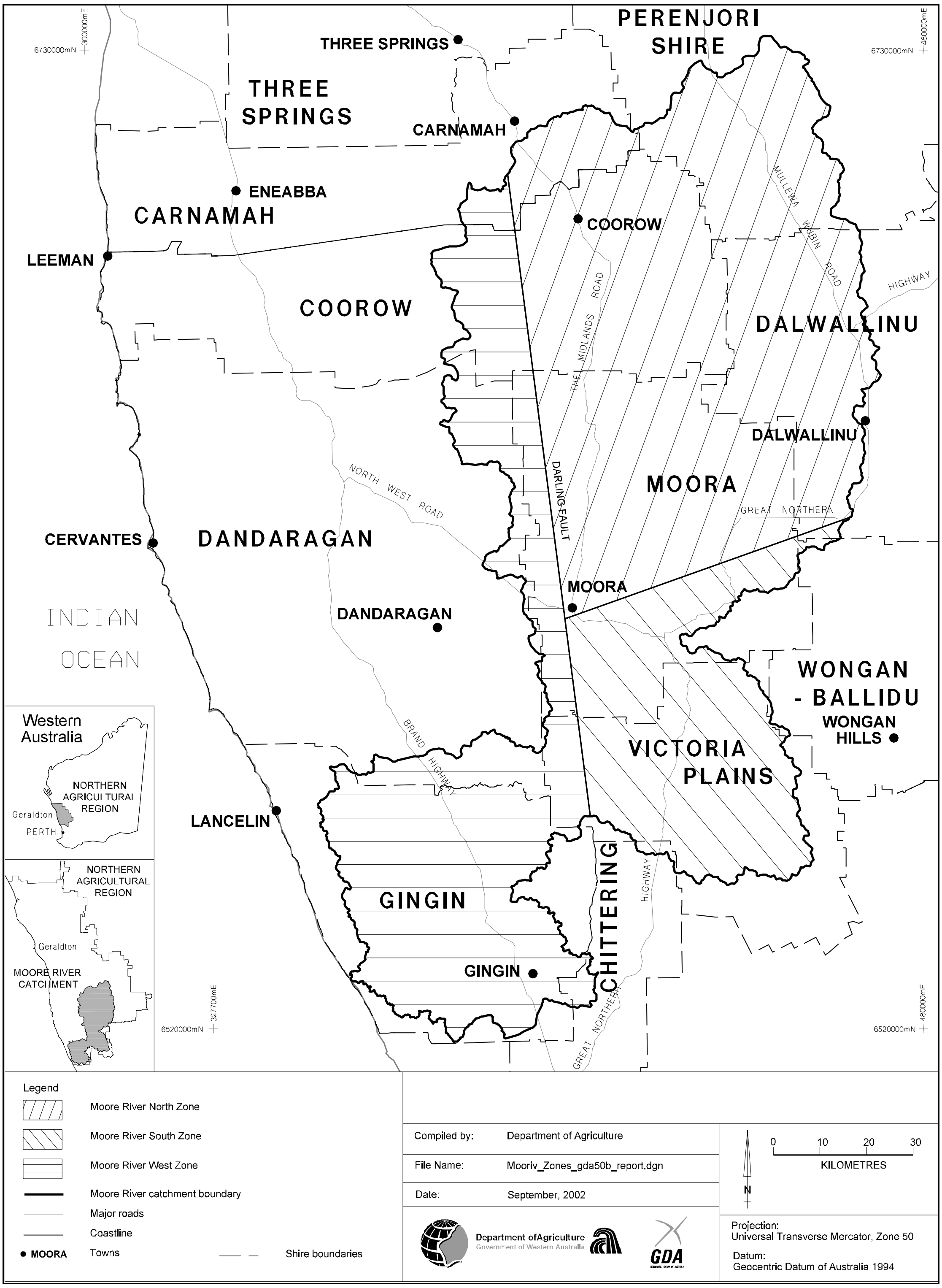

Figure 1: Moore River catchment

2. Natural resource base

2.1 Climate

The climate of the Moore River catchment is Mediterranean, with cool wet winters and warm dry summers. The annual rainfall across the catchment varies from around 800 mm near the mouth of the river, to around 350 mm at the headwaters (Figure 2).

As well as rainfall variations across the catchment, the inland headwater regions are hotter in summer, cooler in winter and have less summer humidity than the lower catchment regions closer to the coast.

Although Dalwallinu receives 100 mm less annual rainfall than Moora (460 mm), it receives more summer rainfall than Moora as a result of summer thunderstorm activity.

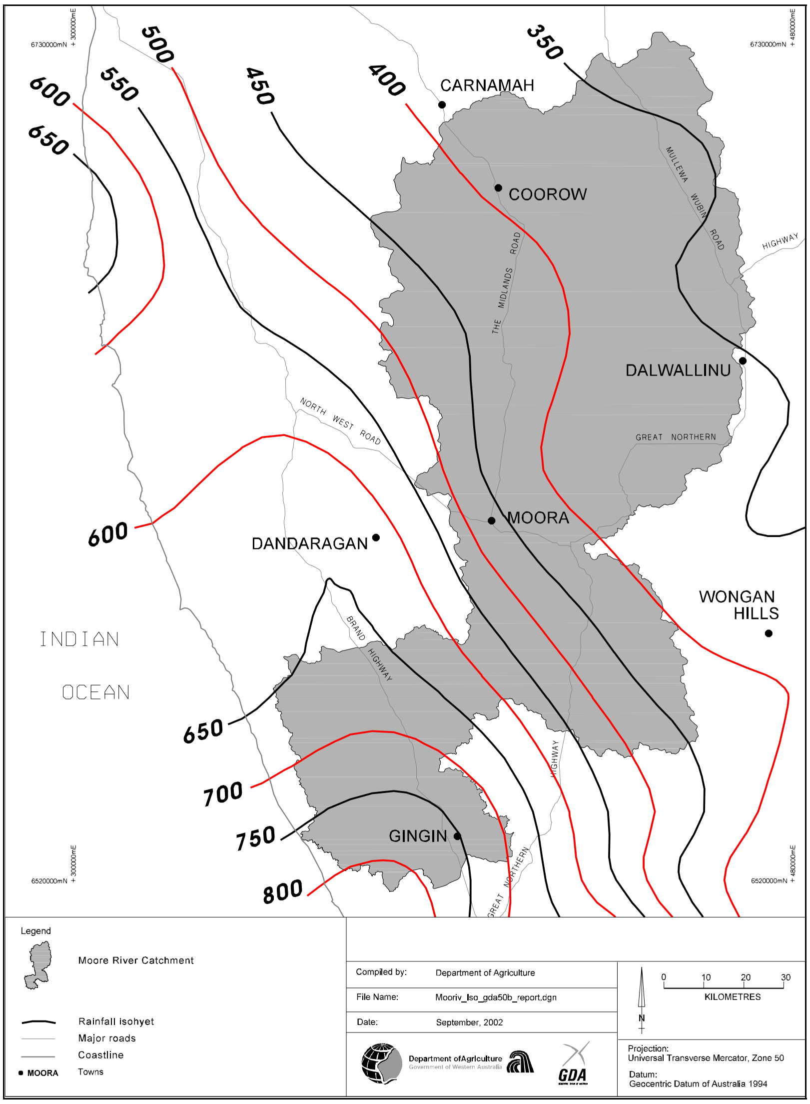

Figure 2: Average annual rainfall distribution across the Moore River catchment

2.2 Geology

Stuart Delphin, Hydrologist

The catchment spans two major geological regions: the Perth Basin and the Yilgarn Craton. The Darling Fault marks the boundary between these regions throughout most of the catchment with the Phanerozoic sedimentary deposits of the Perth Basin to the west and ancient Archaean crystalline basement rocks of the Yilgarn Craton to the east (Figure 3).

The Perth Basin is a deep trough of sedimentary rocks that may exceed 10 km in thickness. The onshore part of the Perth Basin extends north-south for some 1,000 km from the South Coast to north-east of Northampton (Playford et al. 1976). The Perth Basin sediments consist of material deposited in both terrestrial and marine environments. Quaternary sandplain blankets much of the Phanerozoic sediments.

The Yilgarn Craton is a large area of Archaean, granitic, stable, continental crust that underlies most of the south-west of WA. It is intruded by numerous dolerite dykes that dominantly trend north-north-west in the catchment. Aeons of erosion have resulted in subdued relief. A thick profile of gritty clay saprolite (up to 50 m) derived from in-situ weathering typically mantles the crystalline (granitic) basement.

2.2.1 Geomorphology

Peter Whale and Frank Rickwood, Land Conservation Officers

The catchment can be divided into three hydrological zones:

- The Moore River North zone east of the Darling Fault is classified as the Zone of Ancient Drainage. The topography is generally subdued with low slopes and broad flat valleys. Drainage is braided with numerous lakes and often terminates in closed depressions or salt lake chains. Extensive primary and secondary salinity occurs adjacent to and within the drainage lines and lakes.
- The Moore River South zone is classified as the Zone of Rejuvenated Drainage. It covers a 20 to 40 km wide strip on the Yilgarn Craton extending north-south adjacent to the Darling Fault. The zone is characterised by an incised landscape with well-defined and branched drainage.
- The Moore River West zone is bounded on the east by the Darling Fault and is characterised by deep sands and sedimentary deposits of the Perth Basin. The terrain is more subdued than the Zone of Rejuvenated Drainage except where plateau edges form into a number of scarp lines. Stream flows only occur after heavy and sustained rainfall events.

2.3 Soil supergroups

Kari-Lee Falconer, Development Officer and John Bonnardeaux, Soils Resource Officer

The most common soil supergroups (Schoknecht 2002) represent 90 per cent of the catchment (Table 1). Deep sand, Sandy earth and Ironstone gravelly soil represent nearly 60 per cent of the catchment. The Moore River West and Moore River North zones contain 61 per cent and 32 per cent Deep sand respectively, while nearly half of Moore River South zone is Loamy earth and Ironstone gravelly soil (Department of Agriculture 2003).

The distribution of the dominant soil supergroups is illustrated in Figure 4.

2.4 Hydrology

Stuart Delphin, Hydrologist

2.4.1 Groundwater

2.4.1.1 Groundwater flow systems

Groundwater processes causing salinity can be categorised according to their flow systems because the scale (local, intermediate or regional) reflects the ease with which salinisation can be managed (Coram 1998). Local groundwater flow systems recharge and discharge within 1 to 3 km of each other, intermediate groundwater flow systems extend for 5 to 10 km, and regional groundwater flow systems extend over 10 km. All three of these groundwater flow systems occur in the Moore River catchment.

2.4.1.2 Moore River North

The dominant groundwater flow systems are intermediate and local.

Stock quality water tends to be restricted to mid and upper slope positions. Successful bores usually obtain supplies from the gritty saprolite at the base of the weathered zone. The rate of supply and quality of groundwater within weathered regolith of the granitic basement is variable.

Perched aquifers in sandplain or gravelly deposits adjacent to rock outcrops often yield good quality water but can be of low supply. These systems are also less reliable following a number of drier years, which has been the trend for the past three years.

Table 1: Soil supergroups and soil groups by area

Soil supergroup	Definition	Most common soil group	Moore River North		Moore River South		Moore River West		Total area of catchment	
			ha	%	ha	%	ha	%	ha	%
Deep sand	Sand >80 cm deep	Yellow deep sand, Pale deep sand, Gravelly pale deep sand, Red deep sand	158,000	32	22,000	7	308,000	61	488,000	35
Sandy earth	Soil with a sandy surface and grading to loam by 80 cm. May be clayey at depth	Brown sandy earth, Red sandy earth, Yellow sandy earth	110,000	22	55,000	18	4,000	1	169,000	12
Ironstone gravelly soil	Soil with an ironstone gravel layer (>20% and >20 cm thick) or duricrust/ cemented gravels within the top 15 cm. Ironstone gravels are a dominant feature	Loamy gravel, Shallow gravel	45,000	9	68,000	22	31,000	6	144,000	10
Sandy duplex	Soil with a sandy surface and a texture or permeability contrast at 3 to 80 cm	Grey deep sandy duplex, Yellow/Brown shallow sandy duplex, Alkaline grey deep sandy duplex	70,000	14	44,000	14	17,000	3	131,000	9
Loamy earth	Soil with a loamy surface and either loamy throughout or grading to clay by 80 cm	Brown loamy earth, Red loamy earth	56,000	11	71,000	23			127,000	9
Wet or waterlogged soil	Soil seasonally wet within 80 cm of the surface for a major part of the year	Semi-wet soil, Saline wet soil	23,000	5	14,000	5	56,000	11	93,000	7
Loamy duplex	Soil with a loamy surface and a texture contrast at 3 to 80 cm	Yellow/Brown shallow loamy duplex, Red shallow loamy duplex	39,000	8	37,000	12			76,000	6
Other									152,000	11
Total			**501,000**	**36**	**311,000**	**23**	**416,000**	**30**	**1,380,000**	**100**

2.4.1.3 Moore River South

The groundwater flow systems are either local or intermediate. Groundwaters are apparently near or have reached equilibrium in most bore locations (Figure 11).

Proterozoic sediments of the Moora Group—particularly Chert and Dolomite—offer potential supplies of stock quality water and potable water in this zone. For example, Coomberdale Chert mine has exceptional yields of low salinity groundwater (Speed 1995).

2.4.1.4 Moore River West

This zone is located over the Perth Basin, which contains up to 10,000 m of sedimentary sequences that form important and substantial regional aquifers. The groundwater flow systems are regional or local. Local flow systems are found where there is a sufficient thickness of superficial sands. The regional flow systems are made up of multiple sandy aquifer zones separated by silts and clays.

The Gingin Scarp, which runs east of and parallel to the Brand Highway, divides the major aquifer systems in this zone. To the west of the Gingin scarp, the aquifer systems include the Leederville Formation, Lancelin Formation, Parmelia Formation and the Osborne Formation. East of the Gingin Scarp, the aquifer systems include the Poison Hill aquifer; Mirrabooka aquifer and the Leederville-Parmelia Formation (Kay & Diamond 2001).

2.4.2 Groundwater depth and electrical conductivity (EC)

Groundwater monitoring data was assessed from 81 monitoring bores across the catchment. Data was sourced from AgBores database, AQWABase digital data, and the Department of Conservation and Land Management's Recovery Catchment datasets.

Nearly one-third of these bores have groundwater levels at less than 2 m (Table 2). This class has the highest risk of developing salinity, depending on the underlying soil types. These sites are mainly in the low-lying areas of the Moore River North and Moore River South zones.

Table 2: Depth to groundwater of bores

Depth to groundwater (m)	No. of bores	Percentage of bores (%)
<2	26	32
2–5	32	40
>5	23	28

Forty per cent of the bores have a moderate risk of developing salinity and the majority of these bore sites are located mid-slope. Sites with the lowest risk of developing salinity have groundwater levels deeper than 5 m. Bores in this class were generally positioned high in the landscape.

Groundwater EC measurements were available for 50 of the bores. Forty per cent of bores had fresh to brackish water and the remainder had moderately saline to highly saline water. Bores with groundwater levels less than 2 m showed the strongest relationship with moderate to highly saline watertables (Table 3).

Table 3: Water quality of bores and the salinity risk class

Water quality	Electrical conductivity (mS/m)	All bores (%)	Percentage of bores in depth to groundwater classes (%)		
			<2 m	2–5 m	>5 m
Fresh	0–250	12	10	13	14
Brackish	250–1,000	27	18	40	22
Moderately saline	1,000–2,000	26	29	13	36
Highly saline	>2,000	35	43	34	29

Bores with groundwater levels between 2–5 m showed the most promising results for accessing groundwater of a low salinity. Half of these bores contain fresh to brackish groundwater. Bores with groundwater deeper than 5 m had variable salinity levels, with two-thirds of bores containing moderately to highly saline groundwater.

2.4.3 The Moore River

Peter Whale and Frank Rickwood, Land Conservation Officers

The Moore River catchment has nine main subcatchments (Figure 5). In the north, the main tributaries of the Moore River are fed by the Latham Lake chains and Buntine-Marchagee catchments. The tributaries drain through a series of lake chains with the main outfall into Lake Eganu and Lake Pinjarrega which is the largest of the northern lakes. The larger terminal lakes in this system store and evaporate most of the flow in average rainfall years and the smaller lakes allow throughflow. Connected and continuous streamflow only occurs in extreme rainfall events, such as in 1999.

The Coonderoo River flows southwards from Lake Pinjarrega and joins the Moore River tributary just west of Moora. The Moore River flows westwards across the Darling Fault and continues southwards until it meets Gingin Brook, a major tributary that enters the river about 20 km from the coast. The river finally reaches the ocean at Guilderton. The estuary is intermittently closed to the ocean due to the presence of a sand bar across the mouth of the estuary.

The Moore River estuary is affected by water derived from the surrounding catchment and by groundwater discharge. The estuary generally has two hydrological phases during summer and one in winter. The first phase shows a tidal dominated system to approximately 6 km upstream when the bar has been breached, while the second phase occurs when the bar is closed and salinity levels gradually return to a brackish state, due to dilution from groundwater recharge. The third phase during winter occurs when surrounding catchment flows affect the whole system. During this third phase, salinity levels within the upper estuary and lower catchment increase during the winter months due to riverine flow from the Moore River (Cousins 1999).

2.4.4 Water resources

Ten towns in the catchment rely on the Water Corporation's public water supply well fields in confined and unconfined aquifers. Elsewhere, individual landowners generally have rain tanks and bores for self-supply (Black 2001). Farm dams and rain tanks provide water supplies for livestock and spraying.

2.5 Native vegetation

Mike Clarke, Revegetation Officer

Beard (1976, 1979a, 1979b) divides the catchment into 11 major vegetation systems (Table 4 and Figure 6). Prior to clearing, the Marchagee, Perenjori and Victoria Plains Systems covered half of the catchment.

Table 4: Beard's Vegetation Systems

Vegetation system	Area (ha)	Percentage
Marchagee	261,000	19
Perenjori	236,000	17
Victoria Plains	193,000	14
Bassendean	132,000	10
Jibberding	126,000	9
Walebing	123,000	9
Gingin	89,000	6
Warro	67,000	5
Mogumber	65,000	5
Jurien	43,000	3
Koojan	26,000	2
Other	17,000	1
Total area	**1,380,000**	**100**

Marchagee System - associated with an extensive area of deep yellow sand. Contains mostly scrub heath on yellow sandplain with *Actinostrobus arenarius, Adenanthos stictus* and *Banksia prionotes* dominating. The rest of the vegetation is casuarina thicket on ridges of Proterozoic rocks, eucalypt woodlands on red loams, and woodland with mallee and halophytes in the depressions.

Perenjori System - casuarina thicket (*Allocasuarina campestris* and *A. acutivalvis*) on yellow sandplain soils with gravel on the upper slopes, *Eucalyptus loxophleba* woodland on the red loams of the lower slopes and halophytes on the saline valley soils.

Jibberding System - similar to the Perenjori System except with acacia species dominating.

Victoria Plains System - similar to the Perenjori System except *E. wandoo* becomes more frequent on the loamy soils.

Walebing System - casuarina thicket on laterite ridges, *E. wandoo* woodlands on the upper slopes grading to *E. salmonophloia* on the flats. *E. rudis* borders the drainage lines.

Mogumber System - similar to the Walebing System, except with dryandra heath in association with *E. accedens, E. wandoo* and *E. eudesmioides* on the laterite ridges.

Warro System - banksia low woodland *B. attenuata, B. burdettii* and *B. prionotes* dominate in association with *E. todtiana, Nuytsia floribunda* and *Xylomelum angustifolium. E. loxophleba* woodland is found in depressions and *Casuarina obesa, E. loxophleba* and melaleuca woodlands exist around lakes.

Koojan System - covers an area of undulating country of leached pale deep sands. Contains mainly heath with banksia low woodland in the valleys. The dominant heath genera include hakea, verticordia and dryandra, and *B. attenuata, B. menziesii* and *E. todtiana* are found in the valleys.

Gingin System - a mosaic of heath on laterite, scrub heath on shallow gravels, banksia low woodland on pale deep sands and eucalypt woodland on sandy duplexes. *E. calophylla* and *E. marginata* have scattered occurrences throughout the banksia woodland. Swampy depressions are usually surrounded by *Melaleuca preissiana* and *B. littoralis.*

Bassendean System - comprises a sandy plain of pale deep sands on low ridges with tea-tree swamps on seasonally wet soils. The banksia low woodland on the sands include *B. attenuata, B. menziesii,* and *B. ilicifolia,* with scattered occurrences of *E. todtiana and N. floribunda*. The tea-tree swamps consist of *M. priessiana, E. rudis* and *Viminaria denudata.*

Jurien System - predominantly banksia low woodland on the pale deep sands with scrub heath on limestone ridges. Vegetation on these ridges includes *M. huegelii, M. cardiophylla* and *Dryandra sessilis.*

2.6 Agricultural production[a]

Jason Kelly, Regional Economist

2.6.1 Agricultural systems

Farming systems include broad area cropping, which is the largest industry, livestock enterprises, horticulture and agroforestry. Cropping intensity has increased in recent years displacing livestock. The Moore River North zone has the highest proportion of cropped area and the Moore River West zone, which contains predominantly pasture, has the highest numbers of livestock.

2.6.1.1 Cropping

The main crops grown are wheat, barley, oats and lupins. The primary crop rotation is wheat/lupin with continuous cropping on sandy earth and pasture phases on duplex soils. Barley and oats are sown on soil with low fertility. Canola is being increasingly grown as a break crop on duplex and loamy soil types.

2.6.1.2 Livestock

The dominant livestock enterprises are sheep for wool, prime lambs from merinos, and weaner and steer production. Historically livestock enterprises were a self-replacing merino ewe flock or wether producing medium type wool. Continued depressed prices for wool and improved profitability of sheepmeat and beef have seen a shift towards these enterprises. More recently, live export of sheep and beef has provided increased returns.

2.6.1.3 Pasture

Pastures vary from annual-based unimproved pastures on the lighter soils to improved annual and perennial pastures on the heavier soils. Tagasaste is grown on the infertile deep sands. The area sown to perennial pastures has increased significantly in recent years as establishment and management techniques improve.

2.6.1.4 Intensive agriculture

Water availability, proximity to markets, rural subdivision and suitable soil types are contributing to increasing areas of the Moore River West zone being planted with high value crops, such as olives, grapes and plantation trees.

2.6.2 Catchment production

The gross value of agricultural production (GVAP) for the catchment in 1999 was estimated to be $200 M with a contribution to the total State GVAP of 4.8 per cent.

Other trends in the catchment over the period 1989–99 include:

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[a] The statistics included in this profile are derived from ABARE (2001) and Bank of Western Australia (2002).

- The area sown to cereals has shown an increasing trend in recent years. Improved farming practices and higher margins have encouraged producers to expand their cropping enterprises.
- The value of wool produced experienced a significant decline following the collapse of the reserve price scheme. The decline is a symptom of both the fall in prices received and a reduction in the numbers shorn by about one-third.
- Beef cattle numbers have nearly doubled since 1989 due to improved prices and substitution of sheep.
- The number of farms in the Moore River North zone has fallen as broad area farming continues to expand. However, in the South and West zones, numbers have risen due to rural subdivision and the increase in intensive industries.

2.6.3 Farm performance

Table 5 highlights the variation between physical factors and financial performance of farms within the catchment. Farm size decreases from east to west as does the proportion of area cropped. Sheep numbers and wool cut per hectare are greater in the west reflecting the higher productivity. Crop yields in 2000/2001 in western areas were above the 5-year average, while yields in eastern areas were at or below average yields.

2.6.4 Land values

Land values are determined primarily by expected future profitability and prospects for capital gains. Most of the shires in the catchment have shown positive nominal capital gains since 1970, with eastern cropping areas experiencing the largest year on year gains during the 1990s. However, poor seasons and low commodity prices have impacted on land values in recent years resulting in zero or negative returns.

In real terms the 1990s was a period of wealth creation, with farm capital gains exceeding the prevailing low interest rate.

Table 5: Farm surveys (Source: Bank of Western Australia, 2002)

	Northern wheatbelt <350 mm 5-year average	Dalwallinu average 00/01	Central midlands 5-year average	Moora average 00/01
Capital analysis				
Effective area (ha)	3,500	3,700	2,000	1,700
Assets ($/Eff ha)	880	1,020	1,480	1,650
Debt ($/Eff ha)	120	100	220	240
Long term debt ($/Eff ha)	70	50	140	130
Equity (%)	86	90	85	85
Long term debt to Income (%)	30	21	57	37
Return to capital	2	4	2	6
Operating analysis				
Farm income ($/Eff ha)	190	210	240	330
Operating costs ($/Eff ha)	130	130	160	210
Operating return ($/Eff ha)	60	80	80	130
Operating profit ($/Eff ha)	40	60	60	110
Operating cost/farm income (%)	73	66	70	62
Grain % of farm income	84	86	66	66
Sheep & wool % of farm income	10	10	20	20
Crop production & yield				
Total crop area (ha)	2,500	2,600	1,100	900
Crop % of effective area (%)	70	70	55	50
Wheat (t/ha)	1.7	1.7	2.1	2.5
Barley (t/ha)	1.5	1.6	1.9	2.0
Lupins (t/ha)	1.0	0.7	1.3	1.3
Canola (t/ha)	0.8	0.4	1.1	1.3
Sheep production				
Total sheep shorn (head)	2,500	2,900	3,400	3,400
Winter grazed hectares (ha)	1,000	1,100	900	800
Wool cut (kg/WGHa)	15	12	20	20

2.7 Land use

Brendan Nicholas, Soil Resource Officer

Of the land uses shown in Figure 7, dryland agriculture takes up the greatest area with 81 per cent of the total (Table 6).

Table 6: Land use (area and percentage of total) (Source: NLWRA (2001))

Land use	Area (ha)	Percentage
Conservation and natural environments*	259,000	19
Dryland agriculture and plantations	1,112,000	81
Other uses	9,000	<1
Total	**1,380,000**	**100**

* Includes nature reserves and other reserves such as gravel reserves

2.8 Demographics

Jason Kelly, Regional Economist

Two-thirds of the people in the catchment reside in the Moora and Gingin Shires (Figure 8). While this is mainly due to the area of the shire in the catchment, it also reflects the intensity of land use.

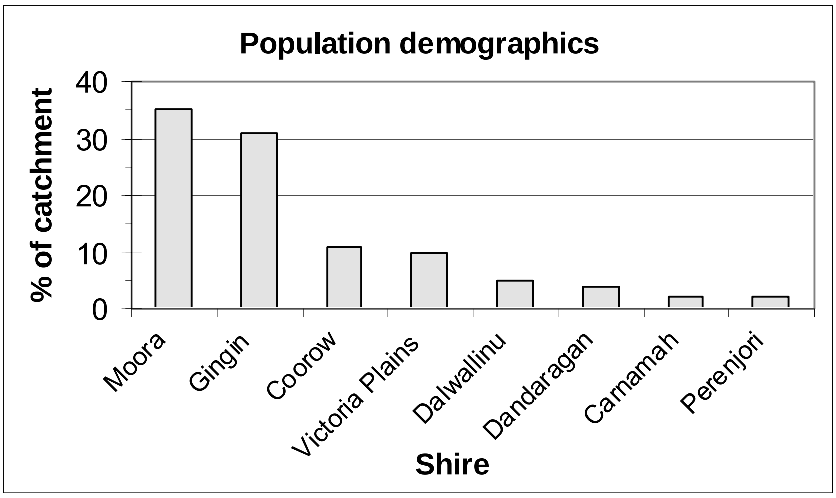


Figure 8: Population demographics in the Moore River catchment (Source: Midwest Development Commission, 1996)

The distribution pattern is becoming increasingly skewed, with shires dominated by broadacre farming, such as Perenjori and Dalwallinu Shires, showing a decreasing and ageing population trend, while shires with enterprise diversity and farm intensification, such as Gingin Shire, are experiencing a population increase. The Gingin and Dandaragan Shires are experiencing some urban to rural migration based on quality of life decisions.

3. Resource condition and future risk

3.1 Climate change impacts

Angela Alderman, Technical Officer

Western Australia is expected to become warmer and drier than at present (Foster 2002). Warming is likely to be greatest in spring and least in winter, and affect daily maximum and minimum temperatures. Average annual temperatures are expected to rise by up to 2 °C by 2030 and up to 6 °C by 2070, with slightly less warming in coastal regions. Rainfall is predicted to decline from autumn to spring by 20 per cent, and evaporation rates are expected to increase with temperature, thereby reducing the moisture balance and potentially affecting plant growth and surface water run-off.

Implications for these projections include:

- growing season may start later and finish sooner
- daily rainfall events may become more intense, increasing episodic recharge
- period between rain events may increase and with increased evaporation rates, run-off generation systems, such as roaded catchments and additional storage could be needed
- more frequent temperature extremes
- rising temperatures may affect field crops via potentially large changes in heat or chill storage. A possible benefit of temperature rise is reduced risk of frost
- reduced pasture production and increased heat stress of stock
- warmer climate may favour some pests and diseases
- possible extinction of species with a restricted range or confined to small areas.

3.2 Land management hazards

Kari-Lee Falconer, Development Officer, and John Bonnardeaux, Soils Resource Officer

Management practice is the major factor in avoiding soil decline; however the soils of the Moore River catchment have some inherent characteristics that predispose them to certain land management hazards. Dominant limiting characteristics are loose sandy topsoils with low water-holding capacity.

There are five major land management hazards and the most widespread are water repellence and subsurface compaction. Subsurface acidity is a concern for nearly 60 per cent of the catchment and given the recent increases in cropping, the risk is probably under-estimated.

Land management hazards are based on the attribution of soil-landscape mapping conducted by the Department of Agriculture. Land qualities are attributed to soil and map units to assist in identifying management, conservation and degradation issues (van Gool & Moore 1999).

3.2.1 Water repellence

- Two-thirds of the catchment has a moderate to high risk of developing water repellence.
- Soil supergroups most at risk are Deep sand and Sandy earth.
- Coarse-textured sandier soils with less than 5 per cent clay content are most at risk.

3.2.2 Subsurface compaction

- Sixty per cent of the catchment has a moderate to high risk of subsurface compaction.
- Soil supergroups most at risk are Deep sand and Sandy earth.
- Soils with loamy sand to sandy loam texture are the most susceptible. Sands with even-sized soil particles are least susceptible.

3.2.3 Subsurface acidity

- Sixty per cent of the catchment has a moderate to high risk of subsurface acidity.
- Deep sand and Ironstone gravelly soil supergroups are most at risk.
- Problems are likely to develop in high rainfall areas, annual pasture systems, lightly textured soils, rotations that include legumes and have a history of nitrogenous fertiliser use.
- Lighter-textured sands and loams with low organic matter levels are most susceptible.

3.2.4 Wind erosion

- Sixty per cent of the catchment has a moderate to high risk of wind erosion.
- All soils are subject to wind erosion given certain conditions; however soil supergroups most at risk are Deep sand and Sandy earth.

3.2.5 Waterlogging

Risk is difficult to estimate because of large seasonal variation. Cereal cropping systems are susceptible to even low waterlogging risk, particularly during critical stages of crop development.

- One-quarter of the catchment has a low to high risk of waterlogging.
- Soil supergroups most at risk are Sandy duplex, Deep sand and Wet or waterlogged soils.
- Soils with shallow, sandy topsoil over a clayey subsoil within 50 cm are most at risk.

3.3 Hydrological risk

3.3.1 Groundwater trends and salinity

Stuart Delphin, Hydrologist

This section illustrates how changes within components of the water balance affect groundwater levels and secondary salinity. These changes, which are expected to continue for several decades until a 'new' equilibrium is reached, increase groundwater recharge, groundwater storage and groundwater discharge from aquifers in the area, causing groundwater levels to rise and secondary salinity to develop.

Hydrographs showing the trends typical of each zone in the catchment follow. Trends varied from falling and rising trends, to trends that suggested the sites were in areas that had reached an apparent hydrological equilibrium.

The hydrograph of bore CA26D, which is located just outside the catchment, shows a typical groundwater trend under a farming system in a lower mid-slope position in the Moore River North zone. There is a rising groundwater trend of 18 cm/yr due to a jump in groundwater levels from 7 m to 4 m below ground level, after the 1999 high rainfall event (Figure 9). Subsequent drier years have seen the trend subside. This trend is representative of bores in the ancient drainage system.

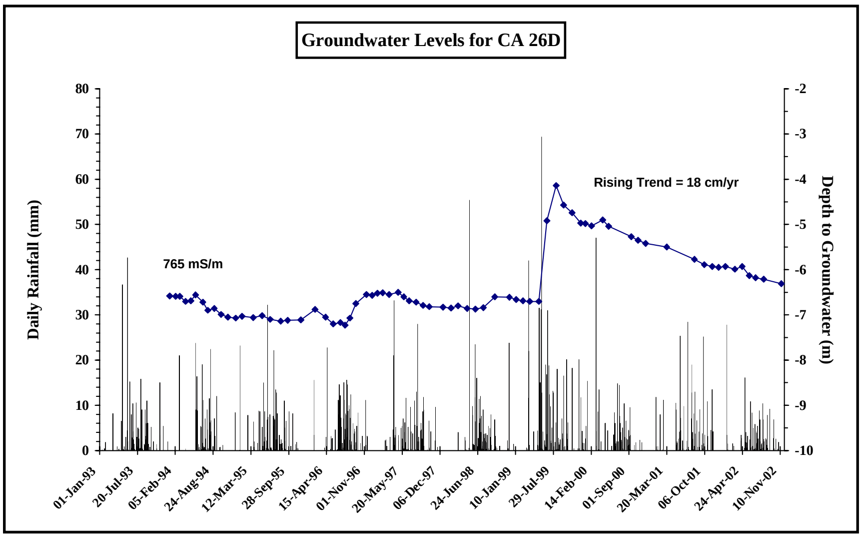


Figure 9: Typical hydrograph of a groundwater monitoring bore in the Moore River North zone

Representing the transitional zone along the Darling Fault is bore MO1D located in the Moora townsite. The hydrograph shows a steady groundwater rise of 13 cm/yr, with only a marginal response to the 1999 high rainfall event (Figure 10). If this trend continues, Moora's groundwater is expected be within 2 m of the surface within 15 years.

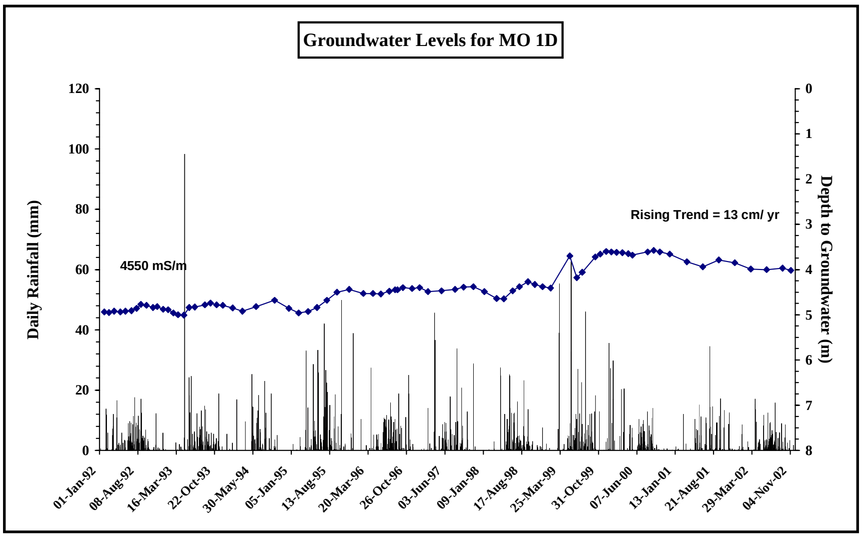


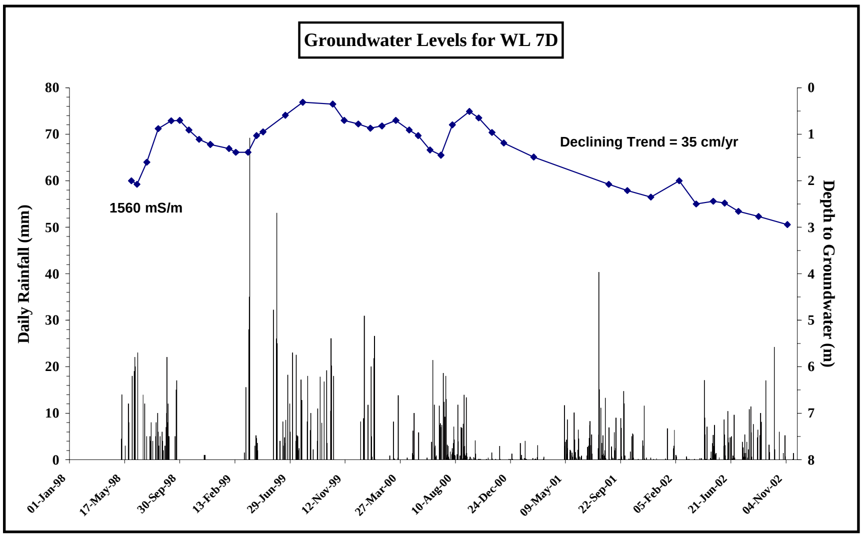
Figure 10: Hydrograph of a bore in the transitional zone along the Darling Fault

Analysis of the groundwater trends in the rejuvenated drainage system of the Moore River South zone indicates that the system may have achieved hydrological equilibrium in terms of groundwater level and the extent of salinity. Bore WL7D shows a response to the 1999 high rainfall event with a declining trend of 35 cm/yr in drier years (Figure 11a). This response was analysed using the Flowtube calculator. Results showed that the groundwater will fluctuate over the next 50 years between its current levels and those in 1999.[b] These results are only an indication of future water levels and should be treated with caution as many simplifications, assumptions and estimates are included in the calculations.

Bore PB2D depicts another monitoring bore with near constant watertable levels that do not vary apart from minor seasonal fluctuations, indicating a system in equilibrium (Figure 11b).

[b] Flowtube is a relatively simple 2-D groundwater balance calculator developed by the Department of Agriculture in collaboration with CSIRO Land and Water and The University of Melbourne. It is designed to predict groundwater levels along a cross-section of a catchment or hillside to represent a flowpath. Flowtube assesses the long-term trends in groundwater levels, estimates rates of groundwater level rise, length of cross-section with groundwater close to the surface, and the periods of time over which groundwater movements will take place.

a)



b)

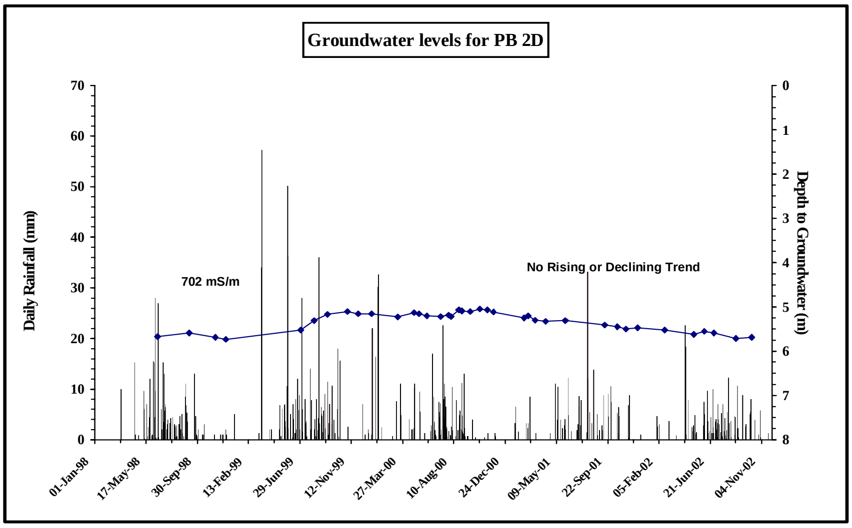
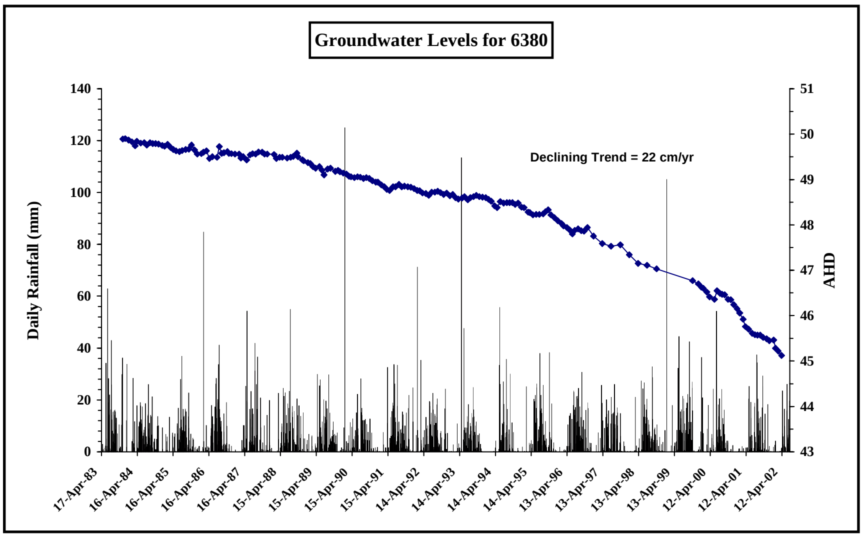


Figure 11: a) and b) Hydrographs depicting groundwater trends in the Moore River South zone

Data from the Department of Environment was analysed to determine groundwater trends for the Moore River West zone. The hydrograph for bore 6380, which is connected to the Leederville Formation near Gingin, shows a declining trend of 22 cm/yr (Figure 12a). This site is located south of the Gingin Brook in an area where groundwater is extracted for private or public use.

North of the Gingin Brook, Bore 6579 is located in native vegetation and is situated on a perched groundwater system in Quaternary sediments. Groundwater trends from this bore represent a system that is at equilibrium and only fluctuates with seasonal changes (Figure 12b).

a)



b)

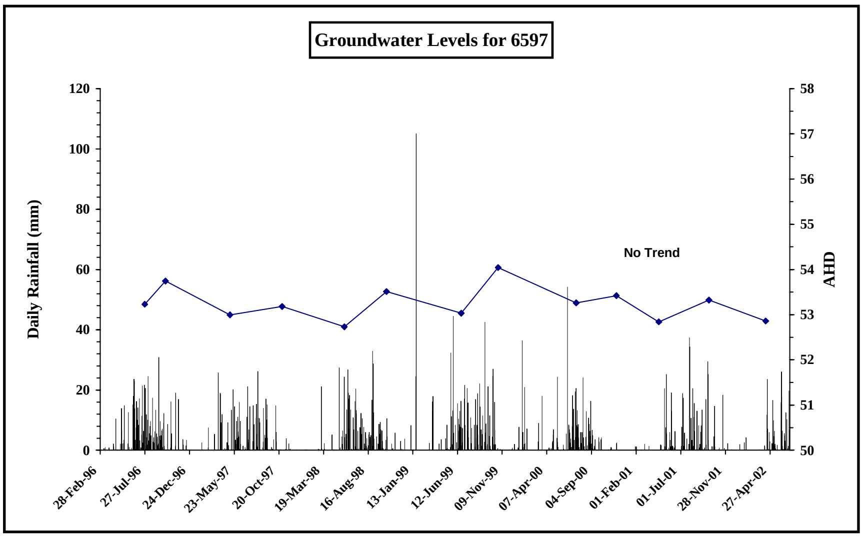


Figure 12: a) and b) Hydrographs depicting groundwater trends in the Moore River West zone

3.3.1.1 Extent of salt-affected land (1990 and 2000)

The Land Monitor Project covered the area east of the Darling Fault on the Yilgarn Craton, representing 80 per cent of the catchment. [c] The Project used satellite data and mapped 10 per cent (104,000 ha) of the valleys on the Yilgarn Craton as salt-affected.[d] Salt-affected land with dense vegetative cover in spring is not mapped using this technique.

[c] The Land Monitor Project was a multi-agency project supported by the Natural Heritage Trust.

[d] Extent of salt-affected land was calculated by combining the Land Monitor Projects' Perth, Moora and Bencubbin Landsat TM scenes. Details and accuracy statements of the data sets can be found in Caccetta et al. (2000), Furby (2001) and Wallace & Bryant (2001).

3.3.1.2 Low-lying areas with the potential for shallow watertables

Dunne & Caccetta (2001) used a Digital Elevation Model (DEM) to map low-lying areas.[e] Nearly one-quarter (251,000 ha) of the area analysed is low-lying. In wetter years the low-lying areas are at risk of flooding, inundation and waterlogging and, where groundwater levels are rising, indicate areas with the potential to become saline and/or waterlogged. Because the maps are a derived product from the DEM they need to be analysed with other hydrological information before being interpreted as indicating areas at hydrological risk.

3.3.1.3 Extent of roads affected by salinity

Six per cent or 550 of the 8,700 km of roads are currently affected by salinity. The current cost of additional construction and maintenance is estimated at $1 M annually. A further 1,000 km of roads are within low-lying areas. In areas of shallow watertables, construction and maintenance costs of standard sealed country roads are increased by 25 to 35 per cent and 15 per cent respectively. The construction and maintenance costs of gravel roads are increased by about 40 per cent and 25 per cent respectively (Department of Agriculture 2001). If shallow watertables affect these roads in the next forty years, additional costs are estimated to be $2.7 M annually.

3.3.2 Moore River

Angela Alderman, Technical Officer

Black (2001) outlined the general condition of the Moore River and Gingin Brook:

- Bank erosion is severe and extensive on the Moore River. Deep pools are now mostly filled with sediment.
- The extent of erosion and the enormous quantity of sediment on the move suggests that the old drainage line of the river may no longer be large enough or strong enough to contain the energy of floodwaters because there is:
  - a greater volume of water flowing off the catchment due to clearing
  - a reduction in the dissipation of the energy of floodwaters due to less fringing vegetation along the river
  - prevention of water dispersal over the floodplains by levee banks.
- Stock have direct access to a large proportion of the river foreshore and septic tanks are used along both waterways, causing concern for human and environmental health.

In 1999, the Department of Environment (formerly the Water and Rivers Commission), regularly sampled five estuarine sites in the Moore River estuary and

[e] They used DEMs to identify surface-water flowpaths, then labelled land lying within 2-m elevation of these flowpaths as 'low-lying'. In well dissected landscapes these correspond with valley floors, and in areas of internal or basin drainage, each basin is labelled as low-lying.

four catchment sites along the lower reaches of the Moore River and Gingin Brook (Cousins 1999).

3.3.2.1 Physical parameters

- Surface salinity levels at the estuarine sites generally ranged from 400 mS/m to 1,800 mS/m.[f] Bottom salinity levels at these sites increase with the intrusion of seawater when catchment flow is minimal. Salinity levels of both the Moore River and Gingin Brook were consistently below 300 mS/m before Moora flooded in March 1999. The salinity of the Moore River increased to 1,400 mS/m by October before slowly becoming fresher. The water salinity of the Gingin Brook did not change and is therefore a different system to both the river and the estuary.
- Summer water temperature ranged from 20 to 26 °C and dropped to 14 °C by July. Temperatures in Gingin Brook tended to be slightly lower than those in the Moore River and the estuary.
- Surface dissolved oxygen levels were fairly consistent in the estuarine sites, ranging between 60 and 105 per cent saturation—a healthy system should have at least 80 per cent oxygen saturation over a daily cycle (ANZECC 1992). Bottom water saturation was generally lower than at the surface and occasionally showed deoxygenated conditions, usually associated with salinity stratification.

3.3.2.2 Chemical parameters

- Surface total nitrogen concentrations within the estuary were generally higher than those from bottom waters. All sites had surface median total nitrogen concentrations exceeding freshwater guideline values. Gingin Brook tended to have higher total nitrogen concentrations than the other sites with concentrations of 1.5–2.2 mg/L for most of the winter months.
- Total phosphorus concentrations in Gingin Brook were very high whereas the estuarine and Moore River sites had low concentrations.
- Concentration of total suspended solids was generally low at all sites, and lowest at Gingin Brook, Median concentrations indicate sediment loads tend to increase with distance from the ocean. Bank stability tends to decrease further upstream due to eroding riverbanks, and this may affect the sediment load. With the amount of suspended sediment decreasing as the river flows to the ocean sedimentation in the river is a concern.

3.3.2.3 Biological parameters

- Total phytoplankton concentrations were generally low at all sites early in the year. The main groupings of phytoplankton flora found in the estuary are diatoms, dinoflagellates, chlorophytes, and cryptophytes.
- Small numbers of cyanobacteria have been noted within the estuary although there have not been enough present to be of major concern.

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[f] Water salinity broad categories are:
Fresh – <90 mS/m; marginal – 90–270 mS/m; brackish – 270–900 mS/m; saline – >900 mS/m; Upper limits for adult sheep – 2,200 mS/m; Seawater – 5,300 mS/m

- *Enteromorpha* species—a filamentous green algae—is indicative of high levels of nitrogen and was noted at a catchment site in October. During summer months algal mats, which deplete the oxygen in water when they decompose, of *Enteromorpha* species are often observed in the estuary.

3.3.2.4 Groundwater springs

When the bar at the mouth of the estuary is open, water levels within the estuary are very low and several groundwater springs are exposed. Samples collected from the groundwater springs indicate the groundwater in the area contains elevated nutrients. Samples from the Water Corporation's production bores in Guilderton indicate the groundwater is generally high in total oxidised nitrogen with median concentrations greater than 3.5 mg/L—the guideline value for the protection of aquatic life in an estuary is 0.1 mg/L and for drinking water is 10 mg/L of nitrate (ANZECC 1992).

Concentrations appear to have increased over the last ten years. Any apparent increase in total oxidised nitrogen in the groundwater around Guilderton is of concern due to discharge into the estuary when riverine flows are low and due to the use of groundwater for human consumption.

3.3.3 Water resources

Angela Alderman, Technical Officer

Depending on the position in the landscape and design of the structure, private farm water supplies may be at risk from salinisation, eutrophication, siltation and significant evaporation losses.

Increased cropping activity has decreased the reliability of high-grade domestic water supplies. Crop spraying uses a significant proportion of the domestic rainwater at the beginning of the growing season, before tank capacities have recovered from the summer/autumn demand.

The interaction between the Moore River system, the Gingin Brook system and their associated groundwater systems is being investigated (Black 2001). Preliminary results show:

- Saline water from the Moore River is leaching into the coastal plain aquifer south-west of Cowalla Bridge. This leaching will lead to rising groundwater salinity in the coastal aquifer and will impact on coastal groundwater public water supplies and further groundwater extraction.
- There is hydraulic conductivity between the Coonderoo River and the Perth Basin aquifers. There is potential for saline river water to drain into and contaminate the Perth Basin aquifers.
- There is increasing demand for groundwater abstraction in the lower Moore River catchment. This demand raises concerns that saline groundwater may migrate from the river as a consequence of large bore abstractions.
- The Gingin Brook is primarily a groundwater fed system.
- Nutrient levels are high in the Gingin Brook. Excess fertilisers are considered to be entering the Brook from surface run-off and groundwater flow.

3.4 Native vegetation representation and risk

Mike Clarke, Revegetation Officer

3.4.1 Native vegetation representation

Most of the clearing in the catchment has occurred on the Yilgarn Craton where agriculture has a longer history than on the Perth Basin and where soil types are more fertile. Less than one-quarter of the catchment's original native vegetation cover is retained. The native vegetation contains 83 species of priority flora and 38 species of declared rare flora (Appendix 1).

A vegetation type is considered under-represented if there is less than 25 per cent of its original distribution remaining (Table 7) (Beard 1976). Examples are:

- *Allocasuarina campestris* shrubland with patches of heath (6 per cent remaining)
- medium woodland of York gum and salmon gum (7 per cent remaining)
- *Acacia neurophylla, A. beauverdiana* and *A. resinomarginea* thicket (10 per cent remaining)
- medium woodland of York gum (11 per cent remaining)
- medium woodland of York gum and wandoo (13 per cent remaining).

3.4.2 Native vegetation at risk

Eight per cent of the remaining native vegetation is salt-affected and 11 per cent occurs in low-lying areas where they will be most affected by rising groundwater levels. The native vegetation is also threatened by excess grazing, damage from herbicide and fertiliser drift, weed invasion and altered fire regimes.

Table 7: Vegetation types and present cover

Vegetation type	Area of original cover (ha)	Proportion of original cover remaining (% of vegetation type)
Shrublands, *Allocasuarina campestris* with patches of heath	66,000	6
Medium woodland York gum and salmon gum	214,000	7
Shrublands, *Acacia neurophylla, A. beauverdiana* & *A. resinomarginea* thicket	70,000	10
Medium woodland York gum	65,000	11
Medium woodland York gum and wandoo	142,000	13
Shrublands, scrub heath on yellow sandplain, *Banksia* spp.–*Xylomelum* spp.	170,000	25
Low woodland *B. attenuata* and *B. menziesii*	37,000	32
Low woodland *B. prionotes*	54,000	46
51 other vegetation types	562,000	

Source: Shepherd et al. (2002)

3.5 Risks to agricultural production

Jason Kelly, Regional Economist

Important farm management issues for the catchment include physical factors, such as herbicide resistance, soil degradation, disease and climatic variation, and financial factors, such as increasing input costs, low return on capital compared to other investments and insufficient retained earnings to fund capital development. The occurrence of these problems varies between the three hydrological zones and between farms within the zones.

Production risk from salinity threatens farm and catchment viability and poses a major challenge in terms of management and amelioration. Land monitor data provides estimates for the extent of salinity encroachment before hydrological equilibrium is reached.

The current on-farm cost of areas of consistently low production in the catchment is around $4 M each year.[9] The increase in saline areas could cost the catchment over $9 M in lost production annually thirty years from now. Accounting for the loss of income of the thirty years results in a net present value of over $66 M, the cost of salinity to the catchment in today's dollars.

3.5.1 Market forecasts

The exchange rate is one of the key domestic macro-economic variables for Australia's primary industries because most international contracts are denominated in United States currency (US$). Significant movements in the Australian Dollar (A$) against the US$ will markedly influence commodity returns.

It is estimated that the A$ will average US$0.55 in 2002–03, primarily due to favourable interest rate differentials with the United States, and the world economy growing by around 3 per cent. Economic growth in Australia is expected to be slightly above 3 per cent in 2002–03, which is around half a per cent point lower than in 2001-02 due to the poor growing season.

3.5.1.1 Beef

In 2002–03, live cattle exports from WA are forecast to be similar to 2001–02 and slaughterings are expected to decline slightly. Saleyard prices are forecast to decline in Australia by more than 20 per cent in part due to subdued demand from Japan following an outbreak of BSE and a rise in Australian production. Over the medium term (2006–07) cattle prices are projected to decline further due to rises in US production and exports.

[9] Assuming the 5-year average operating profit for the catchment represents the cost once an area becomes saline and is taken out of production, and that the spread of salinity is linear over a thirty year period and this area is immediately unproductive.

3.3.1.2 Cropping

WA is forecast to produce nearly 7 million tonnes (Mt) of grain for the 2002–03 growing season, down 4 Mt from the previous year. Grain on average contributes about half of the State's GVAP, although this year will supply only 40 per cent. The impact of lower yields on State GVAP will be a 14 per cent decline from 2001–02 to $4.2 B. The value of agricultural exports is also expected to decline by 10 per cent to approximately $3.4 B.

Australian grain prices in particular are subject to movements in the US$. As little as a one-cent appreciation of the AUS$ reduces the price paid to Australian farmers by $5/tonne. Subsequently, over the medium-term grain prices are expected to fall as the AUS$ is likely to appreciate in line with world economic recovery and growth. Table 8 lists estimated production for 2002–03 and prices in 2003–04 for WA.

Table 8: Estimated crop production for 2002–03 and expected prices for 2003–04, for WA

Crop	Production in 2002–03 ('000 tonnes)	Expected prices 2003–04 ($/t)
Wheat	4,500	240-260
Barley	1,200	220-240 (malt) 170-200 (feed)
Lupins	0.6	220-240

3.3.1.3 Wheat, barley and lupins

Australian wheat prices are forecast to soften in 2003–04 given that the AUS$ is expected to appreciate. Prices could rise if there are production problems in North America. The prospects are for lower world wheat prices with the APW (10 per cent protein) estimated pool price between $240 and $260 per tonne.

Malting barley prices are expected to fall slightly from record highs in 2002 due to anticipated improved production in Australia and Canada.

Lupin prices are also likely to be slightly lower. An appreciating AUS$ has the potential to cut returns to growers over the medium term.

3.3.1.4 Sheep and wool

The focus in 2002–03 is likely to remain on supplies for processing and live export. However, the coming season will continue to be difficult because of low pasture availability in areas with lower rainfall. Demand should remain strong throughout 2002–03 and prices should follow a similar pattern to 2001–02, due to lower availability. ABARE is forecasting a 15 per cent increase in lamb production over the five years to 2006–07. Rising lamb supplies are forecast to result in an easing of prices but strong export demand from the US should ensure prices are not affected too greatly.

Low supply will keep wool prices high. The Western Market Indicator is expected to average 793 cents per kilogram clean in 2002–03, up 4 per cent from the previous season. With wool prices remaining high relative to other fibres, there is likely to be some substitution by processors away from wool. Downward pressure should be maintained on wool over the medium term due to intense competition between fibres.

4. Management options and impacts

This section sets out options for managing hazards. Factors such as soil type, annual rainfall, enterprise mix and financial structure will determine what is the most suitable approach for a farm business.

4.1 Land management

David Rogers and Kari-Lee Falconer, Development Officers

The ability of a plant to use water affects groundwater recharge. Perennial plants use more water than annuals because they have deeper root systems and can use water all-year-round. Perennial pastures, fodder shrubs, commercial tree plantings and either revegetation or protecting remnant vegetation, are ways to reduce recharge.

Some annual crops and pastures can be manipulated to use more water. However, this will have a minimal impact on the level of recharge, so the choice of farming system should be based on profitability.

Warm season crops are often suggested as a tool for assisting in recharge management. A range of species and varieties has been grown with varying success. At present, the overall effect on recharge is not known, but research on this issue is continuing.

Areas such as those with shallow watertables or hillside seeps should be considered for perennials. Some options for these areas are:

- Lucerne - once established will persist on 300 mm annual rain. It will grow in a wide range of soil types with surface and subsurface soil pH higher than 4.8, on a site that is well-drained and has a low weed burden.
- Summer fodder crops - sorghum and millet.
- Tall wheat grass - is waterlogging and mildly salt tolerant, and has good drought tolerance.
- Balansa clover - is waterlogging and mild to moderately salt tolerant. It can be grown on acidic soils with pH greater than 4.5.
- Puccinellia – is salt and waterlogging tolerant.
- Saltbush and bluebush - Saltbush will tolerate some waterlogging and is quite salt and drought tolerant. Bluebush will tolerate waterlogging or flooding for only a few days and is usually seen in areas with well-drained marginal to moderately saline soils.

- Sub-tropical perennial grasses - are recommended for use on areas unsuitable for cropping as once they are established they may be difficult to eradicate. The Setaria's are tolerant of temporary waterlogging and are cold tolerant. Rhodes grass has moderate frost tolerance, Bambatsi is a very drought resistant and cold tolerant, and green panic has good drought resistance.
- Native perennial grasses.
- Tagasaste.

Perennials are generally unprofitable in broadacre systems in the medium to low rainfall areas. Phase farming with lucerne may have potential; however lucerne is unsuitable for large areas of the catchment, particularly in the Moore River North zone, as several soil types are too acidic. In the areas where lucerne is more suited it should be planted in small areas on more heavy ground so that its establishment, persistence and production capabilities can be assessed without a large outlay.

Another option for increasing water use on acid soils unsuitable for lucerne is serradella. For the heavier ground with higher pH, Casbah Biserrula is an option, although this species will not tolerate waterlogging, particularly at germination.

4.1.1 Analysis of perennial pastures in the farming system

David Rogers, Development Officer

A farming systems analysis using STEP, AgET, Catcher and Flowtube was conducted for including perennials into the current farming system for three typical farms in the Moore River North, Moore River South and Moore River West zones[h]. Each farm was assessed on how it would respond under three scenarios:

- current standard practice annual rotations
- phase cropping with lucerne (5 years crop, 3 years lucerne) on cropping areas and appropriate permanent perennials on non-cropping country
- strategic use of perennials on non-cropping country.

The analyses were based on the pessimistic assumption that all low-lying areas mapped by Land Monitor will be affected by shallow watertables within 50 years and become saline. Optimistic assumptions were also made about the effectiveness of lucerne in reducing recharge.

In the Moore River North zone, perennials on non-cropping country are economically competitive and could reduce the potential area of salinity from 28 to 20 per cent over the next 50 years. Lucerne phase-farming plus perennials, however, was unprofitable even if it halved the area affected by salinity (a reduction from 28 to 14 per cent affected).

In the Moore River South zone, modelling shows that perennials on non-cropping country will have no impact on potential salinity, but are economically competitive with current farming systems. Lucerne, however, would have a small impact on the extent of salinity but would reduce incomes significantly in the long term.

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[h] The STEP (Simulated Transitional Economic Planning) decision tool is a whole farm simulation model used to analyse the financial viability of different farming systems over time.

In the Moore River West zone perennials are the best option as they greatly increase economic returns over the current system, and reduce recharge as well. It is also the zone where perennials have a better fit, as there is minimal cropping.

The modelling demonstrates that:

- phase farming with lucerne across the bulk of the landscape is unlikely to increase production and is, therefore, not as economical as current annual rotations;

- there is a benefit from early management of salt-affected areas and having perennial systems in those areas of the farm that are no longer used for annual rotations.

4.1.2 Land hazards

Options for managing common land hazards in the catchment are listed in Table 10.

Table 10: Options for managing hazards

Land management hazard	Principal management options
Water repellence	• claying • furrow sowing • use of wetting agents
Soil compaction	• zero tillage system • reduce traffic and avoid traffic and tillage when the soil is wet • practice tramline farming • select equipment with lower wheel loads • improve drainage of wet soils (both surface and subsurface) • increase and incorporate organic matter in soil
Wind erosion	• maintaining ground cover at adequate levels - on soils at risk, ground cover needs to be at least 50 per cent • claying blowouts • minimising the level of disturbance by mechanical action or by livestock • retaining stubble • managing summer grazing
Subsurface acidity	• liming - given the variability of pH over even small areas, it is recommended that landholders include pH monitoring of high risk soils in management plans • use less acidifying fertilisers, reduce leaching of nitrogen, return plant material to the paddock) • grow more tolerant species • apply more nutrients as they become unavailable in the soil • raise the soil pH
Waterlogging	• agronomic options, such as applying fertiliser to assist crops to recover, and using farming systems that are less susceptible • engineering options, such as surface water management structures and raised bed cropping

4.2 Water management

Section 4.1 provided plant water-use options to reduce recharge and plant species to make productive use of salt-affected land. Other options are increasing discharge with drains and pumps, and reducing recharge through surface water management.

4.2.1 Groundwater management

Stuart Delphin, Hydrologist

To protect priority resources such as prime agricultural land, infrastructure and high value conservation areas, groundwater drainage and/or pumping may need to be considered in some situations to complement other salinity management options. Subsurface drainage and pumping systems can increase groundwater discharge rates and relieve the hydraulic pressure of the aquifer.

The success of any groundwater drainage or pumping system depends on the size and characteristics of the contributing groundwater flow system. These systems are expensive with the costs often exceeding the benefits.

4.2.1.1 Groundwater drainage (open deep or leveed open deep drains)

Deep drains can be used to lower watertables to prevent the additional accumulation of salts, while allowing rainfall to leach salt from the soil profile. They tend to be deeper than 1 m and either open or closed to surface water flow. The effectiveness of deep drains is variable, particularly in flat landscapes with low groundwater gradients and subsoils with low permeability, as found in the Moore River North zone. Deep drains in sandy soils have a high risk of wall instability and slumping. They need to be designed to handle surface and flood flows, as these can cause erosion and sedimentation.

4.2.1.2 Groundwater pumping (mechanical and biological)

Using mechanical pumps (production wells) is also a costly method of removing groundwater to lower watertables. However they can be effective and economic in protecting high value assets, such as town sites. In many situations a single pump will have a minimal radial effect on groundwater levels (perhaps 200–300 m) and therefore most pumping systems require a number of bores and pumps to be installed. The effectiveness of a pumping system relies on the underlying aquifer having a high permeability and hydraulic connection to the soil surface.

Relief wells are cheaper to establish and maintain, as they do not have the costs associated with purchasing, running and maintaining a mechanical pump. However, they are only suitable in situations where there is an aquifer with a hydraulic pressure head (piezometric head) above the land surface. In areas with sloping ground and where the head is below ground, siphons can be used.

Most species of trees, shrubs and perennial pastures do not use groundwater stored within aquifers. In shallow watertables some plants draw water from above the capillary fringe of the watertable and this is then replaced by water drawn up from the aquifer. In these situations trees can lower watertables by 1-2 m, but they are less effective where the groundwater is saline. There is generally only minimal drawdown of watertables 10–30 m away from planted areas. Perennials are most effective on localised groundwater flow systems particularly in reducing seepage from perched aquifers.

4.2.1.3 Responsibilities (legal and community)

Current legislation (*Soil and Land Conservation Act*) requires landholders that are proposing

> "to drain or pump water from under the land surface because of salinity and to discharge that water onto other land, into other water or into a watercourse,"

to notify the Commissioner of Soils and Land Conservation in writing at least 90 days before the works commence (Notice of Intent (NOI) to Drain or Pump).

Disposing excess water from salinity management systems in a responsible manner is essential. It is currently not acceptable for a landholder to increase the volume of water or salt leaving their property if it significantly contributes to waterlogging, salinity or flooding on neighbouring private or public land. In situations where there is a high risk of this occurring, evaporation basins or storage ponds may need to be considered to evaporate or store the excess water. Basins and ponds need to be carefully designed, located and constructed to ensure that they have adequate capacity, are not at risk from flooding and do not leak. Landholders need to be conscious of their duty of care to ensure their management practices do not lead to further land degradation.

4.2.2 Surface water management

Peter Whale and Frank Rickwood, Land Conservation Officers

The recommended approach is to reduce surface water flow with sound soil management practices, and manage the remaining flow with earthwork structures.

4.3.2.1 Land management options

Year-round vegetation cover reduces surface water run-off by using water where it falls. Options include:

- protecting remnant vegetation
- revegetating with native or commercial tree species
- intercropping with lucerne
- phase farming with lucerne
- establishing perennial pastures.

4.2.2.1 Earthwork options

Where the slope and soil characteristics of the land encourages water to move off the land—a shedding landscape (Farmer et al. 2002)—surface water earthworks can reduce the velocity and volume of the water to avoid serious soil erosion. Where there is little slope in the land, water flows from a shedding landscape and accumulates in a receiving landscape causing waterlogging, flooding and groundwater recharge.

The shedding landscapes in the catchment comprise upland hillslopes with slopes exceeding 3 per cent and are the primary source areas for run-off. In large run-off events these areas promote high run-off velocities with the potential to severely erode soils.

Receiving landscapes, which account for three-quarters of the catchment, are areas of lower relief than the adjacent shedding slopes where water may not drain as rapidly, resulting in water accumulation causing waterlogging and flooding. Landscapes with low relief may be alternatively characterised as areas with ‘limited self-drainage’ potential. These are areas that receive in-situ rainfall and have low gradients without defined drainage, leading to waterlogging, ponding, flooding and increased recharge.

Subject to site survey, Table 11 provides a guide to the potential for earthwork structures on landscape elements. Surface water management options for the soil supergroups are outlined in Table 12.

Table 11: Slope classes, landscape elements and suitable earthwork structures

Slope class (%)	Proportion of catchment (%)	Landscape element	Earthwork structures
0–1	32	Valley floors to lower slopes	• W, flat-bottomed, spoon, V drains • leveed open deep drains • levee banks and leveed waterways
1–3	43	Lower slopes to mid-slopes	• grade banks & broad based banks (on slopes >2%) • seepage interceptor & reverse bank seepage interceptor drains • levee banks and leveed waterways
3–5	14	Mid-slopes to upper slopes	• grade banks & broad based banks • seepage interceptor & reverse bank seepage interceptor drains • levee banks and leveed waterways
5–10	9	Upper slopes	• grade banks • level & absorption banks below rocky outcrops or breakaways • levee banks and leveed waterways
>10	2	Steep slopes	• earthworks generally not recommended • good soil conservation management practices required, such as working to the contour, and maintaining a good pasture cover

Table 12: Surface water management options for soil supergroups

Soil supergroup	Degradation risks	Surface water management options
Deep sand	Water erosion generally not a problem	• generally earthwork structures not required • working to the contour and maintaining a healthy pasture cover
Sandy earth	Surface water generally not a problem	• working to the contour and maintaining a healthy ground cover
Ironstone gravelly soil	Water erosion can occur on gravels over a cemented layer of clay	• grade banks • level and absorption banks on upper slopes where there is no suitable waterway
Sandy duplex	Water erosion, waterlogging, flooding on valley floors	• grade banks • seepage interceptor banks • shallow relief drains
Loamy earth	Water erosion, waterlogging, sometimes saline	• grade banks • seepage interceptor banks
Wet or waterlogged soil	Water erosion on slopes, waterlogging, flooding on valley floors, salinity	• grade banks • seepage interceptor banks • shallow relief drains on flatter sections or deep drains
Loamy duplex	Water erosion, waterlogging, flooding on valley floors	• grade banks • seepage interceptor banks • shallow relief drains

4.3 Vegetation management

Mike Clarke, Revegetation Officer

4.3.1 Enhancing remnant vegetation

Remnant vegetation can be enhanced by:

- Fencing out stock to prevent eating of regenerating plants, soil compaction, introduction of weed seeds and nutrients in the form of dung.
- Planting at least five or six rows of trees and shrubs around the perimeter of the remnant to act as a buffer strip against degradation, such as weed invasion and chemical drift. These plantings also enhance water use, particularly if the remnant is found near rocky outcrops.
- Creating links with other remnants through revegetated wildlife corridors. Drainage lines are good sites for corridors as they can link the top of the catchment to the bottom. Wildlife corridors should be wide and structurally diverse and the species planted should reflect the original vegetation.

4.3.2 Revegetation for salinity control

When revegetating to manage sandplain seeps, plantings should extend the entire width of the seep on the upslope side and contain eight to ten rows of trees and shrubs on five by five metre spacing. Tree and shrub plantings need to be located in areas where they can maximise their water using ability. The following areas in the catchment are suggested for strategic plantings:

- at the break of slope, above the valley floor
- above seepage areas
- below rocky outcrops
- at the change of soil type texture, particularly from a sand to loam or clay
- flanking drainage lines
- on salt-affected areas with plants such as melaleuca, saltbush, samphire, bluebush and Balansa clover.

Saltland areas should be fenced to enable salt tolerant plants to establish naturally. In saltland areas which may be waterlogged for periods up to two weeks, saltbush pastures, such as River Saltbush (*Atriplex amnicola*), Wavy Leaf Saltbush (*At. undulata*) and Quail Brush (*At. lentiformis*), are recommended.

4.3.3 Commercial revegetation

At present, potential commercial tree options for the catchment include:

- maritime pine
- oil mallees
- sandalwood
- various eucalypts for commercial timber crops.

Other perennial options may include grasses, lucerne and fodder shrubs such as *Acacia saligna* and tagasaste.

4.3.4 Revegetating drainage lines

Many of the main drainage channels in the catchment have remnant vegetation, which should regenerate if protected from grazing, flanking its margins.

When revegetating areas flanking drainage lines, construct a similar community of plants that would have grown there originally, starting with the most salt-tolerant closest to the drainage channel. A minimum vegetated width of 50 m either side would be suitable for the major drainage lines in the catchment. Also make sure that excess surface water is controlled, particularly if the area to be planted is showing signs of salinity.

5. Further information and contacts

Topic	Organisation	Local contact	Website address
Climate	Bureau of Meteorology		www.bom.gov.au/climate
Soils & land use	Department of Agriculture, Geraldton District Office Tel: (08) 9956 8555 Fax: (08) 9921 8016	Soil Resource Officer	www.agric.wa.gov.au/progserv/natural/assess/ www.agric.wa.gov.au/progserv/natural/assess/lra_soil_mapping.htm
Farming systems and group development		Farming Systems Development Officer	www.agric.wa.gov.au
Productive uses for saline land			
Revegetation		Revegetation Officer	
Economics		Regional Economist	
Surface water management		Land Conservation Officer	www.agric.wa.gov.au/drains
Groundwater & salinity		Hydrologist	
- salinity mapping	Land Monitor		www.landmonitor.wa.gov.au
- national audit	National Land and Water Resource Audit		www.nlwra.gov.au
Native vegetation	Department of Conservation and Land Management, Geraldton District Office Tel: (08) 9921 5955		www.calm.wa.gov.au
Regional planning & funding	Northern Agricultural Catchments Council (NACC), Department of Agriculture, Three Springs Tel: (08) 9954 1101		www.calci.org www.nacc.com.au

Publications — Department of Agriculture

Bulletin 4343	Soil guide: a handbook for understanding and managing agricultural soils
Bulletin 4324	Trees and shrubs for the midlands and northern wheatbelt
Resource Management Technical Report 185	Common conservation works used in Western Australia

Farmnotes

Drainage and pumping

42/2001	Relief wells in Southern WA
20/2001	Groundwater pumping for salinity control
47/1993	Notification of draining or pumping saline land
9/1991	Responsibilities of Landholders under agricultural Acts: Water and Drainage
79/1986	Legal aspects of land drainage
66/1985	Controlling surface water flow above salt-affected areas

General

5/2002	Climate change projections and impacts for WA (replaces Farmnote 8/90)
40/2001	National audit on dryland salinity
8/2000	Salinity at a glance
71/99	Tolerance of plants to salty water
59/88	Livestock and water salinity

Management and monitoring

59/2002	Monitoring groundwater levels (replaces 102/00)
105/2001	Measuring salinity on the farm
39/2001	Recharge management for salinity control
18/2001	Airborne geophysics – a tool for salinity assessment and management
103/2000	Environmental management systems for agriculture
44/97	Sub-catchment management plans
19/96	Does Landcare pay? – benefit and cost studies
78/93	Waterlogging and inundation: why they could be costing you money
79/93	Managing waterlogging and inundation in pastures
80/93	Managing waterlogging and inundation in crops
35/91	A simple way to monitor your saltland
133/84	Saltland management – the catchment approach

Perennial pastures

84/2001	Lucerne: a high water use production package
54/2001	Running breeding cows on tagasaste in conjunction with a cropping enterprise
53/2001	Running breeding cows predominantly on tagasaste
52/2001	Using tagasaste for sheep production
51/2001	Finishing cattle on tagasaste
43/2001	Native perennial grass based pastures for livestock
36/2001	Grazing sheep and cattle on dryland lucerne
135/2000	Lucerne in pasture crop rotations – establishment and management
51/2000	Establishment of the perennial fodder shrub Tagasaste
59/96	Green feed in summer
8/93	Establishing perennials in areas with less than 700 mm rainfall
53/89	Insect pests in lucerne

79/89	Diseases and their control in lucerne

Farmnotes (continued)

Saltland agronomy

3/2001	FRONTIERЉ – an early maturing balansa clover for the wheatbelt
47/2000	Saltland pastures: changing attitudes towards saline land
44/2000	Tall wheat grass and balansa clover: A beneficial partnership for waterlogged, mildly saline soils
84/2002	Establishing balansa and Persian clovers on waterlogged, mildly saline soils
1/99	Puccinellia – for productive saltland pastures
75/96	Harvesting tall wheat grass and puccinellia for seed
81/91	Calculating saltbush seeding rates
87/89	Grazing and management of saltland shrubs
44/86	Saltland management – revegetation
32/86	Saltland management – selecting forage plants for saltland

Soil management

67/2002	Amount of stubble needed to reduce wind erosion
47/2002	Optimum soil pH for crop plants
38/2002	Looking at liming: quality (replaces Farmnote 67/00 and 69/00)
80/2000	Management of soil acidity in agricultural land
78/2000	The importance of soil pH
70/2000	Looking at liming – consider the rate
14/97	Claying water repellent soils
110/96	Assessing water repellence
66/96	Stubble management to control land degradation
65/96	Soil management options to control land degradation
35/96	Preventing wind erosion
57/90	Identifying gypsum-responsive soils

Remnant vegetation

2/2001	Reducing rates and taxes on farm bushland
141/2000	The value and benefits of healthy farm bush
34/99	Regulation 4, governing land clearing

Trees

98/2001	Eucalyptus oil mallees
14/2001	Low rainfall farm forestry for the wheatbelt
46/2000	Pioneer plants in revegetation
38/2000	Vegetation buffer zones
80/99	Specialty timbers for the WA wheatbelt
40/98	Direct seeding of native plants for revegetation
37/98	Site preparation for successful revegetation for agricultural regions
36/98	Site assessment for successful revegetation for agricultural regions with less than 600 mm rainfall
27/98	Southern sandalwood: an introduction
31/91	Tree planting for erosion and salt control

There are also a number of Treenotes, Fact Sheets and Information kits available.

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ANZECC—*see* Australian and New Zealand Environment and Conservation Council.

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Appendix 1: Vegetation types and priority flora

Table A1: Declared rare and priority flora

Species	Status	Species	Status
Acacia aprica	R	*Stylidium coroniforme*	R
Acacia aristulata	R	*Synaphea quartzitica*	R
Acacia cochlocarpa subsp. *cochlocarpa*	R	*Thelymitra stellata*	R
Acacia recurvata	R	*Thomasia* sp.Green Hill (S.Paust 1322)	R
Acacia vassalii	R	*Acacia lineolata* subsp. *multilineata*	P1
Andersonia gracilis	R	*Acacia trinalis*	P1
Caladenia drakeoides	R	*Billardiera* sp.Seabird (G.J.Keighery 12977)	P1
Chorizema humile	R	*Calectasia palustris*	P1
Conospermum densiflorum subsp. *unicephalatum*	R	*Dampiera tephrea*	P1
Darwinia acerosa	R	*Dryandra fuscobractea*	P1
Darwinia carnea	R	*Eucalyptus subangusta* subsp. *virescens*	P1
Darwinia chapmaniana	R	*Eucalyptus* x *mundijongensis*	P1
Darwinia sp.Carnamah (J.Coleby-Williams 148)	R	*Gastrolobium rotundifolium*	P1
Daviesia dielsii	R	*Gnephosis setifera*	P1
Drakaea concolor	R	*Grevillea evanescens*	P1
Dryandra mimica	R	*Micromyrtus rogeri*	P1
Dryandra serratuloides subsp. *serratuloides*	R	*Pityrodia axillaris*	P1
Eleocharis keigheryi	R	*Scholtzia* sp.Gunyidi (J.D.Briggs 1721)	P1
Eremophila pinnatifida	R	*Synaphea panhesya*	P1
Eremophila scaberula	R	*Synaphea sparsiflora*	P1
Eremophila vernicosa	R	*Verticordia huegelii* var. *tridens*	P1
Eucalyptus argutifolia	R	*Acacia chapmanii* subsp. *chapmanii*	P2
Eucalyptus impensa	R	*Acacia flabellifolia*	P2
Eucalyptus pruiniramis	R	*Calytrix platycheiridia*	P2
Eucalyptus rhodantha var. *rhodantha*	R	*Goodenia arthrotricha*	P2
Gastrolobium appressum	R	*Grevillea bracteosa*	P2
Gastrolobium hamulosum	R	*Haloragis aculeolata*	P2
Grevillea christineae	R	*Isotropis cuneifolia* subsp. *glabra*	P2
Grevillea pythara	R	*Melaleuca* sp.Yanchep (G.J.Keighery 11242)	P2
Hemiandra gardneri	R	*Acacia anarthros*	P3
Jacksonia pungens	R	*Acacia cummingiana*	P3
Paracaleana dixonii	R	*Acacia drummondii subsp. affinis*	P3
Ptilotus fasciculatus	R	*Acacia nodiflora*	P3
Ptychosema pusillum	R	*Allocasuarina ramosissima*	P3

Table A1: (continued)

Species	Status	Species	Status
Angianthus micropodioides	P3	*Acacia clydonophora*	P4
Baeckea tenuifolia	P3	*Anigozanthos humilis* subsp. *chrysanthus*	P4
Banksia micrantha	P3	*Anthotium junciforme*	P4
Beaufortia eriocephala	P3	*Astroloma* sp.Cataby (E.A.Griffin 1022)	P4
Blennospora sp.Ruabon (B.J.Keighery & N.Gibson 20)	P3	*Caladenia cristata*	P4
Calothamnus brevifolius	P3	*Caladenia speciosa*	P4
Chamelaucium conostigmum	P3	*Calothamnus pachystachyus*	P4
Dillwynia dillwynioides	P3	*Calytrix sylvana*	P4
Dryandra echinata	P3	*Conostephium minus*	P4
Dryandra lindleyana subsp. *pollosta*	P3	*Diuris recurva*	P4
Eucalyptus macrocarpa x *pyriformis*	P3	*Dodonaea hackettiana*	P4
Grevillea florida	P3	*Drosera occidentalis* subsp. *occidentalis*	P4
Guichenotia tuberculata	P3	*Dryandra polycephala*	P4
Haemodorum loratum	P3	*Eucalyptus rhodantha* var. *petiolaris*	P4
Isopogon drummondii	P3	*Eucalyptus* x *carnabyi*	P4
Leucopogon oliganthus	P3	*Gastrolobium callistachys*	P4
Melaleuca sclerophylla	P3	*Grevillea drummondii*	P4
Monotoca leucantha	P3	*Grevillea saccata*	P4
Myriocephalus appendiculatus	P3	*Hemiandra hancocksiana*	P4
Nemcia axillaris	P3	*Regelia megacephala*	P4
Olax scalariformis	P3	*Schoenus natans*	P4
Persoonia rudis	P3	*Stachystemon axillaris*	P4
Persoonia sulcata	P3	*Stylidium carlquistii*	P4
Petrophile plumosa	P3	*Verticordia lindleyi* subsp. *lindleyi*	P4
Platysace ramosissima	P3	*Verticordia paludosa*	P4
Verticordia insignis subsp. *eomagis*	P3	*Wurmbea drummondii*	P4
Verticordia muelleriana subsp. *muelleriana*	P3		

Source: Department of Conservation and Land Management (2003)

Definitions of conservation codes given to declared rare and priority flora (Atkins 1998).

R: Declared Rare Flora – Extant Taxa

Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.

P1: Priority One – Poorly Known Taxa

Taxa that are known from one or a few (generally less than five) populations, which are under threat, either due to small population size, or being on lands under immediate threat, e.g. road verges, urban areas, farmland, active mineral leases, or the plants are under threat, e.g. from disease, grazing by feral animals. May include taxa with threatened populations on protected lands. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

P2: Priority Two – Poorly Known Taxa

Taxa which are known from one or a few (generally less than five) populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered). Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

P3 Priority Three – Poorly Known Taxa

Taxa that are known from several populations, and the taxa are believed to be not under immediate threat (i.e. not currently endangered), either due to the number of known populations (generally more than five), or known populations being large, and either widespread or protected. Such taxa are under consideration for declaration as 'rare flora', but are in need of further survey.

P4 Priority Four – Rare Taxa

Taxa which are considered to have been adequately surveyed and which, while being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5–10 years.

Note: The need for further survey of poorly known taxa is prioritised into the three categories depending on the perceived urgency for determining the conservation status of those taxa, as indicated by the apparent degree of threat to the taxa on the current information.