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SALINITY SITUATION STATEMENT COLLIE RIVER

GOVERNMENT OF WESTERN AUSTRALIA

SALINITY SITUATION STATEMENT

COLLIE RIVER

WATER AND RIVERS COMMISSION REPORT
WRT 29
WATER RESOURCE TECHNICAL SERIES

Water and Rivers
Commission

SALINITY SITUATION STATEMENT

COLLIE RIVER

BY

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Resource Science Division

Water and Rivers Commission

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Foreword

The State's Salinity Strategy (March 2000) stated that 'the target for the Collie River inflow to the Wellington Dam is to have potable water by 2015'. The Water and Rivers Commission undertook to 'arrange implementation of plans based on a cost-sharing framework that considers public benefit' (page 34). The Commission has established the community-based Collie Recovery Team to assist the Commission to meet its commitments. The Team prepared a Strategic Action Plan to guide its work. This Salinity Situation Statement addresses 9 of the 39 high priority actions listed in the Plan.

Reference Details

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Cover photograph: Wellington Dam [Taken by Pam Maddison]

Acknowledgments

Information on the Collie catchment has been produced from a number of special studies and from long-term monitoring programmes.

The suite of experimental catchments (Salmon, Wights, Lemon, Ernies and Dons) used to study the effects of clearing were set up by the CSIRO, Public Works Department (PWD) and Agriculture Western Australia (AgWA) in the early 1970s. Subsequent management of the catchments was undertaken by the current State Government water management agency, initially the PWD, then the Water Authority, and presently the Water and Rivers Commission ('the Commission').

The experimental catchments used to study the effects of planting trees in valleys (Maringee Farms and Maxon Farm) were set up by the PWD in the late 1970s and subsequently managed in parallel with the CSIRO catchments.

The demonstration of tree planting in alleys was established by the Water Authority in 1992 with the cooperation of the land-owner, Mr David Harrington, and with the assistance of the AgWA's Hydrology Group for detailed design of the farm plan and design and installation of piezometers.

The demonstration at Spencer Gully on the farm owned by Mr Frank Lloyd was initiated by the Collie Recovery Team in 1999. Field investigations have been conducted jointly by AgWA and the Commission. Surface water drainage was designed by Nick Cox of AgWA. Groundwater modelling was undertaken by the Commission.

Stream flows, groundwater levels, and associated salinity from the experimental sites and also from the main stream gauging points, have been recorded by hydrographers from the Commission, and stored in the Commission's WIN database. The data has been further analysed by the Salinity Section of the Commission.

The hydrology of the catchments of Lemon, Maringee Farms and Maxon Farm has been modelled in detail using the WEC-C model developed by James Croton of Water and Environmental Consultants. Data preparation and modelling of revegetation management options for the salt-affected areas of the Collie catchment utilised the MAGIC system developed by Geoff Mauger of the Commission. General mapping and preparation of area statements used ESRI's GIS program ArcView and its extensions.

Commission personnel mainly responsible for compiling the report were Geoff Mauger, Mohammed Bari, Renee Dixon, Lidia Boniecka, Shawan Dogramaci, and John Platt. Thanks go to J.A. Dalton for technical editing of the report, Marg Wilke for desk top publishing, and to all those who offered comments on the draft version of the report that was circulated.

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Summary

Western Australia's State Salinity Strategy identified five catchments as Water Resources Recovery Catchments. They are the catchments of the Denmark River, Kent River, Warren River, Collie River and Helena River. This report addresses the Collie River Catchment, and is the first in a series to present comprehensive information on the salinity situation of these catchments. The information will help land managers in the catchments formulate effective plans to achieve targets for reducing salinity of the water resources.

The Water and Rivers Commission has established a Recovery Team comprising representatives of the community and government agencies with an interest in the catchment, to steer the development of management options and assist with implementation of salinity reduction strategies in the catchment. The Recovery Team has subdivided the catchment into eight 'Management Units' to deal more effectively with local issues and to plan in more detail. Most spatial information presented in this report is summarised into Management Unit areas.

Basic information for the catchment, given as maps and tables, include:

- local government areas with demographic overlay, contours and topography;
- rivers with gauged subcatchments, and rainfall isohyets;
- status of remnant vegetation in 1997;
- soil mapping based on landforms; and
- hydrogeological zones.

Also shown as maps are remote-sensed images of

- 1996 summer vegetation cover from Landsat TM;
- magnetic response of the bedrock (indicating locations of faults and dykes); and
- radiometric response (indicating properties of surface soils).

To ensure land managers have a common understanding, hydrologic processes associated with dryland salinity are described. The pre-clearing situation is explained first, followed by how dryland salinity develops after clearing, and the long-term outcomes to be expected if no countermeasures are taken. Finally, the hydrologic effects of various treatments of salinity are described. Options include planting trees in commercial plantations or alleys, enhancing conservation with trees, varying crop and pasture management, agricultural drainage, major river or groundwater flow diversion with engineering works, and protection of remnant vegetation. Experiments were set up in the catchment to investigate the hydrology. The principal results are given as illustration, showing the effects of:

- clearing in high rainfall areas at Wights and Salmon catchments;
- clearing in medium rainfall areas at Lemon, Dons and Ernies catchments;
- almost complete reforestation at Stene's Arboretum;
- tree planting in valleys at Maxon and Maringee farms;
- a demonstration of planting trees in alleys at Harrington's farm; and
- a demonstration of surface water management with drains at Spencer's Gully.

Historical records of clearing and revegetation with plantations are given as maps and tables. 677 km^2 of the total catchment area of 2823 km^2 had been cleared by 1977, when Clearing Control legislation was introduced; including areas near Wellington Reservoir, cleared by CALM to plant pines. 184 km^2 of this 677 km^2 had been replanted to plantations by 2000, with about 37 km^2 more identified as future plantation.

The records of annual stream flow and salinity as measured on the major tributaries in the catchment are summarised in graphs. The graphs of salinity also show values that are corrected for the difference between the actual stream flow and mean stream flow; these values better reveal the trend in salinity with time. The trend analysis shows that by 1990 the Wellington inflows, Mungalup Tower and Collie River East may have reached a maximum salinity of 870 mg/L, 1130 mg/L, and 1990 mg/L respectively at mean annual flow. Collie River South, James Crossing and James Well had reached 920 mg/L, 5900 mg/L and 2400 mg/L respectively by 1993, and prior to that showed increasing trends of 9 mg/L/yr, 157 mg/L/yr and 34 mg/L/yr respectively. The salinity of Bingham River continues to be less than 300 mg/L.

Records of groundwater levels have been analysed to determine trends based on constant annual rainfall. Sites were selected to show trends in undisturbed forest, land that has been cleared, and in land where trees were planted in the 1980s. When land was cleared or reforested, groundwater levels at the site showed a pattern: no change for 2 or 3 years after the event; then a transition phase of rising after clearing, or falling after reforestation; followed by relative stability at a new level. In reforestation, the falling transition lasted about 5 years. In experimental catchments totally cleared, the rising transition lasted 8 to 10 years. Outside the transition periods only minor trends were not explained by variations in rainfall.

The target for Wellington inflow salinity has been set at 500 mg/L as the annual flow-weighted mean when rainfall equals the 1980 to 1995 average. As 1995 rainfall and inflow was close to this average, 1995 records are used to represent the catchment in its current condition. In 1995, Wellington inflow salinity was 885 mg/L and inflow volume was 145 GL. Current annual output of stream flow and salt is summarised by Management Units in a table to show the distribution between areas of the catchment. The table is then modified to show the change in output needed to achieve the target of 500 mg/L for inflow to the Wellington Reservoir. A number of simple rules are tested for defining how the different Management Units contribute to reduction of salt load, with the corresponding reduction in stream flow that would result if this salt load reduction was achieved by reforestation. One rule, for example, is that all salt loads produced by deep groundwater discharge should be reduced proportionately.

The expected effects of applying various management options are evaluated by analysing cases where a particular option is explored to its feasible maximum. The rates per unit area applied to the proposed areas of treatment with individual options can be used to give preliminary estimates of option combinations. The first option was the installation of commercial tree plantations on all suitable land identified as sold or intended for use as plantations. The resulting salinity and flow is estimated as 758 mg/L and 134 GL/yr. Other options applied individually were then added to the first option, as there is a high degree of confidence that the plantations will proceed. The options evaluated, and the expected outcomes, were:

- alley planting in a range of row densities on upland areas with good soil for growing commercial trees (577 mg/L and 106 GL/yr if all area planted as in plantations);
- planting of lowland areas with commercial or non-commercial trees according to site capability (524 mg/L and 114 GL/yr);
- lucerne on all suitable land (650 mg/L and 119 GL/yr);
- shallow-grade banks on hillsides (738 mg/L and 135 GL/yr);
- groundwater pumping to take 50% of salt load (522 mg/L and 130 GL/yr); and
- diversion of Collie River East below James Crossing (597 mg/L and 126 GL/yr).

The following evaluations assumed that existing plantations remained but there was no additional tree planting:

- complete diversion of eastern tributaries at James Well and below James Crossing (512 mg/L and 130 GL/yr), and
- stream diversion to take 30% of salt load from Collie River East (764 mg/L and 141 GL/yr).

The major conclusions of the report are:

- Since 1990 there has been no trend of increasing salinity of inflow to Wellington Dam. This is thought to be due in part to the rises in groundwater following clearing being substantially complete, and in part to the effects of plantations established by then.
- Further reduction in salinity is expected once all existing and planned plantations have been fully established. This reduction will not, though, be sufficient to meet the inflow salinity targets.
- There are technically feasible management options, in addition to the completion of planned plantations, that have potential to reduce the inflow salinity to its target, including engineering options and/or further tree planting.
- Full effects of treatments can be expected to be realized within 10 years of commencement. Hence all required treatments should be in place by 2005 to meet the 2015 target.

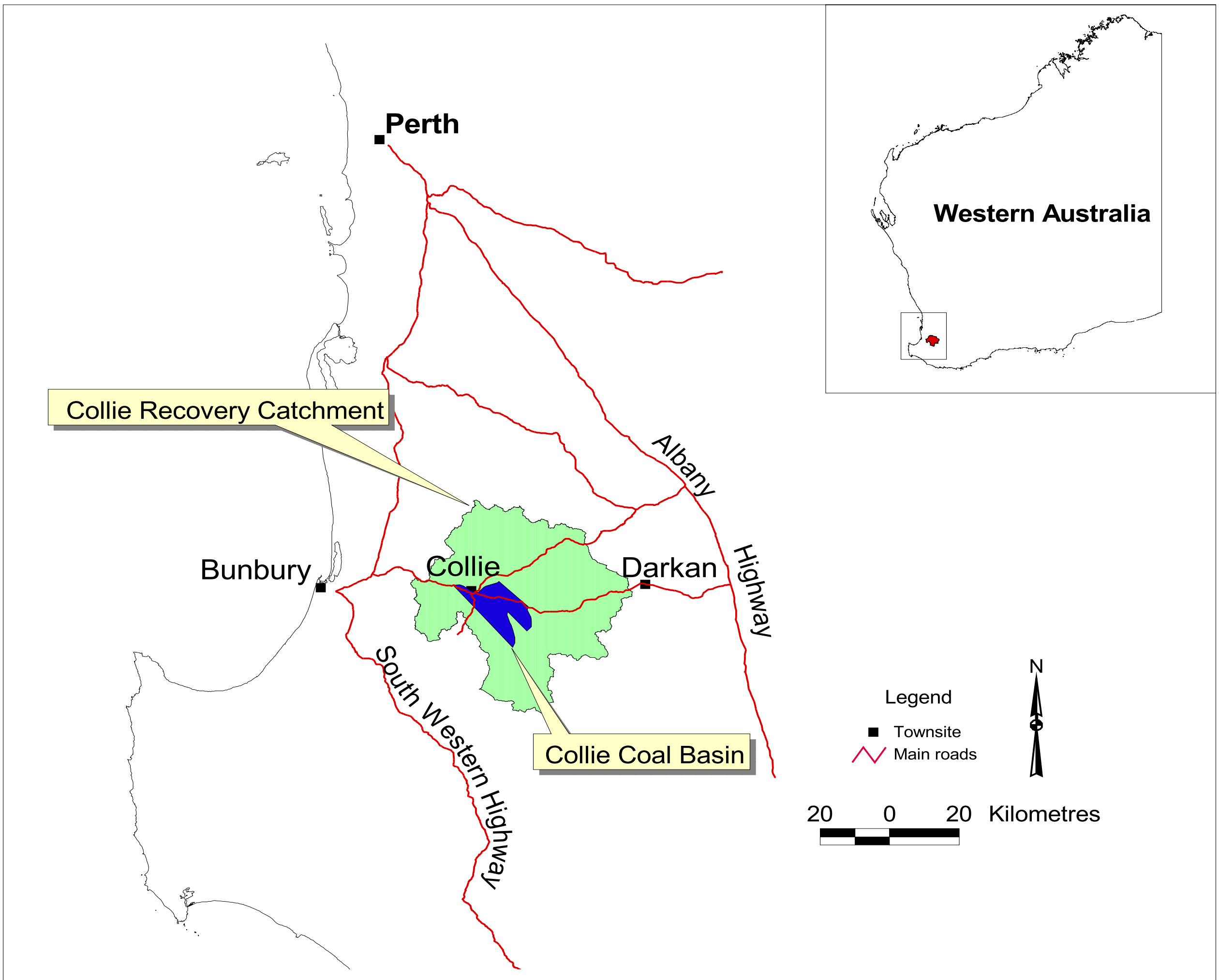
The maps, graphs and tables presented in the report are intended to give an accessible overview of the information. The data from which they are produced is all available digitally in Geographic Information Systems, spreadsheets and databases held by the Water and Rivers Commission; it can be presented in a different or more detailed fashion if required for particular purposes.

1 Introduction

Western Australia's State Salinity Strategy identified five catchments as Water Resources Recovery Catchments (State Salinity Council, 2000). They are the catchments of the Denmark River, Kent River, Warren River, Collie River and Helena River. This report addresses the Collie River Catchment, and is the first in a series to present comprehensive information on the salinity situation of these catchments. The information will help land managers in the catchments formulate effective plans to achieve targets for reducing salinity of the water resources.

The Wellington Dam was originally built on the Collie River 35 km east of Bunbury in 1933 with a capacity of 35 GL (Gigalitres) as a source of water for irrigation on the coastal plain. The dam was raised over the years and completed to its present capacity of 186 GL in 1960. The greater capacity supplied an increased irrigation demand and was the source for domestic use in the Great Southern Town Water Supply Scheme (GSTWS). The yield of the reservoir was about 100 GL per year. Demand is about 80% of the yield, of which about 10% is for the GSTWS and the remainder for irrigation (Loh, 1989).

The Collie River Recovery Catchment is that part of the Collie River Catchment upstream of Wellington Dam, with an area of 2827 km^2. Located in the South West of Western Australia (Map 1.1), the catchment experiences a Mediterranean-type climate of mild wet winters and hot



Map 1.1 Location of the Collie Recovery Catchment

dry summers. The catchment is mostly underlain by igneous rocks, but includes 263 km^2 of coal-bearing Permean sediments. The rural centre and coal mining town of Collie is within the catchment on the north edge of the Collie Coal Basin. Collie has a population of about 8000.

Outside the Permean sediments, the landscape has developed by weathering of the ancient Archaean igneous rocks of the Yilgarn Block. The igneous rocks are mostly granites and granitic gneisses, with frequent intrusions of dolerite dykes. Except for occasional outcrop areas, these rocks are completely weathered to depths of about 20 metres, resulting in sandy clays with laterisation at or near the surface. With increasing severity as rainfall decreases while moving east from Collie, clearing of this landscape for agriculture results in the development of dryland salinity. By the late 1960's clearing had produced a significant increase in the salinity of water supplied from Wellington Reservoir; the 1976 Clearing Control legislation was applied to the catchment to limit the ultimate salinity. In 1990 the Harris Dam replaced the Wellington Dam as the source for the GSTWS. The catchment for the Harris Dam is fully forested and is upstream of the Wellington Dam. An environmental condition for the construction of the Harris Dam is that the water from the Wellington Dam will be returned to potable levels of salinity (EPA, 1987). The State's Salinity Strategy released in March 2000 included as a target that the inflow to Wellington Dam be potable by 2015 (State Salinity Council, 2000).

The Water and Rivers Commission has established a Recovery Team comprising representatives of the community and government agencies with an interest in the catchment, to steer the development of management options and assist with salinity reduction. The Recovery Team has subdivided the catchment into eight 'Management Units' (Map 1.2) to deal more effectively with local issues and to plan in more detail. Most spatial information presented in this report is summarised by Management Unit area.

This report focuses on dryland salinity and the resulting salinity of Wellington Reservoir. Specifically excluded are issues associated with managing water resources of the Collie Coal Basin, or with managing water quality parameters other than salinity in the Wellington Reservoir.

Characteristics of the catchment are presented in the report as a series of maps of the catchment, with accompanying notes; and, where appropriate, as a summary tabulation of the areas of the mapped features within the Management Units. This is followed by summarised historical records of clearing, stream flow and salinity, and groundwater levels within the catchment.

The hydrologic processes associated with dryland salinity are described using results from experimental catchments for illustration where possible. The unmanaged processes occurring before and after clearing are explained, as well as the effects of various treatment options, along with the unmanaged processes before and after clearing. This provides a basis of understanding for subsequent chapters.

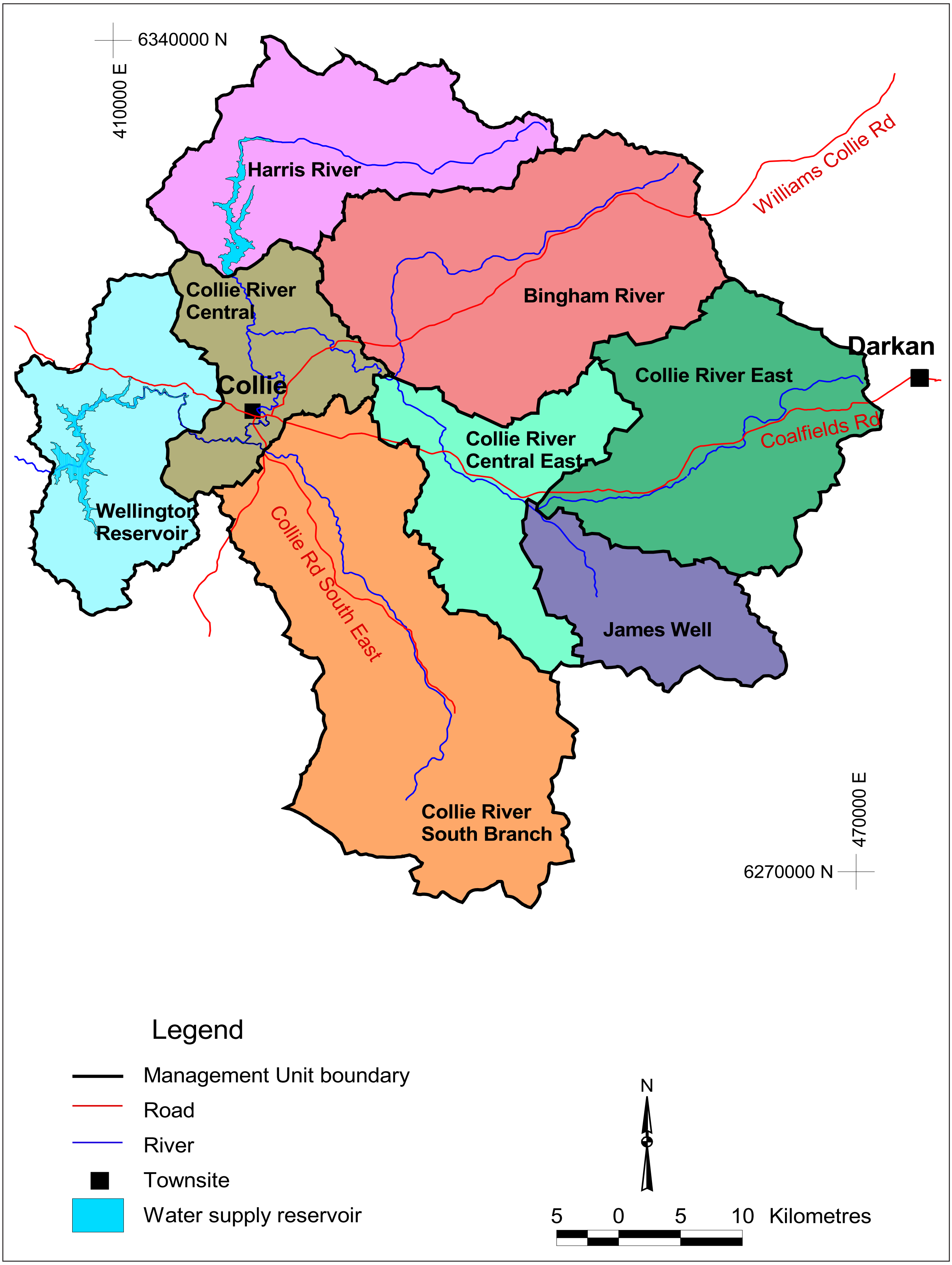
Mean outputs of stream flow and salt loads from each Management Unit are estimated for a range of situations:

- the current clearing condition of the catchment;
- clearing prior to reforestation with plantations;
- the catchment in a fully forested state; and
- the catchment with deep groundwater discharge reduced, by a number of options, to that which gives the target inflow salinity to Wellington Reservoir.

Estimates based on computer modelling are compared with those based on stream gauge records.

Finally, the capacity of individual treatments to reduce salt load is estimated, along with associated changes in stream flow. The treatments investigated are:

- commercial plantations on all land currently identified for that use;
- integration of commercial tree planting on all remaining suitable land, with trees arranged in alleys at a range of alley spacings;
- planting of non-commercial trees on land not suitable for commercial trees;
- establishment of lucerne as a deep-rooted perennial crop on suitable land;
- installation of grade banks;
- pumping groundwater from deep bores in order to lower groundwater levels in valleys; and
- complete or partial diversion of streams draining high salt-output areas, with disposal of diverted water outside the catchment.



Map 1.2 Collie Recovery Team Management Units

2 Catchment characteristics

Information has been compiled on a number of the catchment characteristics relevant to management planning to combat salinity. The data has been prepared in digital form and is shown in this report in maps at a scale of 1:400 000, that give a general overview, and in tables that summarise quantities and qualities within Management Units. Explanatory notes are included where appropriate. The maps and tables also indicate the availability of data which actually contains more detail; most data here has accuracy useful for planning studies at scales of 1:50 000 or less. It is also possible to summarise the areas by different categories and produce maps that combine different types of data. For such additional products, the Water and Rivers Commission should be contacted.

The categories of data presented are:

- Local Government Authorities, with roads and lot boundaries (Map 2.1)
- Hydrology with gauging locations, rivers and isohyets (Map 2.2)
- Geology, including magnetic data currently available (Maps 2.3 and 2.4)
- Soil – Landscape systems, including availability of radiometric data (Maps 2.5 and 2.6)
- Topography (Maps 2.7 and 2.8)
- Native Vegetation Complexes, January 1996 vegetation from Landsat, and remnant vegetation and plantations (Maps 2.9, 2.10 and 2.11).

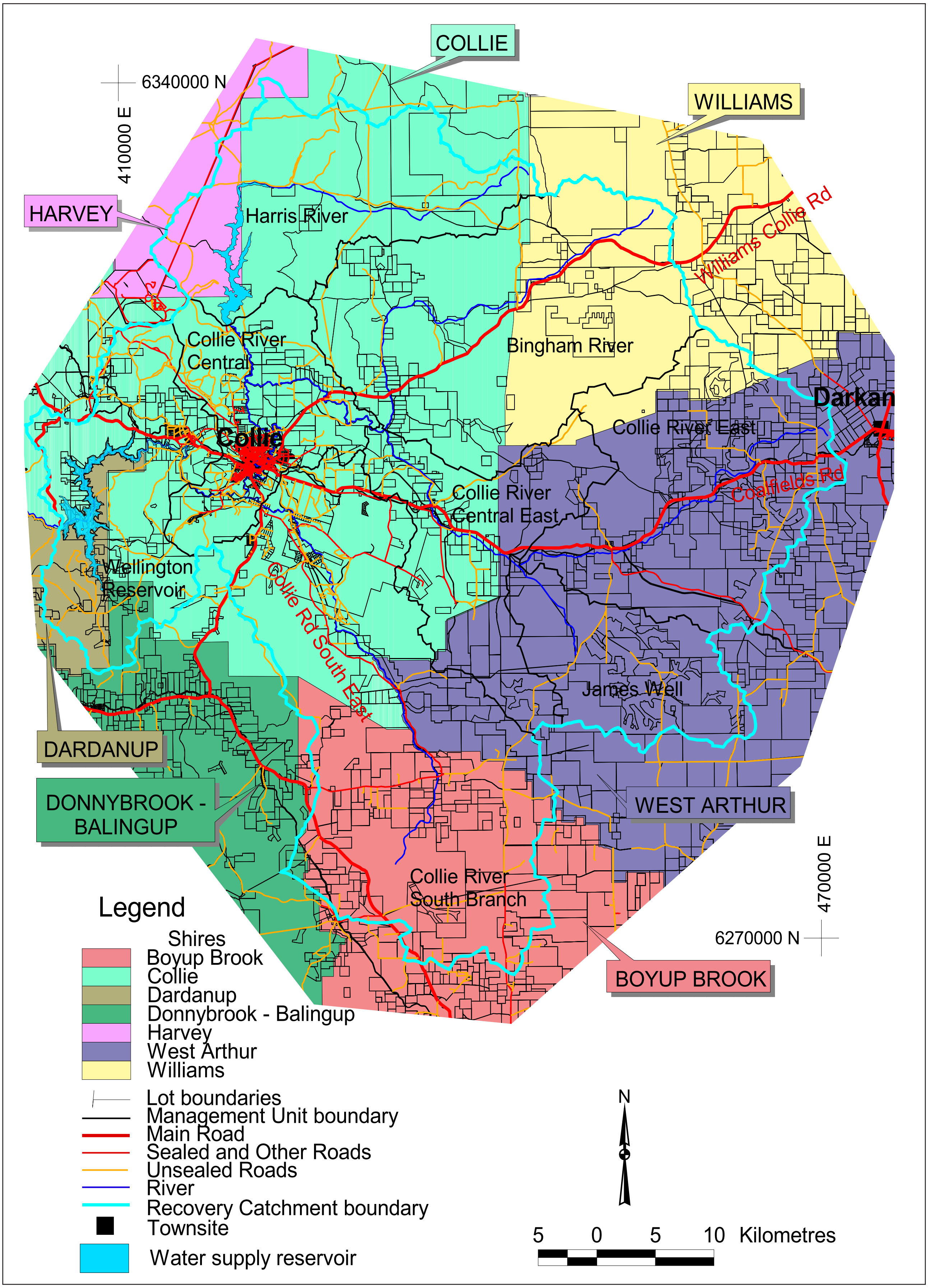
2.1 Local Government Authorities

Table 2.1 Shire areas

Shires (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Boyup Brook	329.00								329.00	329.00
Collie	247.92			268.40	118.99	211.33	264.18	200.39	1110.81	1311.20
Dardanup								61.13		61.13
Donnybrook-Balingup	6.90							20.86	6.90	27.76
Harvey							64.58		64.58	64.58
West Arthur	73.45	183.77	348.75	3.87	120.81				730.65	730.65
Williams			52.18	243.40	5.81		1.51		302.90	302.90
Total	**657.27**	**183.77**	**400.93**	**515.66**	**245.61**	**211.33**	**330.26**	**282.38**	**2544.83**	**2827.21**

Table 2.2 Shire % within management units

% of shires within management units	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Boyup Brook	12%								12%	12%
Collie	15%			16%	7%	12%	16%	12%	65%	77%
Dardanup								12%		12%
Donnybrook-Balingup	0.4%							1%		2%
Harvey							4%		4%	4%
West Arthur	3%	6%	12%	0.1%	4%				26%	26%
Williams			2%	11%	0.3%		0.1%		13%	13%



Map 2.1 Local Government Authorities, roads and lot boundaries

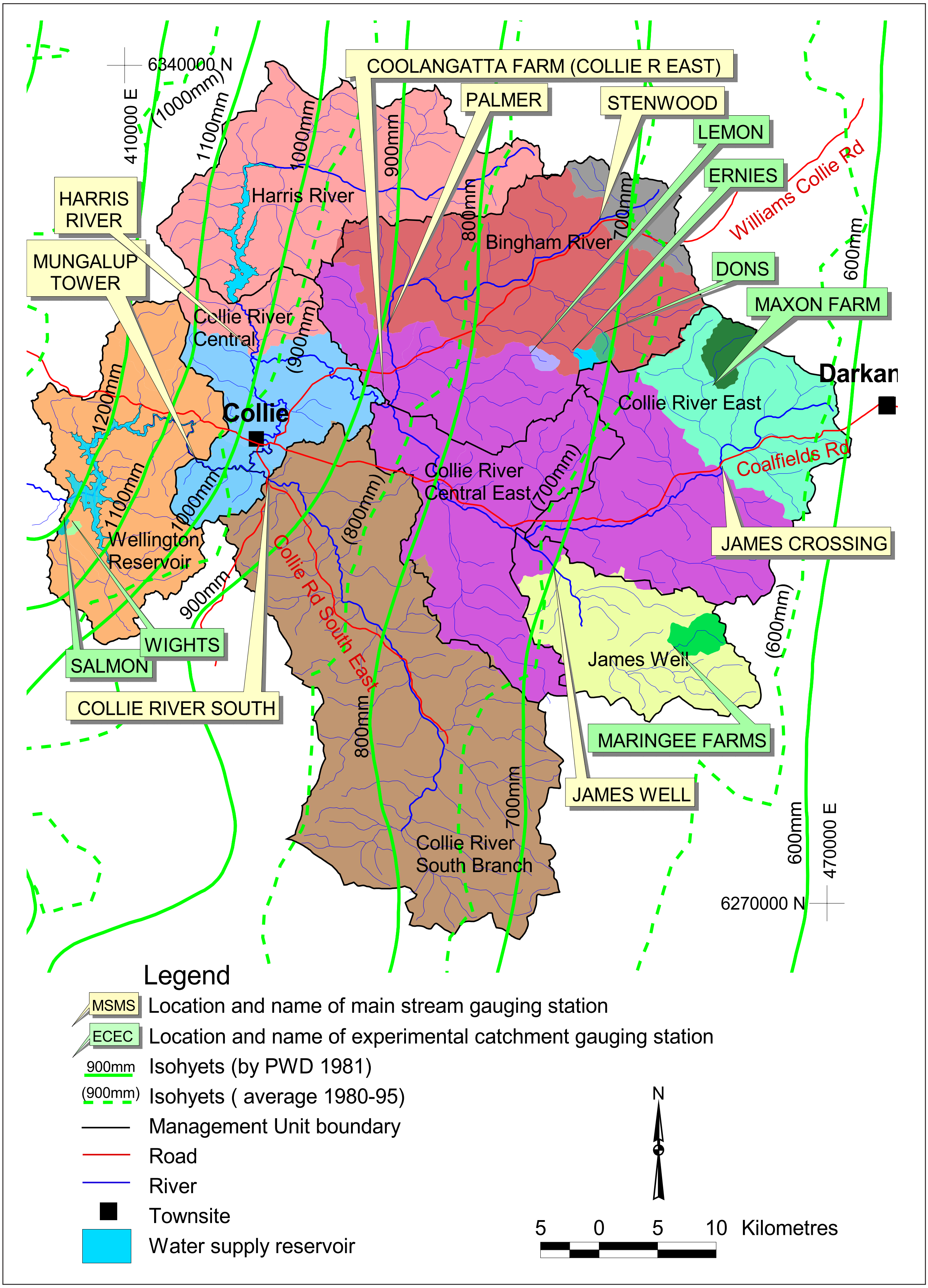
2.2 Hydrology

Table 2.3 Gauged catchment areas within management units

Gauged catchment name	Management units								Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir	
Collie R South	657.27								657.27
James Well		183.77							183.77
Maringee Farm		12.99							12.99
James Crossing			167.81						167.81
Maxon Farm			16.39						101.2
Lemon				3.44					3.44
Dons				3.50					3.50
Ernies				2.70					2.70
Bingham R Stenwood				55.38					55.38
Bingham R Palmer				364.81					364.81
Harris River						52.00	330.26		382.26
Coolangata Farm		183.77	400.93	515.66	245.61				1345.97
Mungalup Tower	657.27	183.77	400.93	515.66	245.61	211.33	330.26		2544.83
Wights								0.94	0.94
Salmon								0.82	0.82
Ungauged								280.62	280.62
Wellington Dam	657.27	183.77	400.93	515.66	245.61	211.33	330.26	282.38	2827.21

Table 2.4. Gauged catchment record summary

Catchment name	Station No.	Period of record	Rainfall (mm)	Streamflow (ML/yr)	Salt load (tonnes/yr)	Salinity mg/L
Collie R South	612034	1952-2000	757	30 016	26 451	881
James Well	612025	1982-2000	652	5730	12 419	2167
Maringee Farm	612026	1982-1999	626	502	2348	4677
James Crossing	612230	1967-2000	628	7643	34 963	4575
Maxon Farm	612016	1976-2000	643	637	2639	4143
Lemon	612009	1974-1999	712	364	520	1429
Dons	612007	1974-2000	712	71	7	94
Ernies	612008	1974-2000	712	16	1	85
Bingham R Stenwood	612021	1978-1999	706	483	126	261
Bingham R Palmer	612014	1975-2000	758	6117	1714	280
Harris River	612017	1976-1993	862	21 360	4700	220
Coolangata Farm	612001	1968-2000	714	45 193	78 492	1737
Mungalup Tower	612002	1969-2000	759	116 094	118 011	1017
Wights	612010	1974-2000	970	448	213	475
Salmon	612011	1974-1999	1121	125	14	113
Ungauged			1050			
Wellington Dam	612003	1951-2000	789	140 489	123 638	880



Map 2.2 Gauged catchments, rivers and isohyets

2.3 Geology

Table 2.5 Geological unit areas

Geological units (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Czg– Cainozoic alluvium	98.95	0.46	0.00	193.67	0.00	1.16	149.80	0.00	444.03	444.03
Pcm – Permian coal measures	169.68	0.00	0.00	0.00	39.77	42.47	0.00	11.18	251.92	263.11
Ag – Archaean granite	322.76	159.00	294.51	289.92	175.14	127.73	164.17	105.09	1533.24	1638.32
Ago – Ag outcrop	65.78	24.32	86.10	28.24	29.35	19.96	8.51	60.18	262.26	322.43
An – Archaean granitoid gneiss	0.10	0.00	10.09	3.74	1.05	13.17	0.00	53.64	28.16	81.80
Ano – An outcrop	0.00	0.00	10.22	0.00	0.30	6.61	0.00	40.48	17.13	57.61
Dams	0.00	0.00	0.00	0.00	0.00	0.22	7.78	11.81	8.00	19.81
Total	**657.27**	**183.77**	**400.93**	**515.57**	**245.61**	**211.33**	**330.26**	**282.38**	**2544.74**	**2827.11**

Notes:

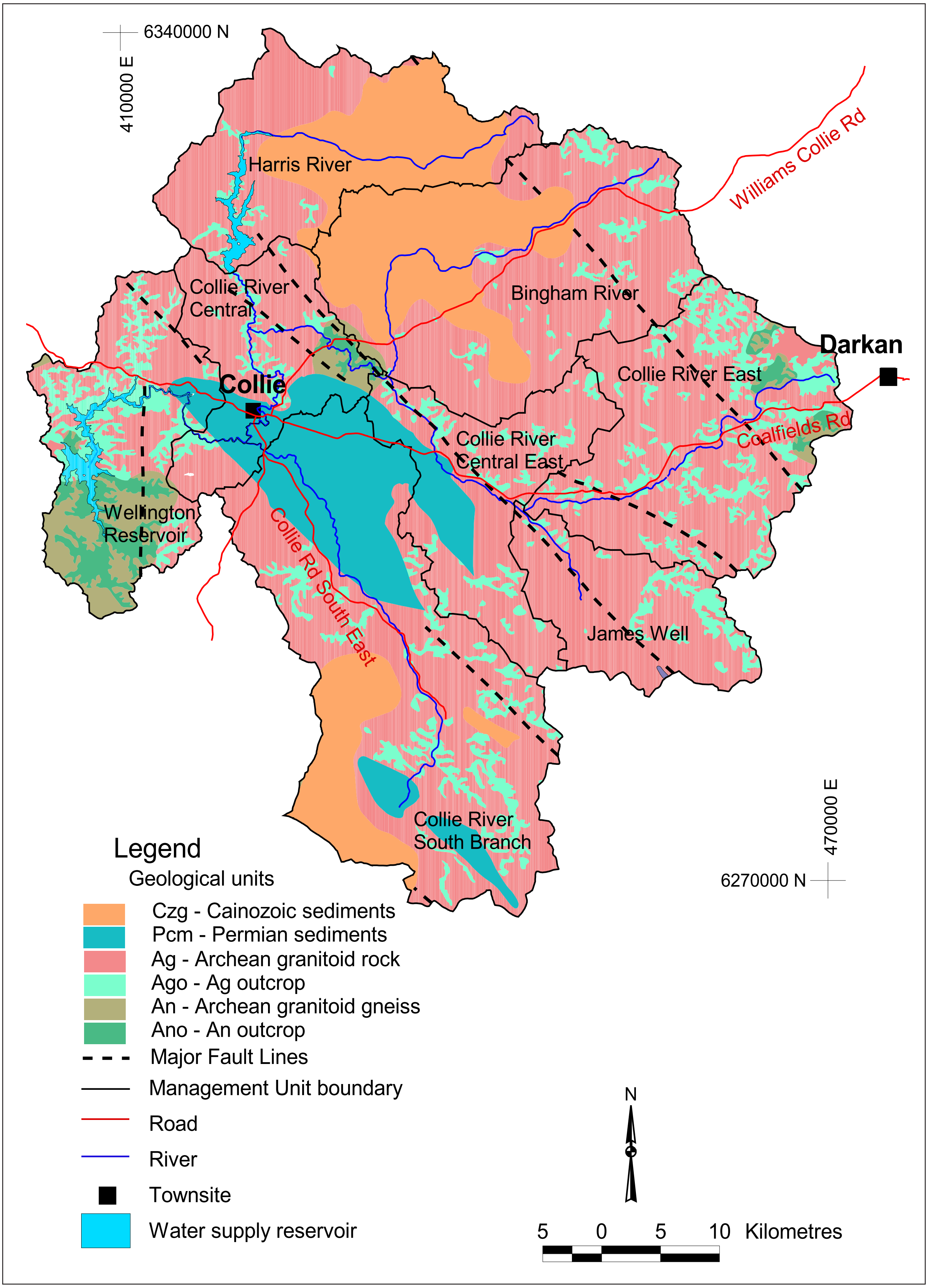
Map 2.3 (Rutherford, 2000) identifies several major faults. These can be detected in Map 2.4, the map of magnetic data produced by air-borne geophysics, as bands of low magnetism compared with nearby surroundings. The magnetic data shows other, similar, features that other geologists have interpreted as faults. Narrow ridge-like features in the magnetic data that trend east-west in many areas have been interpreted as dolerite dykes, which are relatively richer in iron than the surrounding granites.

Note:

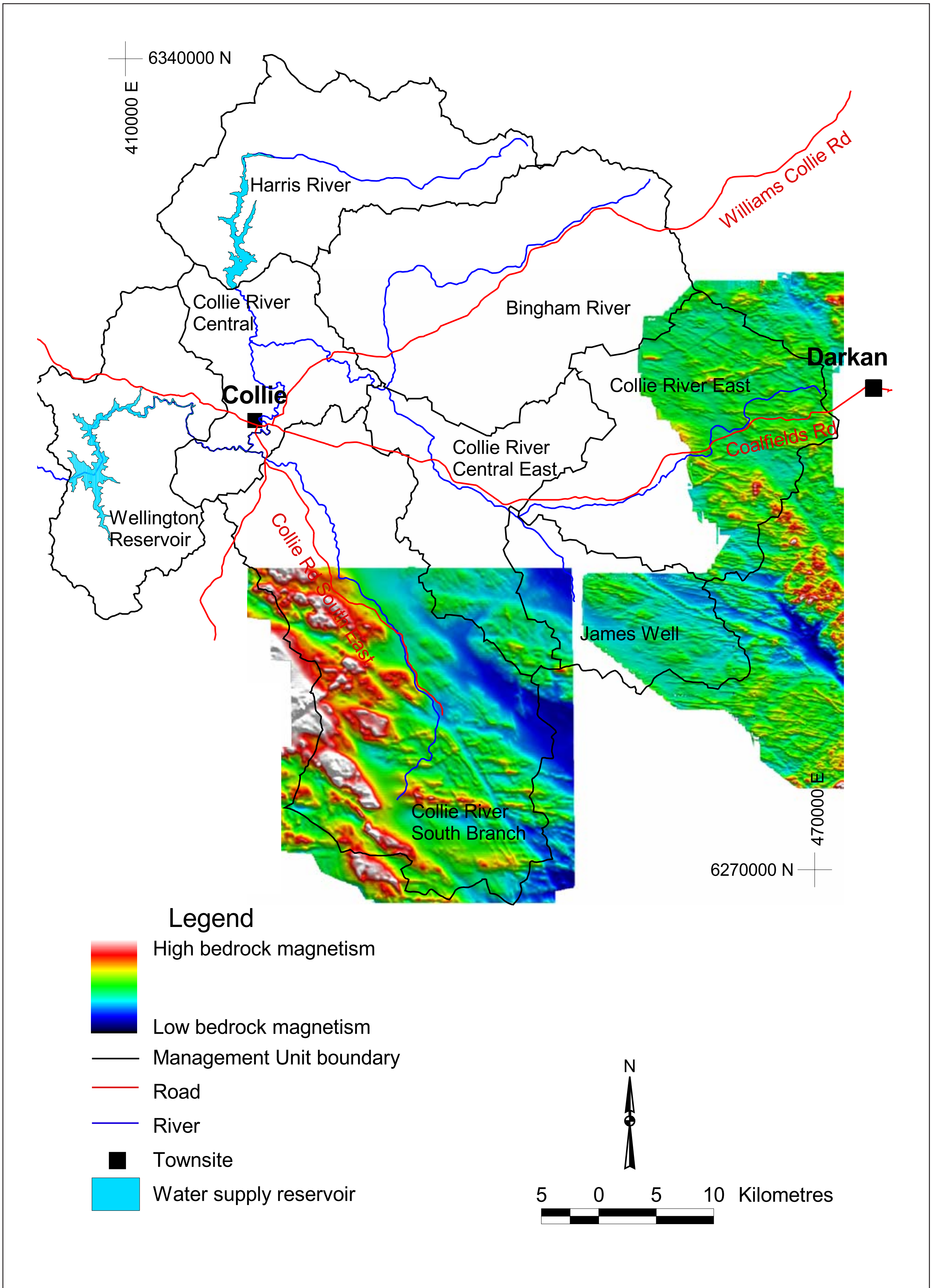
Radiometric data from airborne geophysics

Radiometric data is recorded as ‘counts’ of radiation from radioactive elements on the ground. The available data has counts from uranium, potassium and thorium, as well as a ‘total count’. Map 2.5 has an image of the total count, and shows the area for which data is available. Data points are provided at 25 m intervals on the ground. Separate maps can be produced for the individual elements.

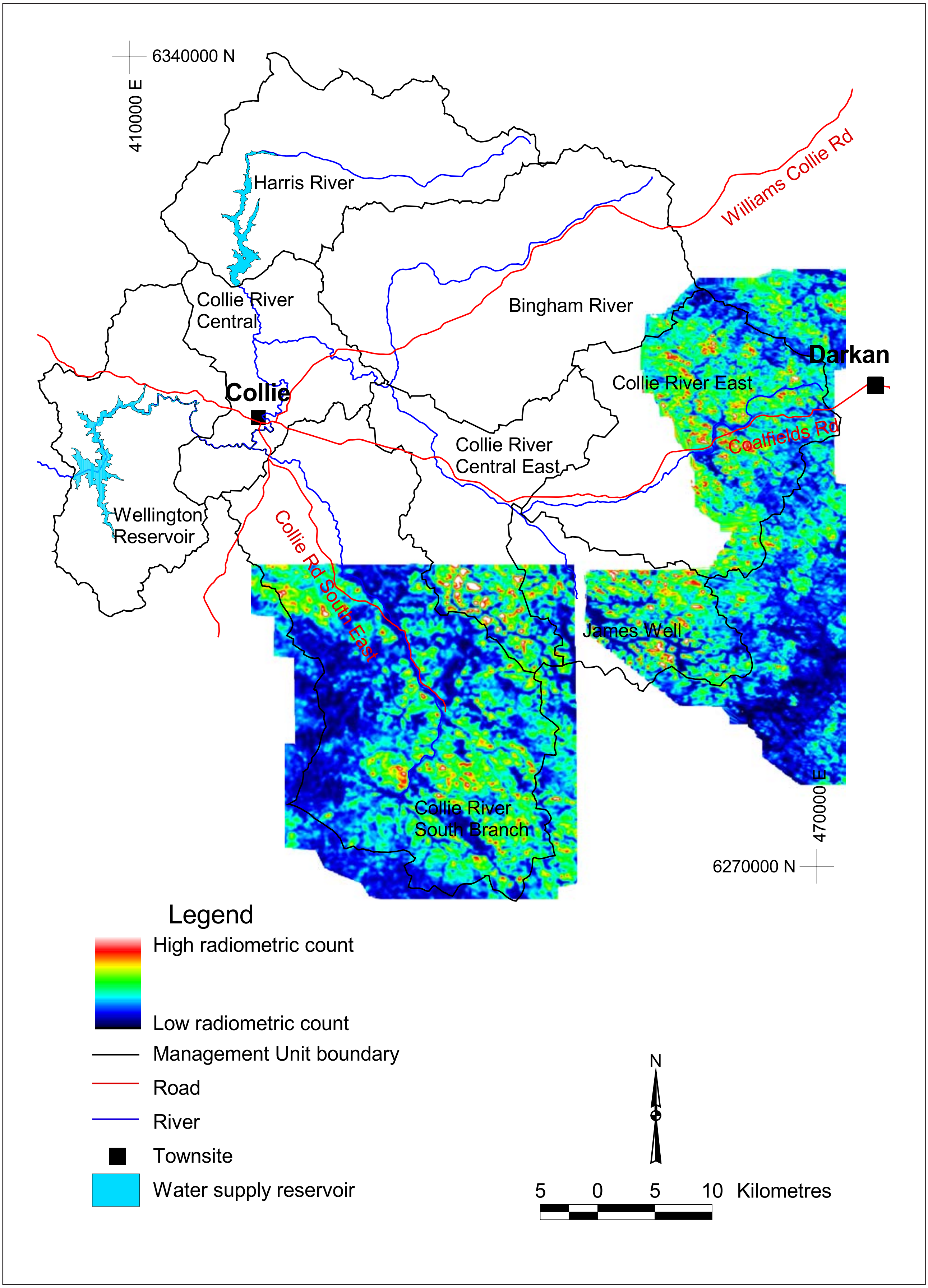
The radiation emanates only from material exposed at the ground surface; therefore the map does not reveal subsurface structures or material types. While data values vary as soil properties vary in an area, the data does not contain unique information that could be used to classify soil types absolutely. However, the data is particularly useful in defining local boundaries between soil types. It can also provide evidence of the source of sedimentary material when, for example, material with high potassium count trails from its erosion area to deposition areas.



Map 2.3 Geology



Map 2.4 Airborne geophysics – magnetic data



Map 2.5 Airborne geophysics – total radiometric count

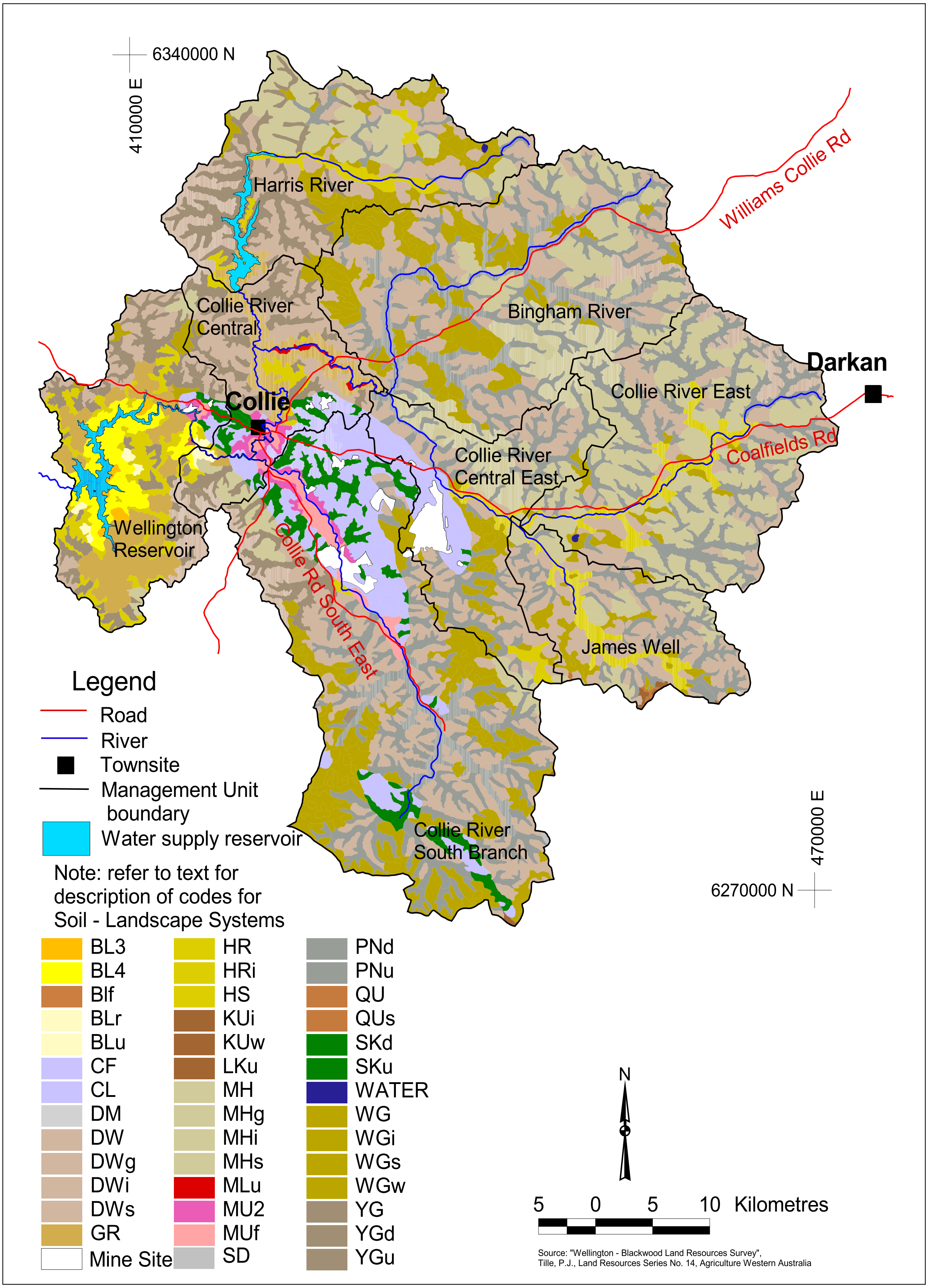
2.4 Soil – Landscape systems

Legend for Soils - Landscape Systems

BL3 - Balingup phase - low slopes have relief of 20-50m and gradients of 5-15%.
BL4 - Balingup phase - moderate slopes have relief of 60-120m and gradients of 15-35%.
Blf - Balingup phase - footslopes are the gentile slopes (gradients of 3-10%) running onto valley floor.
BLr - Balingup phase - rocky slopes have prominent areasof rock outcrop.
BLu - Ballingup phase - upper valleys are found high up in the landscape. They are less deeply incised (30-70m) and have low slopes (gradients 5-15%).
CF - Cardiff subsystem - low lying, poorly drained flats with deep sands and wet soils. There are also scattered rises with gravel.
CL - Collie subsystem - Broad lateritic divides with deep sands and sandy gravels.
DM - Dalmore subsystem - Undulating ridges and hill crests with graves, loamy duplex, and sandy duplex soils.
DW - Dwellingup subsystem - Broad, undulating lateritic divides with gravels and sands.
DWg - Dwellingup phase - granitic divides have loams and loamy gravels.
DWi - Dwellingup phase - ironstone gravel divides have mainly gravels with some sands.
DWs - Dwellingup phase - sandy divides are formed on Kirup conglomerate and other sandy sediments. Sandy gravels are dominant, and there are prominent pockets of sands.
GR - Grimwade subsystem - Valleys (30-70m deep) with low slopes (gradients 5-20%), loams and loamy gravel.
HR - Hester subsystem - Lateritic and granitic ridges and hill crests with gravels and loams.
HRi - Hester phase - gneiss ridges have loamy earths and loamy duplex soils.
HS - Harris subsystem - Broad (250-1250m wide) swampy valley floors with wet soils, often saline.
KUi - Kulikup phase - ironstone gravel flats have sandy gravels, loamy gravels, sandy earths and deep sands.
KUw - Kulikup phase - wet flats are poorly drained depressions and swamps with wet soils.
LKu - Lukin phase - upstream valleys are 5-20m deep, have gentle slopes (gradients 3-10%) and the valley floors tend to be broad. Gravels and sands are more common.
MH - Mornington Hill subsystem - low hills (40-80m high) with gravels, loams and sands.
MHg - Mornington phase - granite hills have loams and gravels.
MHi - Mornington phase - ironstone gravel hills have mainly gravels with some sands.
MHs - Mornington phase - sandy hills have sandy gravels with prominent pockets of sand.
MLu - Mumballup phase - upstream flats usually occur along tributaries. They are 50-250m wide and are more prone to flooding and waterlogging.
MU2 - Muja phase - gentle slopes have gradients of 3-15%.
MUf - Muja phase - flats include the well drained valley flats and footslopes (gradients 1-5%).
Mine Site
PNd - Pindalup phase - downstream valleys are 5-10m deep and have broad (75-250m wide) swampy floors.
PNu - Pindalup phase - upstream valleys are 5-20m deep and have narrow (50-75m wide) swampy floors.
QU - Qualeup subsystem - broad, poorly drained soils flats, lying on Eocene sedimentary deposits, between low hills. The soils are sandy gravels, sands and wet soils.
QUs - Qualeup phase - swampy drainage depressions.
SD - Sandalwood subsystem - low hills (40-80m(with low slopes (gradients 5-20%) and gravels.
SKd - Stockton phase - downstream valleys ususally have broader, swampier floors than the valley upstream valleys.
SKu - Stockton phase - upstream valleys have narrower valley floors than the downstream valleys.
WATER
WG - Wilga subsystem - Gently undulating (gradients 1-5%) upland plains and low rises, formed over sedimentary deposits. Drainage is often restricted and soils are sandy gravels and sands.
WGi - Wilga phase - ironstone gravel flats have mainly gravel with some sands.
WGs - Wilga phase - sandy flats have prominent pockets of sands, although gravels are still common.
WGw - Wilga phase - wet flats are poorly drained flats and depressions.
YG - Yarragil subsytem - minor valleys with swampy floors. The soils are mainly gravels with some sands and loams.
YGd - Yarragal phase - downstream valleys are 20-40m deep with gradients of 5-20% on the sideslopes. The valley floor is narrower than upstream and there is a higher proportion of loams.
YGu - Yarragal phase - upstream valleys are 5-20m deep with gradients of 3-10% on the sideslopes. The valley floor is broader than downstream and there is a higher proportion of gravels and sands.

Note:

In Map 2.6 (from Tille, 1996), areas that are closely related (e.g. some phases of subsystems) have the same colour so that major features can be appreciated. Using the map in more detail will require replotting it at larger scale, with area boundaries outlined and areas labelled.



Map 2.6 Soil – Landscape systems

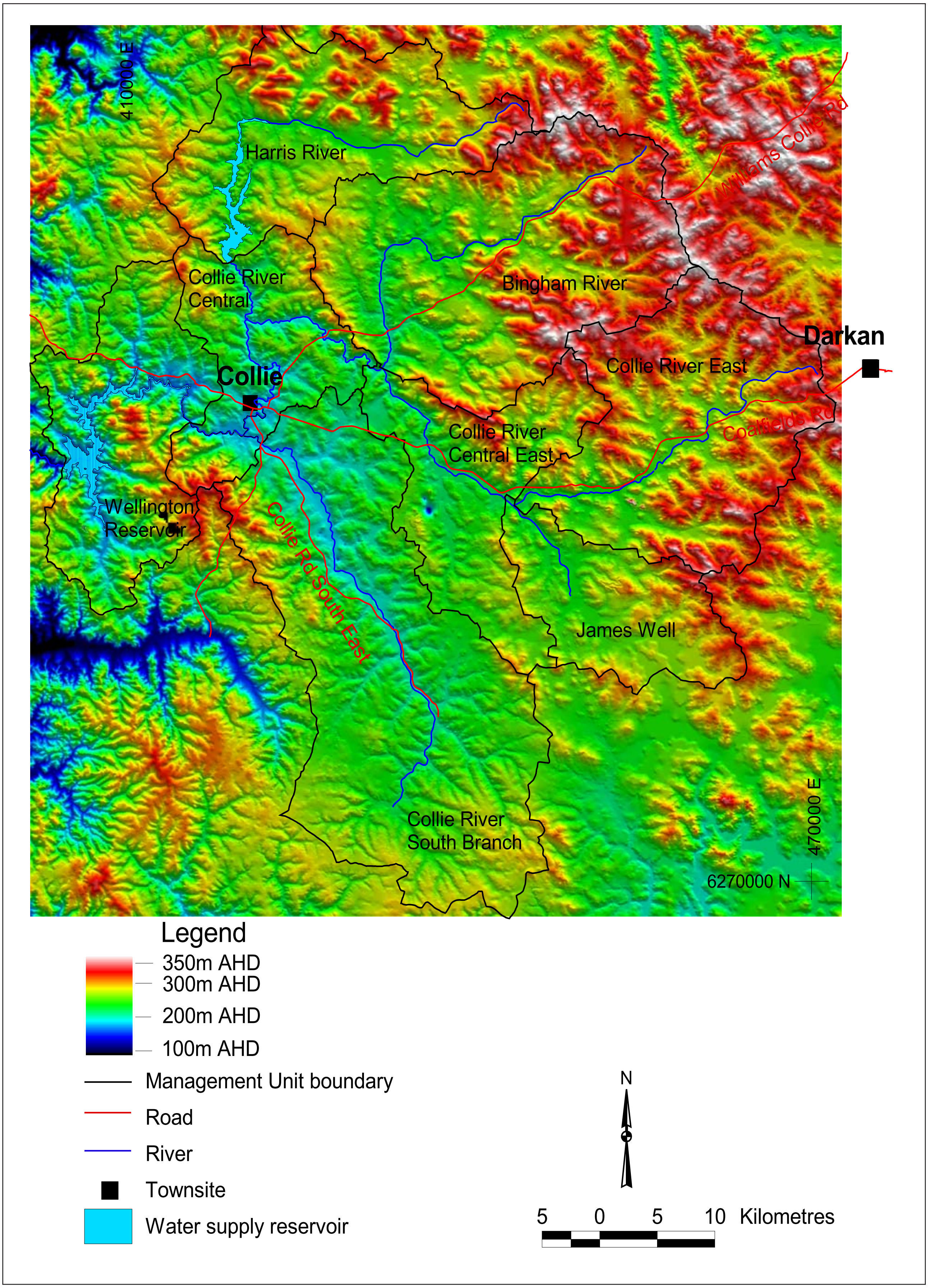
Table 2.6 Soil – Landscape systems areas

Soil – Landscape systems (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
BL3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.49	0.00	3.49
BL4	0.00	0.00	0.00	0.00	0.00	0.71	0.00	36.56	0.71	37.26
BLf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.31
BLr	0.00	0.00	0.00	0.00	0.00	2.09	0.00	0.83	2.09	2.92
BLu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.29	0.00	3.29
CF	21.25	0.00	0.00	0.00	15.29	5.28	0.00	0.98	41.83	42.81
CL	72.35	0.00	0.00	0.00	12.95	12.88	0.00	3.20	98.19	101.39
DM	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12
DW	121.86	42.78	70.22	46.78	34.45	3.91	31.07	1.95	351.07	353.01
DWg	5.87	0.00	1.73	1.63	4.51	0.00	0.00	0.00	13.74	13.74
DWi	15.47	0.00	3.98	67.21	8.77	58.20	53.66	38.68	207.29	245.98
DWs	14.89	30.95	5.93	34.31	11.04	0.17	17.44	0.50	114.73	115.23
GR	0.00	0.00	0.00	0.00	0.05	37.46	9.01	69.33	46.52	115.85
HR	0.00	0.00	0.00	0.00	0.00	0.18	0.00	4.80	0.18	4.98
HRi	0.00	0.00	0.00	0.00	0.00	8.80	3.06	37.25	11.86	49.10
HS	1.08	20.76	29.38	0.00	10.81	0.00	17.22	0.00	79.26	79.26
KUi	0.61	1.61	0.00	0.00	0.00	0.00	0.00	0.00	2.21	2.21
KUw	0.07	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16
MH	8.30	21.15	162.08	78.82	42.51	1.72	17.98	2.19	332.57	334.76
MHg	0.96	5.37	6.50	10.96	7.46	0.00	0.00	0.00	31.24	31.24
MHi	5.52	0.00	0.00	23.96	0.00	6.32	50.87	2.20	86.66	88.86
MHs	0.00	0.88	0.00	2.57	0.86	0.00	1.33	0.00	5.64	5.64
Mine Site	12.71	0.00	0.00	0.00	12.13	1.11	0.00	0.76	25.94	26.70
MLu	0.00	0.00	0.00	0.00	0.00	2.83	0.00	0.00	2.83	2.83
MU2	6.39	0.00	0.00	0.00	0.00	7.38	0.00	1.36	13.77	15.12
MUf	15.55	0.00	0.00	0.00	0.00	4.61	0.00	1.07	20.16	21.23
PNd	54.71	11.39	38.49	59.19	19.19	0.11	8.59	0.00	191.67	191.67
PNu	95.36	29.99	69.36	88.15	36.76	0.00	8.64	0.00	328.27	328.27
QU	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
QUs	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.62
SD	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.53
SKd	24.76	0.00	0.00	0.00	0.00	4.97	0.00	2.07	29.73	31.80
SKu	20.35	0.00	0.00	0.00	0.53	5.38	0.00	1.12	26.26	27.38

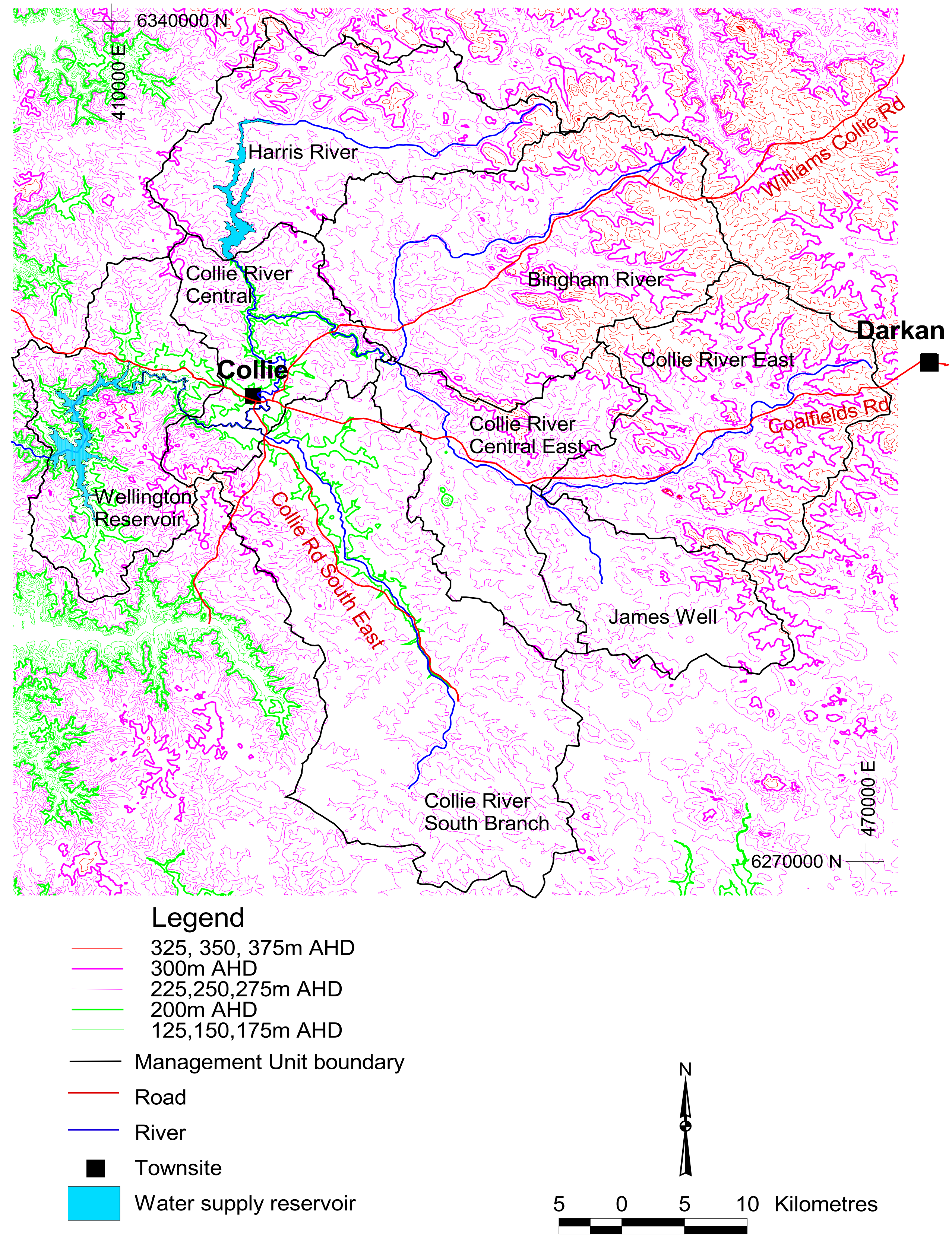
Continued

Table 2.6 Soil – Landscape systems areas (cont.)

Soil – Landscape systems (areas in km²)	Management units								**Mungalup Tower**	**Reservoir Total**
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
WATER	0.00	0.00	0.34	0.00	0.00	0.00	0.33	14.99	0.67	15.66
WG	77.39	9.83	12.70	41.72	18.74	0.73	17.94	0.14	179.06	179.20
WGi	4.53	0.00	0.00	12.41	3.56	2.18	5.72	2.67	28.40	31.06
WGs	4.89	0.00	0.00	16.27	0.00	0.70	5.99	0.42	27.85	28.27
WGw	49.72	7.97	0.00	31.50	6.01	0.00	19.73	2.66	114.93	117.59
YG	0.00	0.00	0.00	0.00	0.00	3.82	2.55	11.60	6.36	17.96
YGd	10.14	0.00	0.00	0.00	0.00	20.68	23.94	19.21	54.75	73.96
YGu	11.82	0.00	0.00	0.00	0.00	19.07	34.58	18.50	65.47	83.97
Grand Total	**657.10**	**183.71**	**400.74**	**515.47**	**245.61**	**211.31**	**329.65**	**282.13**	**2543.59**	**2825.72**



Map 2.7 Topography



Map 2.8 25-metre contours

2.5 Topography

Notes:

Map 2.7 is an enhanced view of the digital elevation model (DEM) used for hydrologic modelling of the catchment. Data points are available at 25 m centres on the ground. Other datasets generated from the DEM with values at 25 m centres, are slope, aspect and curvature of the ground, and drainage linkages. When the data is considered as a two dimensional array of 'cells', the drainage linkage in any particular cell identifies which adjacent cell or cells would receive water running off the surface of that cell in accordance with its aspect and plan curvature. The drainage linkage allows a computer to accumulate the values of other features over the complete catchment area upstream of each cell; it also facilitates the automatic generation of catchment boundaries.

The source data for the DEM was the mapping of 5 metre contours by the Department of Land Administration. Cell elevations were determined by interpolating between the contours. While the original data is to be preferred for contours that are multiples of 5 m, contours at smaller intervals are best prepared by generation from the DEM. Contours can be prepared at whatever interval local planning requires, recognising that accuracy will be relatively low. Map 2.8 shows the contours generated at 25 m intervals as an example and to give better definition of elevations within the catchment.

2.6 Vegetation

Notes:

Vegetation complexes

A vegetation complex is the mix of native vegetation that would have occurred in the area prior to European settlement. The following notes extracted from Mattiske and Havel, 1998, describe the vegetation complexes for the codes shown on Map 2.9.

Darling Plateau

Uplands

Cooke (Ce)

Mosaic of open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* (subhumid zone) and open forest of *Eucalyptus marginata* subsp. *thalassica*-*Corymbia calophylla* (semiarid and arid zones) and on deeper soils adjacent to outcrops, closed heath of Myrtaceae-Proteaceae species and lithic complex on granite rocks and associated soils in all climate zones, with some *Eucalyptus laeliae* (semiarid), and *Allocasuarina huegeliana* and *Eucalyptus wandoo* (mainly semiarid to perarid zones).

Dwellingup (D1)

Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on lateritic uplands in mainly humid and subhumid zones.

Dwellingup 2 (D2)

Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on lateritic uplands in subhumid and semiarid zones.

Dwellingup 4 (D4)

Open forest to woodland of *Eucalyptus marginata subsp. thalassica*-*Corymbia calophylla* on lateritic uplands in semiarid and arid zones.

Hester (HR)

Tall open forest to open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on lateritic uplands in perhumid and humid zones.

Yalanbee (Y5)

Mixture of open forest of *Eucalyptus marginata* subsp. *thalassica*-*Corymbia calophylla* and woodland of *Eucalyptus wandoo* on lateritic uplands in semiarid to perarid zones.

Mornington (MH)

Open forest to woodland of *Eucalyptus wandoo*-*Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on lateritic uplands in the semiarid zone.

Sandalwood (SD)

Woodland of *Eucalyptus marginata* subsp. *marginata* with some *Corymbia calophylla* and *Eucalyptus wandoo* over *Hakea prostrata* and *Dryandra sessilis* on steeper uplands in the semiarid zone.

Dalmore 2 (DM2)

Woodland of *Eucalyptus wandoo*-*Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on uplands in semiarid and arid zones.

Wilga (WG)

Woodland of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on sandy-gravels on low divides in the subhumid zone.

Kulikup 2 (KU2)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* with some *Eucalyptus wandoo* and occasional *Eucalyptus astringens*
fs24 (near breakaways) over *Acacia microbotrya* on undulating uplands in the semiarid zone.

Depressions and Swamps on Uplands

Goonaping (G)
Mosaic of open forest of *Eucalyptus marginata* subsp. *marginata* (humid zones) and *Eucalyptus marginata* subsp. *thalassica* (semiarid to perarid zones) on the sandy-gravels, low woodland of *Banksia attenuata* on the drier sandier sites (humid to perarid zones) with some *Banksia menziesii* (northern arid and perarid zones) and low open woodland of *Melaleuca preissiana*-*Banksia littoralis* on the moister sandy soils (humid to perarid zones).

Swamp (S)
Mosaic of low open woodland of *Melaleuca preissiana*-*Banksia littoralis,* closed scrub of Myrtaceae spp., closed heath of Myrtaceae spp. and sedgelands of *Baumea* and *Leptocarpus* spp. on seasonally wet or moist sand, peat and clay soils on valley floors in all climatic zones.

Qualeup (QUw)
Woodland of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on drier soils ranging to woodland of *Eucalyptus rudis*-5*Melaleuca rhaphiophylla* and low woodland of *Melaleuca preissiana*-*Banksia littoralis* on lower slopes in the semiarid zone.

Stockton (SK)
Woodland of *Eucalyptus marginata* subsp. *marginata*-*Nuytsia floribunda*-*Banksia* spp. with tall shrublands of *Melaleuca* spp. and occasional *Eucalyptus rudis* on upland depressions in the

Valleys

Balingup (BL)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on slopes and woodland of *Eucalyptus rudis* on the valley floor in the humid zone.

Murray 1 (My1)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla*-*Eucalyptus patens* on valley slopes to woodland of *fs24 Eucalyptus rudis*-*Melaleuca rhaphiophylla* on the valley floors in humid and subhumid zones.

Murray 2 (My2)
Open forest of *Eucalyptus marginata* subsp. *thalassica*-*Corymbia calophylla*-*Eucalyptus patens* and woodland of *Eucalyptus wandoo* with some *Eucalyptus accedens* on valley slopes to woodland of *Eucalyptus rudis*-*Melaleuca rhaphiophylla* on the valley floors in semiarid and arid zones.

Catterick (CC1)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* mixed with *Eucalyptus patens* on slopes, *Eucalyptus rudis* and *Banksia littoralis* on valley floors in the humid zone.

Yarragil 1 (Yg1)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla* on slopes with mixtures of *Eucalyptus patens* and *Eucalyptus megacarpa* on the valley floors in humid and subhumid zones.

Yarragil 2 (Yg2)
Open forest of *Eucalyptus marginata* subsp. *thalassica*-*Corymbia calophylla* on slopes, woodland of *Eucalyptus patens*-*Eucalyptus rudis* with *Hakea prostrata* and *Melaleuca viminea*

Pindalup (Pn)
Open forest of *Eucalyptus marginata* subsp. *thalassica*-*Corymbia calophylla* on slopes and open woodland of *Eucalyptus wandoo* with some *Eucalyptus patens* on the lower slopes in semiarid and arid zones.

Lukin 2 (LK2)
Woodland of *Eucalyptus wandoo* with some mixtures of *Eucalyptus marginata* subsp. *thalassica* and *Corymbia calophylla* on the valley slopes with occasional *Eucalyptus rudis* on valley floors in semiarid and arid zones.

Darkin 2 (Dk2)
Mixture of open woodland of *Eucalyptus marginata* subsp. *marginata*-*Banksia attenuata* and low open woodland of *Eucalyptus wandoo* and stands of *Eucalyptus drummondii* (northern) and *Eucalyptus decipiens* (southern) on lower slopes in the arid zone.

Darkin 3 (Dk3)
Open woodland of *Allocasuarina huegeliana*-*Acacia acuminata* with occasional *Eucalyptus rudis* and *Eucalyptus wandoo* on variable slopes near granite outcrops and woodland of *Eucalyptus astringens*-*Eucalyptus wandoo* on breakaways in the arid zone.

Valley floors and swamps

Collie Plain

Uplands

Collie (CI)
Open forest of *Eucalyptus marginata* subsp. *marginata*-*Corymbia calophylla*-*Allocasuarina fraseriana* on gravelly-sandy upland soils in the subhumid zone.

Cardiff (CF)
Open woodland of *Allocasuarina fraseriana*-*Banksia* spp.-*Xylomelum occidentale-Nuytsia floribunda* on sandy soils on valley slopes in the subhumid zone.

Depressions and swamps

Muja (MJ)
Open woodland of *Melaleuca preissiana*-*Banksia littoralis*-*Banksia ilicifolia* with some *Eucalyptus patens* on moister sites, *s24 Banksia* spp. on drier sites of valley floors in the subhumid zone.

January 1996 vegetation from Landsat

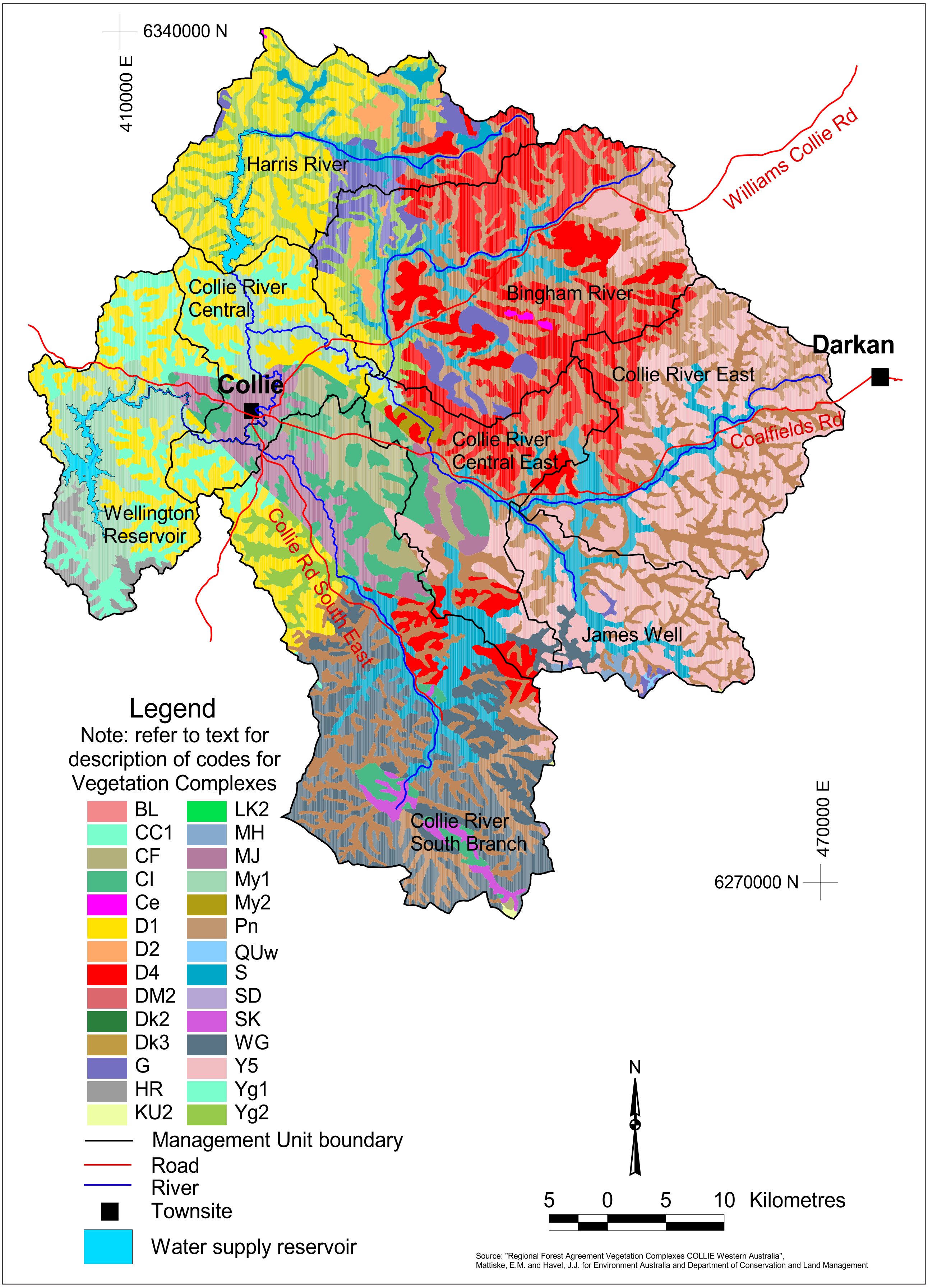
Map 2.10 shows an image of the catchment which reveals the status of vegetation in 1996. The brighter the green, the more vigorous and dense is the tree cover. Cleared land appears in a range of pink to grey colours. There is one point of data every 25 m on the ground, which represents an average of vegetation conditions around that point. Landsat 'scenes' at other dates are also available.

The data is used in hydrologic modelling of the catchment to estimate the density of trees in forested areas; and to identify areas cleared for pasture and crops, information subsequently used to estimate quantities of water transpired.

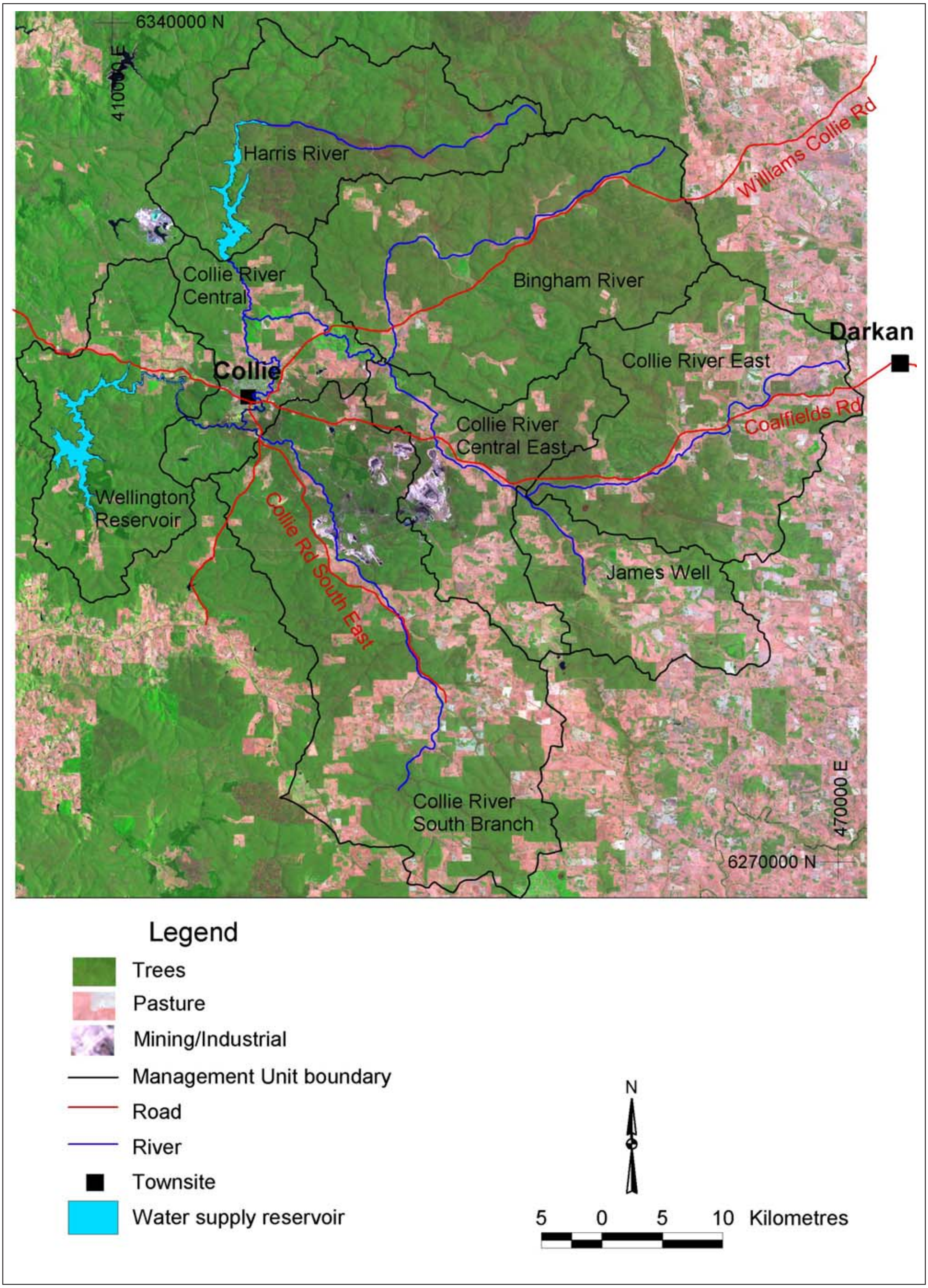
Remnant vegetation and plantations

Map 2.11 classifies the status of trees in the catchment. It is based on a detailed survey undertaken in 1997 that used Landsat data, aerial photographs and field checks to map and classify remnant vegetation and plantation areas (Strawbridge, 1999). The map has been supplemented by recent information on areas where private plantations have been established and areas where private plantations are intended. Within these areas, only land suitable for commercial trees is committed to being planted.

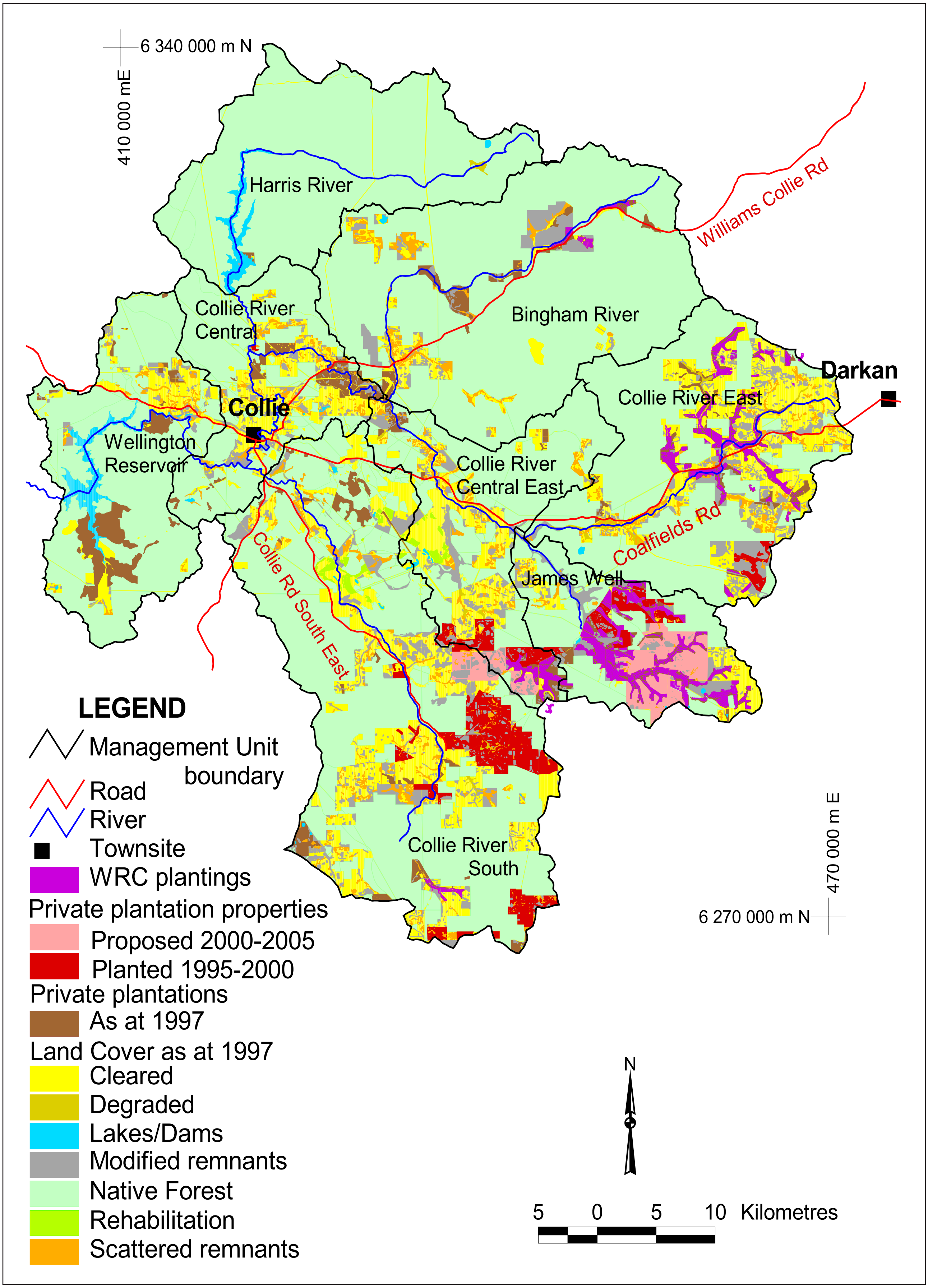
Within the areas of Water and Rivers Commission plantings, mapping which shows the species and year of planting is available. Summary tables of this information are included here.



Map 2.9 Vegetation complexes



Map 2.10 January 1996 vegetation from Landsat



Map 2.11 Remnant vegetation and plantations

Table 2.7 Vegetation complexes areas

Vegetation complexes (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
BL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
CC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.21	0.00	7.21
Ce	0.00	0.00	0.00	1.73	0.00	0.00	0.19	0.00	1.93	1.93
CF	41.78	0.00	0.00	0.00	12.44	6.91	0.00	0.00	61.14	61.14
CI	64.96	0.00	0.00	0.00	21.39	16.00	0.00	4.19	102.35	106.54
D1	42.10	0.00	0.00	13.59	1.79	79.19	126.98	82.60	263.65	346.25
D2	0.00	0.00	0.00	8.66	0.00	0.00	14.72	0.00	23.38	23.38
D4	22.15	0.02	33.56	185.62	63.69	0.00	26.45	0.00	331.49	331.49
Dk2	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Dk3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DM2	0.00	0.13	0.22	0.00	0.00	0.00	0.00	0.00	0.35	0.35
G	0.03	3.52	0.00	42.77	0.07	0.62	24.00	0.00	71.02	71.02
HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.72	0.00	23.72
KU2	0.88	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.97
LK2	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
MH	0.00	3.76	0.00	0.00	0.52	0.00	0.00	0.00	4.28	4.28
MJ	46.84	0.00	0.00	0.00	14.37	32.70	0.00	8.10	93.90	102.00
My1	0.00	0.00	0.00	0.20	4.67	39.67	0.83	91.02	45.37	136.39
My2	0.00	0.00	0.00	0.00	7.27	0.00	0.00	0.00	7.27	7.27
Pn	133.45	45.37	139.04	152.54	63.86	0.00	14.30	0.00	548.56	548.56
QUw	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.77
S	54.68	27.88	43.09	43.65	24.67	0.00	34.40	0.00	228.37	228.37
SD	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.56
SK	16.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.34	16.34
WG	193.74	6.19	0.00	0.00	5.51	0.00	0.00	0.00	205.44	205.44
Y5	7.22	96.03	184.98	34.36	24.35	0.00	0.00	0.00	346.94	346.94
Yg1	5.33	0.00	0.00	0.00	0.00	35.42	0.00	65.50	40.75	106.25
Yg2	27.20	0.00	0.00	32.54	1.00	0.82	88.40	0.00	149.97	149.97
Grand Total	**657.27**	**183.77**	**400.93**	**515.66**	**245.61**	**211.33**	**330.26**	**282.38**	**2544.83**	**2827.21**

Table 2.8 1997 vegetation status areas

1997 Vegetation status (areas in km^2)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Scattered Trees	19.28	2.50	10.68	11.56	9.05	6.67	0.00	3.47	59.74	63.21
Modified Forest	45.14	20.20	34.11	21.59	22.28	12.50	0.05	5.55	155.86	161.41
Native Forest	392.31	73.96	219.17	446.24	131.91	129.30	314.92	207.49	1707.81	1915.30
Plantations	14.75	33.03	28.05	13.47	10.83	9.91	0.28	22.16	110.32	132.49
Coalfields Rehabilitation	4.18	0.00	0.01	0.00	2.10	0.00	0.00	0.00	6.29	6.29
Total uncleared	**475.66**	**129.69**	**292.02**	**492.87**	**176.16**	**158.38**	**315.25**	**238.67**	**2040.01**	**2278.69**
Cleared	179.72	53.21	103.55	22.52	68.03	52.10	1.87	28.14	480.99	509.13
Degraded Forest	0.99	0.45	4.53	0.00	1.07	0.00	0.80	0.01	7.84	7.85
Lakes/Dams	0.65	0.36	0.31	0.31	0.35	0.74	9.94	14.67	12.66	27.33
Total cleared	**181.37**	**54.01**	**108.39**	**22.83**	**69.45**	**52.84**	**12.61**	**42.82**	**501.49**	**544.31**
Total	**657.02**	**183.70**	**400.41**	**515.70**	**245.61**	**211.22**	**327.86**	**281.49**	**2541.51**	**2823.00**

Table 2.9 1997 vegetation status % within WRC plantations

1997 vegetation status (% of management unit)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Scattered Trees	3%	1%	3%	2%	4%	3%	0%	1%	2%	2%
Modified Forest	7%	11%	9%	4%	9%	6%	0%	2%	6%	6%
Native Forest	60%	40%	55%	87%	54%	61%	96%	74%	67%	68%
Plantations	2%	18%	7%	3%	4%	5%	0%	8%	4%	5%
Coalfields Rehabilitation	1%	0%	0%	0%	1%	0%	0%	0%	0%	0%
Total uncleared	**72%**	**71%**	**73%**	**96%**	**72%**	**75%**	**96%**	**85%**	**80%**	**81%**
Cleared	27%	29%	26%	4%	28%	25%	1%	10%	19%	18%
Degraded Forest	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Lakes/Dams	0%	0%	0%	0%	0%	0%	3%	5%	0%	1%
Total cleared	**28%**	**29%**	**27%**	**4%**	**28%**	**25%**	**4%**	**15%**	**20%**	**19%**
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: More details of clearing history and history of plantations are given in Chapter 5 (Historical Records)

Table 2.10 Areas of tree species within WRC plantations

WRC plantations by species (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
C. obesa	0.10	0.01	1.11	0.00	0.29				1.52	1.52
E. accedens	0.00	0.30	0.21	0.00	0.00				0.51	0.51
E. calcicola	0.00	0.00	0.03	0.00	0.00				0.03	0.03
E. calophylla	0.00	0.43	0.18	0.00	0.00				0.60	0.60
E. camaldulensis	0.56	10.35	4.13	0.50	1.79				17.33	17.33
E. citriodora	0.00	0.00	0.04	0.00	0.00				0.04	0.04
E. cladocalyx	0.00	0.10	0.00	0.01	0.00				0.11	0.11
E. cornuta	0.00	0.11	0.51	0.00	0.00				0.63	0.63
E. globulus	0.01	5.77	2.24	0.38	0.45				8.84	8.84
E. huberana	0.00	0.00	0.01	0.00	0.00				0.01	0.01
E. huegeliana	0.00	0.00	0.03	0.00	0.00				0.03	0.03
E. largiflorens	0.00	0.36	0.01	0.00	0.10				0.47	0.47
E. loxophleba	0.00	0.12	0.00	0.00	0.00				0.12	0.12
E. maculata	0.00	0.20	0.10	0.05	0.00				0.34	0.34
E. melliodora	0.00	0.26	0.14	0.00	0.00				0.39	0.39
E. microcarpa	0.20	0.16	0.22	0.00	0.56				1.14	1.14
E. mixed	0.01	0.65	0.97	0.48	0.11				2.23	2.23
E. occidentalis	0.00	0.29	0.56	0.00	0.00				0.84	0.84
E. platyphylla	0.00	0.00	0.26	0.04	0.00				0.30	0.30
E. platypus	0.00	0.00	0.23	0.00	0.00				0.23	0.23
E. polyanthemos	0.00	0.00	0.04	0.00	0.05				0.08	0.08
E. resinifera	0.00	0.51	1.29	0.09	0.00				1.88	1.88
E. robusta	0.00	0.23	0.33	0.01	0.00				0.58	0.58
E. rubida	0.00	0.00	0.21	0.01	0.00				0.21	0.21
E. rudis	0.00	0.79	1.23	0.24	0.00				2.27	2.27
E. saligna	0.27	1.67	0.94	0.01	0.25				3.14	3.14
E. sargentii	0.01	0.37	0.61	0.05	0.56				1.61	1.61
E. sideroxylon	0.00	0.00	0.35	0.00	0.26				0.61	0.61
E. viminalis	0.00	1.03	0.78	0.04	0.20				2.05	2.05
E. wandoo	0.03	2.03	3.00	0.10	0.00				5.16	5.16
E. sargentii	0.00	0.00	0.01	0.00	0.00				0.01	0.01
Melaleuca preissiana	0.00	0.00	0.00	0.00	0.20				0.20	0.20
Melaleuca various species	0.00	0.00	0.03	0.00	0.00				0.03	0.03
P. pinaster	0.00	0.00	0.00	0.02	0.00				0.02	0.02
P. radiata	0.00	0.27	0.03	0.03	0.00				0.33	0.33
unknown	0.02	0.49	0.31	0.10	0.08				1.01	1.01
Grand Total	**1.22**	**26.49**	**20.14**	**2.15**	**4.90**				**54.91**	**54.91**

3 History

Salinity of the stream flow from the Collie Catchment began to increase before 1960 due to clearing of native forest for pasture development (Loh, 1985). The Government legislated to control the release of Crown land, in 1961, and, in 1976, legislated to control the clearing of native forest (Country Areas Water Supply Act, 1947, Part IIA). Even so, the clearing by then was already causing the stream salinity of the Collie River just upstream of the Wellington Reservoir to increase by 42 mg/L/yr (Schofield et al., 1988). It was estimated that if no further action was taken, the stream salinity would rise to a flow-weighted mean value of 1500 mg/L, resulting in 1150 mg/L in the reservoir (Loh, 1985).

With Wellington Reservoir becoming excessively saline the Harris Dam was built to replace it as the source for the Great Southern Town Water Supply scheme. An environmental commitment made as a condition of approval to build Harris Dam, was that the Collie River salinity would be reduced to a level such that the water supplied from Wellington Reservoir would be suitable for domestic purposes (EPA, 1987).

There is a program to reforest 8000 ha of land acquired through the compensation process which was part of the Clearing Control Legislation. Land became available when landowners who were eligible for compensation because they were refused licences to clear, decided that they would prefer to sell the whole farm rather than accept payment for the uncleared portion. Land thus purchased was subdivided so that areas to be planted were in lots separate from the remainder of the farm. Land not required for planting was then sold, or exchanged for suitable land on other farms. An exchange would be achieved by subdividing the other farm. So far there has been 6743 ha planted on land purchased by the then Water Authority, and there are no further obvious opportunities for the Government to acquire more land to achieve the target of 8000 ha. Some additional areas have been planted by private interests.

The trees planted were intended to reduce the deep groundwater discharge that carries additional salt into the river. The reduction expected from planting 8000 ha was estimated to be insufficient to reduce the salinity of Wellington Reservoir to the desired domestic supply standard (Loh, 1985). Further improvement was to come from helping farmers manage their cleared land differently, in ways that would maintain or improve their livelihood but result in less recharge to deep groundwater.

In the early 1970s, a series of five experimental catchments (Salmon, Wights, Lemon, Ernies and Dons) were established within the Collie River Basin to better understand the causes of salinity. This was followed, in the late 1970s and early 1980s, by experimental sites (at Batalling Creek and Maringee Farms) to investigate how effectively various reforestation strategies reduced stream salinity (Bari and Boyd, 1992). In 1995 a demonstration based on information from modelling was established on a local farmer's land (Harrington's). More details of these experiments are given later in this report.

Western Australia's Salinity Strategy that was launched in March 2000 (State Salinity Council, 2000) provides the framework within which the catchment will now be managed to achieve salinity objectives.

4 Water Resource Recovery Catchment

The Collie River catchment above Wellington Reservoir was designated as one of the five Water Resource Recovery Catchments in the State's Salinity Strategy (State Salinity Council, 2000). The others are the Warren, Kent, Denmark and Helena catchments. The Water and Rivers Commission is the lead agency in these catchments for implementing the Salinity Action Plan. To achieve the aims in the Collie Catchment with full involvement of stakeholders, the WRC has established a Recovery Team.

4.1 The Collie Recovery Team

The Recovery Team has members who represent landowners, government agencies and instrumentalities, local government, other organisations and industry. The Water and Rivers Commission (WRC) has lead agency responsibility and provides resource support.

The Team comprises 11 members, representing:

- Landholders from the East and South-East Branch of the river;
- Landholders from the South Branch;
- The West Arthur and Collie Shire Councils;
- Water and Rivers Commission;
- Agriculture Western Australia;
- CALM;
- Water Corporation; and
- Western Power.

4.2 Strategic Action Plan

A Strategic Action Plan for managing salinity in the Collie River catchment above the Wellington Dam has been prepared by the Collie Recovery Team as required in the State Salinity Strategy, 2000.

The plan is based on a clear water-quality target: to reduce the salinity of the Collie River at Mungalup Tower Gauging Station (the nearest point of measurement to the Wellington Dam) to 680 mg/L TDS by the year 2015; the current level is about 1000 mg/L. The target average in the dam itself is 500 mg/L TDS.

The Collie Recovery Team vision is as follows:
The Collie Catchment has a healthy and productive environment, delivering adequate potable water to the Wellington Dam, and is capable of sustaining a stable and prosperous community.

4.3 Objectives

The Plan has twenty social, economic and environmental objectives; the following selections try to be indicative:

- build a mechanism for the community to plan for the future through a partnership with agencies and local government;
- assist existing and new groups involved in natural resource management in the community to work towards recovery objectives;
- maintain viable communities in the catchment, with a diversity of landuses, business and employment opportunities;
- integrate the goals and responsibilities of other community and industry groups;
- ensure that landuse changes for salinity management retain an attractive landscape where people enjoy working and living;
- improve the value of water in the Wellington Dam;
- raise awareness about the economic benefits resulting from managing salinity in the Collie catchment;
- develop mechanisms for sharing the costs of catchment recovery;
- increase employment opportunities;
- develop new landuse systems that enhance water use and income for landowners;
- lower salinity levels in streams throughout the catchment;
- minimise the area of land affected by secondary salinity;
- protect and rebuild biodiversity; and
- manage the health and function of the landscape, creeks and rivers.

4.4 Strategic directions

The above objectives will be achieved through four strategic directions. The directions reflect the issues and provide a co-ordinated opportunity for implementation of the plan. Key issues and options requiring assessment are presented below.

4.4.1 Enhancing knowledge and information

- trends and predictions for water quality, and priorities for implementation;
- large and small scale engineering options; and
- research and development effort.

4.4.2 Facilitating fundamental change

- best management practice and decision-making;
- community and industry working towards water quality targets;
- supporting community management and decision making; and
- communication.

4.4.3 Maximising freshwater and minimising salt

- trends and predictions for water quality, and priorities for implementation;
- sustainable forest management for maximum freshwater yield;
- knowledge and skills in new farming systems; and
- on-farm water-harvesting and surface water management.

4.4.4 Monitoring and feedback

- trends and predictions for water quality.

4.5 Actions

The Strategic Action Plan recommends 39 high priority actions. Already in place are three-year Operations Plans and associated projects that address these actions. The Salinity Situation Statement is one of the projects that addressess 9 of the high priority actions.

4.6 Management Units

For planning purposes the Recovery Catchment has been divided spatially into eight Management Units, described by the physical catchments of the major tributaries or by collections of smaller tributaries. The choice of management units has also been influenced by current management boundaries, location of established gauging stations on the main stream, and social groupings. These units have been termed (see map, from east to west):

- Collie River East;
- James Well;
- Collie River Central East;
- Bingham River;
- Harris River;
- Collie River Central;
- Collie River South; and
- Wellington Reservoir.

The broadacre farming (sheep, cattle and some crops) is mostly in the upper halves of the Collie River South, Collie River Central East, James Well and Collie River East units. Elsewhere, cleared or partially cleared land is used for “hobby” farms or coal mining.

The Bingham River, Harris River and Wellington Reservoir units are mostly native forest.

The township of Collie and the coal basin occupy the Collie River Central management unit and the lower parts of the Collie River South and Collie River Central East units.

The areas of land within each Management Unit, classified according to the status of its vegetation cover, are tabulated in Section 2.6. The stream flow and salinity coming from each Management Unit are tabulated in Chapter 7.

5 Historical records

Initial evidence of increasing salinity in the Collie River came from stream gauging records on the main stream and tributaries. The main gauging points are shown on Map 2.2. This chapter summarises the time sequence of data from these gauges in the context of the history of clearing and reforestation with plantations. Statistical analysis has been used to identify trends in salinity that underlie the natural variations caused by year to year variation in rainfall. Groundwater levels measured in deep piezometers have also been analysed by the HARTT (Hydrograph Analysis: Rainfall and Time Trend) method, to identify trends concealed by response to rainfall variation (Ferdowsian et al., 2000).

5.1 Progress of cleared area

5.1.1 Clearing

Map 5.1 shows the record of clearing based on mapping from aerial photographs. The clearing adjacent to Wellington Reservoir was for establishing pine plantations. Some areas within the Collie Coal Basin were cleared for mining. Apart from Collie townsite, all other cleared areas were for agriculture. The last date mapped is 1977, representing the catchment just after clearing controls were introduced.

5.1.2 Plantations on land acquired by Government

The land shown as 'WRC plantings' in Map 2.11 was progressively planted to a variety of tree species, over the period 1980 to 1990. Digital maps are available giving details of the location of areas planted, with the year planted.

5.1.3 Plantations on private land

Details of planting dates for areas planted before 1995 are not available. Since 1995, a number of properties have been bought by companies whose business is commercial tree plantations. A review of private land has identified properties that are already planted (with the year of planting if available), those scheduled for planting this year (2001), those that will shortly be planted (say before 2005), and those with no definite plan though they are still owned by commercial tree companies. As for future plantings, the actual area may be less than the full property size, but planting area details are not yet known. Map 2.11 shows the locations of private plantation land with categories for pre-1995 plantings, post-1995 plantings and future plantings.

5.2 River flow and salinity

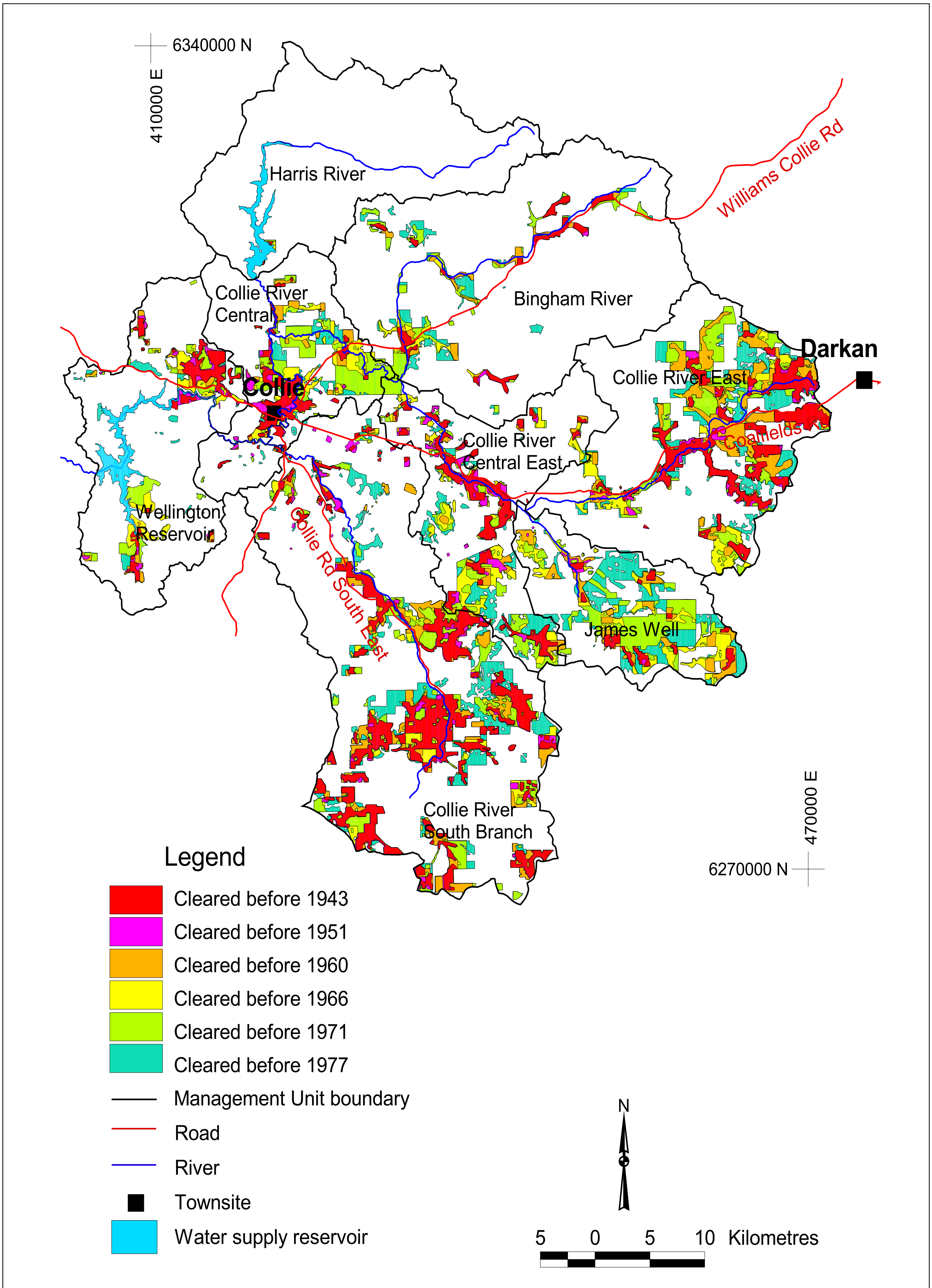
In the following Figs 5.1 – 5.7, the stream flow and salinity records from each main stream-gauging station and the estimated total inflow to Wellington Reservoir have been summarised graphically as annual values. The graph of salinity also shows the progress of clearing within the catchment of the gauging station.

At any point in time, there is a strong relationship between annual flow and the mean flow-weighted salinity for the year. This relationship has been determined for each year by fitting the equation of a power curve to the flow and salinity values from the 4 years before and the 4 years after that year, giving 9 data points. The salinity at the mean flow can be estimated from the resulting equation. The mean flow for the period 1980 to 1995 is used for all stations so that values for different stations are comparable. The graph of salinity at mean flow reveals time trends largely independent of variations in rainfall. All stations show a period of consistent trend in the period 1980 to 1990. This trend has been reported in a table at the foot of the figures, that also includes the values of mean annual flow and salt load for the 1980 to 1995 period.

The graphs of Wellington Reservoir inflow, Mungalup Tower and Coolangatta Farm all show a possible change to zero trend in salinity at mean flow, commencing in 1990. A change in trend is not evident at James Crossing, James Well or Collie River South.

5.3 Groundwater levels

Here 'groundwater level' describes the pressure in the deep groundwater (located in the partially weathered granite just above bedrock) expressed as height above or below ground; it is measured as a water level in deep piezometers. In contrast, 'watertable' is the highest level at which a pool of water would form in a hole dug from the ground surface. When the groundwater level is higher than the watertable, there is a tendency for upward flow from the deep groundwater to the surface. Conversely, a watertable



Map 5.1 Clearing history

Table 5.1 Clearing history of the Collie Catchment

Clearing history (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
1943	81.66	5.98	41.06	9.07	21.63	14.53	0.85	11.92	174.78	186.70
1951	90.15	7.09	46.88	9.67	27.98	18.14	0.82	14.81	200.73	215.55
1960	113.78	20.94	83.93	15.78	32.74	23.45	1.00	15.37	291.61	306.98
1966	127.31	36.34	97.20	19.79	49.24	35.28	1.22	25.53	366.38	391.91
1971	157.69	63.94	127.53	33.47	65.66	58.38	1.72	33.20	508.38	541.58
1977	191.80	94.30	152.92	45.45	78.82	65.02	1.72	30.79	630.04	660.82

Table 5.2 Year of planting WRC plantations

WRC plantations by year of planting (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
unknown	0.02	0.49	0.31	0.10	0.08				1.01	1.01
1976	0.00	0.00	0.00	0.32	0.00				0.32	0.32
1977	0.00	0.00	0.00	0.10	0.00				0.10	0.10
1978	0.00	0.00	0.00	0.24	0.00				0.24	0.24
1979	0.00	0.00	0.00	0.57	0.00				0.57	0.57
1980	0.00	3.34	0.00	0.05	0.00				3.39	3.39
1981	0.00	5.84	0.00	0.00	0.00				5.84	5.84
1982	0.00	1.20	4.18	0.00	0.00				5.37	5.37
1983	0.00	4.94	0.13	0.00	0.00				5.07	5.07
1984	0.00	0.61	4.96	0.30	0.00				5.87	5.87
1985	0.00	0.43	4.83	0.00	0.00				5.25	5.25
1986	0.00	2.11	0.15	0.00	0.00				2.26	2.26
1987	0.82	1.28	1.18	0.00	0.00				3.28	3.28
1988	0.00	0.38	0.74	0.00	3.33				4.45	4.45
1989	0.00	0.46	0.39	0.00	0.00				0.85	0.85
1990	0.00	0.00	1.59	0.00	0.00				1.59	1.59
1991	0.00	4.31	1.42	0.00	0.00				5.72	5.72
1992	0.00	0.00	0.13	0.48	1.38				2.00	2.00
1993	0.00	0.63	0.02	0.00	0.00				0.65	0.65
1994	0.37	0.09	0.07	0.00	0.11				0.64	0.64
1995	0.00	0.38	0.02	0.00	0.00				0.40	0.40
1996	0.00	0.00	0.02	0.00	0.00				0.02	0.02
Grand Total	**1.22**	**26.49**	**20.14**	**2.15**	**4.90**				**54.91**	**54.91**

Table 5.3 Year of planting recent and proposed plantations

Plantations (areas in km²)	Management units									
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir	**Mungalup Tower**	**Reservoir Total**
cleared before plantations	196.12	87.04	136.43	36.31	80.27	62.75	12.89	64.99	611.81	676.80
pre-1995 plantations	14.75	33.03	28.05	13.47	10.83	9.91	0.28	22.16	110.32	132.49
% of clearing pre-plantation	8%	38%	21%	37%	13%	16%	2%	34%	18%	20%
New plantations										
unknown date	9.31	0.46	0.00	0.00	3.36	0.00	0.00	0.00	13.14	13.14
1995	0.89	0.00	0.00	0.00	4.35	0.00	0.00	0.00	5.25	5.25
1996	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27
1997	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29
1998	3.97	0.00	0.00	0.00	0.00	0.15	0.00	0.00	4.11	4.11
1999	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.07	0.07
2000	17.17	7.92	3.44	0.00	0.00	0.00	0.00	0.00	28.52	28.52
To date Total	46.65	41.41	31.48	13.54	18.55	10.06	0.28	22.16	161.97	184.14
% of clearing pre-plantation	24%	48%	23%	37%	23%	16%	2%	34%	26%	27%
Future plantations										
2001	4.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.85	4.85
2005	0.00	24.01	0.00	0.00	0.00	0.00	0.00	0.00	24.01	24.01
2020	4.47	0.00	0.00	0.00	3.54	0.00	0.00	0.00	8.01	8.01
Future Total	**55.97**	**65.90**	**31.71**	**13.92**	**22.32**	**10.22**	**0.30**	**22.51**	**199.11**	**221.28**
% of clearing pre-plantation	**29%**	**76%**	**23%**	**38%**	**28%**	**16%**	**2%**	**35%**	**33%**	**33%**

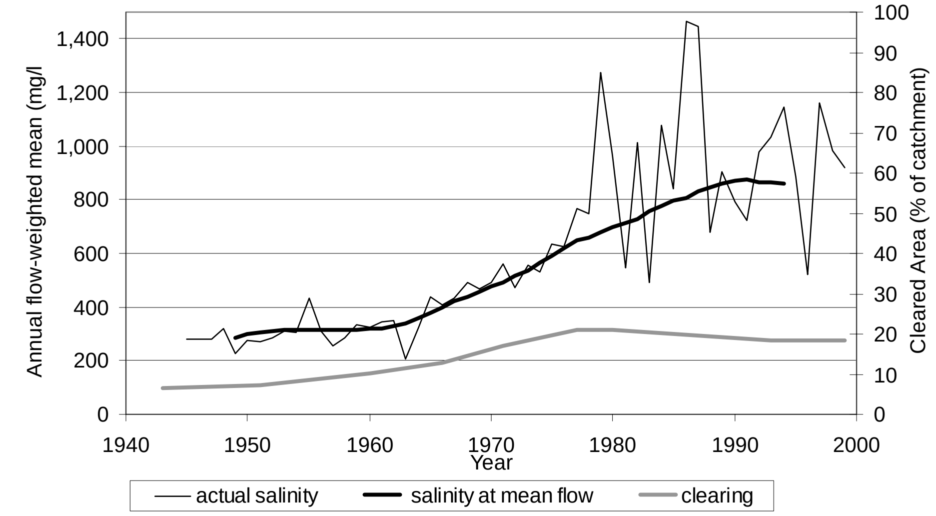
higher than groundwater level indicates a potential for recharge to the deep groundwater at that location.

Recording groundwater level over a period of time gives an indication of how the volume and/or flow rates of the deep groundwater are responding to changes in recharge to the deep groundwater.

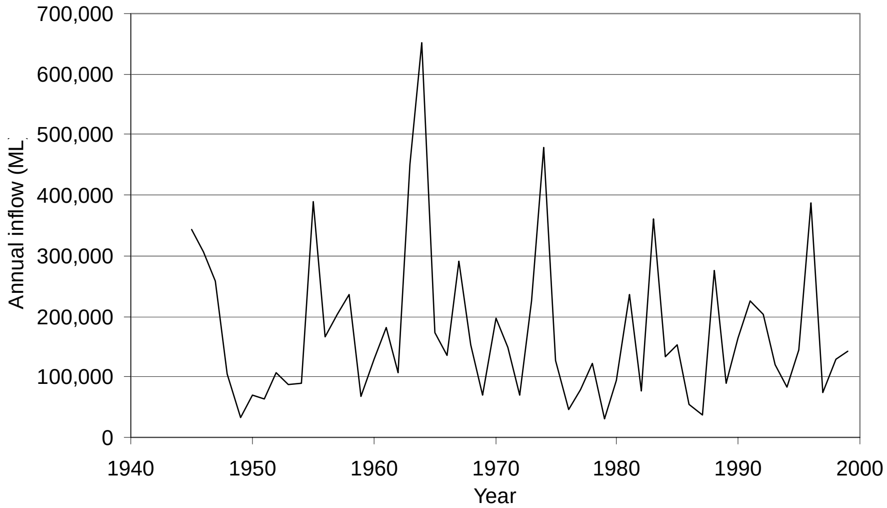
There is a relatively large variation in groundwater level in response to short term variations in rainfall. The HARTT analysis has been devised to separate this from variations due to changes in vegetation cover. HARTT (Hydrograph Analysis: Rainfall and Time Trend) is a spreadsheet type computer model developed by Agriculture WA and Faculty of Agriculture, UWA (Ferdowsian et al., 2000). Based on monthly rainfall and observed groundwater level, it predicts what the trend of the groundwater level would be if the landscape had long-term average rainfall.

Most of the piezometer records available in the Collie catchment have been analysed by the HARTT method. Of these some have been selected as typical of the recent performance and current condition of the Collie Recovery Catchment in three land use situations: native forest, pasture and reforestation. Forest has changed to pasture, and pasture has been reforested. In these two cases the records may show: a period before the change, 'Pretreatment'; a period after the change, while the deep groundwater is responding, 'Transition'; and a recent period when the deep groundwater has reached a new stability; 'Current'. Trends are reported for each of these periods where possible. Each land use has one typical graph to illustrate the nature of the record (Fig. 5.8).

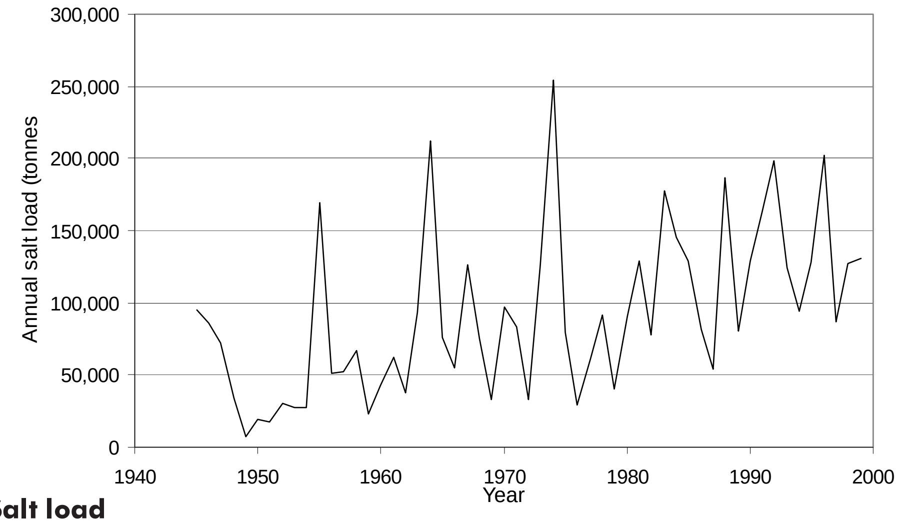
Experimental sites east of Collie have shown that from the time a treatment is applied (clearing or reforestation) there may be 2 to 4 years when there is only minor response in the deep groundwater. There is then a period of consistent trend from 5 to 10 or more years until the end of the transition period; a minor trend may continue beyond that. Thus it should be expected that the major changes in the deep groundwater system arising from a change in land use will be completed within 15 years of the change.



(a) Salinity trend



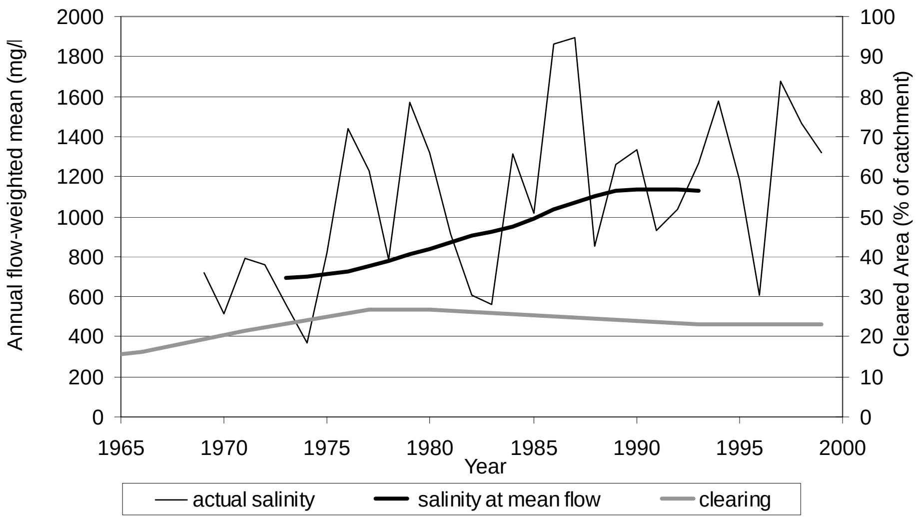
(b) Streamflow



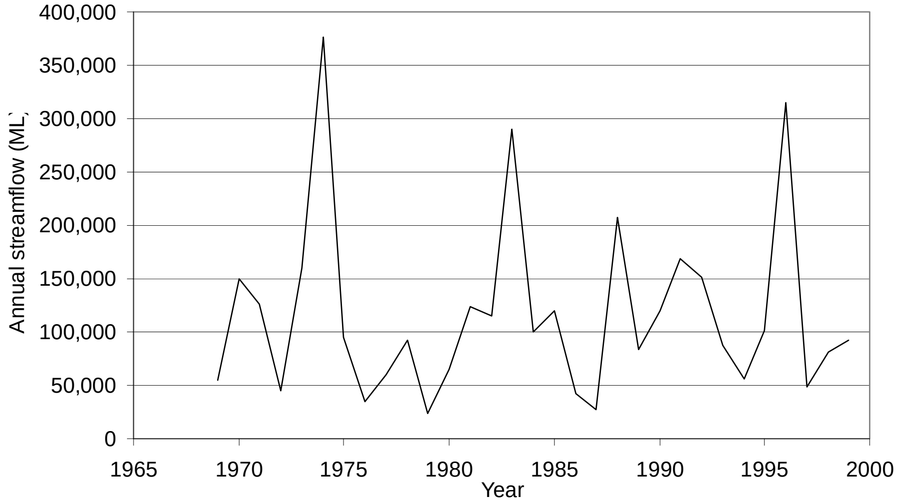
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
	2830 km^2	140 489 ML	123 638 tonnes	18 mg/L/year

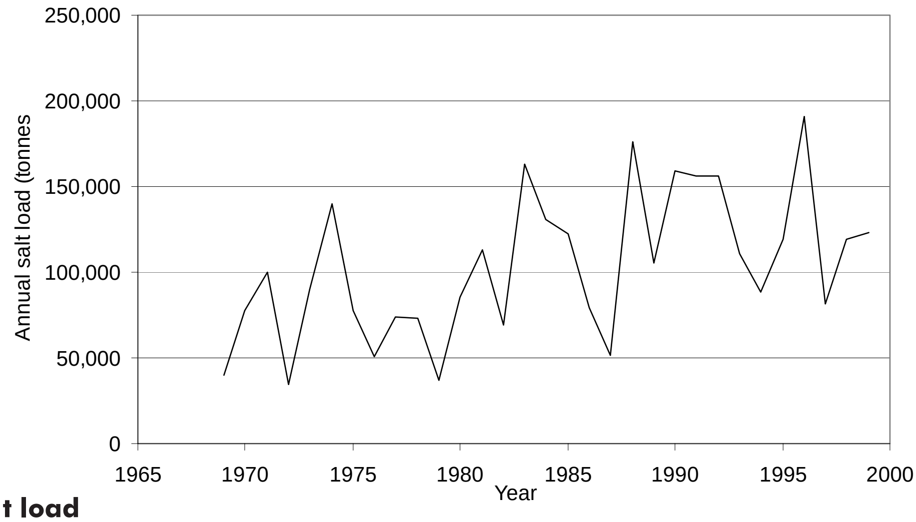
Figure 5.1 Stream salinity trend of Wellington Reservoir total inflow



(a) Salinity trend



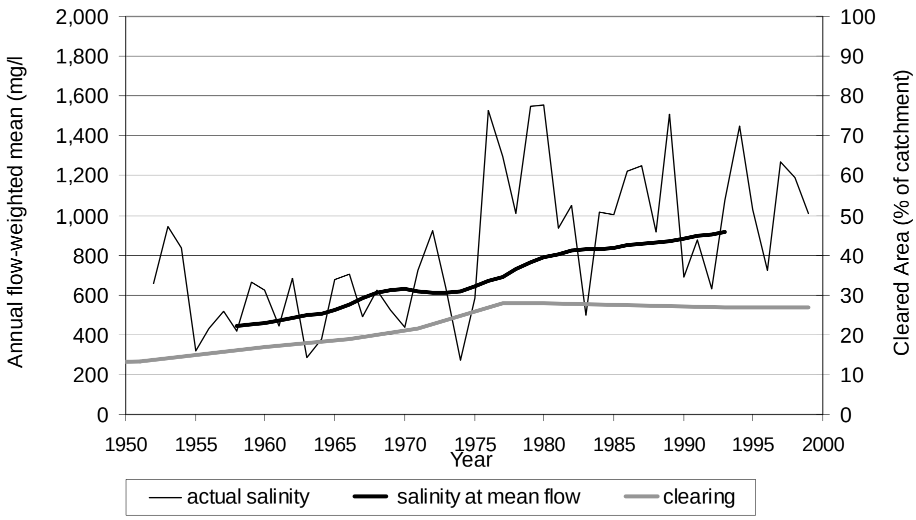
(b) Streamflow



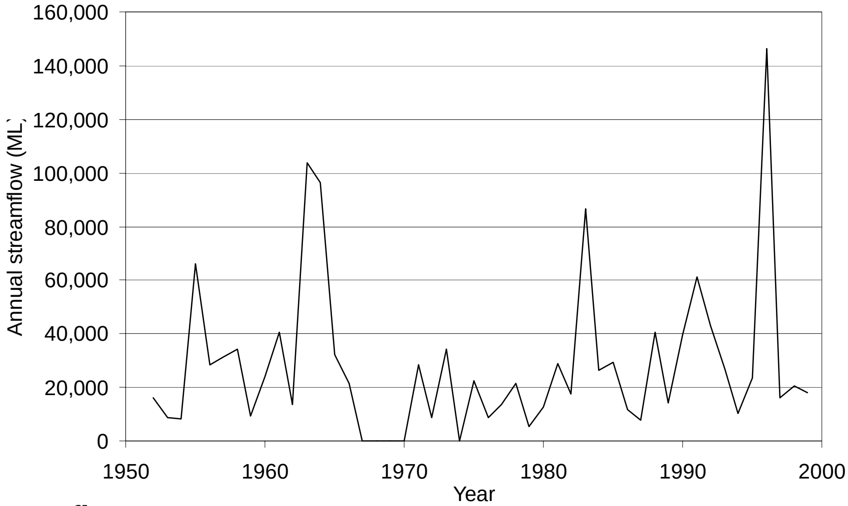
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612002	2223 km^2	116 094 ML	118 011 tonnes	32 mg/L/year

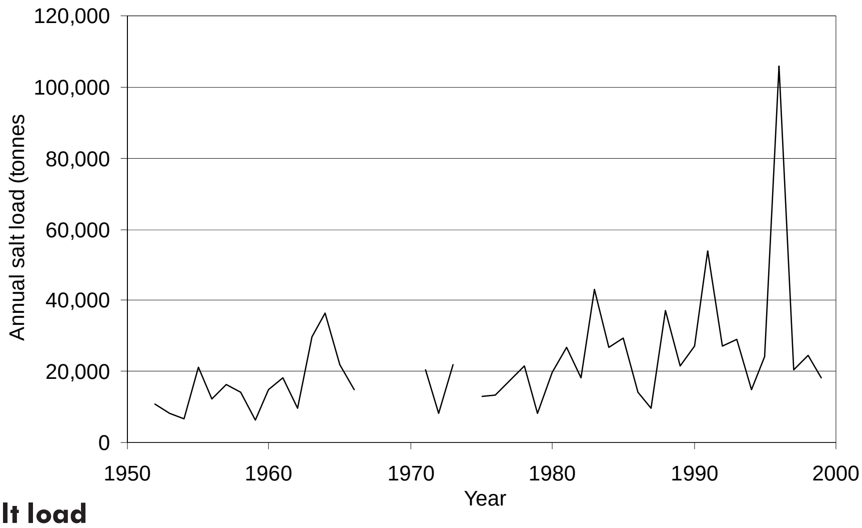
Figure 5.2 Stream salinity trend of Collie River Catchment at Mungalup Tower



(a) Salinity trend



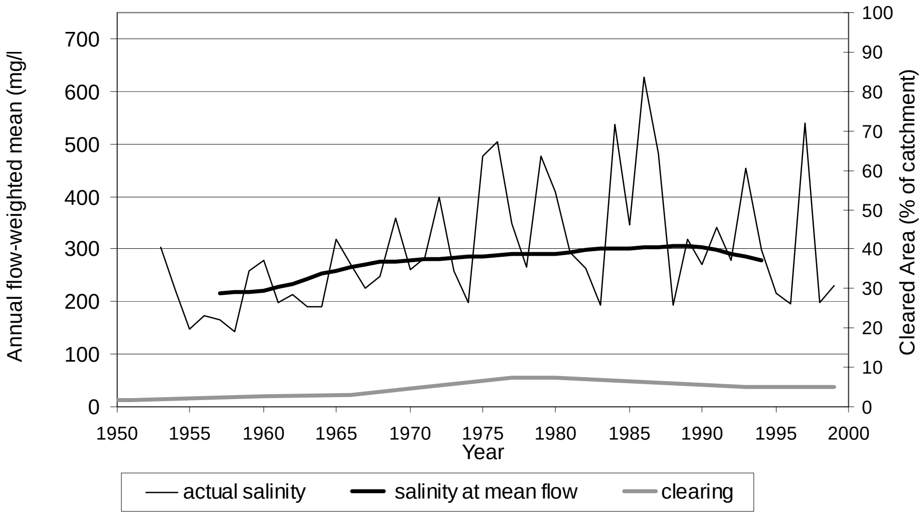
(b) Streamflow



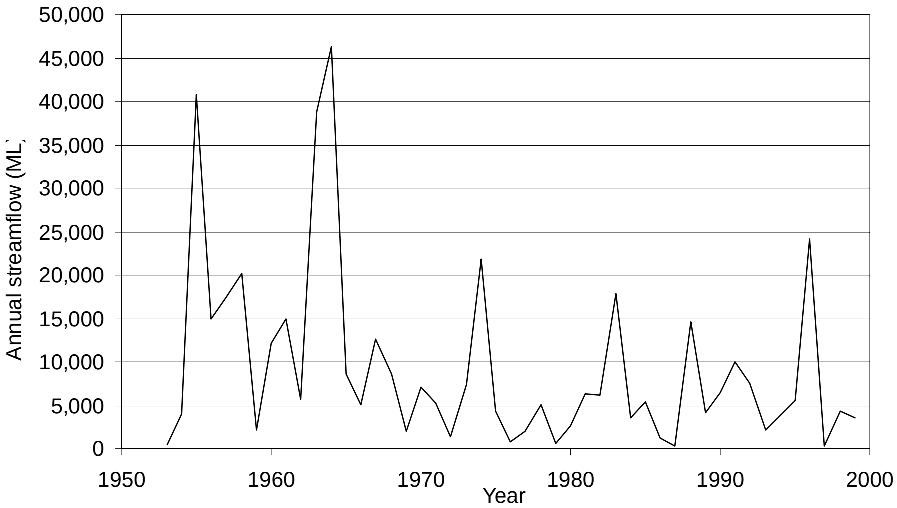
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612034	663 km^2	30 016 ML	26 451 tonnes	9 mg/L/year

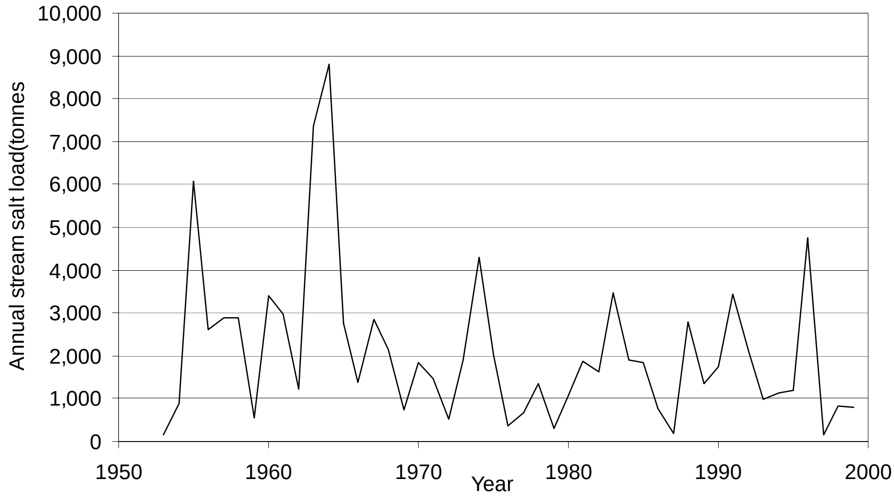
Figure 5.3 Stream salinity trend of Collie River South Catchment



(a) Salinity trend



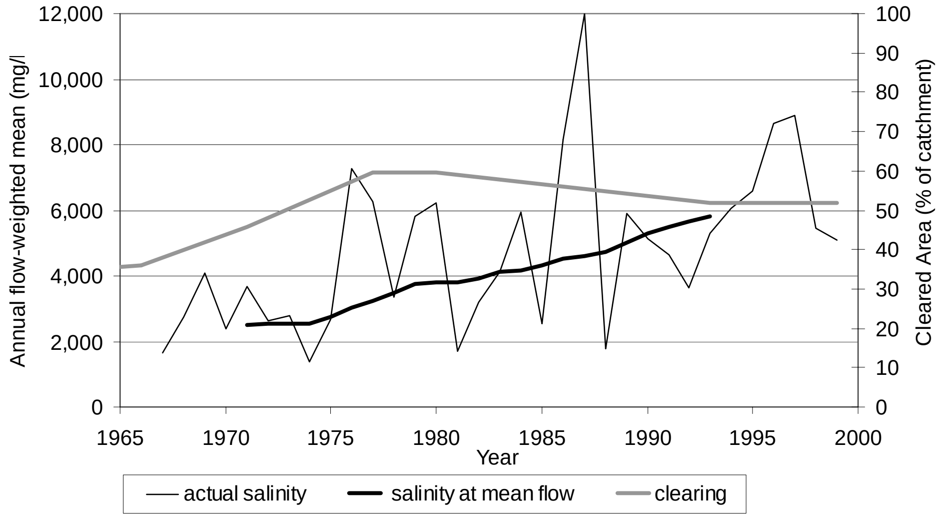
(b) Streamflow



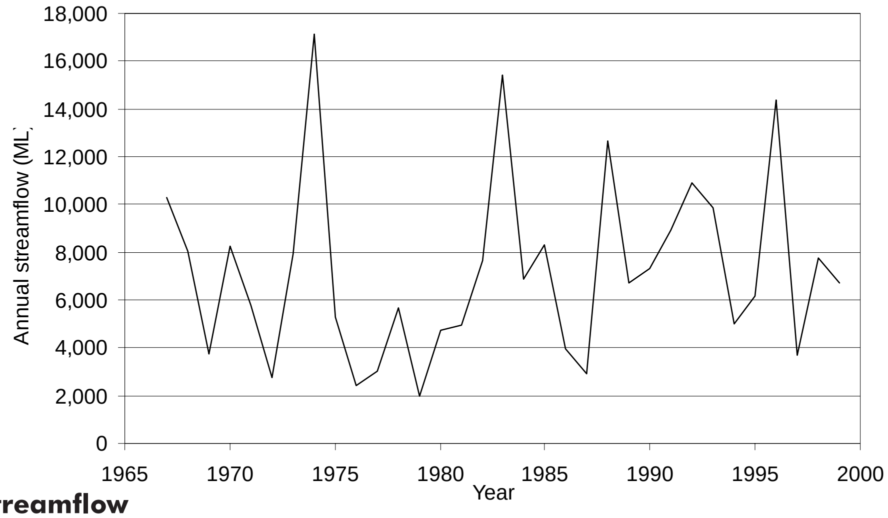
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612037	365 km^2	6117 ML	1714 tonnes	1 mg/L/year

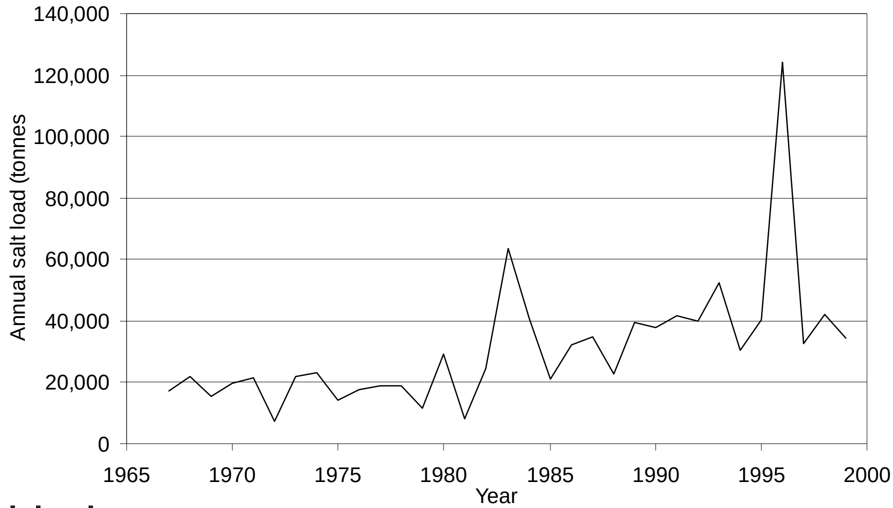
Figure 5.4 Stream salinity trend of Bingham River Catchment at Palmer



(a) Salinity trend



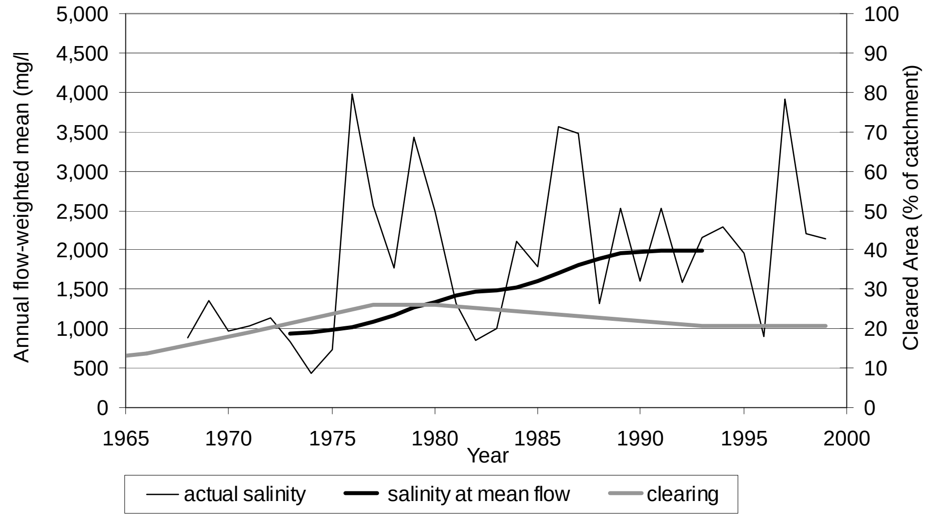
(b) Streamflow



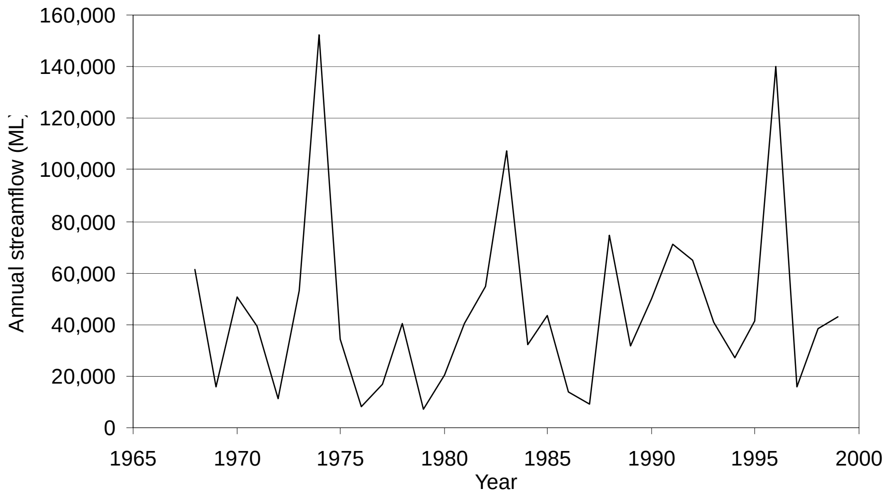
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612230	168 km^2	7643 ML	34 963 tonnes	152 mg/L/year

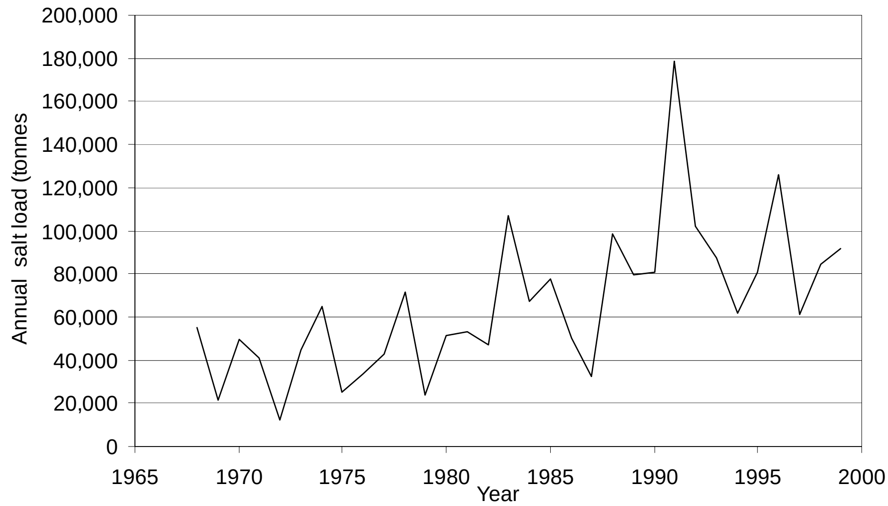
Figure 5.5 Stream salinity trend of Collie River East Catchment at James Crossing



(a) Salinity trend



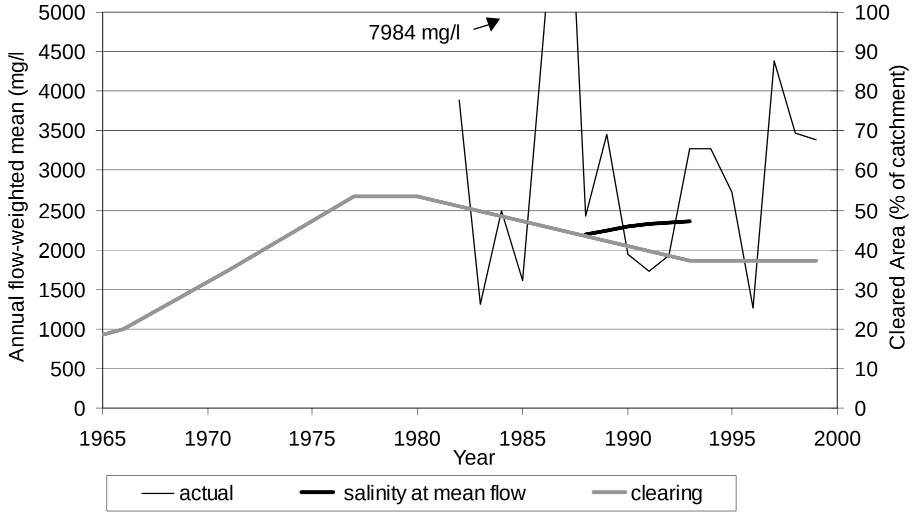
(b) Streamflow



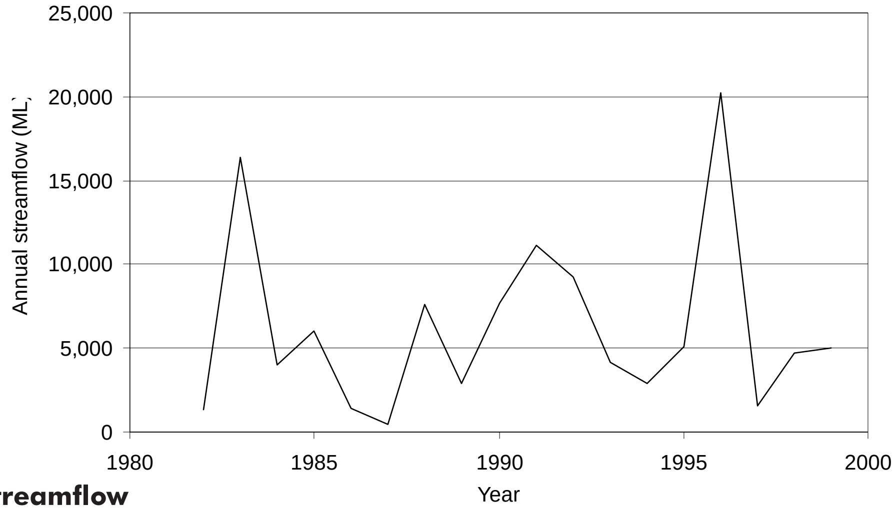
(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612001	1344 km^2	45 193 ML	78 492 tonnes	67 mg/L/year

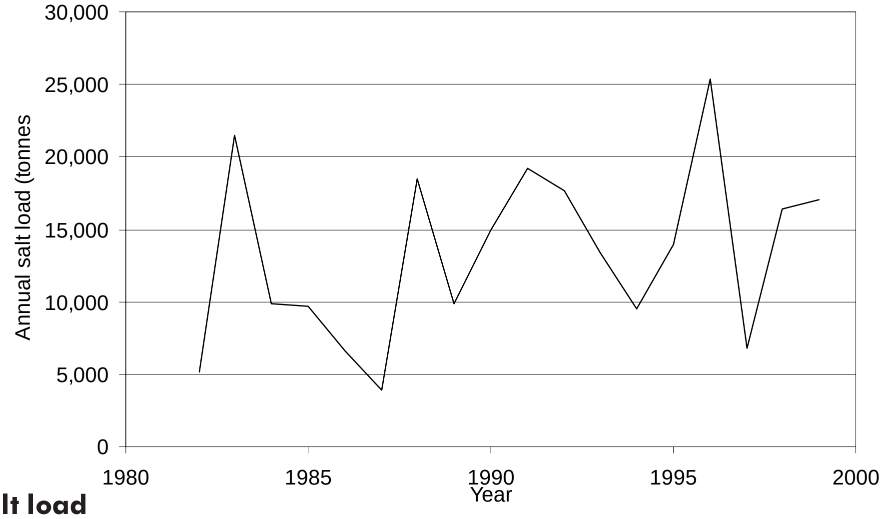
Figure 5.6 Stream salinity trend of Collie River East Catchment at Coolangatta Farm



(a) Salinity trend



(b) Streamflow



(c) Salt load

Station No.	Catchment area	Mean annual flow (1980-95)	Mean annual salt load	Salinity trend (1980-90)
612025	170 km^2	5730 ML	12 419 tonnes	35 mg/L/year

Figure 5.7 Stream salinity trend of Collie River East Catchment at James Well

Table 5.4 Groundwater trends for typical situations in the Collie River catchment

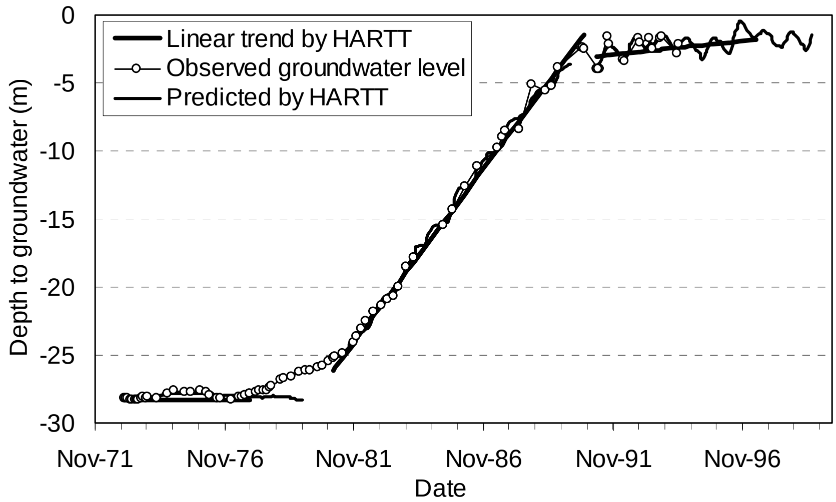
Vegetation type	Site (Rainfall) *Landscape position*	Piezometer No.[1]	Groundwater development phase (period of years)	Rate of change (m/year)	Statistical significance
Pasture	Maringee (630 mm)	G61218121	Transition (82-89)	+1.16	***
			Current (91-97)	+0.08	NS
	Mid-slope				
	Wights (970 mm)	G61219158	Transition (72-80)	+0.12	***
			Current (88-97)	-0.04	***
	Near stream	G61219144	Transition (74-81)	+0.80	***
	Mid-slope		Current (81-97)	+0.02	***
	Lemon (710 mm)	G61218708	Pretreatment (73-78)	-0.05	NS
			Transition (79-92)	+1.78	***
	Near stream		Current (92-97)	+0.11	***
		G61218766	Transition (79-90)	+1.89	***
	Mid-slope		Current (90-97)	+0.47	***
	Dons (710 mm) *Lower slope partially cleared*	G61218623	Transition (90-97)	+0.79	***
Reforestation	Maringee (630 mm) *Near stream*	G61218187	Pretreatment	No data	
			Transition (82-90)	-0.18	***
			Current(91-97)	+0.04	NS
	Stene's Arboretum (740 mm)	G61218379	Pretreatment (79-83)	+0.01	NS
			Transition (85-93)	-0.61	***
			Current (94-98)	-0.06	**
	Mid-slope	G61218378	Pretreatment (79-82)	+0.25	**
			Transition (85-95)	-0.64	***
	Lower slope		Current (96-98)	-0.37	***
	Maxon Farm (640 mm) *Lower slope*	G61219051	Current (88-98)	-0.19	***
Native forest	Ernies (710 mm) *Near stream*	G61219195	Current (72-97)	-0.03	***
	Lemon (710 mm) *Upper valley*	G61218704	Current(73-97)	-0.10	***
	Salmon (1120 mm) *Upper slope*	G61219175	Current(90-97)	-0.09	***
	Maxon Farm (640 mm) *Upper slope*	G61230245	Current(94-98)	+0.02	NS
	Dons (710 mm) *Upper slope*	G61218695	Current(90-97)	+0.18	***

[1] Positions of piezometers are shown as follows:

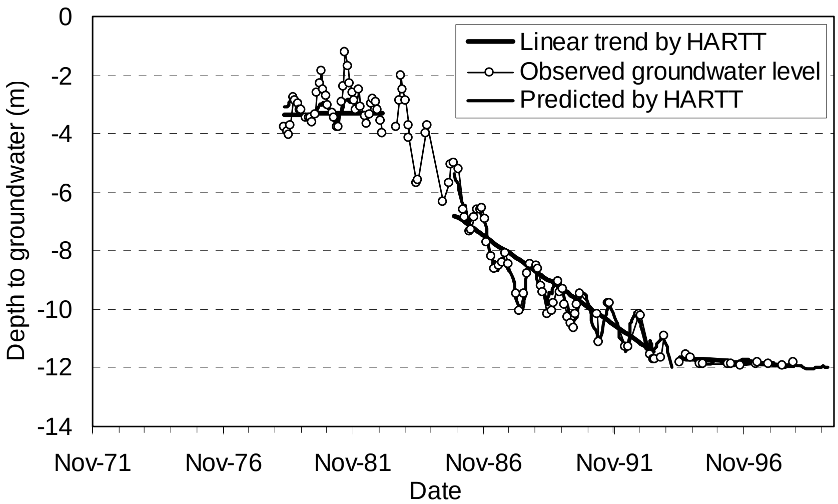
Salmon, Wights	Map 6.2
Lemon, Ernies, Dons	Map 6.3
Stene's Arboretum	Map 6.4
Maringee	Map 6.5
Maxon Farm	Map 6.6

Statistical significance of rates of change:

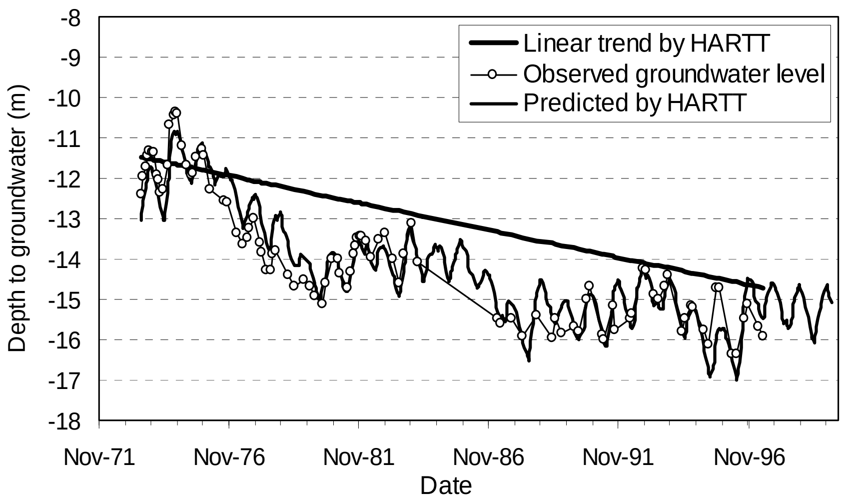
NS	Not significantly different from zero
**	Less than 5% chance that rate is zero
***	Less than 1% chance that rate is zero



a) Pasture site (Lemon catchment - cleared in 1976)



b) Reforestation site (Stene's Arboretum – replanted 1979)



c) Native forest site (Salmon catchment)

Figure 5.8 Groundwater level trends for some typcial land use situations with HARTT analysis

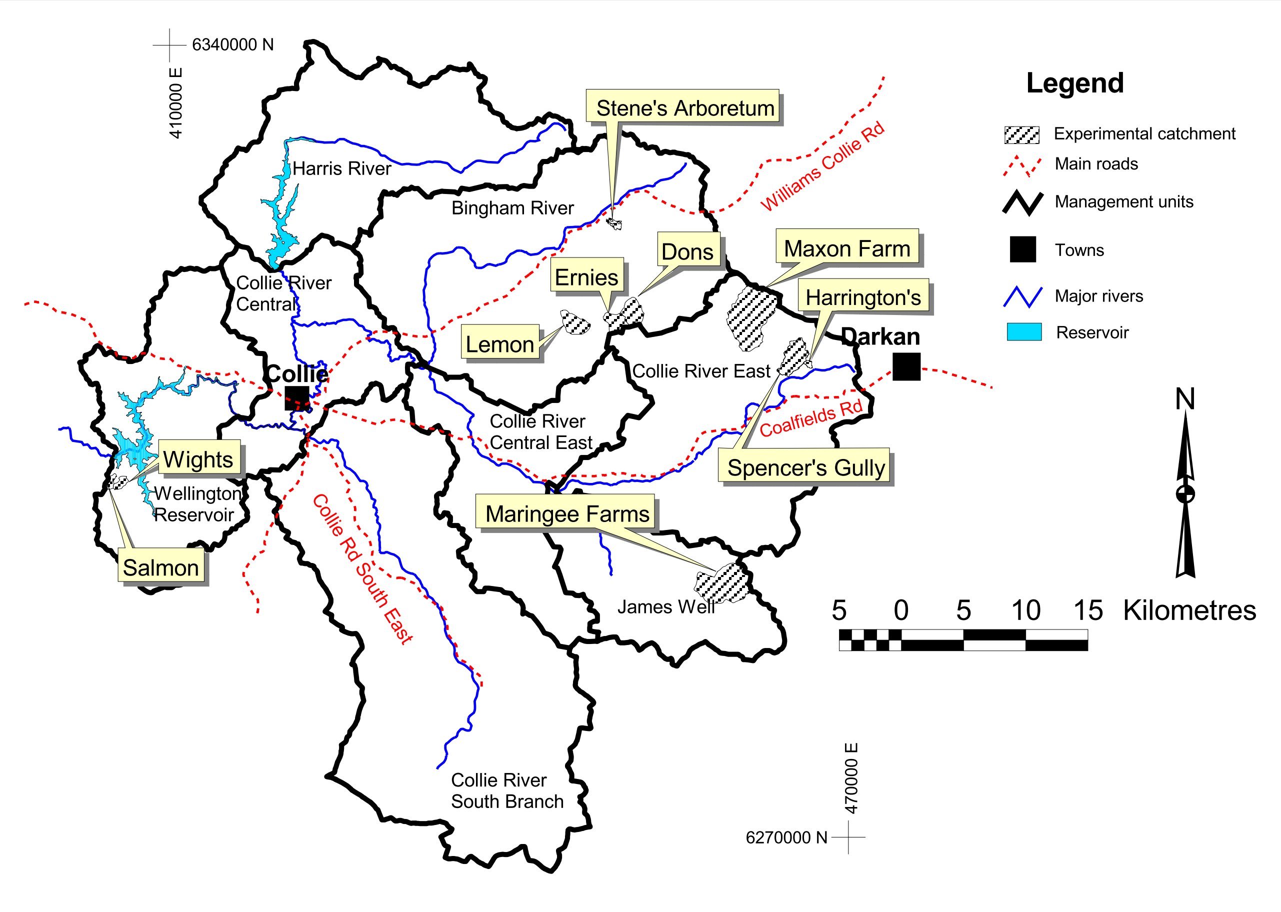
6 Dryland salinity

In the Collie Catchment, dryland salinity is predominantly a problem associated with permanent replacement of deep-rooted native vegetation with shallow-rooted annual crops and pastures on areas that have a deeply weathered soil profile of Archaean origin and relatively low rainfall (Water Authority, 1989). This chapter gives an explanation of the hydrologic processes associated with dryland salinity and the expected effects of treatments, supported where possible by observations from experimental catchments in the Collie Catchment. The locations of the experimental catchments are shown in Map 6.1. Numbers given in general discussion are approximate and are only intended to give an idea of the magnitude of the processes. Fig. 6.1 shows the main features of a typical hill-slope section that control the hydrology. In the following discussion, 'low rainfall' is less than 900 mm/year, 'intermediate rainfall' is 900 mm to 1100 mm/year, and 'high rainfall' is more than 1100 mm/year.

6.1 Pre-clearing situation

Direct run-off from forested land is rare except where the ground near a stream is saturated at the surface. About 15% of rainfall re-evaporates soon after wetting leaves and other surfaces (Croton & Norton, 1998).

Nearly all the remainder of the rain infiltrates into the upper soil layer, taking into the soil salt that was carried from the ocean by the rain or as dry particles in the wind. The upper soil layer has a relatively high permeability of about 1 m/day and is 1 to 2 metres deep on average (Sharma et al., 1987). The layer is composed mostly of clayey sand containing varying amounts of laterite. The laterite is often cemented into a duricrust that can give the impression of an impermeable barrier. However, the duricrust contains large cracks and holes that allow water to readily penetrate it (Johnston, 1987).



Map 6.1 Locality map for experimental catchments

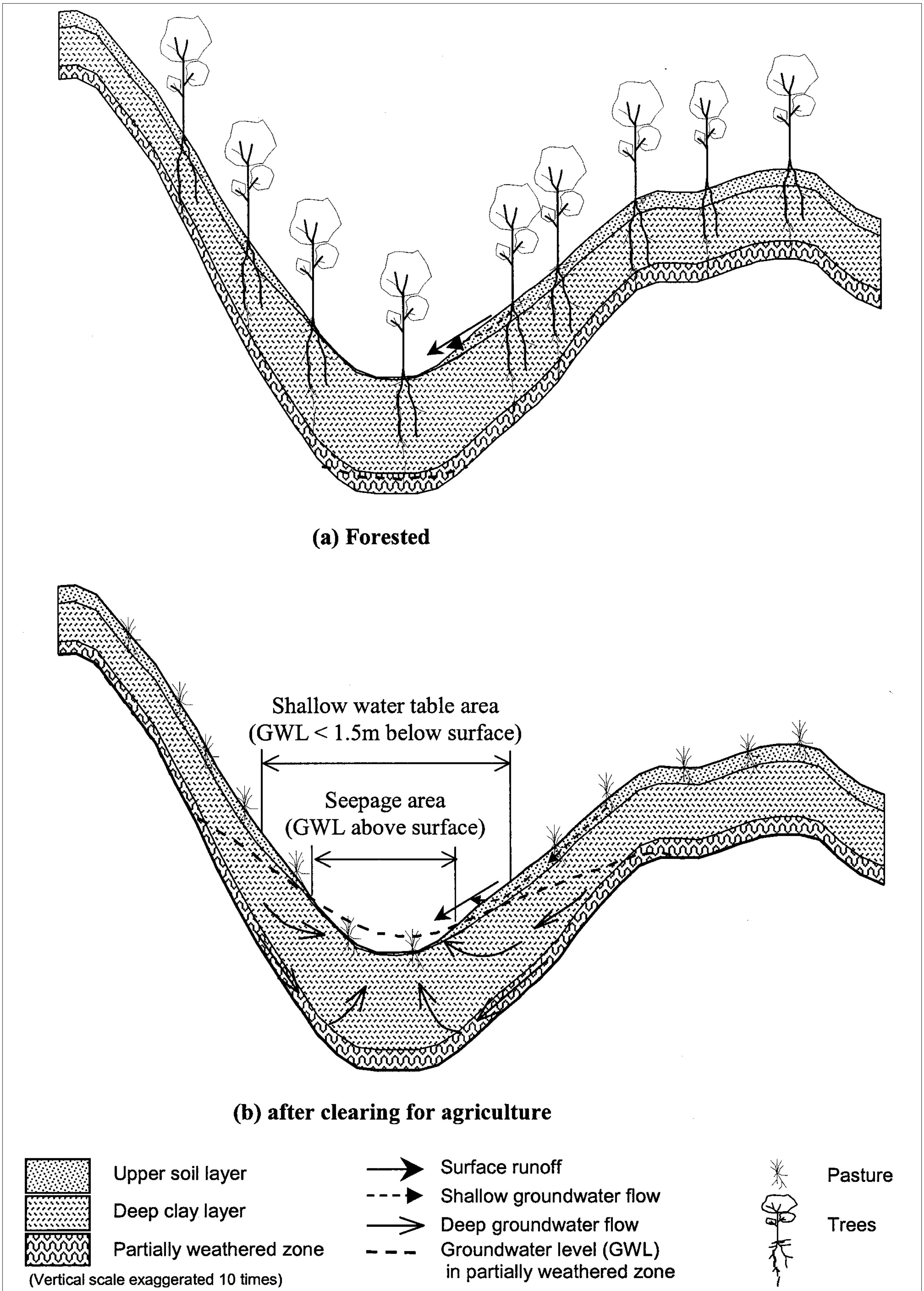


Figure 6.1 Features of a typical hill-slope section in the Darling Ranges

Because the deep roots of plants follow the holes and cracks to obtain water, the duricrust has negligible effect on the hydrology of dryland salinity at the scales of hillslopes and small catchments.

A key feature of the soil profile is that the upper soil layer, including duricrust, overlies a deep clay layer that has much lower permeability. The clay prevents most of the water draining vertically downwards. Near streamzones, the lateral downslope flow of water in the upper soil layer re-emerges to the surface or drains directly into the stream, and is the source of 'base flow' for the stream. However, most of the water 'perched' in the upper soil layer is transpired back to the atmosphere by the shallow roots of the native vegetation.

Despite its low permeability, water does infiltrate into the clay while there is free water available in the upper soil layer. The infiltrating water carries into the clay about 25% of the salt that falls on the catchment (Arumugasamy and Mauger, 1994). As summer progresses, the upper soil layer becomes dry from lateral drainage and transpiration, and plants depend on deep roots extending into the clay to supply water. While deep roots extract water from the clay, the salt is left behind, gradually accumulating from year to year, and forming a 'bulge' of high salt concentration in the trees' deep root zone 4 to 8 m below the ground (Johnston, 1987). The remaining 75% of salt is carried out of the catchment in the annual stream flow, producing a salinity of about 100 to 250 mg/L from uncleared catchments.

In lower rainfall areas the natural density of the forest is water-limited: nearly all water infiltrating into the clay during winter transpires over summer. Only occasionally is there sufficient excess water to infiltrate past the clay to the deep groundwater above bedrock. Consequently, holes drilled to bedrock will commonly find deep groundwater with high and variable salinity, but the groundwater does not accumulate, because natural attrition processes of downslope drainage, evaporation, or transpiration from very deep roots, balance the rate of recharge (Peck and Williamson, 1987b).

6.2 Development of salinity after clearing

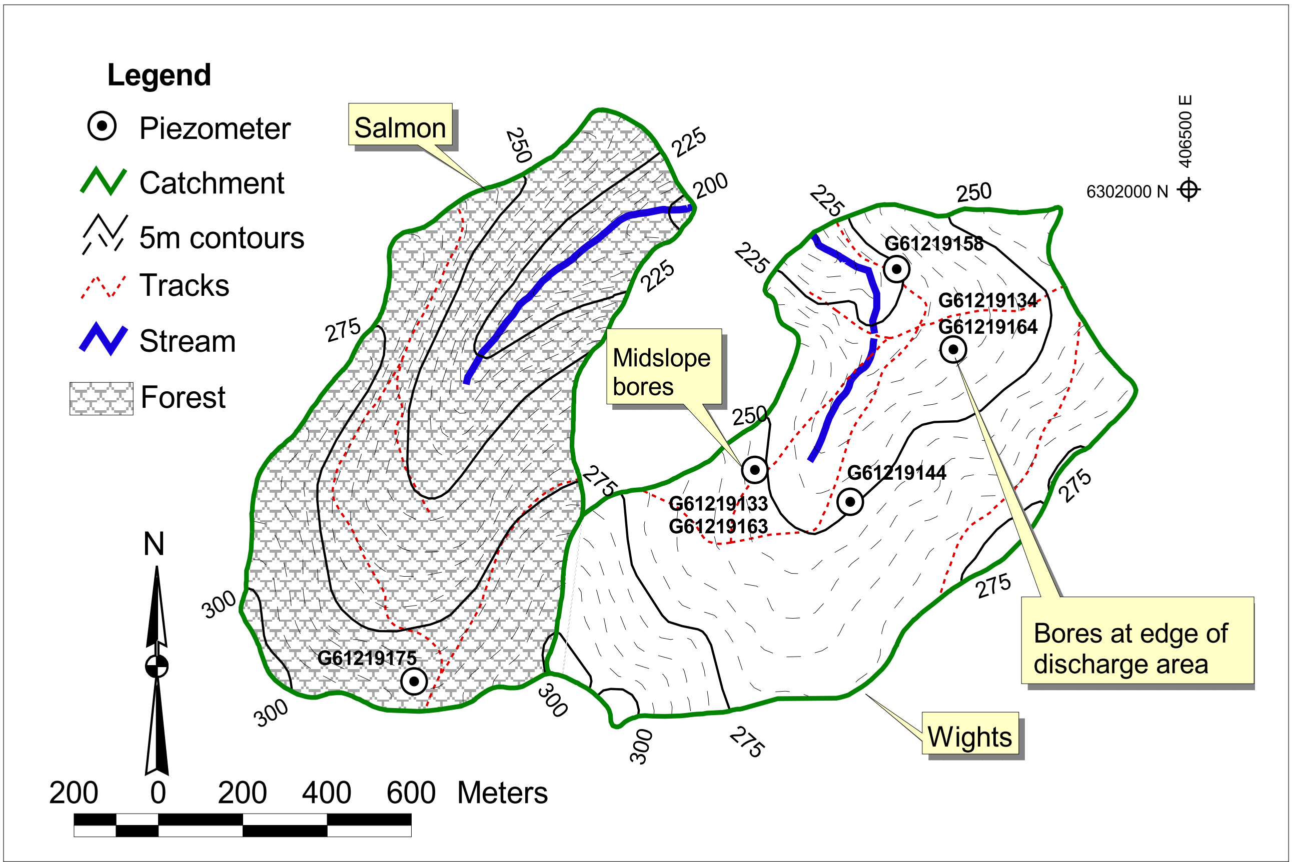
The change in the annual cycle from 'before clearing' to 'after clearing' that has most significance in the development of dryland salinity, is that the top of the clay is not dried out over summer because the plants with deep roots have been removed. Water infiltrates into the clay as before via preferred pathways (Johnston et al, 1983) (perhaps at a slower rate because the clay is not dry) but passes directly on to recharge the deep groundwater. If replacement vegetation does not have as great a capacity for transpiration water may also be available for infiltration longer than before. The rate of recharge exceeds the rate of losses and the deep groundwater level starts to rise. Where there previously may have been pockets of water in the partially weathered zone, now it becomes a fully saturated layer and tends to flow downhill like water in a pipe.

Deep groundwater draining from the valley sides accumulates in the valley bottom, lifting old groundwater towards the surface. If the valley floor has also been cleared, recharge will be added from the top, increasing the rate of rise of groundwater level in that area. When the groundwater level approaches the surface, higher water availability in the upper soil layer is briefly noticed as better crop performance. However, once the flow of saline deep groundwater to the surface is established, vegetation loss is substantial, the land being scalded and salt-encrusted in extreme cases. In less severe cases, barley grass and other more salt-tolerant vegetation becomes dominant. Often, the stream develops perennial flow where none existed before, draining the area.

There is an immediate increase in annual stream flow after clearing, as agricultural crops transpire less than the native vegetation they replace (Williamson et al, 1987). The annual stream flow increases much more when the deep groundwater level reaches the surface and discharge commences: due partly to the volume discharged, and partly to the increased area of saturated surface soils during winter causing increased direct run-off. Shallow groundwater discharge is also increased, because after deep groundwater discharge commences water is no longer removed from the upper soil layer by recharge to the clay.

6.2.1 Wights and Salmon

The Wights and Salmon catchments (Map 6.2) are an experiment to show how groundwater and stream flow respond to clearing native forest in high rainfall areas. Located just south of Wellington Reservoir, with mean rainfall over 1000 mm per year, development of dryland salinity is not considered a serious issue for agriculture or water resources in the area. However, the topography,



Map 6.2 Salmon and Wights catchments

soil profile and hydrology have characteristics similar to those of the lower rainfall areas where salinity is a severe problem. Wights was cleared in early 1977: it was expected that the hydrologic processes associated with the development of dryland salinity could be observed occurring faster than in lower rainfall areas; Salmon has been left uncleared as the 'control' for comparison.

Fig 6.2 shows the groundwater level at a point on the upper valley flank. The deep groundwater took 5 years to rise to the higher level apparently being maintained. The record from the shallow piezometer shows how groundwater is seasonally 'perched' on the clay. That the shallow level is higher than the deep level indicates the tendency for downward flow, i.e. recharge at this site.

Fig 6.3 shows the groundwater levels at a point within the final area of deep groundwater discharge in the valley. Before clearing, the deep groundwater level was relatively near the surface, but without discharge there. The year after clearing saw the deep groundwater level fail to recede, and discharge was well established a couple of years later, as indicated by the deep groundwater level exceeding the level in the shallow piezometer.

Fig 6.4 shows the record of stream flow and salinity from Wights catchment. Stream flow increased almost immediately after clearing to about three times its uncleared rate, as estimated by comparison with the stream flow from Salmon catchment. Salt output doubled for the first couple of years; then increased to 5 times, as deep groundwater discharge became established at its new high rate. Stream salinity at mean flow has stabilised at 550 mg/L.

6.2.2 Lemon, Ernies and Dons

The Lemon, Dons and Ernies catchments (Map 6.3) are an experiment to show how groundwater and stream flow respond to clearing native forest in low rainfall areas. Located 30 km northeast of Collie, with mean rainfall of 750 mm per year, development of dryland salinity was expected to be typical of the eastern part of the Collie Catchment where the effects on agriculture and water resources were most evident.

Monitoring of the catchment started in 1972. In 1976, parts of Lemon and Dons catchments were cleared to establish agriculture. 186 ha (53%) of Lemon catchment was cleared completely, from ridgeline to streamline over

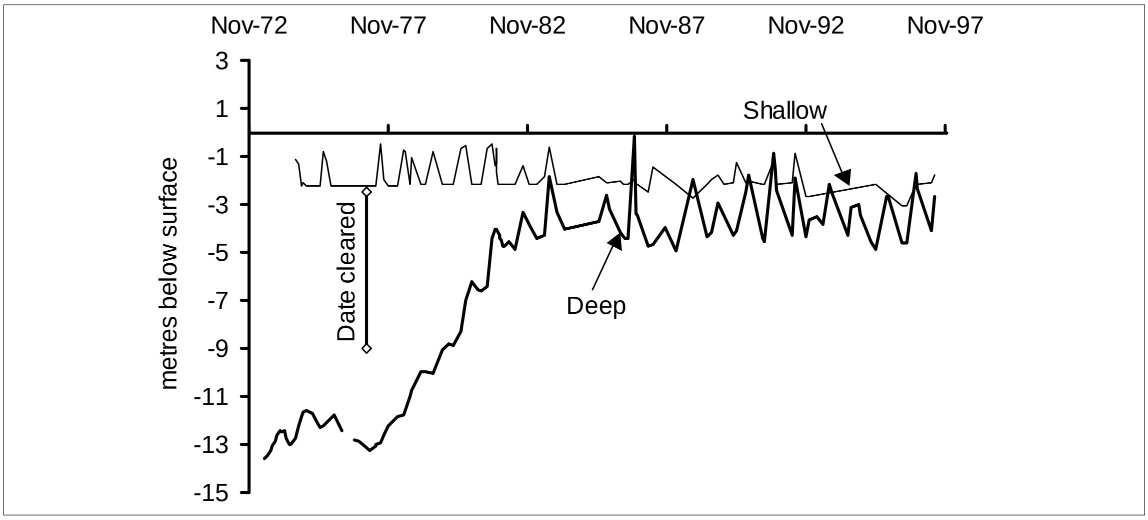


Figure 6.2 Groundwater levels in Wights Catchment (from shallow and deep piezometers at midslope)

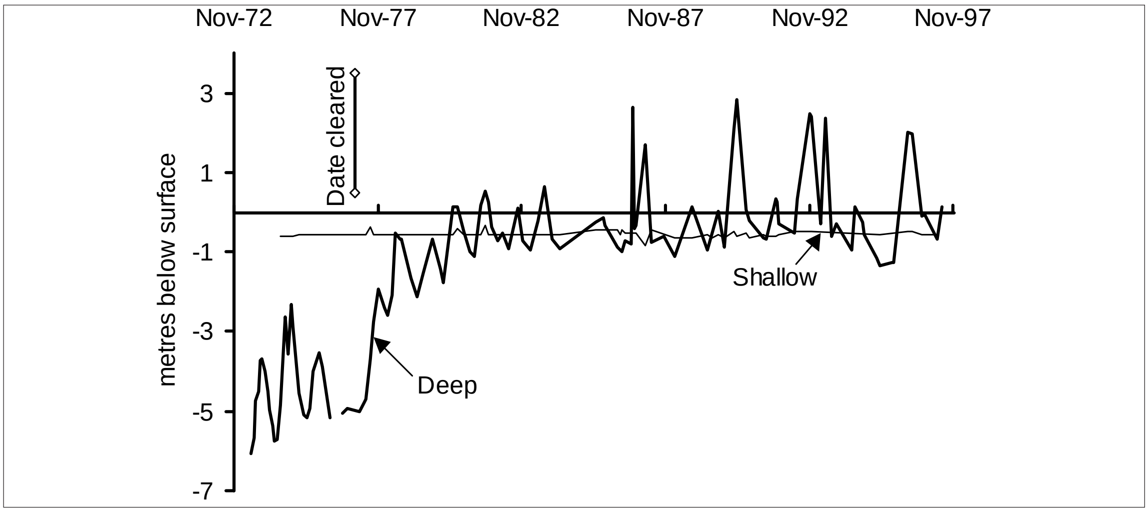


Figure 6.3 Groundwater levels in Wights Catchment (from shallow and deep piezometers in discharge area)

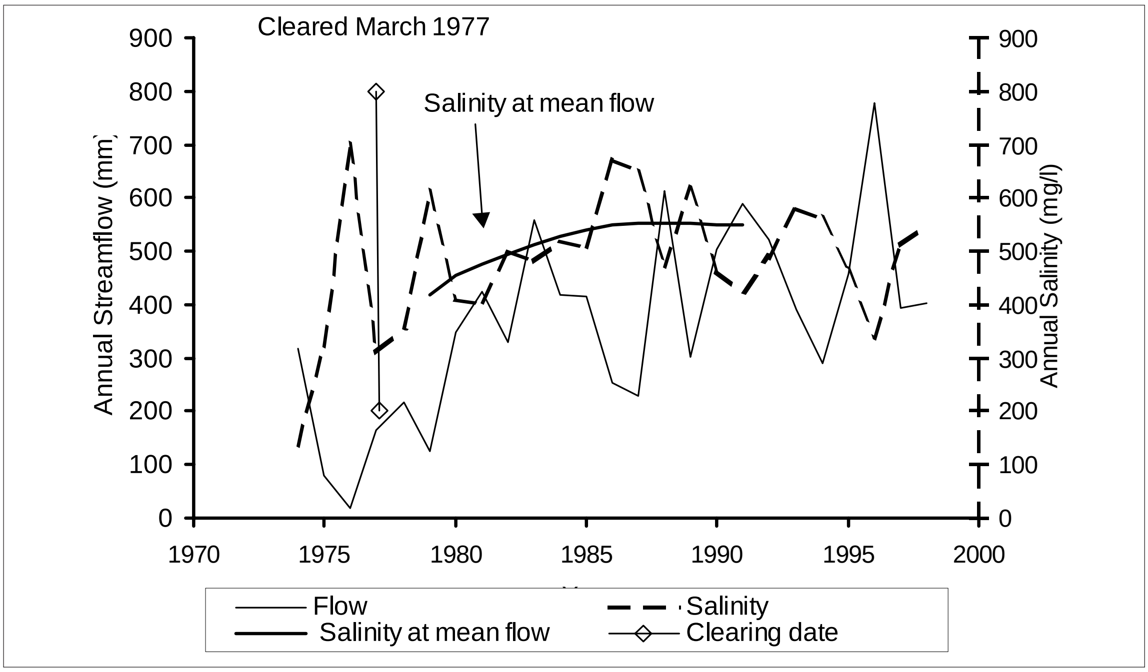


Figure 6.4 Wights Catchment streamflow and salinity

the lower half of the catchment. 133 ha (38%) of Dons catchment was partially cleared in 4 areas: 2 where clearing was in strips of varying width, roughly aligned with the contour and with narrow tree belts left between the strips; 1 area of parkland style clearing; and 1 area where upland soil types were left uncleared. Ernies catchment has been left uncleared as the ‘control’.

Lemon catchment demonstrates far more clearly than Wights, the difference between stream flow response in the period before deep groundwater begins to discharge in the valley floor and that in the subsequent period.
From 1978 to 1987, stream flow increased to 1.8 times the pre-clearing rate and salt load increased to 2.5 times, resulting in a 30% increase in salinity(Croton and Bari, 2001; Bari and Mauger, 2001a). After a transition period from 1988 to 1991, stream flow had increased to 10 times the pre-clearing rate, and salt load to 160 times. Average salinity is now about 1600 mg/L compared to the pre-clearing rate of about 100 mg/L. This is illustrated by Fig. 6.5 showing the stream flow and salinity record.

Fig. 6.6 shows a record of groundwater levels from near the valley floor. Comparison with Fig. 6.5 shows how the increase in stream flow and salinity was associated with deep groundwater levels reaching the surface. Piezometers in Dons catchment are showing a similar trend of deep groundwater level rising after the clearing, but the rate is slower, commensurate with the smaller area cleared. Levels are not yet high enough for discharge into the stream. From trends in piezometers near the valley floor, it appears the deep groundwater should reach the surface in about 2004.

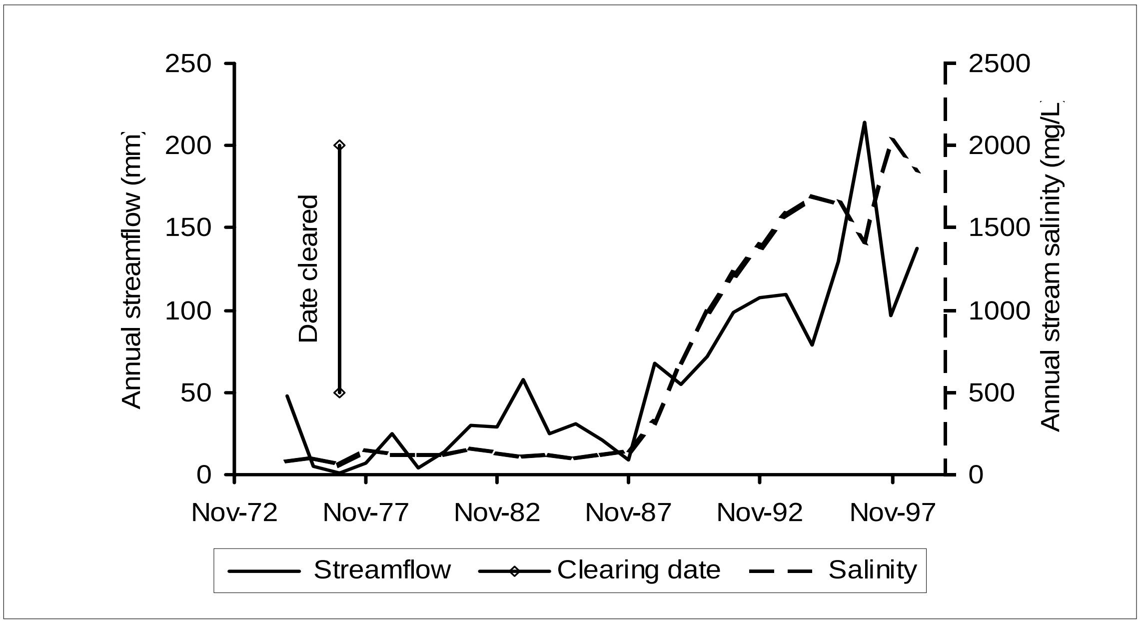


Figure 6.5 Lemon Catchment streamflow and salinity

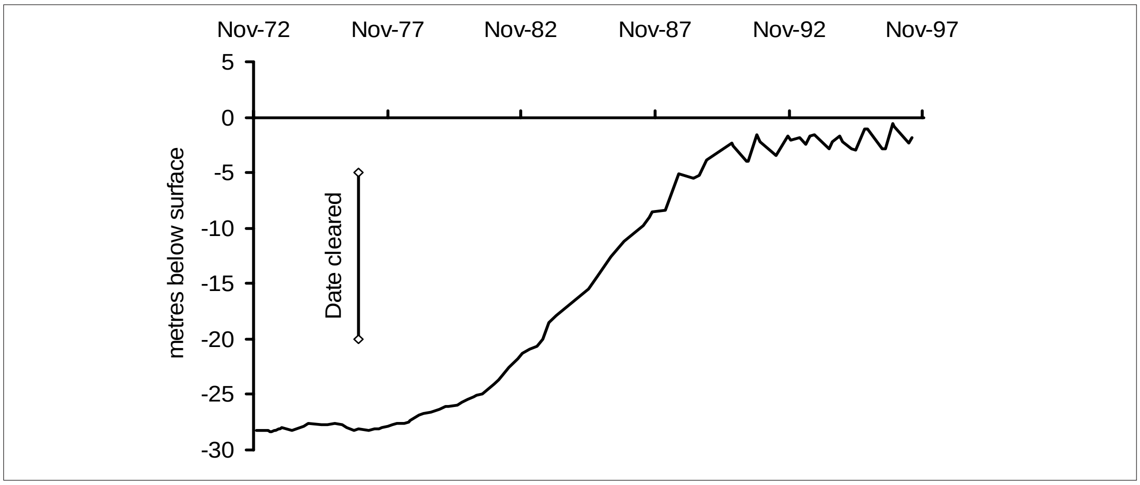
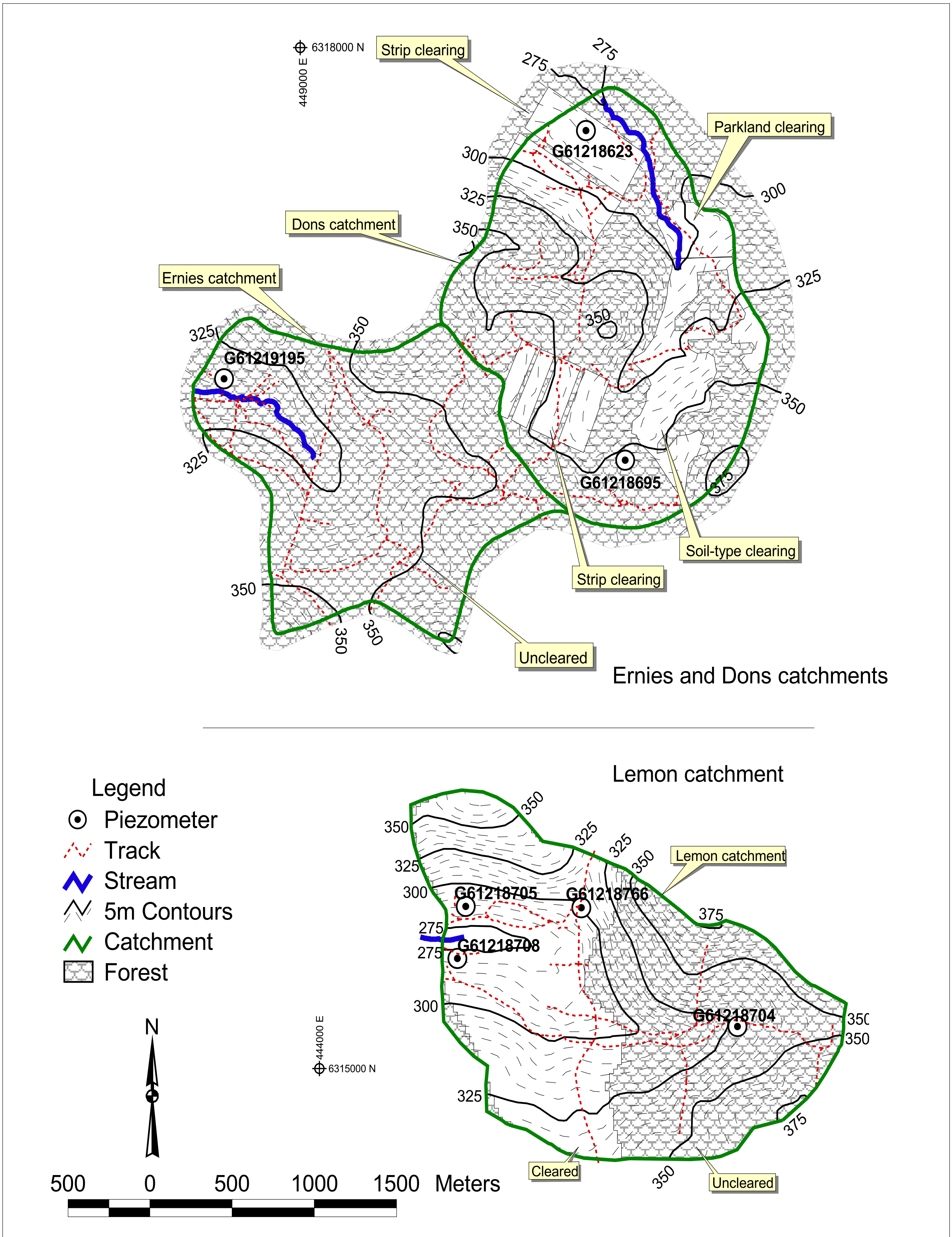


Figure 6.6 Groundwater levels in Lemon Catchment (from piezometer near valley floor)



Map 6.3 Lemon, Ernies and Dons catchments

6.3 Long-term expected outcomes

Changing the area of cleared land in a catchment causes a change in the flows and salinity of streams draining the catchment, as well as to the area of land that is salt-affected. It is useful to estimate the expected result in the catchment if the area of clearing remains unaltered for a very long period, to judge whether the objectives of the catchment require further changes in management. It is also useful to estimate the time before the current amount of clearing has produced its full impact, to assess the feasibility of treatments intended to produce results within a certain time, or the benefits of treatments intended to 'buy time' before the full effects occur.

The most rapid response to change in clearing is in the hydraulic status of the catchment, seen in the pressures and flow rates of groundwater, leading to changes in stream flow (hydraulic outcomes). Further changes are associated with the movement of groundwater from one location to another, a much slower process (long-term salt output). The condition of the soil may also be altered due to change in rate and quality of water flowing through it, which may affect the hydraulic outcome in the very long-term.

Changes in the area of clearing or management of the cleared land often change the expected long-term outcome before it is actually experienced.

6.3.1 Hydraulic outcomes

Hydraulic outcomes arise from groundwater within a catchment experiencing changes in flow rates, pressures, and volumes of water. Laws of physics link flow rates, pressures and volumes: a change in any one produces an immediate response in the others. Change of volume is detected as a change in depth to watertable. Response to a change in inflow rate is complete when the total volume has changed to the point where depth to watertable represents the pressure needed to make outflow equal to inflow.

When recharge to deep groundwater increases, the expected changes are:

- increased area where deep groundwater discharge occurs;
- increased volume and duration of baseflow in streams, due to increase in rate of deep groundwater discharge;
- increased flood volumes and peak flow rates due to increase in saturated area contributing direct runoff;
- reduction in depth to groundwater; and
- increased variability in flows and salinity.

The difference between observed records and the long-term outcome, and the time it may take to achieve the long-term result, can be estimated in several ways. **Note that all calculations of trends are with reference to an assumed long-term average annual rainfall. Part of a trend may be due to a trend in the series of annual rainfall.** In this report, the assumed average rainfall is for the period 1980 to 1995.

Method 1: A short period of record is used to establish the statistics of flows at that time. From the statistics, estimates are made of flows and salinities that would have occurred if rainfall had been average. Periodic evaluations reveal trends in time. This does not predict when the trend will end, but does indicate when changes in trends did occur.

Method 2: A statistical regression analysis can be applied to the historical record to estimate how much variation in the record is due to variation in rainfall and how much is due to an underlying trend. A required assumption is that the trend is constant over the period of the record, or at least between assumed times of change in trend. This technique has been applied using the HARTT method to analyse trends in groundwater levels measured in piezometers (Ferdowsian et al., 2000).

Method 3: A computer model of the catchment (such as the MAGIC model used in this report to evaluate management options (Mauger, 1996)) is used to simulate the expected long-term outputs under average rainfall conditions and with a fixed distribution of vegetation cover. The time to reach full discharge rates can be derived from model outputs by reference to the clearing history for the catchment.

Method 4: A computer model of the catchment (such as WEC-C (Croton and Barry, 2001) or LASCAM (Sivapalan et al., 1996)) is used to simulate the stream flows over time in response to changing vegetation cover. The model is calibrated against existing record, and then allowed to simulate the catchment over the historical period, but with vegetation set constant at the desired coverage. The difference between observed and modelled records can be used to identify trends, and to estimate how long before the difference becomes zero.

6.3.2 Long-term salt output

Rates of deep groundwater discharge are associated with pressure gradients (as shown by groundwater levels) that start in recharge sites and end at discharge sites; the rate of discharge can therefore be influenced by changing the groundwater level at a point quite remote from the discharge site. The salinity of the discharge though is set from the body of groundwater that is right at the point of discharge; rate of salt load output is the product of flow rate and salinity.

When deep groundwater first discharges after clearing, the actual water is what lay directly beneath the site; it is groundwater pushed to the surface by lateral inflow driven by higher pressures in recharge areas on adjacent sides of the valley. The first water may be recent recharge from just before the upward flow reaches the surface; but what follows once this has been pushed out of the clay would initially be the old groundwater that had accumulated in the saprolite grit prior to clearing.

It has been noted that discharging deep groundwater flows through preferred pathways in the clay. The major source of early salinity in the discharging water is the salinity of the nearby old deep groundwater that can be sampled from piezometers drilled to bedrock. The salt stored in the soil between preferred pathways (i.e. in the clay matrix) may add to the salinity of water in the preferred pathways by a diffusion process, if the concentration in the water saturating the matrix of the clay layer is higher than that of the old deep groundwater.

Eventually, new recharge water would complete the path from recharge on the valley sides to discharge in the valley bottom. The salinity of such water would depend on salt gained from diffusion in passing through preferred pathways, downwards through the clay in the recharge area and upwards in the discharge area. It must be less than or equal to that of the initially discharged old groundwater.

In the very much longer term, the diffusion process would deplete the salt stored in the matrix of the clay until the salinity gradient between water in the matrix and the preferred pathways was negligible. The average salt load output from the catchment would then equal the average input from rainfall.

6.3.3 Long-term soil changes

Areas where deep groundwater discharge becomes established after clearing experience a change from being occasionally saturated with relatively fresh water, to being continually saturated with high salinity water. The full consequences of this change have not been explored. Conceivably, chemical and/or biological effects could reduce the permeability of the clay and its preferred pathways, increasing the resistance to discharge. This increase in resistance could be offset by increases in groundwater levels and area of discharge.

6.4 Effects of treatment

'Treatment' is the application of a change in land management that is intended to reduce the effects of salinity. A treatment may further one objective of salinity reduction more than another. This section explains the expected effects of treatments that could be applied in the Collie Catchment.

6.4.1 Reforestation

The function of planted trees as a treatment for salinity is to remove water from the clay layer during summer. The effect is different depending on whether the tree is located where the deep groundwater is discharging or where recharge to deep groundwater is possible. However, a tree will draw up, with its shallow root system, mostly water from the surface soil layer while moisture is available there. The relatively high water-use of the trees can bring the additional benefit of drying out the surface layer sooner after winter, thereby reducing recharge and waterlogging.

Reforestation at a recharge site slows or stops recharge there; allowing the water pressures at the upstream end of the groundwater flow path to decline, as accumulated water drains away without being replaced; and leading to a reduced rate of discharge at the downstream end, as the driving pressures reduce. The reduction in discharge would ultimately equal the reduction in recharge; the reduction in recharge may be offset by additional recharge on cleared downslope areas where discharge ceases as a result of the reduced pressure.

At a discharge site, the trees may reduce the volume of water leaving the site in stream flow, but the effect on the salt load is uncertain. If sufficient trees are planted, and the species are capable of using the water quality, so that the clay is dried to sufficient depth over summer, salt in the discharging deep groundwater could accumulate in the clay. Also, if a proportion of the salt output at the site was being leached from salt stored in the clay, removal of water from the clay would stop that salt being mobilised; the rate of accumulation might then be much less than expected from salt discharge observed before tree planting.

Although it is unlikely that a site could grow trees indefinitely while there is no limit to the accumulation of salt in the clay, planting on discharge areas might, in the short term, produce a rapid reduction in salt output while other treatments to reduce recharge are yet to take effect. On the other hand, if the transpiration rate of the trees is unable to exceed the rate of deep groundwater inflow over summer, the salt will continue to be carried into the surface soil layer and thence into the streams, and in a quantity of water reduced by whatever the trees have managed to use. This could lead to higher salinity of local streams.

A number of reforestation alternatives have been considered for the Collie Catchment and some have been trialled at experimental sites: short descriptions follow.

6.4.1.1 Stenes Arboretum

The Stenes Arboretum (Map 6.4) demonstrates the effects of reforesting most of the cleared area in a catchment. The effects of the planting are expected to be similar to the effects of planting whole farms to commercial trees (Schofield et al., 1989).

The area of the arboretum is 84 ha and rainfall is 725 mm per year. The site lies along a 1.5 km reach of the Bingham River, 35 km NE of Collie. The site was the only part of the local catchment that was cleared, and most of the clearing had occurred before 1943. Groundwater level was within 1.2 m of the surface near the river and the groundwater salinity was about 5400 mg/L.

The whole cleared area was divided into 123 plots of about 0.5 ha each, and in 1979 each plot was planted with one of the trial species at a density of 625 stems/ha. By 1985, survival in a number of the plots was less than 20%. The remaining plots covered about 70% of the cleared area (Bari and Boyd, 1994). The groundwater showed little net change for 4 years after planting, and then declined rapidly over the next 4 years to be up to 4 m lower in the central area of the plantation. By 1998 the groundwater level had declined a further 6 m in the central area (see Map 6.4). Piezometers in nearby pasture areas showed a trend for increasing level over the same period. 'Failed' plots were planted with Bluegums (*Eucalyptus Globulus)* in 1998.

6.4.1.2 Maringee and Maxon Farms

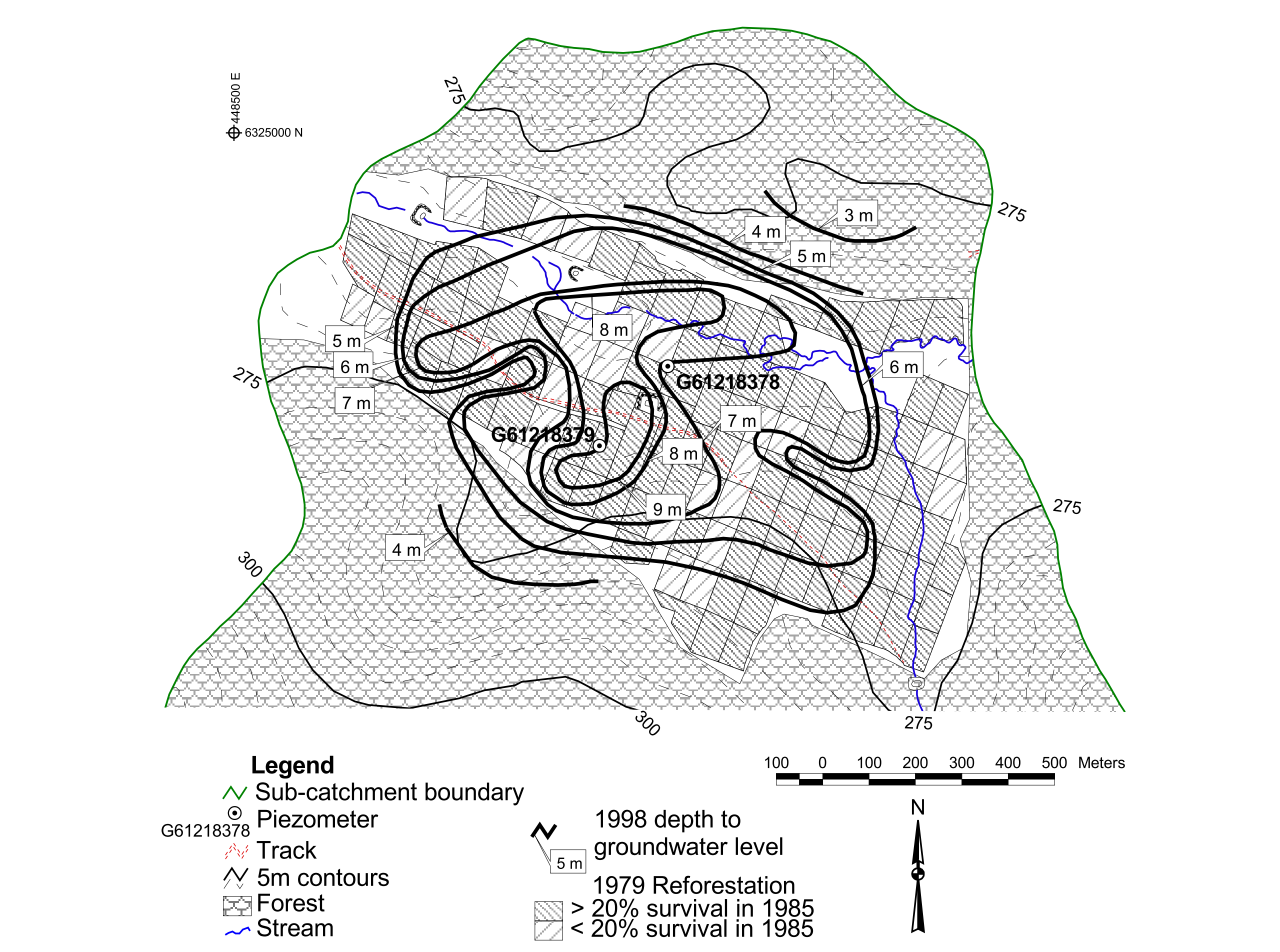
Maringee and Maxon Farms are two sites where trees have been planted on the predominantly discharge sites of valley lower slopes. Some planted areas have commercial potential; but in many the tree species must be saline tolerant, and these can be better characterised as 'conservation style' plantings.

The Maringee Farms catchment (Map 6.5)

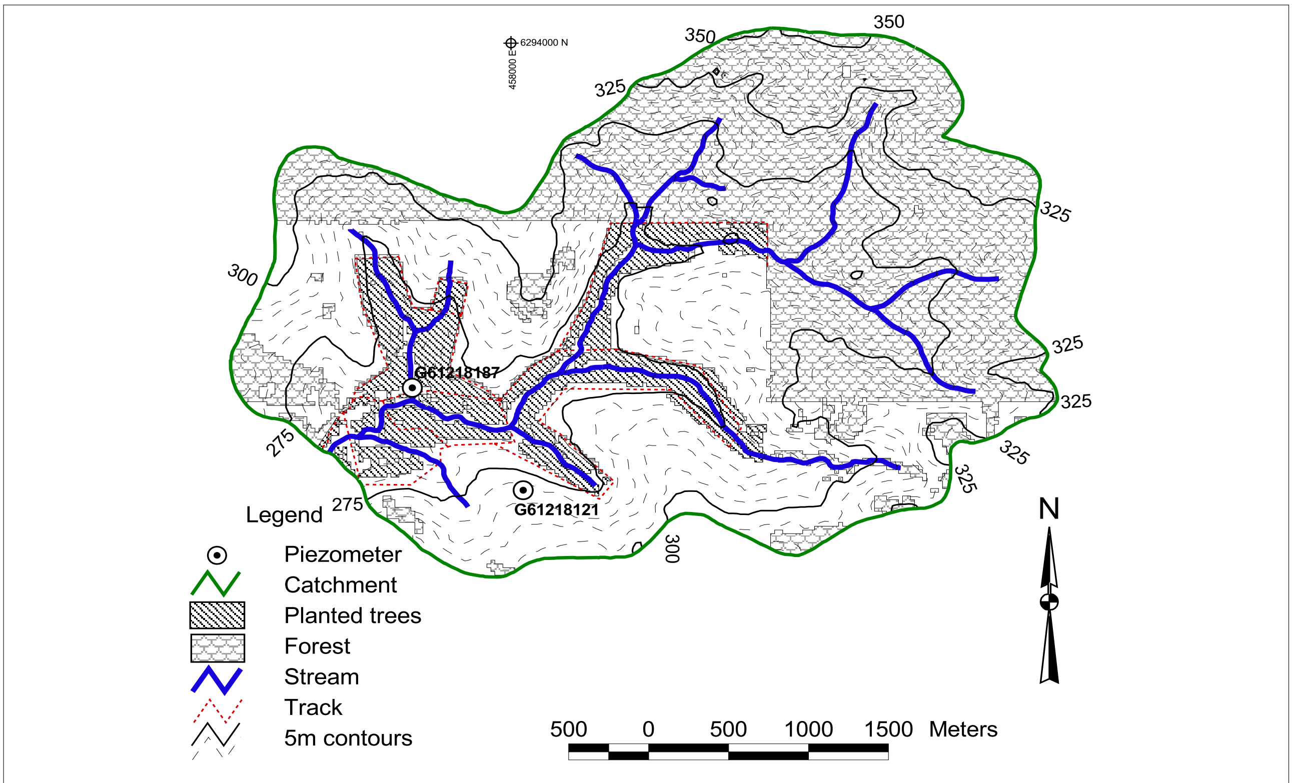
The area of the monitored catchment is 1299 ha and its mean annual rainfall is 626 mm. The catchment is located in the headwaters of the Camballan Creek tributary of the Collie River. By 1971 most of the present clearing (50% of the catchment) had been completed, more than 70% of that within the previous 5 years. After clearing control was imposed in 1976, the Government negotiated to purchase the lower slopes of the valley as part of the compensation process. The purchased land in the catchment has an area of 180 ha, or 30% of the cleared area. Trees were planted on this land, mostly in 1981 and 1982, but with some minor extension in 1986. After allowing for areas unsuitable for trees, about 20% of the cleared land was planted.

Monitoring of the catchment commenced in 1981 with installation of a stream gauge and a number of piezometers. A computer model of the catchment has recently been completed, which explains the observations of groundwater pressures and stream flows and salinity in terms of the physical processes that produced them (Bari and Mauger, 2000b). Graphs of stream flow and salt load through the stream gauge, versus rainfall are shown in Figs 6.7 and 6.8, together with the response that the model estimated would have occurred had trees not been planted. The computer model gives reduction in salt discharge as about 20% and that in stream flow as about 10%, compared with the situation were the land left as pasture.

The record from piezometer G61218187 (Fig. 6.9) shows a response characteristic of deep groundwater levels where trees are successfully planted in discharge areas. The groundwater level is seen to decline for about 5 years after planting, and thereafter keep reasonably stable, but with



Map 6.4 Stene's Aboretum with reduction in groundwater level



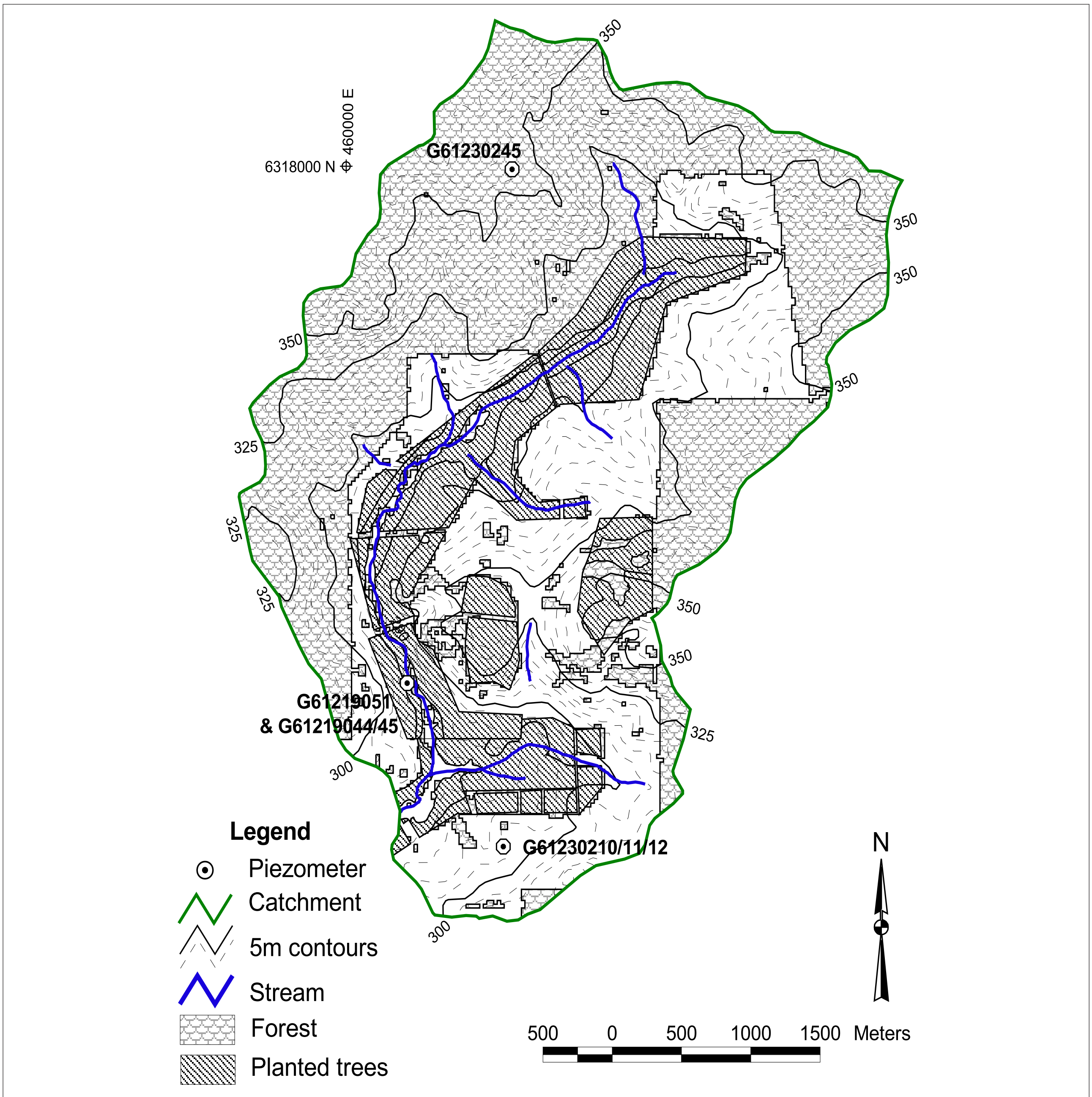
Map 6.5 Maringee Farms Catchment

a larger seasonal variation than before planting. An upward pressure gradient remains

- Some areas where salinity would be expected eventually in the absence of tree planting, but which are not far upslope from the plantings, have become salt-affected since monitoring began.
- Tree survival close to the stream channel has been poor, but replanting with more salt-tolerant species has been successful in several areas.

The Maxon Farm catchment (Map 6.6)

The area of the monitored catchment is 1660 ha and its mean annual rainfall is 640 mm. The catchment is located in the headwaters of the Batalling Creek tributary of the Collie River, about 40 km east of Collie. During the 1950s and 60s the cleared area comprised a strip about 500 m wide along the full length of the valley, amounting to less than 20% of the catchment. In the late 60s substantial additional clearing brought the total to 51% of the catchment area. After clearing control was imposed in 1976, the Government negotiated to purchase the lower slopes of the valley as part of the compensation process. The purchased land in the catchment has an area of 342 ha, or 40% of the cleared area. Trees were planted on this land, mostly in 1985, but with some minor extension in 1986. After allowing for areas unsuitable for trees, about 35% of the cleared land was planted (Bari, 1992b).



Map 6.6 Maxon Farm Catchment

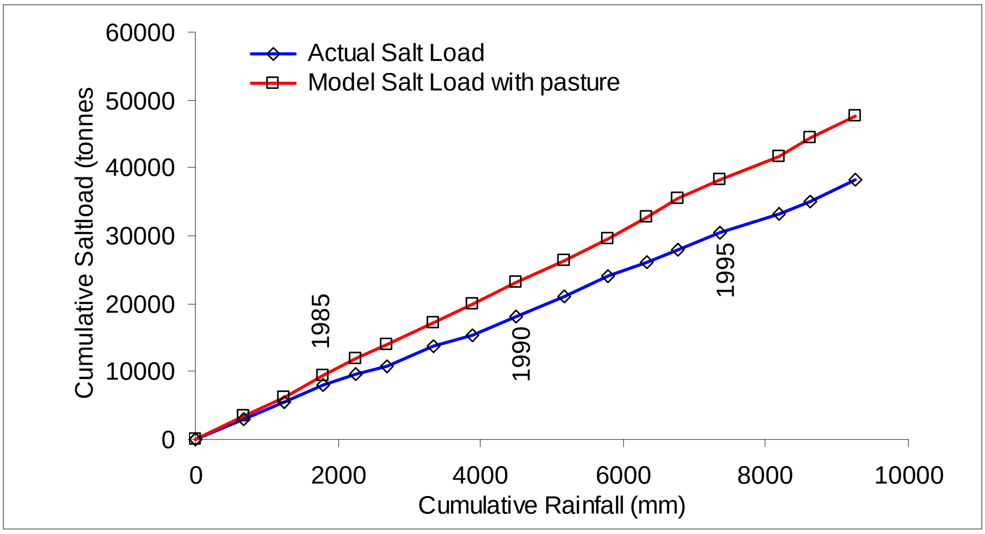


Figure 6.7 Maringee Farms Catchment salt-load

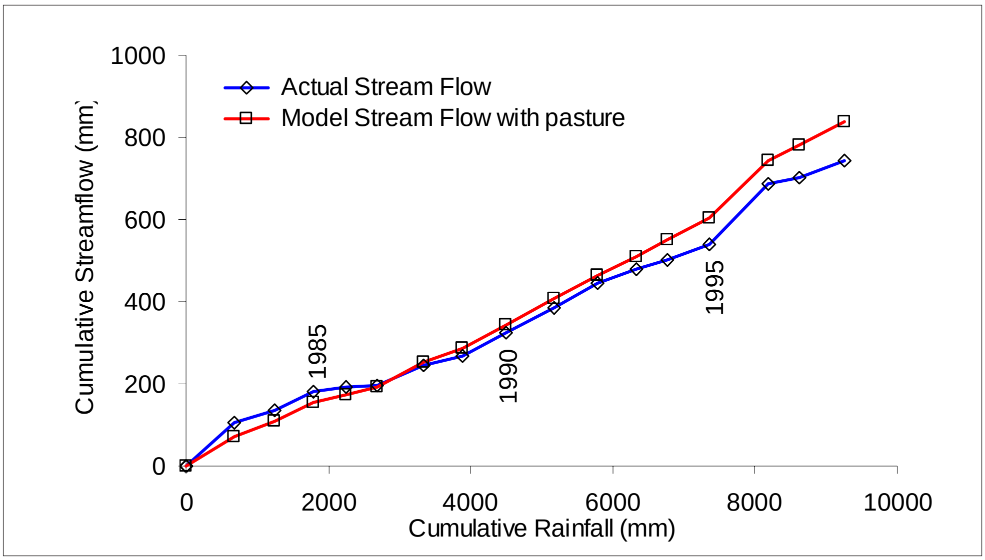


Figure 6.8 Maringee Farms Catchment streamflow

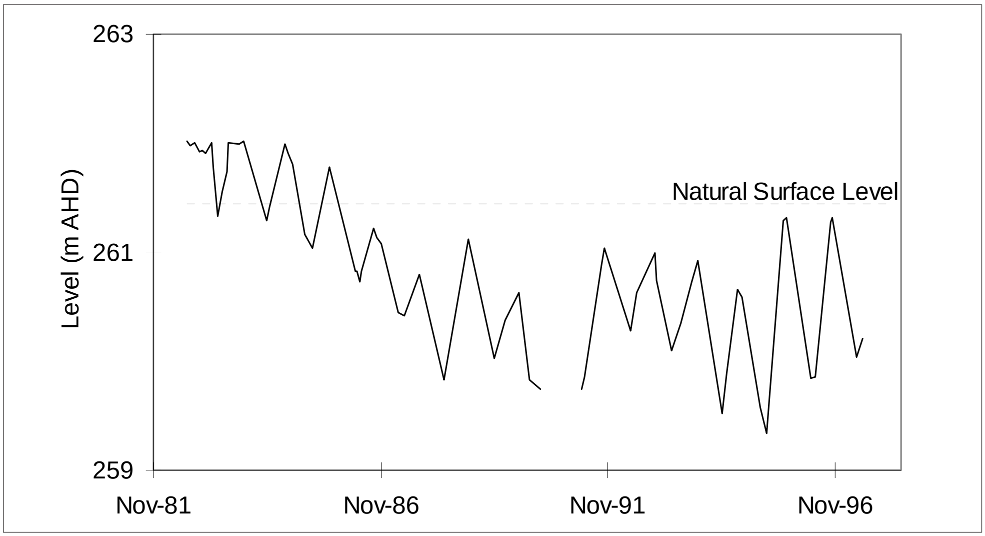


Figure 6.9 Piezometer G61218187 in Maringee Farms reforestation

Stream gauging commenced in 1976 as part of the State's Water Resources Assessment Program. In 1978, to assess the effects of interceptor banks on salt output from the catchment, piezometers were installed about 500 m upstream of the gauge; they were arranged in a relatively small area to intensely monitor a local effect.

In 1992 data from the catchment was reviewed for effects of the trees planted; as these effects did not appear strongly in the data, one recommendation from this was that groundwater levels be more extensively monitored. Thus in 1994 piezometers were installed at 20 other locations distributed over the catchment, with one deep and one shallow piezometer at each point. Deep piezometers were drilled to 20 m or bedrock. After 1994 the piezometers were generally read twice yearly: at their maximum and minimum levels. Piezometers are not currently monitored; last readings were in April 1997.

As with Maringee Farms, the effect of tree planting is not strongly evident in the stream gauging data. To show the catchment response expected if the trees had not been planted requires detailed modelling. Salt loads and stream flows estimated by the computer model are summarised in Figs 6.10 and 6.11. It can be deduced from these figures that salt discharge has been reduced by about 30% and the stream flow also by about 30% since 1987, compared to the situation where the land was left as pasture.

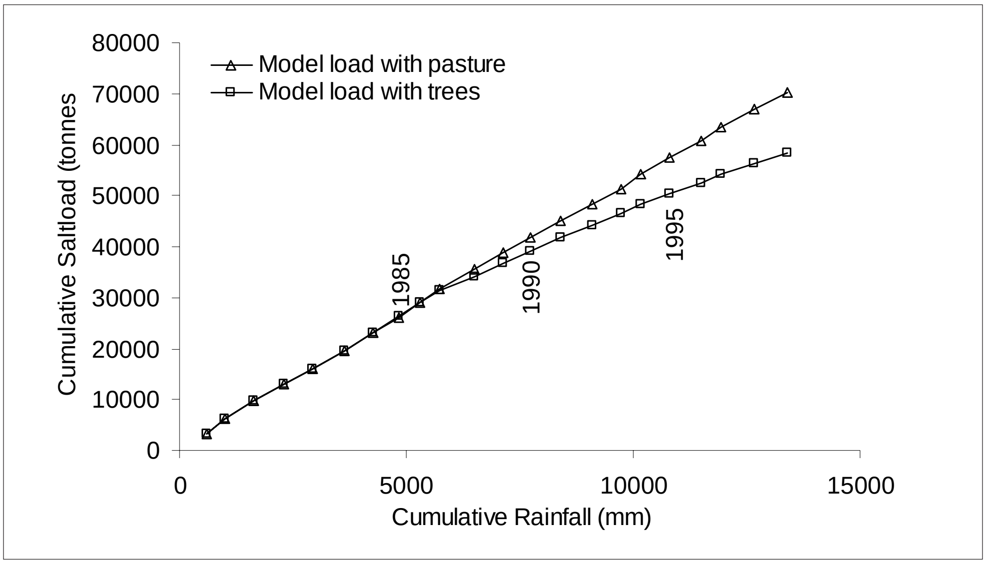


Figure 6.10 Maxon Farm Catchment salt-load

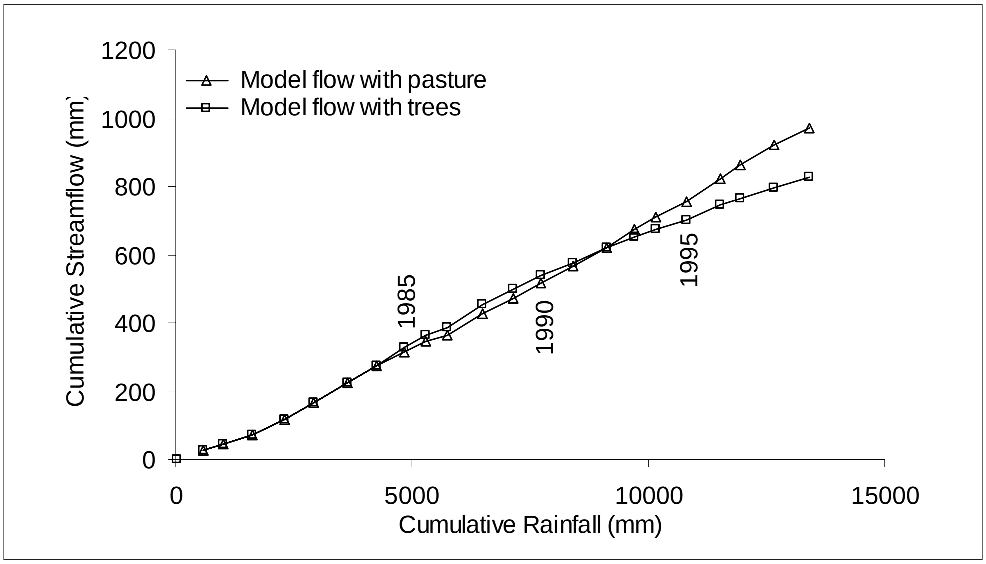


Figure 6.11 Maxon Farm Catchment streamflow

On the other hand some of the 1978 piezometers (Fig. 6.12) have been affected by the tree planting, in a similar manner to equivalently positioned piezometers in the Maringee Farms site: an increase in the variation from summer to winter groundwater levels, with summer minimums being 1 to 2 m less than before planting while winter maximums are not noticeably less. The maximum effect is reached about 5 years after planting. The post-1994 piezometers (Fig. 6.13) respond strongly to seasonal and annual rainfall variation; further analysis should detect any underlying trend.

6.4.1.3 Harrington Demonstration

The demonstration on Harrington's farm integrates tree planting for salinity control with normal farm management.

The monitored catchment is 31 ha in area and has a mean annual rainfall of 625 mm. It is located 9 km west of Darkan, near the eastern boundary of the Collie River East Branch. About 60% of the catchment was cleared by 1960 and the remainder by 1966. The valley line showed strong saline seepage by 1996, extending above a farm dam; some drains cut in the seep area flowed steadily.

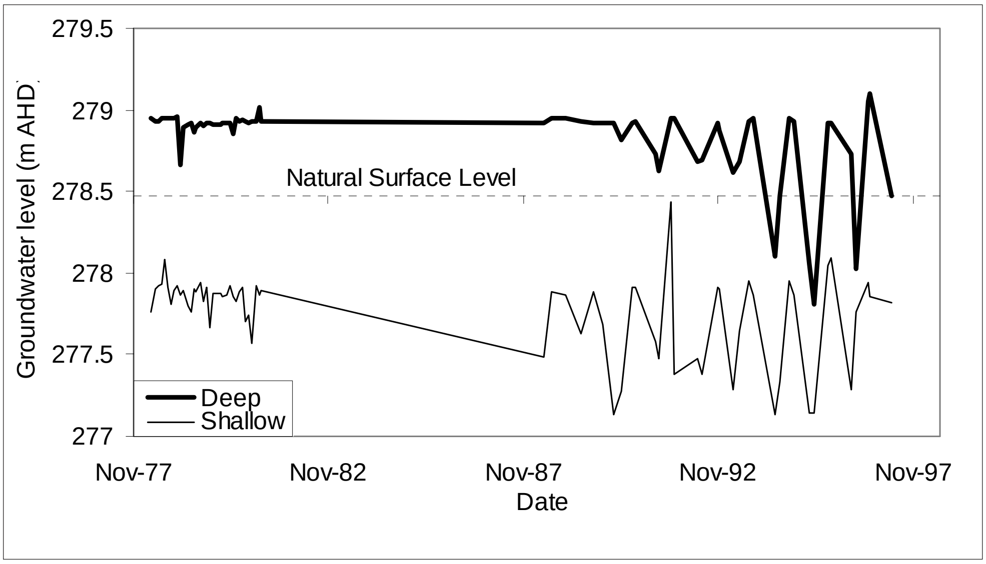


Figure 6.12 Piezometers G61219044/45 in Maxon Farm reforestation

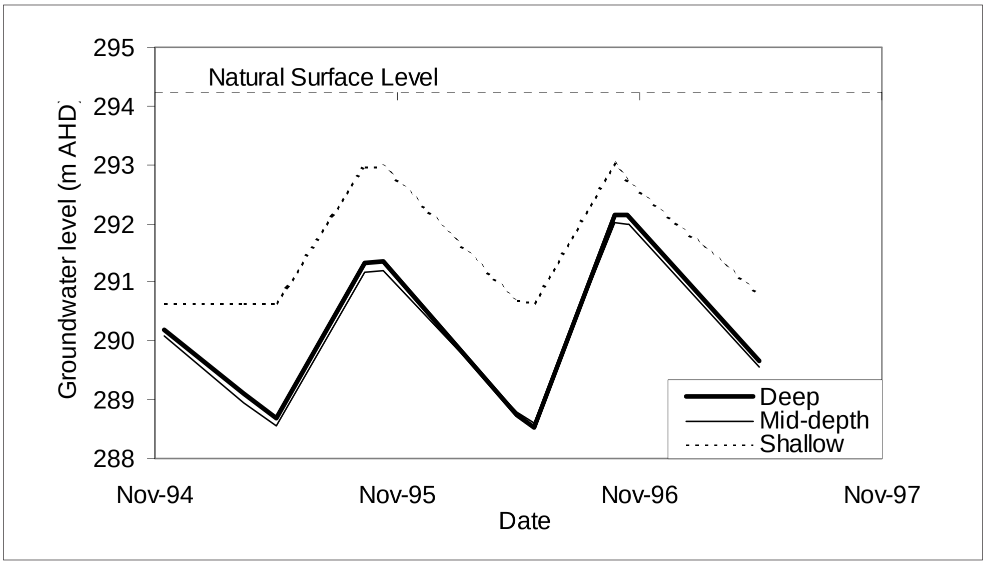


Figure 6.13 Piezometers G61230210/11/12 in Maxon Farm clearing

The layout of the demonstration is shown in Map 6.7. Trees were planted in spring 1995. Ten piezometers were installed in March 1996 to confirm the local geology and to record groundwater behaviour during the trial. The soil profile was typical for in situ deep weathering of granite and dolerite. Depth to bedrock varied from 5 m to 25 m, with an average of 16 m. The salinity of the deep groundwater varied from 2500 mg/L to 8500 mg/L.

Tree growth was measured in 1998. The Bluegums' mean annual increment was estimated at 18 cubic metres/ha/yr.

HARTT analysis was applied to the records of groundwater level measured at the piezometers to remove variations due to variations in rainfall. The best-fit trend at each piezometer is reported on Map 6.7. These computed trends could be partly due to the difference between long-term average rainfall and recent average rainfall. However, comparison between piezometers is valid. The piezometer in the adjacent catchment (61230431D) and the one above the uppermost belt of trees (61230429) gave positive trends. The trends for all other piezometers were less, suggesting that the planting has reduced groundwater levels at the rate of between 0.3 to 0.8 m/year compared with a situation of no planting.

6.4.2 Cropping options

Changing the type or management of crops will alter the hydrologic processes of dryland salinity through changes in volume and timing of water use. Options applicable in recharge areas include:

- growing shallow-rooted annual crops more densely;
- growing shallow-rooted perennial pasture crops;
- growing deep-rooted perennial pasture crops; and
- growing shallow-rooted annual crops in rotation with deep-rooted perennial pastures.

In discharge areas, salt-tolerant perennial crops can be beneficial.

6.4.2.1 Increased density of shallow-rooted crops

This option may produce a marginal benefit of reduced recharge to deep groundwater, through reducing the time free water is available in the surface soil layer. It cannot prevent recharge altogether: every winter will have some free water in the surface soil, and the underlying clays are saturated from lack of deep-rooted vegetation to dry them out over summer. Moreover, that the crops require constant water for survival to maturity limits its effectiveness.

6.4.2.2 Shallow-rooted perennial pasture

This option works similarly to a more dense annual pasture, but perhaps more effectively. Rather than waiting for a crop to be planted and to then germinate, this option uses new water as soon as it becomes available in early winter, and water from summer storms reducing their resultant recharge. The total effectiveness depends on maintaining sufficient leaf density for effective transpiration.

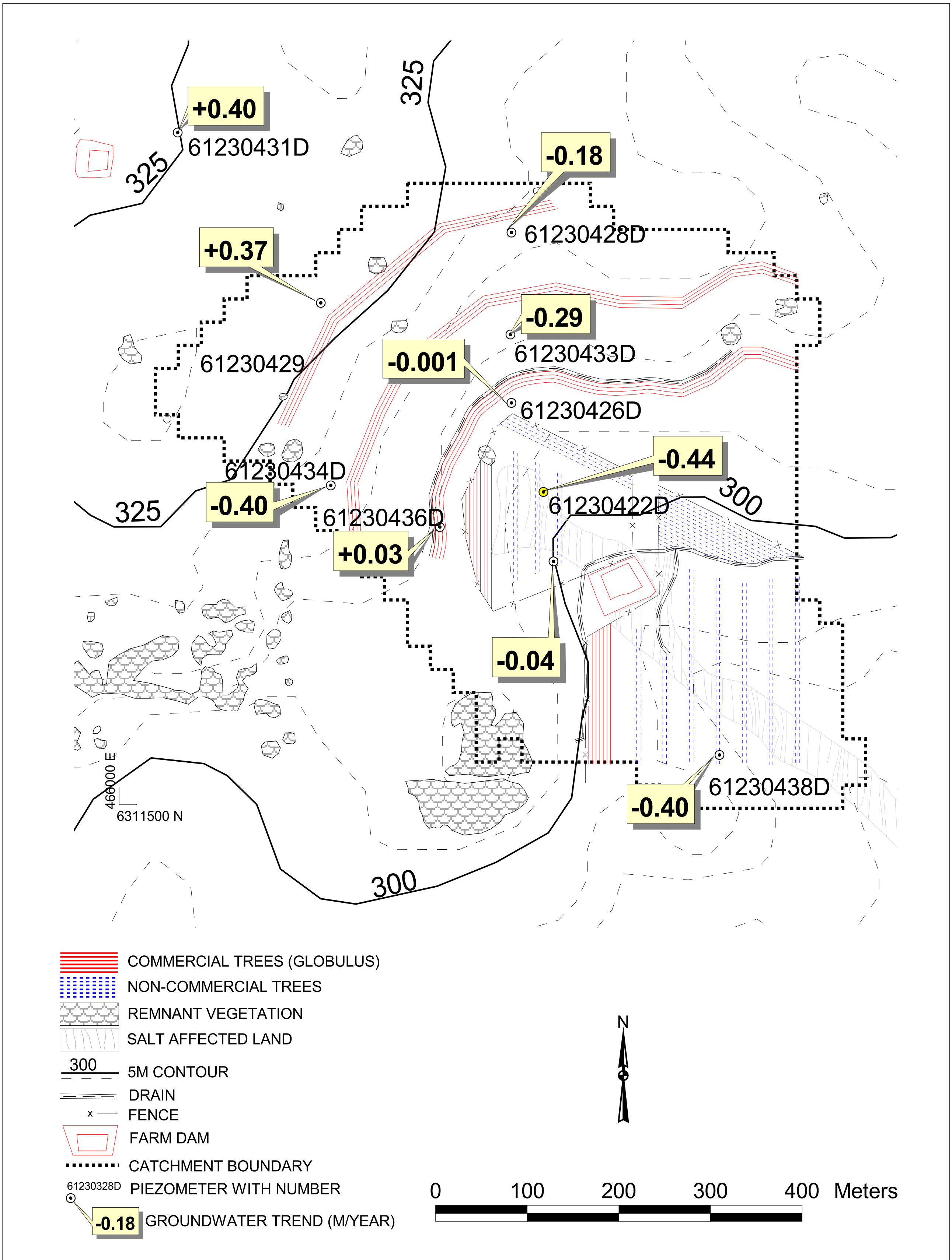
6.4.2.3 Deep-rooted perennial pasture

These crops can extract moisture from soil several meters below ground. Their important characteristic for recharge reduction is that they remove moisture from the clay layer after free water has ceased to be available in the surface soil. A moisture deficit is thus provided and there is no recharge to the deep groundwater until free water again becomes available in the surface soil. Recharge to deep groundwater could possibly be prevented altogether with sufficient crop density.

Lucerne is one such crop being assessed for recharge reduction. Farmers in the Collie Catchment were offered a financial assistance to establish trial areas as part of the Collie Recovery Team's Strategic Action Plan (Collie Recovery Team, 2000). The trials will explore the practicalities of managing lucerne for its hydrologic benefit. Each site has at least one piezometer to observe effects on groundwater level, and there will be associated studies of soil moisture characteristics.

6.4.2.4 Shallow-rooted crops in rotation with deep-rooted pastures

If a deep-rooted pasture (e.g. lucerne) can be grown at sufficient density, then it may use more water from the clay layer over summer than can be replenished from the surface layer in winter. If repeated over a number of years, the moisture deficit in the clay could become quite large, possibly limited by the rooting depth of the lucerne. If the site was then converted to a shallow-rooted crop, there could be a number of years before the clay became saturated again and recharge to deep groundwater recommenced. Some years of recharge could be acceptable if the objective was to only reduce salt output, not eliminate it. Thus the agricultural benefits of rotating crops could be integrated with salinity management.



Map 6.7 Harrington demonstration with groundwater level trends

6.4.2.5 Salt-tolerant perennial crops in discharge areas

Improving plant water use in discharge areas should reduce waterlogging and help agricultural productivity and soil protection. By itself, removing water from near the surface will not reduce salt discharge. However, if trees have been planted nearby, the drier surface conditions should make the site more favourable for those trees, and enhance the effect of trees planted in discharge areas as explained above.

6.4.3 Agricultural drainage

Agricultural drainage attempts to control the movement of water in the landscape. According to their location and form, they act in different ways.

6.4.3.1 Recharge control on hillslopes

Cut generally on the contour, drains for recharge control direct water into a farm dam or creek. They collect surface run-off and possibly some of the lateral flow in the surface soil layer. When cut down to the clay layer, their important role is to prevent lateral flow in the surface soil layer from progressing to lower areas. Diversion of surface run-off also reduces the amount of water available in the surface soil layer for some distance downslope of the drain. With less water available, the time when free water in the surface soil layer is available to recharge to deep groundwater is reduced. However, the amount of reduction in recharge is much less than the volume of water diverted. If the drain does not have sufficient grade for the water to flow to its end, the drain itself will become a site for recharge with no benefit for salinity.

Drains intercepting flows down hillsides usually further benefit agriculture by reducing waterlogging in downslope areas. However, they may cause more severe waterlogging at their discharge point if due consideration has not been given to disposal of the water.

6.4.3.2 Discharge control

Discharge control drains, commonly located in valleys, are to prevent high salinity deep groundwater discharge from emerging at the ground surface. Often referred to as ‘deep drains’, they may be over 2 m deep. A strip of land each side of the drain is protected as desired, width dependent on the permeability of the soils. Drain excavation spoil may be placed as levees to prevent surface run-off entering the drain and causing excessive erosion. To be effective, the water must be able to flow freely from the drain. Disposal of the saline water at the end of the drain may pose many environmental questions.

A drain cut into the discharge area results in a slightly higher flow rate for deep groundwater, by effectively reducing the pressure against which the groundwater must flow to emerge from the ground. The rate of salt discharge is probably more seasonally consistent because, without the drain, part of the discharge evaporates during summer leaving salt in the soil or on the surface to be washed downstream in winter. Thus when a drain is constructed water bodies downstream may experience a change in inflow rates and their salinity distribution; but the total salt received over a year or more will be, although slightly higher, almost the same (Dogramaci et al, 2001).

Within the strip of land protected by the drain: salt is not being added to the soil where the deep groundwater is diverted to the drain, waterlogging is reduced, infiltrating rain can leach salt already in the soil then carry it into the drain; all of which benefit agriculture.

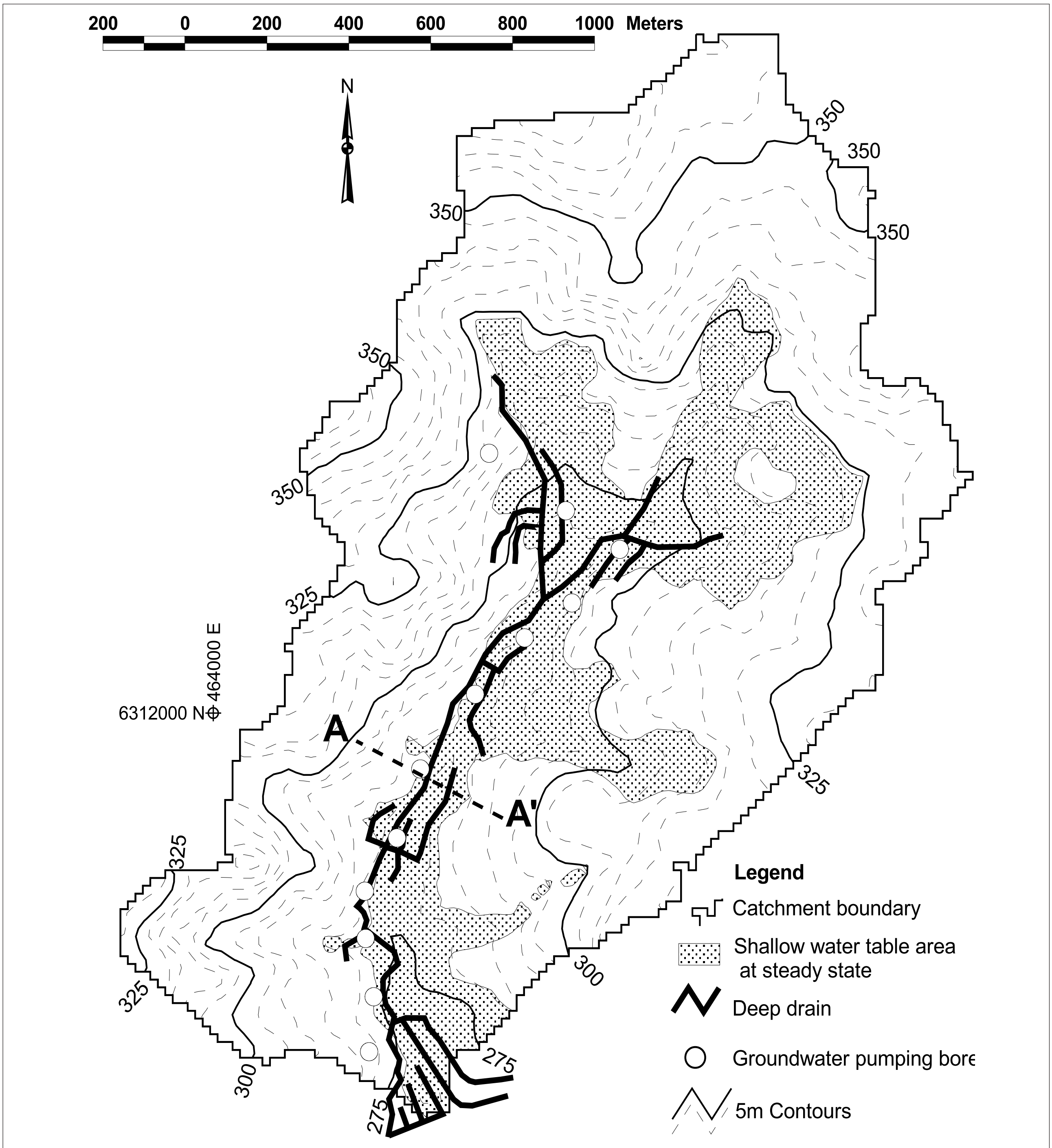
6.4.3.3 Shallow drains in discharge areas

Shallow drains in discharge areas reduce inundation and waterlogging by channelling surface and near-surface water from the site. They do not affect the total discharge of salt from a site, but collect saline waters that would otherwise tend to lay at the site and move them downstream a little sooner. Shallow drains may be used in combination with mounding to aid vegetation establishment; the seedling is raised above the waterlogging, and soil salts in the mound can leach away.

6.4.3.4 Spencer Gully

The farmland in Spencer Gully is typical of the East Collie catchment. A demonstration of agricultural drainage is in progress in 2001 in the subcatchment of Spencer Gully (Map 6.8), which has an area of 5.36 km^2. The behaviour of the deep groundwater in the catchment has been simulated using the computer model MODFLOW (MacDonald and Harbaugh, 1988). Analyses using the model have examined the current conditions; and changes to be expected from construction of deep drains, relief wells within the drains, or arrays of groundwater pumping bores. Information on the depths of soils, permeabilities and current groundwater levels have been obtained by field surveys including the drilling of 16 piezometers to bedrock. Recharge to deep groundwater was estimated by water balance modelling based on current vegetation cover, and soils information using the MAGIC computer system. Results of the analyses have been reported in Dogramaci et al, 2001, in which shallow watertable areas have been defined as areas where the deep groundwater level is higher than 2m below ground surface. (Note that in chapter 8 of this report, areas of shallow watertable are based on a maximum depth of 1.5 m, which is the assumed average depth to clay.)

The most recent clearing in the catchment was before 1977. Analysis of the current condition suggested that some further rise in groundwater levels is possible in higher parts of the landscape, but that differences between present discharge areas and those predicted by a steady state model would be insignificant. Map 6.8 shows ground surface contours within the catchment and that area considered subject to shallow watertables. The locations of deep drains and groundwater pumping bores used to analyse the impacts of these treatments are also shown on



Map 6.8 Spencer Gully demonstration

the map. Fig 6.14. shows the modelled groundwater levels on a typical cross-section.

The deep drains simulated were on the alignment of the demonstration drains and were set to a uniform depth of 2 m. Fig 6.14. shows the resulting steady state groundwater level on the typical cross-section. There are three main features:

1. A general reduction in groundwater level in the discharge zone, resulting in the shallow watertable area being reduced from 25% to 18% of the catchment.
2. Increased rates of vertical flow upwards into the drain, compared with vertical flow at the site without the drain.
3. A reduction in seepage area with a corresponding reduction in discharge, other than within the drain, to the surface. The total discharge for the catchment remains the same or slightly greater, but more of the discharge occurs directly in the drain.

A relief well consists of a bore drilled in the bottom of the deep drain down to bedrock. It provides a point of slightly lower head for deep groundwater to discharge to. The head reduction equals the head loss normally required for deep groundwater flow upwards from bedrock to the bottom of the drain; in the analysis of Spencer Gully, this was about 20 to 30 cm. As the head reduction was slight and the wells scarce (about every 200 m along the drain), their effect on groundwater levels was indistinguishable from that associated with drains alone. About 5% of the water discharged in the drains was discharged via the relief wells.

Groundwater pumping bores also draw deep groundwater from close to bedrock. In the analysis, they were generally located along the bottom of the valley at about 200 m spacing as shown in Map 6.8. The pumping drew down the head to about 5 to 10 m above bedrock level at a bore location. The bores abstracted an average of 15 kL/day each, totalling about 30% of the deep groundwater discharge from the catchment. Fig 6.14. shows the resulting steady state groundwater level on the typical cross-section. There are three main features:

1. A general reduction in groundwater level in the discharge zone, resulting in the shallow watertable area being reduced from 25% to 18% of the catchment (similar to the effect of the deep drains).
2. A drawdown cone extending about 70 m radially about each bore, within which groundwater flow is downwards towards the bore. However, the watertable in the area of a cone is much less depressed than the pressure at the pump intake; in most areas it is still within a metre below the surface.
3. A reduction in seepage area with a corresponding reduction in discharge to the surface. The total discharge for the catchment, including the volume pumped, remains the same or slightly greater than without pumping.

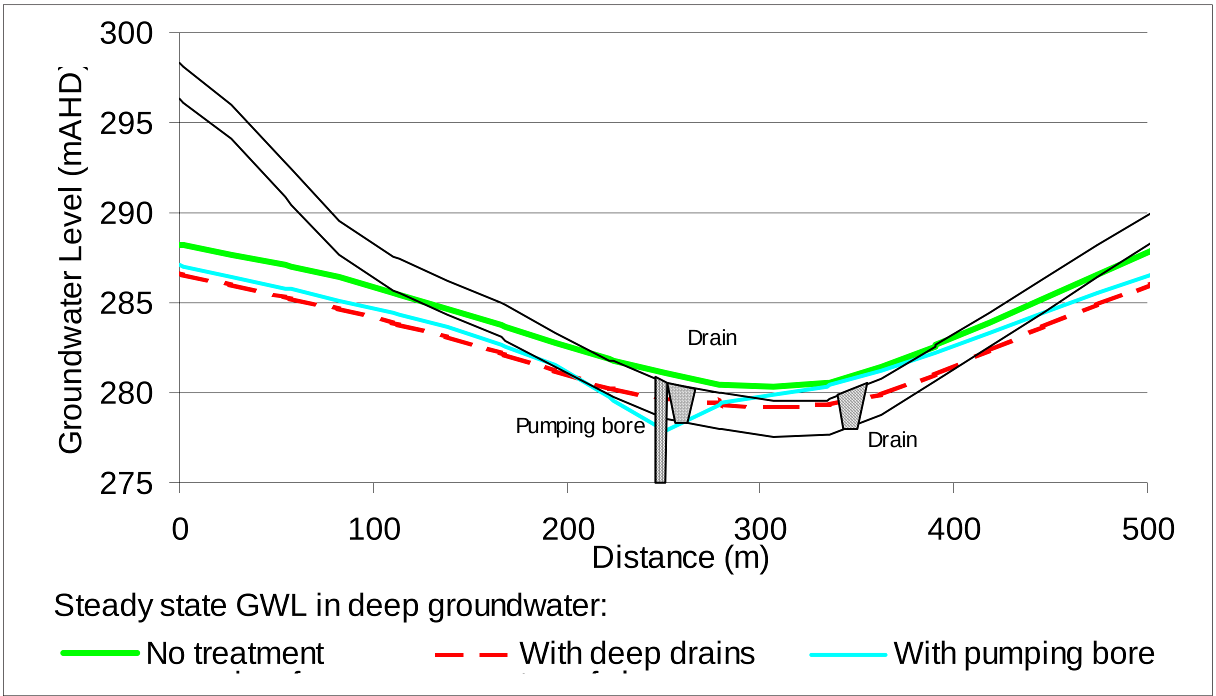


Figure 6.14 Spencer Gully groundwater level cross-section A – A'

4. The effectiveness of groundwater pumping in reducing seepage area can be improved by careful consideration of bore alignments, spacing and pumping rate.

6.4.4 Other engineering options

Agricultural drainage is a class of engineering works aimed primarily at reducing salinity in adjacent land. The prime objective of other engineering options is to reduce the effects of salinity on downstream wetlands and water resources: two main elements of these options are the means to prevent salt flowing to downstream areas, and the means of disposing of the salt thus collected.

6.4.4.1 Methods to prevent salt flowing downstream

Dewatering

A series of deep groundwater extraction bores can be located in areas where deep groundwater discharge would otherwise occur; deep groundwater inflow from recharge areas then has easier exit, thus reducing groundwater levels over the area generally. The bores are drilled into the aquifer carrying the deep groundwater, the saprolite grit just above bedrock; pumping rates and distance between bores is determined by the aquifer transmissivity and the total recharge on the catchment upstream of the bores (Dogramaci et al., 2001).

The recharge area contributing to a bore is thus limited by the physical ability of water to flow to the bore. This may require the bore network to be very extensive, in order to control the salt output of a significant proportion of the catchment area.

The salt prevented from discharging may be more than that contained in the water pumped; because this water will not have passed through upper layers of soil in the discharge area that may add salt.

The water pumped out by the bores must be transferred to a collection point without mixing with natural surface drainage or being allowed to re-enter the ground.

The land over which the groundwater level is reduced should regain its agricultural productivity to a greater extent than could be expected had deep agricultural drains been chosen.

Low flow diversion

The low stream flows over summer are noticeably much more saline than the high flows during winter storms. If low flows could be prevented from continuing to downstream areas, salinities there would be significantly less. The graphs in Fig. 6.15 are the result of analysing the stream flow and salinity records

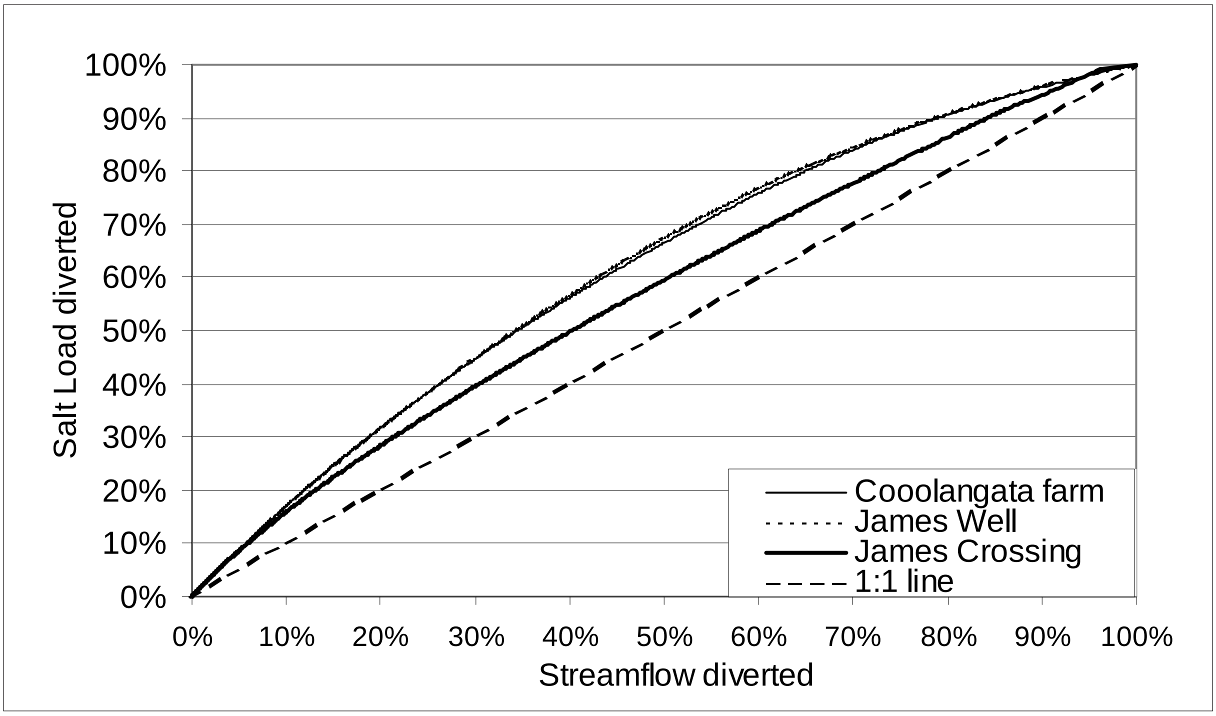


Figure 6.15 Streamflow vs salt-load for low flow diversion

of salt-affected subcatchments in the Collie catchment. If a pipehead dam is built on a tributary, the pipe can collect: all flows less than the outflow capacity of the pipeline; plus the pipe capacity every day that stream flows exceed that capacity. The salt diverted is: all of it on days when the stream flow is less than pipe capacity; plus the pipe capacity multiplied by the salinity on the day, for all days when stream flows exceed the pipe capacity. Fig. 6.16 shows the percentage of annual salt load that can be diverted on this basis, for any pipe capacity expressed as a percentage of mean annual stream flow.

The pipehead dams are assumed to have a storage capacity of about one-day's outflow capacity, and would generally be about the size of a large farm dam.

Major flow diversion

This option involves the construction of major dams on salt-affected tributaries to prevent high salinity water proceeding downstream. The dams are provided with an outflow capacity of about one mean annual stream flow, which leads to a disposal point outside the Collie catchment. The present record of salinity versus stream flow at Mungalup Tower shows that for years when the annual flow is more than 3.5 times the mean annual flow, the flow-weighted mean salinity for those years is less than the target salinity for the stream flow at Mungalup Tower. Thus inflow from salt-affected catchments does not have to be diverted in those years. To divert all flow in all years of lesser stream flow, the upstream dams need a capacity of 2.5 times their mean inflow to hold the surplus over the amount that can be exported in one year.

The dams are necessarily located in valleys, and, in combination with the form of the land, the storage capacity requirement determines the area occupied by the reservoir. A possible site on the East Collie would require about 8 km^2, most of which is presently cleared farmland, albeit partly salt-affected.

6.4.4.2 Methods to dispose of salt

Pipelines

A pipeline with associated pumping stations can move water from its point of collection to the desired disposal point. What must be considered are the environmental effects of the water being discharged at the disposal point. For the East Collie catchment, possible disposal points appear to be:

- the ocean north of the Leschenault Inlet;
- the Collie River near Roelands;
- the Blackwood River; or
- the Murray River.

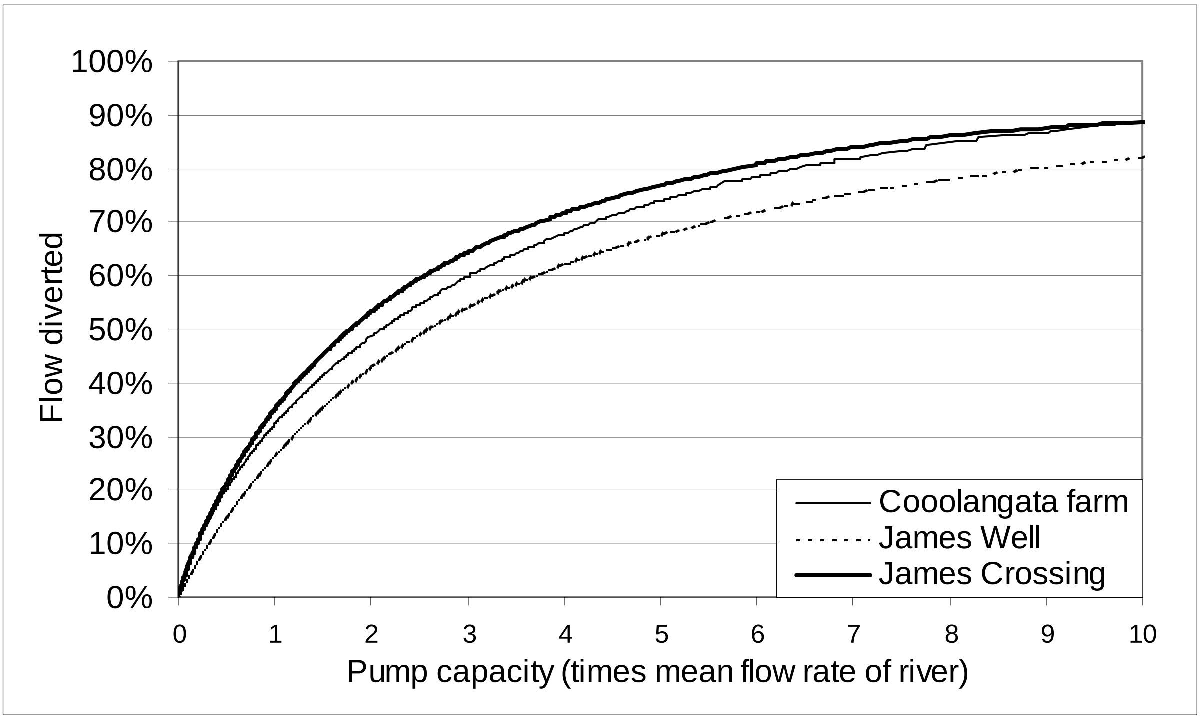


Figure 6.16 Pump capacity for low flow diversion

An ocean outfall should have little effect, except that there may be some nutrients that could disturb the local marine environment.

The Collie River near Roelands is below the offtake point for irrigation water. An outfall here is effectively replacing in the river what was removed by the diversion works. There is some change in the timing of flows and salinity downstream; and the salinity would be slightly higher than if there had been no diversion, as upstream fresher water is withdrawn for irrigation and public use. The benefits of using an ocean outfall instead of this option need to be balanced against the cost of an extra 20 km of pipeline to reach the coast, and the possible effect on riparian users between the outfall and estuarine section of the river.

The salinity of diverted water from the Collie River will be slightly higher than the Blackwood or Murray Rivers near the outfall points, although the total load will be a small fraction of the present loads in those rivers. However, the local communities in the Blackwood or Murray catchments might consider the addition of diverted water contrary to their efforts in reducing the salinity of their rivers

In selecting proposed outfall points in the Blackwood or Murray, the pipes have been extended into the receiving catchment to a point where the area upstream of the disposal point is similar in size to the area of the catchment from which the water is diverted. This should ensure that the receiving stream channel is adequate for the additional flows.

Evaporation basins

Evaporation basins have been used in some parts of the world to dispose of saline water. In the East Collie catchment, free water evaporation is about 1200 mm per year (70% of pan evaporation =0.7x1700=1190 mm) and rainfall is about 700 mm. Thus to evaporate a given amount of diverted water, a basin needs an area of about 2 km^2/GL, and an average depth of about 1.2 m (to hold rainfall and water to be evaporated) on fairly level ground, with run-off from outside the basin excluded. If any of the land does not have deep groundwater discharge, the basin bottom is sealed to prevent leakage. In the various diversion options, diverted volumes range from 1 to 10 GL/yr, which requires 2 to 20 km^2 of land if evaporation basins are the sole means of disposal of diverted water.

6.4.5 Forest management

Logging has been undertaken in the Northern Jarrah Forest for very many years. After an area has been logged, it is usually left to regenerate naturally for over 30 years before being logged again. Stream flow from forested catchments subject to logging is normally fresh, with mean annual salinity ranging from 100 to 200 mg/L (Robinson et al, 1997). However, the local stream flow generated from an area after it is logged does react to the change in forest density. The degree of reaction depends on the rainfall zone of the forest. The following observations come from catchments subject to 'heavy selection logging' that left about 10% of overstorey (Bari and Boyd, 1993).

Low rainfall (<900 mm)

Stream flow from an unlogged catchment is usually less than 5% of rainfall and there is no deep groundwater discharge evident. In the period up to 5 years after logging, a minor increase in stream flow may occur (less than 5% of rainfall), and a negligible change in salt output.

Intermediate rainfall (900 mm – 1100 mm)

Stream flow from an unlogged catchment is usually about 10% of rainfall and there is some deep groundwater discharge evident. Following logging, stream flow may more than double, and there is a similar increase in salt output. Salinity may increase, depending on the relative size of the increases in stream flow and salt output. The maximum annual salinity increase for a clear-felled catchment is over 200 mg/L, while a catchment thinned to 20% of its overstorey saw a reduction of 50 mg/L. The peak of stream flow and salt output occurs in the first 2 or 3 years after logging. After peaking, there is a slow decline towards pre-logging rates of stream flow and salt output, lasting well over a decade.

High rainfall (>1100 mm)

Stream flow from an unlogged catchment is usually up to 20% of rainfall and there is normally a contribution of deep groundwater discharge. The reaction after logging is similar to that of the intermediate rainfall zone, but salinities are unlikely to increase.

Potential for increasing low salinity run-off

The recorded stream flows on which water yield estimates are based have been produced from areas subject to normal cycles of logging. To increase in water yield overall would require additional and continuous thinning to keep the forest at below its natural density. In either the high or intermediate rainfall zones the water volume benefits may justify the cost of such management, but not in the low rainfall zone. The intermediate rainfall zone does tend to develop permanent discharge areas of saline deep groundwater. It was in an intermediate rainfall zone of Helena catchment that an area of 6400 ha was ringbarked in 1903 to improve run-off for the reservoir, but was allowed to regenerate after salinity was found to be increasing (Ward, 1977).

6.4.6 Protection of remnant vegetation

Remnant native vegetation may be located over potential recharge areas, and over potential or actual discharge areas. A discharge area may develop in remnant vegetation due to clearing of upslope areas. The desirable outcome is always that the remnant remains in or returns to an ecologically sustainable state. This requires that an appropriate range and density of species exist in both understorey and overstorey, and that the overstorey is able to regenerate naturally, with young seedlings ready to replace old trees that die. It has been found that overgrazing has been a major cause of loss of understorey and the ability to recruit new overstorey (Strawbridge, 1999). Fencing to control stock access is a necessary step for restoration or preservation of remnants. If a remnant is severely degraded it may not be able to recover without additional management such as weed control and restocking with suitable native species.

The aim of protecting remnant native vegetation in potential recharge areas is to preserve its effectiveness in transpiring water from the clay layer over summer. When the area of such remnants in a catchment suffers attrition, the lost area joins the area of recharge, offsetting the effects of other efforts to reduce recharge.

Remnants in newly discharging areas have a salinity role similar to that of planted trees. When discharge areas develop under remnants, deaths of mature trees are especially noticeable; new trees will grow if protected from grazing. To survive in these circumstances, remnants need sufficient vegetation capable of using the quantity and quality of deep groundwater discharge. When preserving a remnant for its ecological values a buffer strip of trees adjacent to upslope boundaries can provide additional transpiration capacity. Apart from their other benefits, healthy remnants in the riparian zone beside streamlines protect water quality and stream bank stability.

7 Salinity targets

The performance of the whole catchment has been assessed under a number of different 'scenarios', according to the dryland salinity hydrology explained in chapter 6. Basically, saline deep groundwater discharges to the surface in quantities related to area of agricultural land clearing. This renders inflow to Wellington Reservoir each year proportionately more saline than would result from just the salt in the current year's rainfall.

Fig 7.1 shows the historical record of inflow salinity to Wellington Reservoir with projections according to three different scenarios:

i) if clearing continued unrestricted and no reforestation ('without Clearing Controls');

ii) if clearing stopped when clearing controls were introduced but no reforestation occurred ('without reforestation'); and

iii) if clearing stopped and land acquired by the government was fully reforested ('with WRC land replanted').

Fig. 7.1 also shows the target inflow salinity.

The estimated contributions from the Management Units for various scenarios are given in tables. The estimates are in the form of annual averages to be expected if the catchment has been in a particular condition for a very long time. The scenarios presented are:

i) Scenario iii) illustrated on Fig. 7.1 above;

ii) Naturally fully-forested catchment; and

iii) 4 options for reducing salt output to meet the salinity target for inflow to Wellington Reservoir.

The last four options assume varying degrees of reforestation to achieve the salt load reduction, but do not address the practicality of implementing the treatment. Chapter 8 examines the practical limits to implementation of various treatment options.

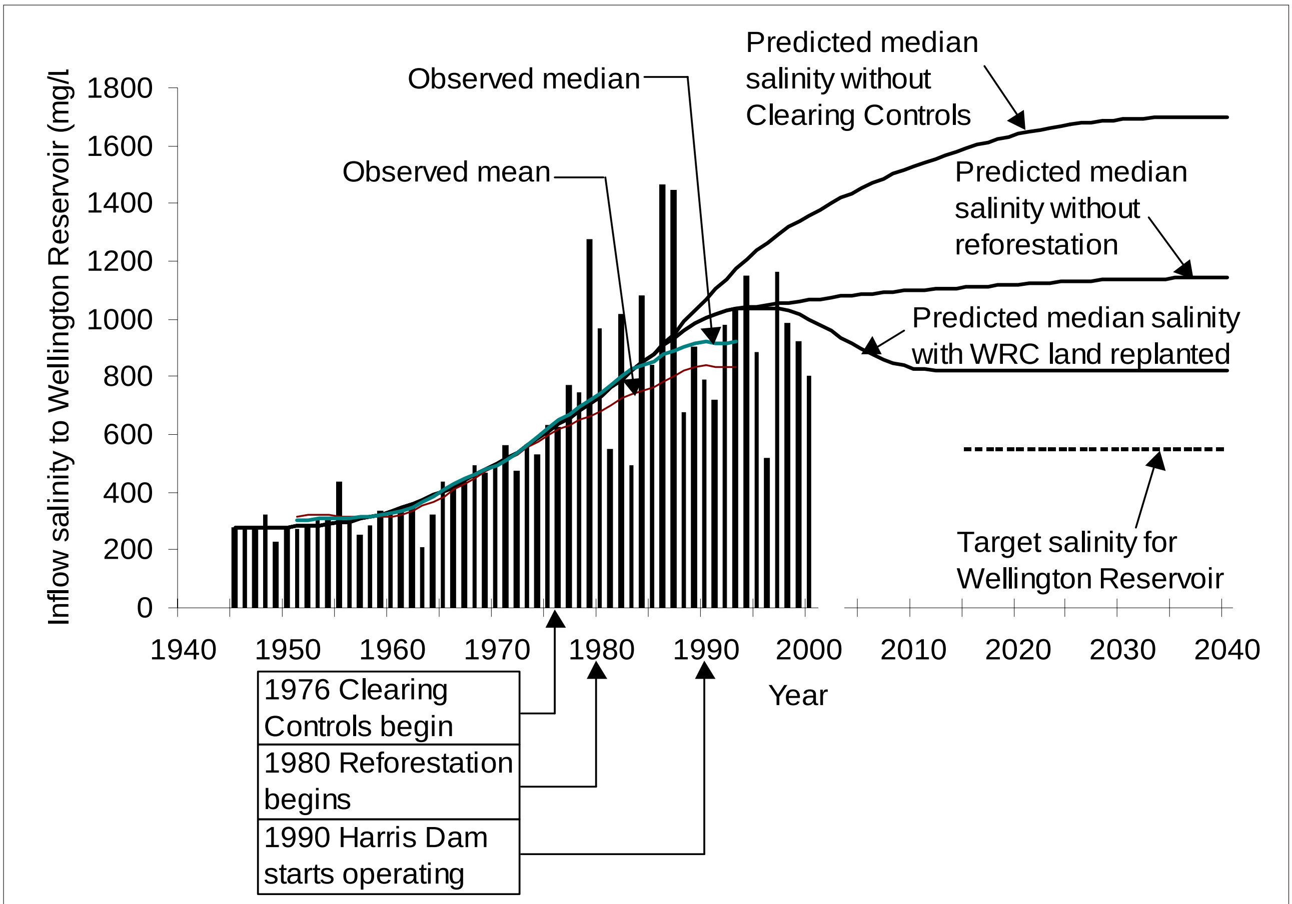


Figure 7.1 Surface water quality in the Collie Catchment

Table 7.1 Average annual hydrologic data with government land reforested (=1995 record)

Shires (areas in km²)	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Area (km²)	663	183	402	514	246	216	327	280	2550	2830
Rainfall (mm)	757	656	644	770	751	909	862	1050	759	789
Flow (GL/yr)	23.3	5.5	14.5	7.3	14.3	29.3	7	43.62	101.2	144.8
Salt (tonnes/yr)	23978	19228	49420	1572	10566	13199	1460	8655	119243	128078
Salinity (mg/L TDS)	1031	3466	3418	216	741	450	209	198	1180	885

Table 7.2. Fully forested average annual hydrologic data

Forested condition	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
Salt (tonnes/yr)	4043	843	1772	1572	1897	1595	3435	3032	15157	18189
Flow (GL/yr)	11.55	1.87	7.09	7.28	8.62	6.38	15	16.84	58	74.64
Salinity (mg/L TDS)	350	450	250	216	220	250	229	180	262	244

Table 7.3. Effects of salinity reduction options on average annual hydrologic data

	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
OPTION 1										
Salt (tonnes/yr)	10172	6496	16422	1572	4562	5163	1460	4761	46639	51400
Flow (GL/yr)	18.05	3.63	9.45	7.29	9.32	19.19	7	28.52	76.49	102.8
Salinity (mg/L TDS)	564	1791	1737	216	489	269	209	167	610	500
OPTION 2										
Salt (tonnes/yr)	23978	842	1772	1572	10566	13199	1460	8655	54275	62930
Flow (GL/yr)	23.26	1.87	7.09	14.19	14.26	29.35	7	43.62	90.12	133.74
Salinity (mg/L TDS)	1031	451	250	216	741	450	209	198	602	471
OPTION 3										
Salt (tonnes/yr)	23978	2313	4746	1572	10566	13199	1460	8655	58720	67375
Flow (GL/yr)	23.26	2.16	7.68	14.19	14.26	29.35	7	43.62	91	134.62
Salinity (mg/L TDS)	1031	1070	618	216	741	450	209	198	645	500
OPTION 4										
Salt (tonnes/yr)	9087	5494	12989	1572	10566	13199	1460	8655	55253	63907
Flow (GL/yr)	14.51	2.8	8.95	14.19	14.26	29.35	7	43.62	84.16	127.79
Salinity (mg/L TDS)	626	1963	1451	216	741	450	209	198	656	500

OPTION 1 Salt load from each area reduced in proportion to present salt load in deep groundwater discharge
OPTION 2 Maximum reduction from James Well and Collie R East
OPTION 3 Reduction only from James Well and Collie R East to achieve 500 mg/L
OPTION 4 James Well Collie R East and Collie R South to achieve 500 mg/L

8 Catchment management options

Several catchment management options (salinity treatments) were assessed for their contribution to reaching the salinity targets of the Wellington Reservoir:

1. Tree plantations
2. Upland Commercial Trees in Alleys
3. Lowland Trees
4. Lucerne
5. Shallow Drainage
6. Groundwater pumping
7. Diversion

Table 8.1 summarises the analysis of these options. Details of analysis methods and assumptions, and results within Management Units and for variations of the options, are given in the remainder of the chapter and Tables 8.2 to 8.18.

8.1 Model formulation

Management options 1 to 5 were assessed using a Geographical Information System model developed by the Water and Rivers Commission called MAGIC (Mauger 1996). The hydrologic model produced a catchment water balance and estimated the location and quantity of deep groundwater discharge (seepage), volume of stream flow, and other water use components important in assessing some catchment management options. The expected effects of applying various management options are evaluated by analysing cases where a particular option is applied to its feasible maximum. The rates per unit area applied to the proposed areas of treatment with each option can be used to give preliminary estimates of option combinations.

Most of the Collie catchment was modelled using MAGIC. Excluded were areas in the coal basin, Harris catchment and downstream of Mungalup gauging station. The modelled area was 1982 km^2 and consisted of 84 sub-catchments varying in size from 3 to 40 km^2, gridded into 25 m square cells. The model has been previously applied to the Collie catchment twice (Arumugasamy and Mauger, 1994) and (Davies and Rogers, 2000) and was further improved for this assessment. The model has changed from 2 to 3 layers and the spread of deep groundwater discharge has been modified to better represent observed discharge areas at Spencer Gully, a small catchment studied in detail in the Collie River East Management Unit (Dogramaci et al, 2001).

The MAGIC model is run with monthly time steps for three years. At the end of the three years the model is in 'steady state' for the vegetation cover applied to it. The model is based on the predominant soil profile of salinity-affected areas in the South West of Western Australia. It assumed a deep weathered profile with three layers parallel to the surface. The model consisted of: a highly permeable surface top layer 1.5m deep, with a saturated transmissivity of 30m/month and a porosity of 0.2; a clay layer 15.5m deep, with a lower transmissivity of 0.1 m/month; and a partially weathered layer 3m deep just above bedrock, with a transmissivity of 0.8 m/month. Inputs to the model included average annual rainfall (1980-1995) and pan-evaporation, elevation gridded from 5m contours, and Landsat Thematic Mapper imagery taken in January 1996. The native vegetation cover and pasture were derived from the Landsat Thematic Mapper image. The annual transpiration of the native trees was also, indirectly, derived from the rainfall and from the 'greenness' factor which proportional to the sunlit green leaves' reflectance derived from the satellite imagery. The transpiration of annual pasture assumed a maximum Leaf Area Index (LAI) of 2.4. Local geology was not input to the model; it was found to have little effect at the large catchment scale (Davies and Rogers, 2000).

8.2 Model calibration

Initially the model was calibrated to gauged stream volumes and deep groundwater discharge (seepage from pasture) loads. The modelled seepage from pasture was estimated by dividing gauged salt-flux minus salt-flux from rainfall by typical deep groundwater salinity for the gauged region. The gauged stream flow and salt-fluxes were taken from the year 1995, which was an average rainfall year for the period 1980 to 1995. A maximum infiltration rate from top layer into saturated clay en route to the bottom layer (i.e. rate limit for recharge to deep groundwater) was assumed to be 48 mm/year. This infiltration rate and the LAI of annual pasture were the parameters varied to calibrate the salt load and stream volume from the model.

Table 8.1. Summary of analysis of management options

Management scenario	Cleared area used		Inflow to Wellington Reservoir			Shallow water table area		Seepage area	
	area km²	% pre-plantation cleared area	Salinity mg/L	Flow GL/yr	Saltload Tonnes/yr	area km²	% pre-plantation cleared area	area km²	% pre-plantation cleared area
1995 gauging/calibration	120	18%	885	145	128 078	127	20%	52	8%
Low-flow Diversion 30% with 1995 plantations	0	0%	764	141	107 483	127	20%	52	8%
Full Diversion with 1995 plantations	13	2%	512	130	66 822	118	18%	47	7%
Pre-plantation	0	0%	875	157	137 035	137	21%	67	10%
Only upland commercial trees in alleys	190	29%	752	115	86405	94	14%	27	4%
Only lowland trees	97	15%	738	139	102 278	106	16%	40	6%
Only lucerne	225	35%	797	142	112 853	121	19%	47	7%
Only shallow drainage	0	0%	857	158	135 329	136	21%	62	10%
All plantations	174	27%	758	134	101 395	104	16%	39	6%
Upland commercial trees with all plantations	364	56%	577	106	61 285	65	10%	16	2%
Lowland trees with all plantations	282	43%	524	114	59 905	59	9%	13	2%
Upland & lowland trees with plantations [1]	461	71%	216	74	16 008	30	5%	11	2%
Lucerne with plantations [2]	399	61%	650	119	77 213	89	14%	33	5%
Shallow drainage with plantations [3]	174	27%	738	135	99 688	103	16%	38	6%
Groundwater pumping 50 % with all plantations	174	27%	522	130	67 724	?	?	?	?
Collie R East diversion with all plantations [4]	182	28%	597	126	75 170	95	15%	34	5%

Notes:

1. Salt load, flow and areas estimated by summation of changes recorded in Tables 8.9 & 8.12 applied to 'All plantations' case
2. Salt load, flow and areas estimated by summation of changes recorded in Table 8.14 applied to 'All plantations' case
3. Salt load, flow and areas estimated by summation of changes recorded in Table 8.15 applied to 'All plantations' case
4. Salt load, flow and areas estimated by subtracting streamflow and saltload at the diversion site from the 'All plantations' case

Only seepage from 'outside forest' cells was assumed to carry salt. Seepage inside large forest areas was assumed to be fresh. The seepage salt load from cleared land within largely forested catchments such as Bingham River were overestimated by the model. The native forest and pasture areas derived from Landsat scene 1996 are shown in Map 2.10.

In the modelling, 'shallow water table area' is defined as all cells where seepage emerges from the clay layer into the top layer, which is equivalent to saying that the groundwater level is higher than 1.5 metres below the surface. The 'seepage area' is defined as all cells where the groundwater level is above the ground surface. These areas are shown diagrammatically in Figure 6.1. In Tables 8.2-8.15, catchment totals of shallow water table areas and seepage areas exclude areas not modelled.

The results of the calibration run are in Table 8.2. Parts of the catchment that were not directly modelled have been estimated using rates from nearby similar catchments that were modelled. Sub-catchments not modelled keep a constant output in simulations of all options, because treatments are not applied within them. Remaining differences between modelled and gauged streamflows were attributed to un-modelled streamzone losses and applied as constants when modelling all options.

Once the model was calibrated, a pre-plantation case was run to use as a base to compare each salinity treatment modelled by MAGIC (Management options 1 to 5). All plantations that existed in the 1996 Landsat scene, with exception of the pine plantations in the Wellington Reservoir management unit, were returned to pasture. The results of this case are in Table 8.3 and the native forest and pasture areas modelled are shown in Map 8.1. Maps of the shallow water table and seepage areas predicted by the modelling for all options can be produced on request; an example is shown in Map 8.2. The shallow water table and seepage areas are shown for the Collie River East management unit for the Pre-plantation case; most lie in the bottom of the valleys.

8.3 Tree plantations

In this case, all existing and future plantations were simulated. Most existing plantations were Bluegums, except for some Pines north of Collie in the Collie River Central management unit. The model treated Bluegums and Pines the same. The plantations modelled were the same as those shown in Map 2.11. The private plantation properties shown in Map 2.11 indicate the properties that are leased or bought to plant Bluegums, mainly by large plantation companies. It is most likely that only the land capable of sustaining commercial trees was or will be planted. To assess whether land is suitable for commercial trees, the following procedure was adopted:
Soil-landscape systems for the Wellington-Blackwood region (Tille, 1996) were classified by the capacity of their land to support commercial trees. Soil-landscape units used are shown in Map 2.5. Each soil-landscape unit in the Collie catchment was then interpreted and classified by the following:

1. No conditions. Good to plant commercial trees.
2. Add nutrients. Suitable for commercial trees if nutrients are added.
3. No streamlines. Can plant commercial trees on this unit, but not along areas of stream zones since they may be prone to salinity or waterlogging. A stream zone region was calculated by assuming it extended 6 m vertical elevation above the bottom of the valley. Stream zones were automatically generated from topography by a procedure using the MAGIC system.
4. No upper slopes. Can plant trees on this unit, but not on slopes greater than 10% since the soil depth is likely to be too shallow for planting commercial trees. This classification was produced using the slope map in the MAGIC model.
5. No wandoo forest. Tille (1996) mentioned that some soil-landscape units were good for commercial trees except in areas that used to contain wandoo (*Eucalyptus Wandoo*) forest; a way of estimating what cleared land had been wandoo forest was needed. Mattiske (personnel communication.) said that commercial trees were unlikely to perform well on the stream zones of the following vegetation complexes: S, SK, MJ, PN, YG1 and Yg2, as shown in Map 2.9. All those vegetation complexes in the soil-landscape classification 5 that extended 6 m vertical elevation above the bottom of the valley were removed.

The plantation areas simulated for this management option are shown in Map 8.3. A greenness based on natural forest density was assigned to the trees, dependent on rainfall and the water available to the trees; the transpiration of the planted trees was deemed proportional to this greenness. Whatever WRC (Water and Rivers

Commission) plantations and Private plantings existed in 1997 were deemed planted. Only those existing or proposed private properties that had land suitable for commercial trees were deemed planted. The modelling results are in Table 8.4, which also shows the areas planted (simulated) for each management unit. This case was also used as a base for Upland Commercial Trees in alleys and Lowland Trees, to check the combined effects of these treatments.

8.4 Upland commercial trees in alleys

For this modelling case only land that was suitable for planting commercial trees and was neither native vegetation nor existing or proposed plantation was considered. All existing or proposed plantations were deemed pasture. Land suitable for planting Upland Commercial Trees was classified by the same method as for commercial trees in plantations as detailed in Section 8.3. Five cases were modelled and the results shown in Tables 8.5-8.9. The alleys were automatically generated in the above mentioned land by using the MAGIC system. A natural greenness was then assigned to the trees as mentioned in Section 8.1. Case 1 deemed 200 m spacing of alleys, thinly planted. Alleys in cases 2-4 were at 100 m. In Case 2 the alleys were thin, and gradually thickened for Cases 3 and 4. In Case 5 the trees were not in alleys, but all land available and suitable for upland commercial trees was deemed planted. Map 8.3 identifies the areas of trees deemed planted in Case 5. This was so that the extreme case could be determined, as plotted in Fig. 8.1. These graphs in Fig. 8.1 can be used to estimate the effects of planting at different densities. Upland commercial trees in alleys Cases 3 and 5 were modelled with the existing and proposed plantations (Plantation Case) and are also shown in Fig. 8.1. The model predicted that if all available land suitable for commercial trees was planted, with the existing and proposed plantations, (Point 8 in Fig. 8.1), then the total reservoir inflow salinity would be as low as 577 mg/L. Map 8.4 shows the trees deemed planted in 100 m alleys, used in Case 2 for the Collie River East management unit.

8.5 Lowland trees

This modelling case planted trees with a natural greenness on all land left after excluding all that was suitable for Upland Commercial Trees (Upland commercial trees in alleys Case 5), all existing and proposed tree plantations, and all native forest. Existing and proposed plantations were deemed returned to pasture. This management option represents land unsuitable for Bluegums; but which could possibly be planted with non-commercial, or other commercial, varieties. This land is usually situated in the lower parts of the landscape which could be subject to salinity or/and waterlogging and/or have poor soils. The areas deemed planted are shown in Map 8.3; further study could select appropriate species. The results of the modelling are in Table 8.12. The 'Lowland Trees' case was then modelled with the plantation case: the results are in Table 8.13.

8.6 Lucerne

Lucerne is a deep-rooted perennial pasture that can draw water from the clay layer. It was deemed planted on all land identified as suitable, excluding all existing and proposed tree plantations and all native forest. Existing and proposed plantations were deemed returned to pasture. The lucerne was assumed to have an LAI of 1.0 and a root system that extended to 5 m below ground. The results of the modelling are in Table 8.14 and the areas planted to lucerne are in Map 8.5.

The results of the model are highly dependent on the LAI assigned to the deep-rooted pasture, and there was not a sound basis for choice. A study on assigning LAI under certain grazing regimes and water availability is recommended. The sensitivity of the model to LAI of lucerne was tested on Catchment 79 in Collie River East Management Unit. For an LAI of 2.4, area planted divided by cleared area was proportional to seepage reduction, while using an LAI of 1.0 gave: area planted divided by cleared area was proportional to 0.62 multiplied by seepage reduction.

The suitability of land for lucerne was determined as follows:

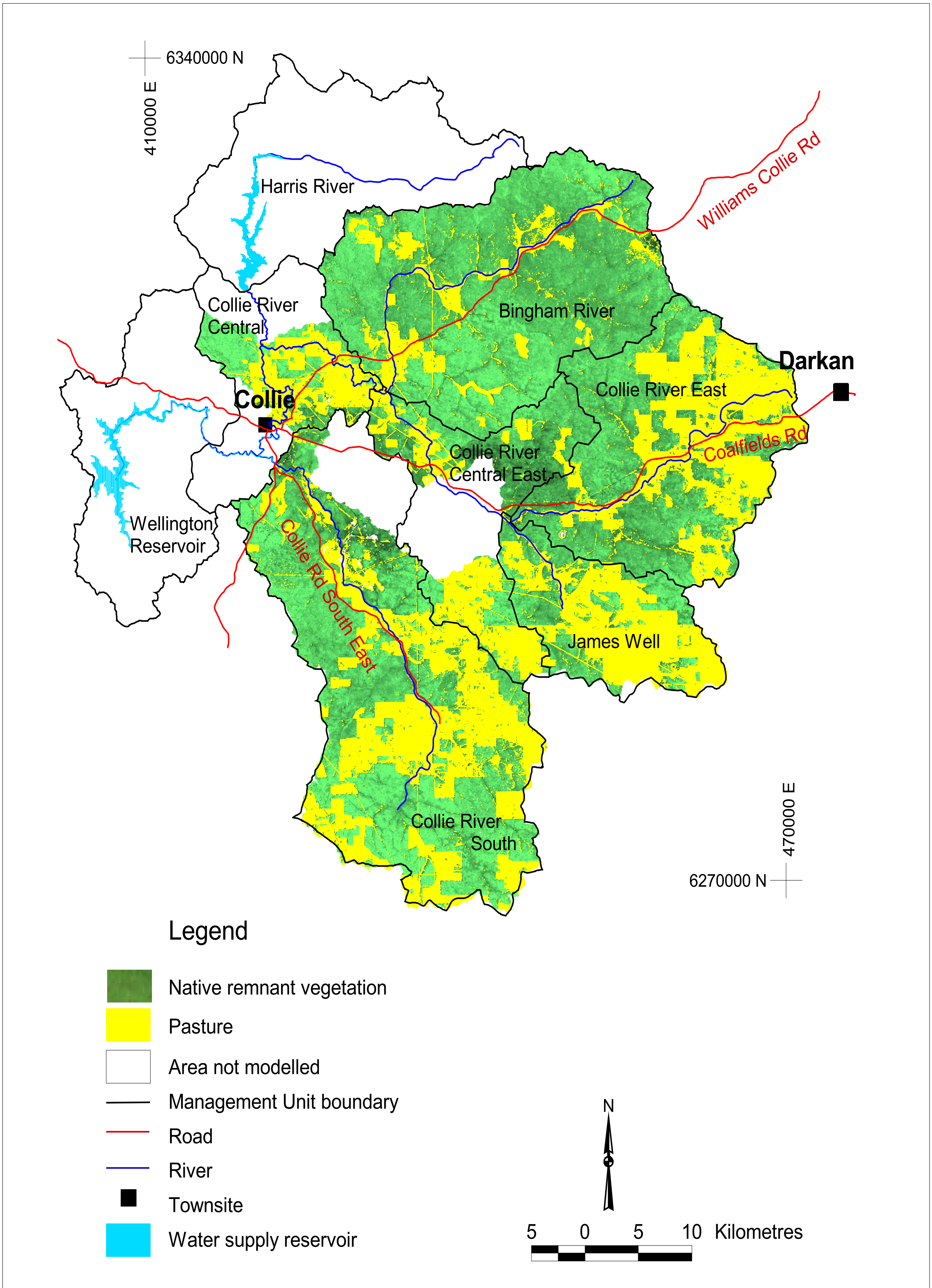
Soil-landscape systems for the Wellington-Blackwood region (Tille 1996) were classified by the capacity of their land to support grazing. Soil-landscape units used are shown in Map 2.5; each unit in the Collie catchment was interpreted, and classified not suitable for planting lucerne by the following criteria:

1. Unsuitable sandy soil. These soils might be too acidic or low in nutrients. Soil landscape units DMs, Kuw, Qus, Cl, MU2, MUf, DWs, MHs, WGs.

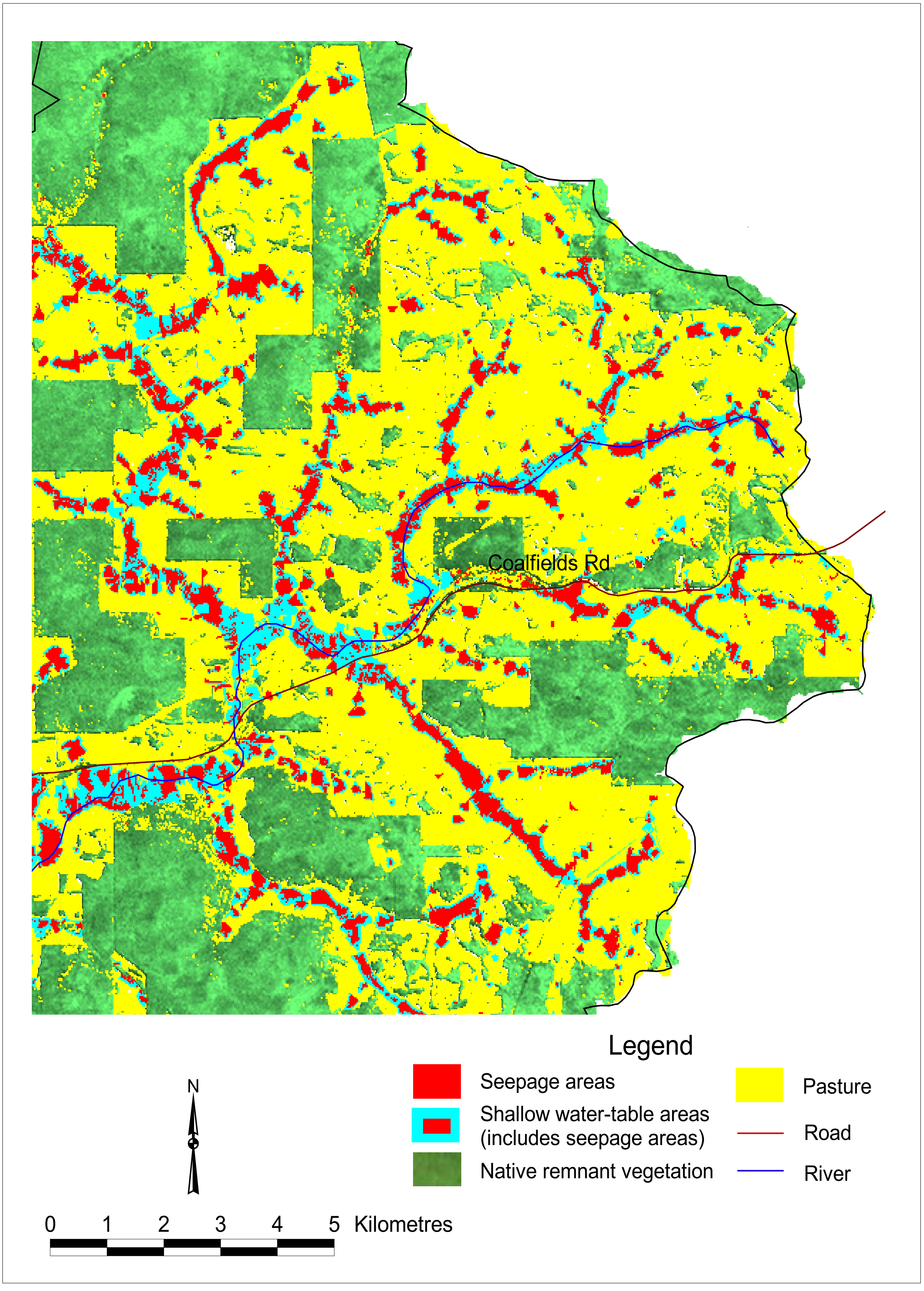
2. Poorly drained. Soil landscape units Kuw, Quv, Quw, HS, Mlu
3. Too shallow or steep. Soil landscape units BL4, BL5, HL
4. Prone to waterlogging or salinity. Soil landscape units LKk, Lku, QU
5. Check and exclude in stream zones only areas prone to waterlogging or salinity. Soil landscape units CF, SKd, PHd, WGw
6. Check for steep areas and exclude steep areas only. Soil landscape unit Ygd was checked. Slopes greater than 10% were excluded.

8.7 Shallow drainage

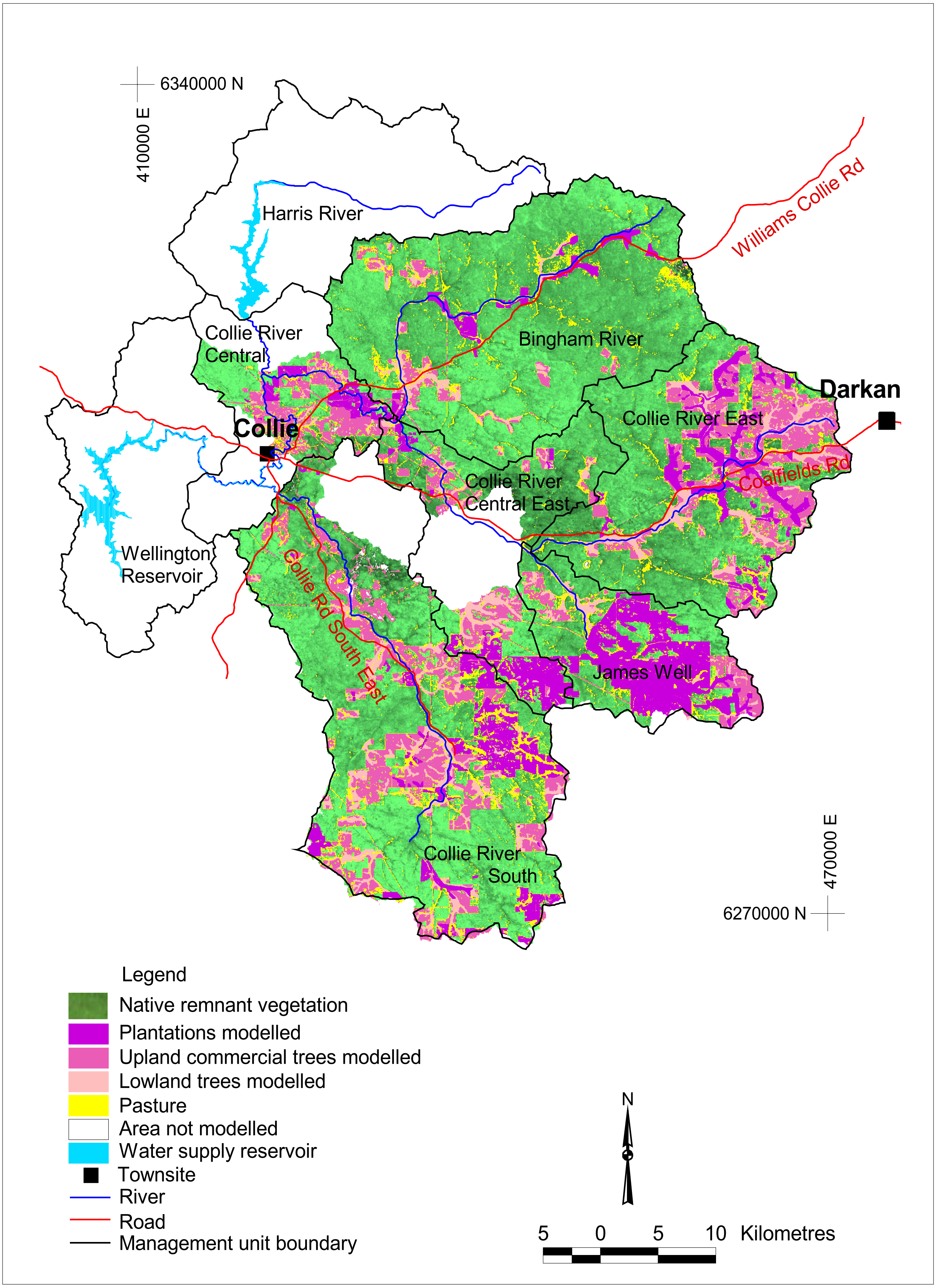
Because nothing was planted for this option it resembled the Pre-plantation case, except that drains following the surface contours were placed on the landscape at 100 m centres (using the same alignment as the tree alleys shown in Map 8.4). All proposed and existing plantations were deemed set to pasture, which was easy to automatically generate in MAGIC. The drains were assumed to be 1.0 m deep and were thus simulating interceptor banks. The water in the drains was calculated and the results shown in Table 8.11. The drains reduced seepage from pasture by only 1 to 2%; but did dry out land nearby, which could improve crop production.



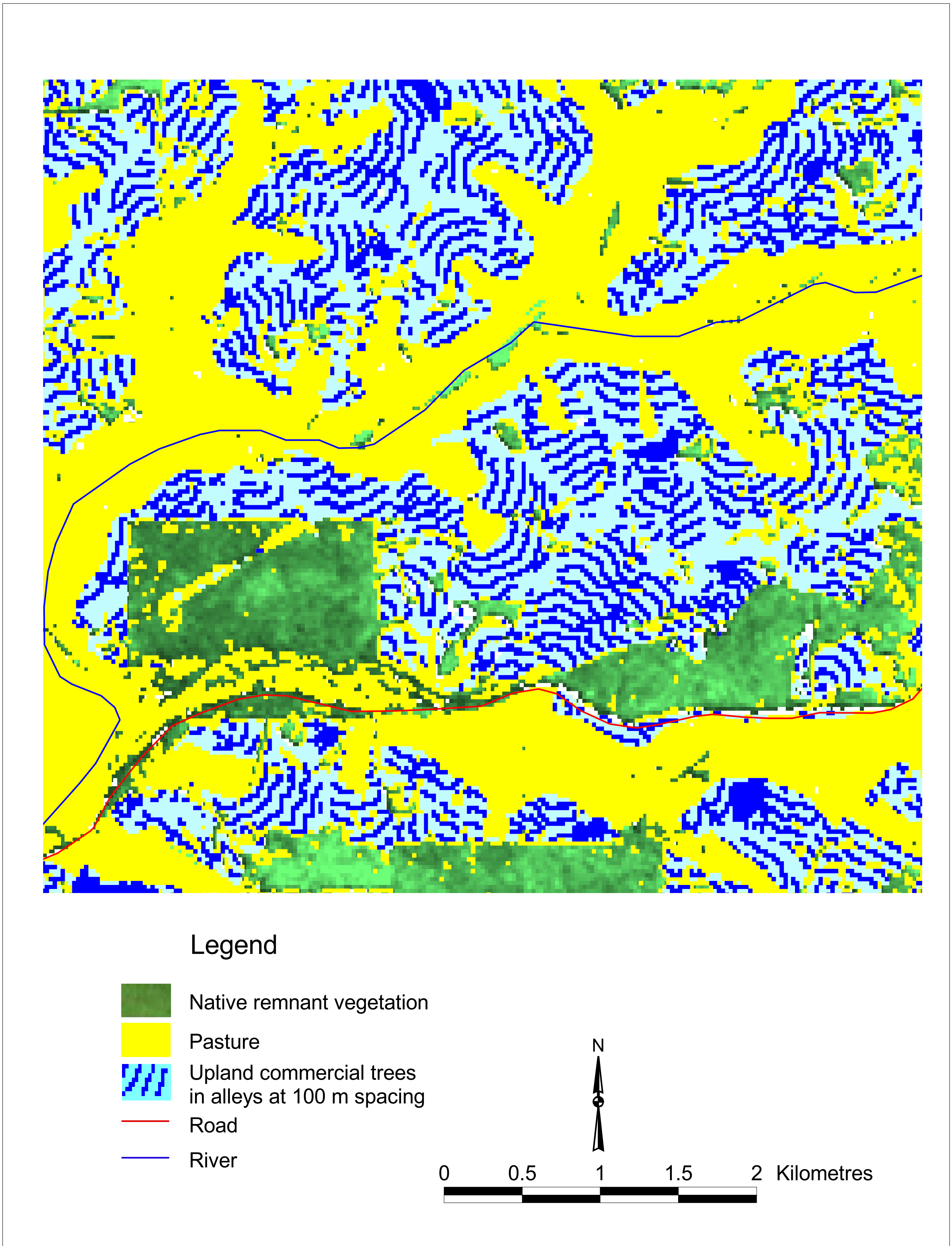
Map 8.1 Collie management option modelling – pre-plantation case



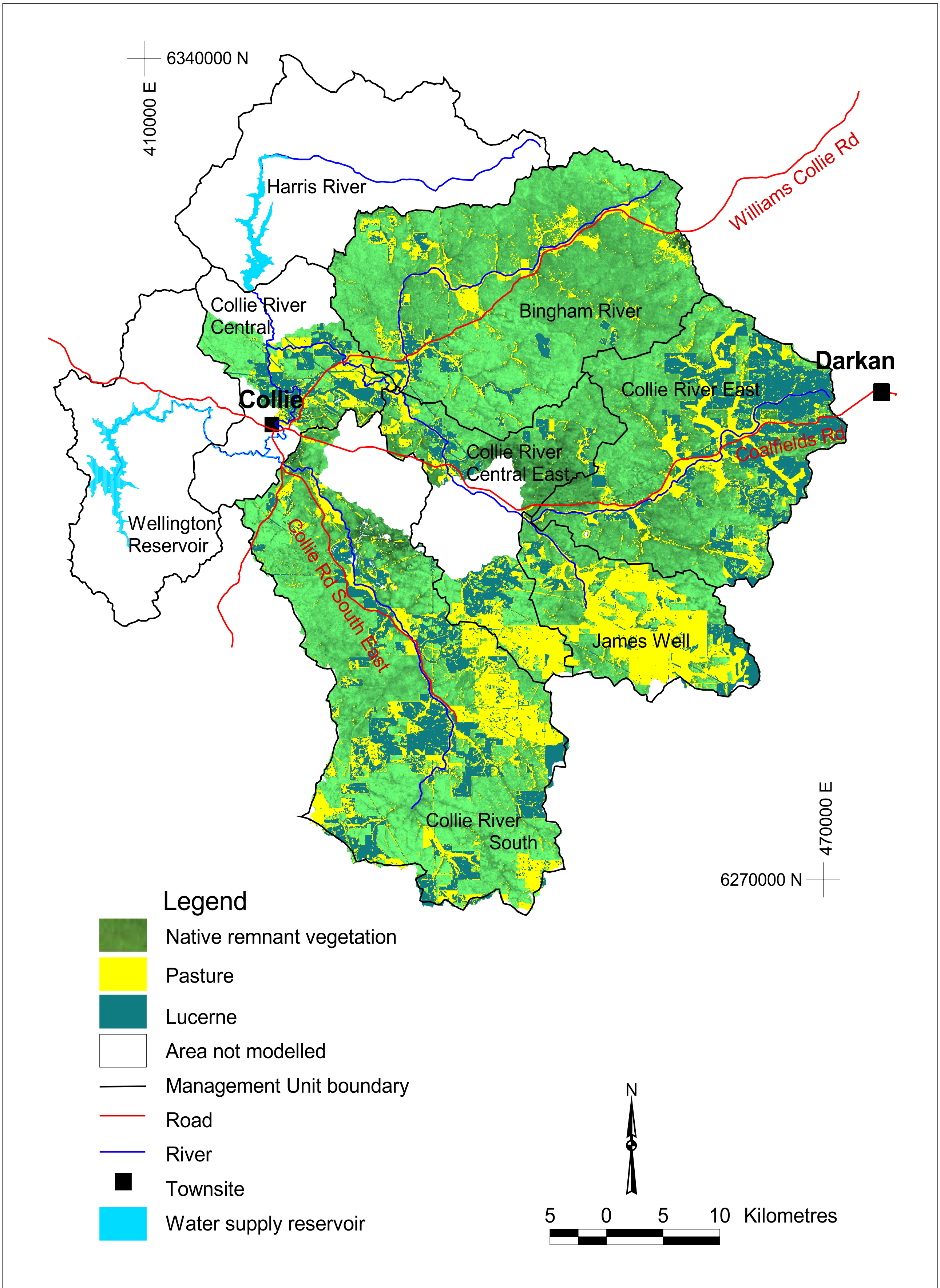
Map 8.2 Collie management option modelling – pre-plantation case in Collie River East, predicted shallow water-table and seepage areas



Map 8.3 Collie management option modelling – tree planting areas



Map 8.4 Collie management option modelling – commercial trees in alleys at 100m-spacing in Collie River East



Map 8.5 Collie management option modelling – lucerne planting areas

Table 8.2 Model calibration to current average flow year (1995)

Model calibration	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
1996 Cleared area (km²)	182.39	60.99	118.11	30.06	68.26	36.57	17.55	43.00	513.93	556.93
1996 Cleared area / Catchment area	28%	33%	29%	6%	28%	23%	5%	15%	20%	20%
Rainfall (GL/yr)	502	120	259	396	185	146	329	294	1936	2230
Rainfall (mm/year)	757	656	644	770	751	903	862	1050	759	788
Streamflow based on 1995 gauging (GL/yr)	23.26	5.53	14.40	7.00	14.63	20.95	15.40	43.62	101.17	144.79
Mean stream salinity based on 1995 gauging (mg/L)	1031	3466	3428	216	736	546	100	198	1180	885
Modelled Streamflow (GL/yr)	23.26	5.16	13.98	7.72	16.22	18.08	15.40	43.62	99.81	143.44
Modelled Streamflow (mm/year)	35.1	28.2	34.8	15.0	66.0	112.2	61.3	155.8	39.1	50.7
Modelled stream salinity (mg/L)	1194	3765	2818	900	881	582	100	198	1209	902
Modelled seepage from pasture (GL/yr)	4.80	1.75	3.25	0.82	1.39	0.84	0.00	5.49	12.86	18.35
Modelled seepage from pasture (mm/year)	23.4	24.2	25.9	29.2	19.9	18.2	0.0	127.6	22.8	30.2
Salt Load based on 1995 gauging (tonnes/year)	20 744	18 477	47 934	0	9687	10 171	0	6009	106 492	112 500
Modelled seepage salt load (tonnes/year)	24 535	18 750	37 982	4046	13 193	9256	0	6009	107 763	113 771
Modelled shallow water table area (km²)	48.0	19.6	29.8	8.9	14.4	6.6	0.0	0.0	127.4	127.4
Modelled shallow water table area / 1996 cleared area	26%	32%	25%	30%	21%	18%	0%	0%	25%	23%
Modelled seepage area (km²)	21.6	4.9	12.9	2.9	6.4	3.0	0.0	0.0	51.8	51.8
Modelled seepage area / 1996 cleared area	12%	8%	11%	10%	9%	8%	0%	0%	10%	9%

*51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.3. Modelling of pre-plantation case

Pre-plantation case	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km^2)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km^2)	190.26	89.25	138.43	40.08	85.80	45.34	17.83	43.00	607.00	650.00
Cleared area / Catchment area	29%	49%	34%	8%	35%	28%	5%	15%	24%	23%
Streamflow (GL/yr)	24.80	8.22	16.23	9.53	18.29	20.00	15.40	43.62	112.98	156.60
Streamflow (mm/yr)	37.4	45.0	40.4	18.5	74.5	124.1	40.3	155.8	44.3	55.3
Mean stream salinity (mg/L)	1140	2501	2573	772	832	550	100	198	1136	875
Seepage from pasture (GL/yr)	4.90	1.82	3.45	0.88	1.49	1.00	0.00	5.49	13.75	19.24
Seepage from pasture (mm/yr)	23.9	25.2	27.5	31.4	18.5	21.4	0.0	127.6	23.9	29.8
Seepage salt load (tonnes/yr)	25 046	19 890	40 332	4461	14 140	9729	0	6009	115 449	121 458
Shallow water table area (km^2)	51.8	18.5	32.1	9.5	15.7	7.5	0.0	0.0	136.8	136.8
Seepage area (km^2)	21.6	11.7	17.5	3.7	8.5	3.8	0.0	0.0	66.8	66.8

* 51 km^2 of Collie Central MU, including 4.83 km^2 of cleared land, was transferred to Harris River MU for modelling.

Table 8.4. Modelling of tree plantations

Modelling of tree plantations	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	152.62	27.19	106.50	26.78	66.25	36.27	17.83	43.00	433.45	476.45
Cleared area / Catchment Area (%)	23%	15%	27%	5%	27%	22%	5%	15%	17%	17%
Planted Area (km²)	38.45	62.43	31.98	11.93	19.79	9.08	0.28	0.00	173.93	173.93
Planted Area / Pre-plantation cleared area (%)	20%	70%	23%	30%	23%	20%	2%	0%	29%	27%
Streamflow (GL/yr)	19.59	3.00	12.30	7.12	14.86	17.85	15.40	43.62	90.17	133.79
Streamflow (mm/yr)	29.6	16.4	30.6	13.8	60.5	110.7	40.3	155.8	35.4	47.3
Streamflow % of pre-plantation case	79%	37%	76%	75%	81%	89%	100%	100%	80%	85%
Mean stream salinity (mg/L)	1154	2542	2609	902	735	584	100	198	1029	758
Seepage from pasture (GL/yr)	3.79	0.67	2.63	0.74	1.04	0.82	0.00	5.49	9.68	15.17
Seepage from pasture (mm/yr)	18.5	9.3	21.0	26.4	12.9	17.6	0.0	117.9	16.8	24.4
Seepage Salt Load (tonnes/yr)	19 370	7264	30 676	3525	9827	9148	0	6009	79 809	85 817
Seepage % of pre-plantation case	77%	33%	76%	84%	69%	82%	100%	100%	70%	79%
Shallow water table area (km²)	42.1	8.4	27.0	8.5	11.4	6.7	0.0	0.0	104.0	104.0
Shallow water table area/ Pre-plantation Shallow water table area (%)	81%	42%	84%	89%	73%	89%	100%	100%	76%	76%
Seepage area (km²)	16.1	2.3	9.8	2.7	4.8	3.0	0.0	0.0	38.7	38.7
Seepage area / Pre-plantation Seepage area (%)	75%	20%	56%	73%	56%	78%	100%	100%	58%	58%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.5. Modelling of upland commercial trees in alleys: Case 1 (alleys 200m-spacing, thinly planted)

Modelling of upland commercial trees in alleys: Case 1	Management units									
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir	**Mungalup Tower**	**Reservoir Total**
Catchment area (km^2)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km^2)	178.01	86.80	127.42	38.30	82.88	41.73	17.83	43.00	572.97	615.97
Cleared area / Catchment Area (%)	27%	48%	32%	7%	34%	26%	5%	15%	22%	22%
Planted Area (km^2)	12.25	2.44	11.01	1.79	2.92	3.62	0.00	0.00	34.03	34.03
Planted Area / Pre-plantation cleared area (%)	6%	3%	8%	4%	3%	8%	0%	0%	6%	5%
Streamflow (GL/yr)	20.01	4.56	12.80	7.16	15.16	15.52	15.40	43.62	90.60	134.23
Streamflow (mm/yr)	30.2	25.0	31.9	13.9	61.7	96.2	40.3	155.8	35.5	47.4
Streamflow % of pre-plantation case	81%	55%	79%	75%	83%	78%	100%	100%	81%	86%
Mean stream salinity (mg/L)	1263	3717	2754	906	873	611	100	198	1203	877
Seepage from pasture (GL/yr)	4.31	1.66	2.90	0.75	1.28	0.69	0.00	5.49	11.59	17.08
Seepage from pasture (mm/yr)	21.0	22.9	23.1	26.7	15.9	14.8	0.0	127.6	20.1	27.6
Seepage Salt Load (tonnes/yr)	22 043	17 763	33 840	3592	12 138	8197	0	6009	97 573	103 582
Seepage % of pre-plantation case	88%	82%	84%	85%	86%	69%	100%	100%	84%	89%
Shallow water table area (km^2)	47.9	17.7	29.1	8.6	14.5	6.0	0.0	0.0	123.9	123.9
Shallow water table area/ Pre-plantation Shallow water table area (%)	92%	88%	91%	91%	92%	80%	100%	100%	91%	91%
Seepage area (km^2)	18.0	4.8	11.3	2.5	5.6	2.1	0.0	0.0	44.3	44.3
Seepage area / Pre-plantation Seepage area (%)	84%	41%	65%	66%	65%	56%	100%	100%	66%	66%

* 51 km^2 of Collie Central MU, including 4.83 km^2 of cleared land, was transferred to Harris River MU for modelling.

Table 8.6. Modelling of upland commercial trees in alleys: Case 2 (alleys 100m-spacing, thinly planted)

Modelling of upland commercial trees in alleys: Case 2	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	166.22	84.41	116.49	36.51	80.09	38.36	17.83	64.96	539.92	582.88
Cleared area / Catchment Area (%)	25%	46%	29%	7%	33%	24%	5%	23%	21%	21%
Planted Area (km²)	24.05	4.83	21.95	3.57	5.70	6.98	0.00	0.00	67.08	67.12
Planted Area / Pre-plantation cleared area (%)	13%	5%	16%	9%	7%	15%	0%	0%	11%	10%
Streamflow (GL/yr)	17.69	4.40	12.15	6.80	14.30	13.60	15.40	43.62	84.35	128.20
Streamflow (mm/yr)	26.7	24.1	30.2	13.2	58.2	84.4	40.3	155.8	33.1	45.3
Streamflow % of pre-plantation case	71%	54%	75%	71%	78%	68%	100%	100%	75%	82%
Mean stream salinity (mg/L)	1323	3682	2635	908	862	631	100	198	1198	867
Seepage from pasture (GL/yr)	3.95	1.59	2.62	0.70	1.18	0.57	0.00	0.00	10.61	16.10
Seepage from pasture (mm/yr)	19.3	21.9	20.9	25.0	14.7	12.2	0.0	0.0	18.4	26.0
Seepage Salt Load (tonnes/yr)	20 178	16 991	30 599	3279	11 242	7306	0	6009	89 595	95 604
Seepage % of pre-plantation case	81%	78%	76%	80%	80%	57%	100%	100%	77%	84%
Shallow water table area (km²)	45.2	17.3	27.7	8.3	13.8	5.3	0.0	0.0	117.5	117.5
Shallow water table area/ Pre-plantation Shallow water table area (%)	87%	86%	86%	87%	88%	71%	100%	100%	86%	86%
Seepage area (km²)	15.8	4.5	10.0	2.2	4.9	1.6	0.0	0.0	39.1	39.1
Seepage area / Pre-plantation Seepage area (%)	73%	39%	57%	59%	58%	42%	100%	100%	59%	59%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.7. Modelling of upland commercial trees in alleys: Case 3 (alleys 100m-spacing, thicker planting)

Modelling of upland commercial trees in alleys: Case 3	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	157.83	82.64	108.46	35.26	78.08	35.80	17.83	43.00	515.91	558.85
Cleared area / Catchment Area (%)	24%	45%	27%	7%	32%	22%	5%	15%	20%	20%
Planted Area (km²)	32.44	6.60	29.97	4.82	7.72	9.54	0.00	0.00	91.09	91.15
Planted Area / Pre-plantation cleared area (%)	17%	7%	22%	12%	9%	21%	0%	0%	15%	14%
Streamflow (GL/yr)	16.80	4.34	11.92	6.65	13.96	12.76	15.40	43.62	81.83	125.68
Streamflow (mm/yr)	25.4	23.7	29.7	12.9	56.8	79.2	40.3	155.8	32.1	44.4
Streamflow % of pre-plantation case	68%	53%	73%	70%	76%	64%	100%	100%	73%	80%
Mean stream salinity (mg/L)	1308	3597	2505	891	833	616	100	198	1163	838
Seepage from pasture (GL/yr)	3.67	1.53	2.43	0.67	1.11	0.46	0.00	5.49	9.87	15.36
Seepage from pasture (mm/yr)	17.9	21.1	19.4	23.7	13.8	10.0	0.0	127.6	17.2	24.8
Seepage Salt Load (tonnes/yr)	18 741	16 343	28 438	3035	10 541	6585	0	6009	83 682	89 691
Seepage % of pre-plantation case	75%	75%	71%	76%	75%	47%	100%	100%	72%	80%
Shallow water table area (km²)	43.2	17.0	26.7	8.0	13.4	4.6	0.0	0.0	112.9	112.9
Shallow water table area / Pre-plantation Shallow water table area (%)	83%	84%	83%	84%	85%	61%	100%	100%	82%	82%
Seepage area (km²)	14.4	4.4	9.3	2.1	4.7	1.2	0.0	0.0	36.1	36.1
Seepage area / Pre-plantation Seepage area (%)	67%	37%	54%	55%	55%	31%	100%	100%	54%	54%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.8. Modelling of upland commercial trees in alleys: Case 4 (alleys 100m-spacing, thickest planting)

Modelling of upland commercial trees in alleys: Case 4	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	145.55	80.13	96.58	33.44	75.13	32.04	17.83	43.00	480.70	523.62
Cleared area / Catchment Area (%)	22%	44%	24%	7%	31%	20%	5%	15%	19%	19%
Planted Area (km²)	44.72	9.12	41.85	6.64	10.66	13.30	0.00	0.00	126.30	126.38
Planted Area / Pre-plantation cleared area (%)	24%	10%	30%	17%	12%	29%	0%	0%	21%	19%
Streamflow (GL/yr)	15.16	4.20	11.48	6.41	13.34	11.46	15.40	43.62	77.45	121.32
Streamflow (mm/yr)	22.9	23.0	28.6	12.5	54.3	71.1	40.3	155.8	30.4	42.9
Streamflow % of pre-plantation case	61%	51%	71%	67%	73%	57%	100%	100%	69%	77%
Mean stream salinity (mg/L)	1338	3540	2319	880	809	613	100	198	1131	805
Seepage from pasture (GL/yr)	3.34	1.46	2.16	0.62	1.02	0.34	0.00	5.49	8.94	14.43
Seepage from pasture (mm/yr)	16.3	20.1	17.2	22.2	12.7	7.4	0.0	127.6	15.5	23.3
Seepage Salt Load (tonnes/yr)	17 054	15 578	25 204	2751	9709	5751	0	6009	76 048	82 056
Seepage % of pre-plantation case	68%	72%	62%	71%	69%	34%	100%	100%	65%	75%
Shallow water table area (km²)	40.5	16.4	25.1	7.6	12.7	3.8	0.0	0.0	106.1	106.1
Shallow water table area / Pre-plantation Shallow water table area (%)	78%	81%	78%	80%	81%	51%	100%	100%	78%	78%
Seepage area (km²)	13.0	4.1	8.3	1.9	4.2	0.8	0.0	0.0	32.3	32.3
Seepage area / Pre-plantation Seepage area (%)	60%	35%	47%	51%	50%	20%	100%	100%	48%	48%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.9. Modelling of all upland commercial trees: Case 5 (full plantation)

Modelling of all upland commercial trees	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	120.48	75.34	77.64	30.16	70.03	25.56	17.83	43.00	417.03	460.03
Cleared area / Catchment Area (%)	18%	41%	19%	6%	29%	16%	5%	15%	16%	16%
Planted Area (km²)	69.78	13.91	60.80	9.93	15.77	19.78	0.00	0.00	189.97	189.97
Planted Area / Pre-plantation cleared area (%)	37%	16%	44%	25%	18%	44%	0%	0%	31%	29%
Streamflow (GL/yr)	12.50	4.26	10.98	6.05	12.28	9.83	15.40	43.62	71.30	114.93
Streamflow (mm/yr)	18.9	23.3	27.3	11.8	50.0	61.0	40.3	155.8	28.0	40.6
Streamflow % of pre-plantation case	50%	49%	68%	63%	67%	49%	100%	100%	63%	73%
Mean stream salinity (mg/L)	1392	3532	1999	865	780	629	100	198	1090	752
Seepage from pasture (GL/yr)	2.77	1.35	1.76	0.56	0.89	0.23	0.00	5.49	7.56	13.05
Seepage from pasture (mm/yr)	13.5	18.6	14.0	20.0	11.1	4.9	0.0	127.6	13.1	21.1
Seepage Salt Load (tonnes/yr)	14 166	14 386	20 527	2338	8493	4909	0	6009	64 819	70 828
Seepage % of pre-plantation case	57%	66%	51%	64%	60%	23%	100%	100%	55%	68%
Shallow water table area (km²)	34.8	15.4	22.1	7.1	11.4	2.9	0.0	0.0	93.6	93.6
Shallow water table area / Pre-plantation Shallow water table area (%)	67%	76%	69%	75%	73%	38%	100%	100%	68%	68%
Seepage area (km²)	10.9	3.7	6.8	1.6	3.6	0.4	0.0	0.0	26.9	26.9
Seepage area / Pre-plantation Seepage area (%)	50%	32%	39%	44%	42%	11%	100%	100%	40%	40%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.10. Modelling of upland commercial trees in alleys: Case 3 after plantations

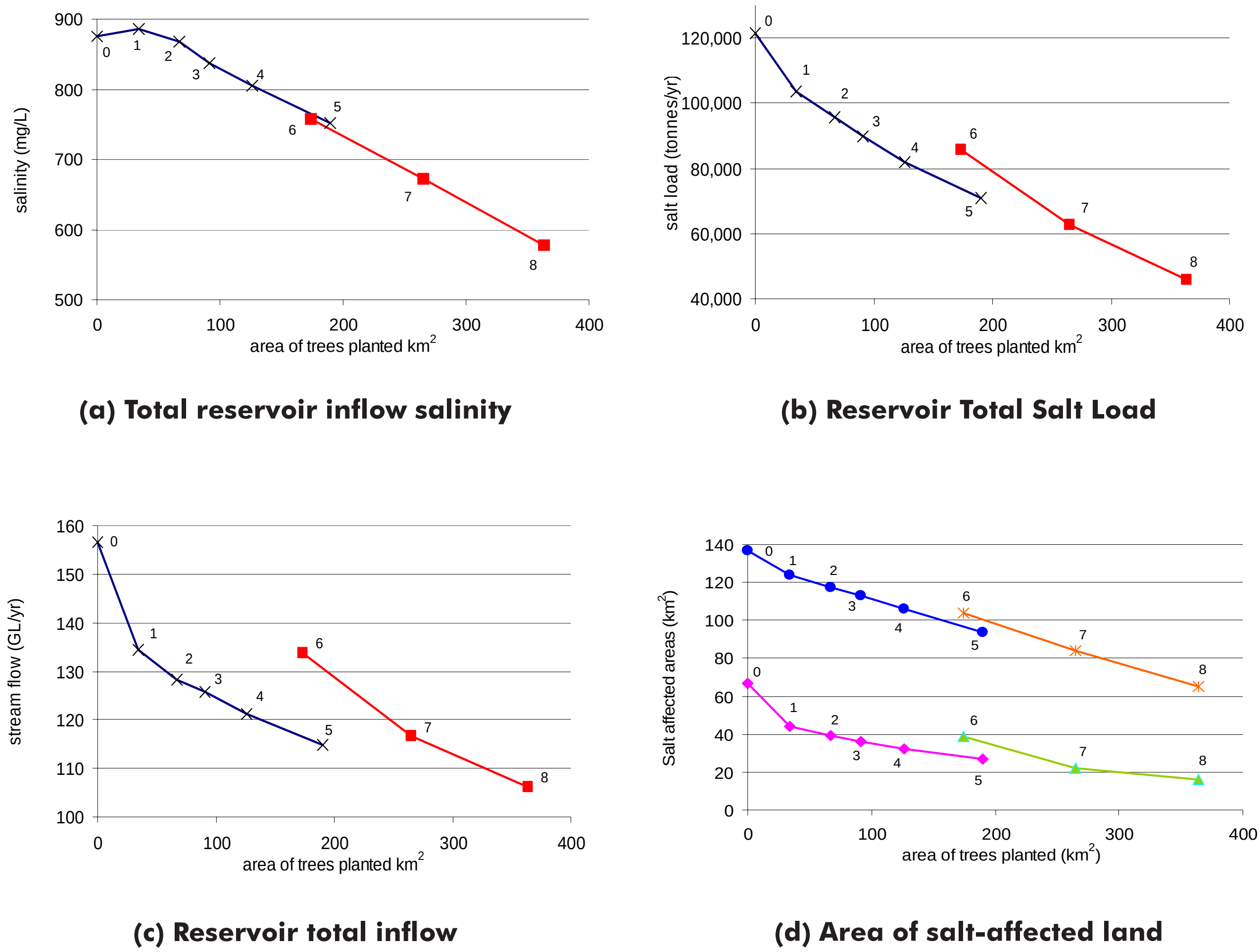
Modelling of upland commercial trees in alleys: Case 3 after plantations	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	119.37	20.16	76.49	23.33	58.29	26.72	17.55	43.00	341.92	384.92
Cleared area / Catchment Area (%)	18%	11%	19%	5%	24%	17%	5%	15%	13%	14%
Planted Area (km²)	70.89	69.09	61.95	16.75	27.50	18.62	0.28	0.00	265.08	265.08
Planted Area / Pre-plantation cleared area (%)	37%	77%	45%	42%	32%	41%	2%	0%	44%	41%
Streamflow (GL/yr)	13.36	2.55	10.54	6.11	12.42	12.55	15.40	43.62	72.93	116.55
Streamflow (mm/yr)	20.2	13.9	26.2	11.9	50.6	77.8	40.3	155.8	28.6	41.2
Streamflow % of pre-plantation case	54%	29%	65%	64%	68%	63%	100%	100%	65%	74%
Mean stream salinity (mg/L)	1281	2277	2152	890	677	626	100	198	955	672
Seepage from pasture (GL/yr)	2.72	0.47	1.82	0.59	0.77	0.45	0.00	5.49	6.83	12.32
Seepage from pasture (mm/yr)	13.3	6.6	14.5	21.1	9.6	9.7	0.0	127.6	11.9	19.9
Seepage Salt Load (tonnes/yr)	13 885	5127	21 254	2544	7321	6578	0	6009	56 709	62 718
Seepage % of pre-plantation case	55%	23%	53%	67%	52%	45%	100%	100%	50%	64%
Shallow water table area (km²)	34.0	6.9	22.0	7.3	9.6	4.4	0.0	0.0	84.2	84.2
Shallow water table area / Pre-plantation Shallow water table area (%)	66%	34%	68%	77%	62%	59%	100%	100%	62%	62%
Seepage area (km²)	9.5	1.5	5.1	1.8	3.2	1.2	0.0	0.0	22.3	22.3
Seepage area / Pre-plantation Seepage area (%)	44%	13%	29%	49%	37%	31%	100%	100%	33%	33%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.11. Modelling of upland commercial trees in alleys: Case 5 after plantations

Modelling of upland commercial trees in alleys: Case 5 after plantations	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	82.03	12.91	45.66	18.23	50.24	16.48	17.55	43.00	243.10	285.55
Cleared area / Catchment Area (%)	12%	7%	11%	4%	20%	10%	5%	15%	10%	10%
Planted Area (km²)	108.24	76.33	92.78	21.85	35.56	28.86	0.28	0.00	363.90	386.41
Planted Area / Pre-plantation cleared area (%)	57%	86%	67%	55%	41%	64%	2%	0%	60%	58%
Streamflow (GL/yr)	9.18	2.30	9.77	5.51	10.78	9.63	15.40	43.62	62.57	106.19
Streamflow (mm/yr)	13.9	12.6	24.3	10.7	43.9	59.7	40.3	155.8	24.5	37.5
Streamflow % of pre-plantation case	37%	26%	60%	58%	59%	48%	100%	100%	55%	68%
Mean stream salinity (mg/L)	1388	1842	1637	859	592	644	100	198	841	577
Seepage from pasture (GL/yr)	1.86	0.33	1.25	0.49	0.56	0.22	0.00	5.49	4.70	4.70
Seepage from pasture (mm/yr)	9.1	4.6	10.0	17.3	7.0	4.7	0.0	127.6	8.2	9.2
Seepage Salt Load (tonnes/yr)	9510	3558	14 572	1836	5299	4924	0	6009	39 699	45 708
Seepage % of pre-plantation case	38%	16%	36%	55%	37%	22%	100%	100%	34%	34%
Shallow water table area (km²)	25.7	5.4	17.1	6.4	7.7	2.7	0.0	0.0	65.1	65.1
Shallow water table area / Pre-plantation Shallow water table area (%)	49%	27%	53%	68%	49%	36%	100%	100%	48%	48%
Seepage area (km²)	6.3	1.0	5.0	1.4	2.2	0.4	0.0	0.0	16.2	16.2
Seepage area / Pre-plantation Seepage area (%)	29%	8%	29%	38%	25%	11%	100%	100%	24%	24%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.



Legend for graph lines

- Shallow water table areas without plantations
- Shallow water table areas with plantations
- Seepage areas without plantations
- Seepage areas with plantations
- Without planned & existing plantations
- With planned & existing plantations

Legend for point numbers

0 Pre-plantation case: All existing plantations removed. 24% of the catchment cleared
1 Upland commercial trees in alleys Case 1: Alleys at 200 m spacing, thinly planted
2 Upland commercial trees in alleys Case 2: Alleys at 100 m spacing, thinly planted
3 Upland commercial trees in alleys Case 3: Alleys at 100 m spacing, thicker planted
4 Upland commercial trees in alleys Case 4: Alleys at 100 m spacing, thicker planted
5 Upland commercial trees in alleys Case 5: Planted on all suitable land (full plantation)
6 Plantation case: Existing and proposed plantations
7 Upland commercial trees in alleys Case 3 with plantations
8 Upland commercial trees in alleys Case 5 with plantations

Figure 8.1 Modelled results of planting trees in alleys on suitable land

Table 8.12. Modelling of lowland trees

Modelling of lowland trees	Management units									
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir	**Mungalup Tower**	**Reservoir Total**
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	160.04	82.53	103.01	30.71	74.99	40.92	17.83	43.00	510.03	553.03
Cleared area / Catchment Area (%)	24%	45%	26%	6%	31%	25%	5%	15%	20%	20%
Planted Area (km²)	30.22	6.71	35.43	9.37	10.81	4.42	0.00	0.00	96.96	96.96
Planted Area / Pre-plantation cleared area (%)	16%	8%	26%	23%	13%	10%	0%	0%	16%	15%
Streamflow (GL/yr)	18.56	7.67	11.90	7.33	15.60	18.47	15.40	43.62	94.94	138.56
Streamflow (mm/yr)	28.0	42.0	29.6	14.3	63.5	114.6	40.3	155.8	37.2	49.0
Streamflow % of pre-plantation case	75%	88%	73%	77%	85%	92%	100%	100%	84%	88%
Mean stream salinity (mg/L)	1112	2533	2242	647	642	529	100	198	986	738
Seepage from pasture (GL/yr)	3.41	1.75	2.16	0.49	0.94	0.77	0.00	5.49	9.51	15.00
Seepage from pasture (mm/yr)	16.6	24.2	17.3	17.3	11.7	16.5	0.0	127.6	16.5	24.3
Seepage Salt Load (tonnes/yr)	17 401	18 759	25 260	1851	8929	8493	0	6009	80 692	86 701
Seepage % of pre-plantation case	69%	86%	63%	55%	63%	77%	100%	100%	69%	78%
Shallow water table area (km²)	41.1	17.7	22.8	6.4	11.4	6.3	0.0	0.0	105.7	105.7
Shallow water table area / Pre-plantation Shallow water table area (%)	79%	88%	71%	68%	72%	84%	100%	100%	77%	77%
Seepage area (km²)	13.0	9.8	8.4	1.5	4.8	2.6	0.0	0.0	40.1	40.1
Seepage area / Pre-plantation Seepage area (%)	60%	84%	48%	40%	56%	69%	100%	100%	60%	60%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.13. Modelling of lowland trees after plantations

Modelling of lowland trees after plantations	Management units									
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir	**Mungalup Tower**	**Reservoir Total**
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	121.59	20.11	71.03	18.79	55.20	31.84	17.55	43.00	336.10	379.10
Cleared area / Catchment Area (%)	18%	11%	18%	4%	22%	20%	5%	15%	13%	13%
Planted Area (km²)	75.59	71.09	68.59	21.29	31.28	13.51	0.28	0.00	281.63	281.63
Planted Area / Pre-plantation cleared area (%)	40%	80%	50%	53%	36%	30%	2%	0%	46%	43%
Streamflow (GL/yr)	12.45	1.88	8.11	4.81	11.97	16.05	15.40	43.62	70.67	114.29
Streamflow (mm/yr)	18.8	10.3	20.2	9.4	48.7	99.5	40.3	155.8	27.7	40.4
Streamflow % of pre-plantation case	50%	22%	50%	50%	65%	80%	100%	100%	63%	73%
Mean stream salinity (mg/L)	1109	2104	1549	780	457	583	100	198	725	524
Seepage from pasture (GL/yr)	2.07	0.30	0.95	0.34	0.46	0.59	0.00	5.49	4.72	10.21
Seepage from pasture (mm/yr)	10.1	4.2	7.6	12.0	5.7	12.7	0.0	127.6	8.2	16.5
Seepage Salt Load (tonnes/yr)	10 579	3289	11143	857	4380	8071	0	6009	38 318	44 327
Seepage % of pre-plantation case	42%	15%	28%	38%	31%	59%	100%	100%	34%	53%
Shallow water table area (km²)	27.7	3.9	11.3	4.9	6.0	5.4	0.0	0.0	59.2	59.2
Shallow water table area / Pre-plantation Shallow water table area (%)	54%	19%	35%	52%	38%	71%	100%	100%	43%	43%
Seepage area (km²)	6.0	0.7	2.0	0.6	1.4	2.0	0.0	0.0	12.7	12.7
Seepage area / Pre-plantation Seepage area (%)	28%	6%	12%	17%	16%	51%	100%	100%	19%	19%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.14. Modelling of lucerne

Modelling of lucerne	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	113.84	75.53	56.03	27.29	66.53	24.61	17.83	43.00	381.66	424.66
Cleared area / Catchment Area (%)	17%	41%	14%	5%	27%	15%	5%	15%	15%	15%
Planted Area (km²)	76.42	13.72	82.40	12.79	19.27	20.73	0.00	0.00	225.34	225.34
Planted Area / Pre-plantation cleared area (%)	40%	15%	60%	32%	22%	46%	0%	0%	37%	35%
Streamflow (GL/yr)	18.83	8.05	13.69	8.57	16.38	17.06	15.40	43.62	97.97	141.60
Streamflow (mm/yr)	28.4	44.1	34.1	16.7	66.7	105.8	40.3	155.8	38.4	50.0
Streamflow % of pre-plantation case	76%	92%	84%	90%	90%	85%	100%	100%	87%	90%
Mean stream salinity (mg/L)	1278	2511	2046	767	804	577	100	198	1064	797
Seepage from pasture (GL/yr)	4.08	1.82	2.28	0.76	1.27	0.81	0.00	5.49	11.02	16.51
Seepage from pasture (mm/yr)	19.9	25.2	18.2	27.2	15.8	17.4	0.0	127.6	19.2	26.7
Seepage Salt Load (tonnes/yr)	20 829	19 542	26 579	3679	12 080	8558	0	6009	91 267	97 276
Seepage % of pre-plantation case	83%	90%	66%	87%	85%	81%	100%	100%	80%	86%
Shallow water table area (km²)	46.9	18.8	25.7	8.8	14.7	6.5	0.0	0.0	121.4	121.4
Shallow water table area / Pre-plantation Shallow water table area (%)	90%	93%	80%	93%	94%	87%	100%	100%	89%	89%
Seepage area (km²)	14.9	10.0	10.9	2.8	6.1	2.3	0.0	0.0	47.0	47.0
Seepage area / Pre-plantation Seepage area (%)	69%	86%	62%	75%	72%	59%	100%	100%	70%	70%

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

Table 8.15. Modelling of shallow drainage

Modelling of shallow drainage	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central*	Harris River*	Wellington Reservoir		
Catchment area (km²)	663	183	402	514	246	161	382	280	2550	2830
Cleared area (km²)	190.26	89.25	138.43	40.08	85.80	45.34	17.83	43.00	607.00	650.00
Cleared area / Catchment Area (%)	29%	49%	34%	8%	35%	28%	5%	15%	24%	23%
Planted Area (km²)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planted Area / Pre-plantation cleared area (%)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Streamflow (GL/yr)	25.27	8.73	16.13	9.65	18.55	20.50	15.40	43.62	114.22	157.85
Streamflow (mm/yr)	38.1	47.8	40.1	18.8	75.5	127.1	40.3	155.8	44.8	55.8
Streamflow % of pre-plantation case	102%	100%	99%	101%	101%	102%	100%	100%	101%	101%
Mean stream salinity (mg/L)	1105	2531	2549	756	809	532	100	198	1109	857
Seepage from pasture (GL/yr)	4.83	2.00	3.40	0.87	1.47	0.98	0.00	5.49	13.54	19.03
Seepage from pasture (mm/yr)	23.6	27.6	27.1	31.1	18.3	21.0	0.0	127.6	23.5	30.8
Seepage Salt Load (tonnes/yr)	24 683	21 421	39 683	4399	13 926	9630	0	6009	113 743	119 751
Seepage % of pre-plantation case	99%	98%	98%	99%	98%	98%	100%	100%	98%	99%
Shallow water table area (km²)	51.6	19.8	31.8	9.4	15.7	7.4	0.0	0.0	135.8	135.8
Shallow water table area / Pre-plantation Shallow water table area (%)	100%	98%	99%	99%	100%	99%	100%	100%	99%	99%
Seepage area (km²)	20.0	11.3	16.5	3.4	7.9	3.2	0.0	0.0	62.3	62.3
Seepage area / Pre-plantation Seepage area (%)	93%	97%	95%	91%	92%	83%	100%	100%	93%	93%
Water in Drains (GL/yr)	13.07	0.88	2.30	0.01	0.09	5.83	0.00	0.00	22.17	22.17
Water in Drains (mm/yr)	19.7	4.8	5.7	0.0	0.4	36.2	0.0	0.0	8.7	7.8

* 51 km² of Collie Central MU, including 4.83 km² of cleared land, was transferred to Harris River MU for modelling.

8.8 Groundwater pumping

An estimate was made of quantities associated with groundwater pumping on the catchment after all committed plantations are installed, i.e. using the case 'Plantations' as a base. The MODFLOW simulation of Spencer's Gully (see Section 6.4.3.4) indicated that a reasonable rate per bore was 15 kL/day and that a single line of bores through major seepage areas could collect about 50% of the total seepage (Dogramaci et al, 2001). Rough measurement of the length of seepage areas indicates that connecting pipelines to collect pumped water need a length of approximately 400 m per bore. Pipelines to remove the collected water from the catchment would be similar to those proposed for diversion options (Section 8.9). 'Salinity result' and 'salinity reduction' are in terms of inflow to Wellington Reservoir. Quantities for independent areas may be summed (except for 'salinity result') to estimate aggregates of areas.

8.9 Diversion

The diversion options considered include:

- Building dams at the James Well and James Crossing sub-catchments, with full diversion of saline water;
- Building pipe-head dams at the James Well and James Crossing gauging stations, and partial diversion of saline water.

Locations of the possible diversion sites are shown in Map 8.6. Site A is situated on a tributary of the eastern branch of the Collie River, some 10 km downstream of the James Crossing gauging station. Site B is situated at the James Well gauging station of the eastern branch of the Collie River. Site C is at the James Crossing gauging station. The catchment attributes of the diversion sites are given in Table 8.17.

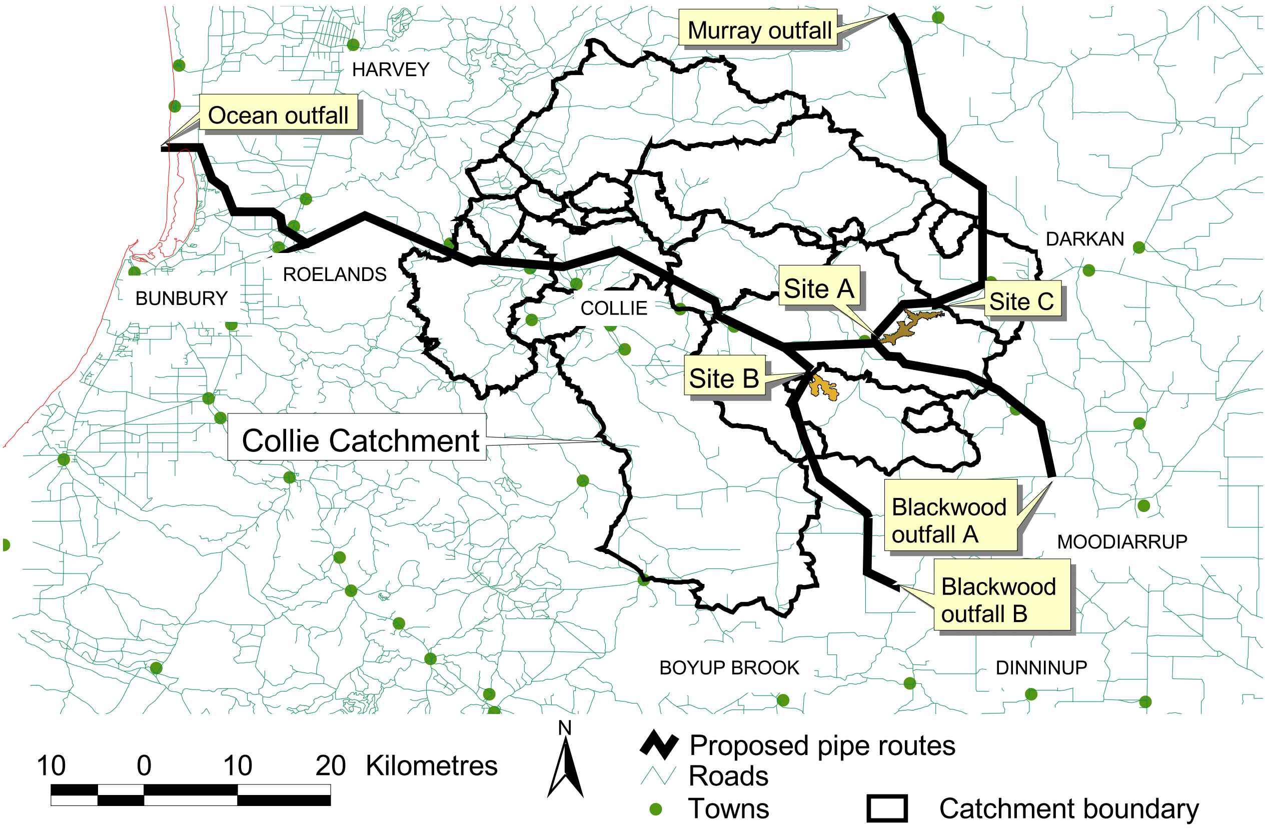
Resulting changes in flows and salinity through the catchment due to different options are given in Table 8.18.

Table 8.16 Quantities associated with groundwater pumping

(after committed plantations) Pump seepage from:	salt load tonnes/yr	volume GL/yr	salinity result mg/L	salinity reduction mg/L	bores # @ 15kL/day	Collector km @ 400m/bore
None	0	0	758			
50% Maxon farm	521	0.04	752	6	7	3
50% James Crossing	9780	0.84	687	71	153	61
50% Collie R. East MU	15 338	1.31	648	110	239	96
50% James Well	3037	0.28	735	23	51	20
50% James Well MU	3478	0.32	732	26	58	23
50% Collie R. Central East MU	4914	0.52	722	36	95	38
50% Collie R. South MU	9685	1.9	693	65	347	139
50% all areas	33 414	4.04	522	236	739	295

Table 8.17 Catchment attributes of stream diversion sites

Catchment attributes	Diversion Site		
	A	B	C
Area (km^2)	283	169	168
Average rainfall (mm)	638	650	630
Mean annual flow (GL)	10.2	4.96	6.1
Mean annual salt load (tonnes)	52 719	17 179	40 240
Mean annual salinity (mg/L TDS)	5168	3463	6585
Catchment area cleared (%)	41	49	54
Catchment area replanted (%)	7.3	16.3	7.8



Notes for Map 8.6 and Table 8.18:

SITE A	is located at 9 km downstream of the James Crossing gauging station.
SITE B	is located at the James Well gauging station.
SITE C	is located at the James Crossing gauging station.
DAM AT SITE A	Maximum flooded area is 800 Ha. Diverts 9 GL/yr and 44,000 tonnes of salt/yr.
DAM AT SITE B	Maximum flooded area is 500 Ha. Diverts 5 GL/yr and 17,000 tonnes of salt/yr.
PIPEHEAD DAM AT SITE B (20%)	20% of salt load and associated flow of 0.66 GL/yr is diverted.
PIPEHEAD DAM AT SITE C (20%)	20% of salt load and associated flow of 1.89 GL/yr is diverted.
PIPEHEAD DAM AT SITE B (30%)	30% of salt load and associated flow of 1.04 GL/yr is diverted.
PIPEHEAD DAM AT SITE C (30%)	30% of salt load and associated flow of 3.1 GL/yr is diverted.

Map 8.6 Location of possible stream diversion sites and pipeline routes

Table 8.18. Salt reduction due to diversion options

Streamflow diversion options	Management units								Mungalup Tower	Reservoir Total
	Collie River South	James Well	Collie River East	Bingham River	Collie River Central East	Collie River Central	Harris River	Wellington Reservoir		
DAM AT SITE-A										
Salt (tonnes/yr)	23 978	19 228	5343	1572	10 566	13 199	1460	8655	75 346	84 001
Flow (GL/yr)	23.26	5.55	5.06	7.29	14.26	29.35	7.00	43.62	91.77	135.39
Salinity (mg/L TDS)	1031	3466	1056	216	741	450	209	198	821	620
DAM AT SITE-B										
Salt (tonnes/yr)	23 978	2049	49 420	1572	10 566	13 199	1460	8655	102 244	110 899
Flow (GL/yr)	23.26	0.59	14.46	7.29	14.26	29.35	7.00	43.62	96.21	139.83
Salinity (mg/L TDS)	1031	3483	3418	216	741	450	209	198	1063	793
DAMS AT SITES-A&B										
Salt (tonnes/yr)	23 978	2049	5343	1572	10 566	13 199	1460	8655	58 167	66 822
Flow (GL/yr)	23.26	0.59	5.06	7.29	14.26	29.35	7.00	43.62	86.81	130.43
Salinity (mg/L TDS)	1031	3483	1056	216	741	450	209	198	670	512
PIPEHEAD DAM AT SITE-B (20%)										
Salt (tonnes/yr)	23 978	15 383	49 420	1572	10 566	13 199	1460	8655	115 577	124 232
Flow (GL/yr)	23.26	4.89	14.46	7.29	14.26	29.35	7.00	43.62	100.51	144.13
Salinity (mg/L TDS)	1031	3144	3418	216	741	450	209	198	1150	862
PIPEHEAD DAM AT SITE-C (20%)										
Salt (tonnes/yr)	23 978	19 228	39 536	1572	10 566	13 199	1460	8655	109 539	118 194
Flow (GL/yr)	23.26	5.55	12.57	7.29	14.26	29.35	7.00	43.62	99.28	142.90
Salinity (mg/L TDS)	1031	3466	3145	216	741	450	209	198	1103	827
PIPEHEAD DAM AT SITE-B (30%)										
Salt (tonnes/yr)	23 978	13 460	49 420	1572	10 566	13 199	1460	8655	113 655	122 309
Flow (GL/yr)	23.26	4.51	14.46	7.29	14.26	29.35	7.00	43.62	100.13	143.75
Salinity (mg/L TDS)	1031	2982	3418	216	741	450	209	198	1135	851
PIPEHEAD DAM AT SITE-C (30%)										
Salt (tonnes/yr)	23 978	19 228	34 594	1572	10 566	13 199	1460	8655	104 597	113 252
Flow (GL/yr)	23.26	5.55	11.36	7.29	14.26	29.35	7.00	43.62	98.07	141.69
Salinity (mg/L TDS)	1031	3466	3046	216	741	450	209	198	1067	799
PIPEHEAD DAMS AT SITES-B&C (30%)										
Salt (tonnes/yr)	23 978	13 460	34 594	1572	10 566	13 199	1460	8655	98 829	107 483
Flow (GL/yr)	23.26	4.51	11.36	7.29	14.26	29.35	7.00	43.62	97.03	140.65
Salinity (mg/L TDS)	1031	2982	3046	216	741	450	209	198	1019	764

9 Conclusions

An environmental condition associated with approval for the construction of the Harris Dam was that the salinity of Wellington Reservoir should be reduced to potable levels. The State's Salinity Strategy set a target date of 2015. To achieve the aims in the Collie Catchment with full involvement of stakeholders, Water and Rivers Commission has established the Collie Recovery Team.

As well as the Commission, the Collie Recovery Team has representatives of landholders from the main salt-affected areas of the Collie catchment; from the Shires of Collie and West Arthur; and from Agriculture WA, CALM, Western Power and the Water Corporation. The Team has divided the catchment upstream of Wellington Reservoir, referred to as the Collie Recovery Catchment, into 8 Management Units based on the boundaries of subcatchments. The Team wants more than to simply meet the inflow water quality target: it has a vision of the Collie Recovery Catchment with a healthy and productive environment; delivering adequate potable water to Wellington Dam, while sustaining a stable and prosperous community.

This review of the salinity situation in the Collie Recovery Catchment concludes that:

- Since 1990 there has been no trend of increasing salinity of inflow to Wellington Dam. This is thought to be due in part to the rises in groundwater following clearing being substantially complete, and in part to the effects of plantations established by then.
- Further reduction in salinity is expected once all existing and planned plantations have been fully established. This will not, though, be sufficient to meet the inflow salinity targets.
- There are other technically feasible management options with potential to reduce the inflow salinity to its target, including engineering options and/or further tree planting.
- Full effects of treatments can be expected to be realized within 10 years of commencement. Hence all required treatments should be in place by 2005 to meet the 2015 target.
- Continuing protection of remnant native vegetation is important to maintain its water-use functions, loss of which negates efforts to reduce salinity by other means.

Geographic data relevant to land management decisions has been prepared in a digital format. To give an overview of the data, the report presents small scale maps, and tabulates different categories of areas within Management Units areas; this is adequate for general information, but for more intensive studies more detail can be made available from the digital data. Topics covered are: cadastre and roads; rivers, gauging stations and isohyets; geology and airborne magnetic data; soil-landscape systems and airborne radiometric data; elevation as digital elevation models and contours; natural vegetation complexes, Landsat scene showing current vegetation cover, and mapping of the status of trees over the catchment.

The clearing history is shown as a map with associated area tabulations. 677 km^2 of the total catchment area of 2823 km^2 had been cleared by 1977, when Clearing Control legislation was introduced, including areas cleared by CALM to plant pines near Wellington Reservoir. 184 km^2 of the 677 km^2 had been replanted to plantations by 2000, with about 37 km^2 more identified as future planting areas.

The records of stream flow and stream salinity are summarised for the mainstream gauging stations at Mungalup Tower, Collie River South, Bingham River, Collie River East, James Crossing and James Well, and also the estimated total inflows to Wellington Reservoir. The trend analysis shows that since 1990 the Wellington inflows, Mungalup Tower and Collie River East may have reached a maximum salinity of 870, 1130, and 1990 mg/L respectively at mean annual flow. Collie River South, James Crossing and James Well had reached 920, 5900 and 2400 mg/L respectively by 1993, and prior to that showed increasing trends of 9, 157 and 34 mg/L/yr respectively. The salinity of Bingham River continues to be less than 300 mg/L.

The trends in groundwater level were reviewed in three land use types: cleared land, reforested land and native forest. In cleared and reforested areas, three stages could be recognised: 'pretreatment' (before the clearing or before reforestation); a transition stage; and a final, steady, stage. The transition stage starts 2 or 3 years after the date of clearing or tree planting. In the Lemon catchment, cleared from the watershed to the streamline, the transition stage lasted 10 years. As there has been only minor clearing over the last 25 years, it is concluded that groundwater levels have substantially reached their maximum throughout the catchment. At reforestation sites the transition was 5 years. Thus the full impact on groundwater levels in areas successfully planted with trees can be expected within 10 years.

The relationships between water in the landscape, geological formations, vegetation and salinity have been explained with reference to experimental sites in the Collie catchment. The effects on salinity of diverting stream flow, pumping groundwater, or constructing drains have also been examined. As land managers better understand groundwater flow processes associated with dryland salinity, the success rate of treatments should improve. It is important to recognise that there are two distinct objectives: to reduce the salinity of inflow to Wellington Dam, and to improve productivity on land currently salt-affected; and that any one treatment, such as planting trees, may further one more than the other.

The gross quantities of stream flow and salt load coming from the Management Units give an indication of the salt load reduction required to meet the inflow salinity target: 500 mg/L flow-weighted average for the year, in a year of average flow. The salt load input to Wellington Dam needs to be reduced by about 50%, with some variation depending on where in the catchment reductions are made, and allowing for the expected stream flow reduction caused by treatments.

A range of feasible management options has been assessed. Most of the catchment was computer modelled, and this used to estimate the effects of planting trees, use of lucerne and shallow drainage. Modelling requires some assumptions and generalised data where detailed information is lacking. While results are the best available at present, estimates should be revised with future improvements in information and modelling.

The options considered were: tree plantations on land already committed for such use; alley farming using commercial trees on other suitable land; other suitable tree-species on land not suitable for commercial trees or plantations; lucerne on suitable land; shallow drainage on pasture land; groundwater pumping; and partial or total diversion of stream flow from upstream tributaries.

A summary table was made of the results for each option being applied to its feasible maximum throughout the catchment. As well as affecting inflow salinity, each option had an effect on the volume of stream flow and the areas in the catchment affected by shallow water table and seepage of deep groundwater.

While no single option could achieve the target, Table 9.1 shows that the target could be met, or substantially met, by adding separately any of a variety of options, assuming the committed tree plantations are in place.

Reduced alley density of upland commercial trees, or planting only part of the suitable land, would give proportionately less salinity reduction; the reduction would also be less if not all land suitable for lowland trees was planted, or if groundwater pumping was installed in only some areas. Shallow drainage by itself gave very marginal benefits (approx 1%) for the inflow salinity target.

Even so, these results indicate that a combination of treatments to meet the target salinity can be found.

Table 9.1 Summary of effects of management options

Case	Predicted Mean Inflow Salinity (mg/L)	Predicted Mean Inflow volume (GL/yr)	Estimated shallow water-table area (includes seepage area) (km^2)
State of catchment in 1995	885	145	127
Current and planned plantations	758	134	104
Option added to all plantations			**Further reduction in shallow water-table area**
Diversion of Collie East Branch	597	126	9%
Groundwater pumping	522	130	No estimate, but a substantial reduction expected
Lowland trees on all land not suitable for Upland Commercial trees	524	114	44%
Commercial trees on all suitable land	577	106	37%

10 Recommendations

Management options

- The economic and social costs and benefits of the various management options need to be associated with their physical impacts on stream flow, salinity and salt-affected land.

- The long-term sustainability of commercial tree plantations needs to be determined. Issues to be addressed include the incentives for private owners to embark on a new rotation after harvesting, maintenance of soil fertility, and the possibility of salt accumulation in the root zone if trees are planted where deep groundwater is discharging.

- The practicality of groundwater pumping needs to be tested in field trials whose design is based on computer modelling. The design phase should include estimation of the reduction in salt-affected area to be expected as a result of pumping. The trial should provide information to estimate the effectiveness of groundwater pumping in reducing salt load discharged to rivers, and to estimate the costs of larger scale implementation.

Monitoring and evaluation

- This report should be updated with more recent data at 5 year intervals until the achievement of the salinity target for inflows to Wellington Dam.

- Monitoring of stream flow and salinity should continue at mainstream gauging stations to test whether the peak salinities have passed and when future treatments have a discernible effect on salt loads and stream flow.

- A study should be undertaken to determine appropriate annual cycles of Leaf Area Index (LAI) for lucerne under practical grazing regimes and water availability, to better model the salinity benefits of using lucerne as a management option.

References

Arumugasamy, V., & Mauger, G.W., 1994, *Trees on Farms to Reduce Salinity in the Clearing Control Catchments Volume 2: Wellington Catchment*, Water Authority of Western Australia, Leederville, Perth Report No. WS148.

Bari, M.A. and Mauger, G, 2001a, *Computer modelling of dryland salinity hydrology after clearing native forest in the Lemon catchment*. Water and Rivers Commission, Rep. No. LUI5.

Bari, M.A. and Mauger, G, 2001b, *Predicting the impacts of valley reforestation on streamflow and salinity by a fully distributed catchment model*. Water and Rivers Commission, Rep. No. LUI6.

Bari, M.A and Croton, J.T., 2000, *Predicting the impacts of land use changes on streamflow and salinity by a fully distributed catchment model*. In: Hydro2000, Third International Hydrology and Water resources Symposium, The Institute of Engineers, Australia.

Bari, M.A., 1998, *Reforestation reduces groundwater level and stream salt load*. In: Marcar, N.E. and Hossain, A.K.M.A. (Eds), Managing Saltland into the 21st Century: Doallrs and Sense from Salt, Proceedings of the Productive Use of Saline Land 5th National Conference, Tamworth, Australia, 38-46 pp.

Bari, M.A. and Boyd, D.W. 1994, *A review of reforestation experiments to control land and stream salinity in Western Australia*. Water Authority of WA, Rep. No. WS 141. 35pp.

Bari, M.A. and Boyd, D.W. 1993, *Streamflow and salinity response to logging and regeneration in the southern forest of Western Australia*. Water Authority of WA, Rep. No. WS 116. 91pp.

Bari, M.A., 1992a, *Streamflow and salinity response to non-valley reforestation at Padbury Road catchment in the south-west of Western Australia*. Water Authority of W.A., Rep. No. WS 114. 61pp.

Bari, M.A. 1992b, *Early streamflow and salinity response to Partial Reforestation at Batalling Creek Catchment in the south-west of Western Australia*. Water Authority of WA., Rep. No. WS 107. 82pp.

Bari, M.A. and Boyd, D.W. 1992, *Water and salt balance of a Partially Reforestated Catchment in the south-west of Western Australia*. Water Authority of WA., Rep. No. WS 98. 136pp.

Bettenay, E., Russell, W.G.R., Hudson, D.R., Gilkes, R.J. and Edmiston, R.J., 1980, *A description of experimental catchment in the Collie area, Western Australia*. CSIRO Aust. Div. Land Resour. Manage., Tech. Pap. No. 7.

Collie Recovery Team, 2000, *Salinity Management in the Collie River Catchment – Strategic Action Plan*, Water and Rivers Commission, Unpublished report.

Croton, J.T. and Bari, M.A., 2001, *Using WEC-C, a fully distributed, deterministic catchment model to simulate hydrologic responses to agricultural clearing.* Environmental Modelling and Software (in press).

Croton, J.T. and Barry, D.A., 2001, *WEC-C: A fully distributed, deterministic catchment model-foundation, formation, testing and application.* Environmental Modelling and Software (in press).

Croton, J.T. and Norton, S.M.G. 1998, *Rainfall interception in the Northern jarrah forest of Western Australia. Water and Rivers Commission*, Water Resources Tech. Series No. WRT17, 28pp.

Davies, J.R., and Rogers, A.D.A., 2000, *Collie River Catchment Revision of M.A.G.I.C.*, Report No J2528d.doc, JDA Consultant Hydrologists, Subiaco, Perth.

Dixon, R.N.M. 1966, *Trees on farms to reduce salinity in the Clearing Control Catchments Volume 4: Helena catchment.* Water and Rivers Commission., Rep. No. WRT8. 84pp.

Dixon, R.N.M., Mauger, G. and Rogers, A. 1996. *Trees on farms to reduce salinity in the Clearing Control Catchments Volume 3: Kent catchment*. Water and Rivers Commission, Rep. No. WRT20. 80pp.

Dogramaci, S., Mauger, G.W., George, R., 2001, *Engineering options as tools for salinity management in the Spencer Gully catchment*, Water and Rivers Commission, Internal Rep. No. LUI7. 35pp.

Environmental Protection Authority (EPA), 1987, *Harris River Dam Project: Water Authority of Western Australia, Report and Recommendations of the Environmental Protection Authority*, EPA Bulletin 272.

Ferdowsian, R., Pannell, D. J., McCarron, C., Ryder A. and Crossing, L., 2000, *Explaining groundwater hydrographs: separating atypical rainfall events from time trends.* SEA Working Paper 00/12.

Hayes, R.J. and Garnaut, G. 1981, *Annual rainfall characteristics of the Darling Plateau and the Swan Coastal Plain.* Water Resources Branch, Public Works Department of W.A. Report No. WRB 3.

Hingston, F.J. and Gailitis, V., 1976, *The Geographic Variation of Salt Precipitated over Western Australia.* Australian J. of Soil Res., 14: 319-335.

Johnston, C.D., 1987a. *Preferred Water flow and localised recharge in a variable regolith*. J. Hydrol., 94, 67-88.

Johnston, C.D., 1987b, *Distribution of environmental chloride in relation to sub-surface hydrology.* J. Hydrol., 94, 67-88.

Johnston, C.D., McArthur, W.M. and Peck, A.J., 1987, *Distribution of Soluble Salts in Soils of the Manjimup Woodchip Licence Area, Western Australia.* CSIRO Land Resources Management Technical Paper No. 5, 1980., 29pp.

Loh, I.C., 1985, *Projected Inflow Salinities from Wellington Reservoir, Western Australia, Western Australia.* Water Authority of W.A., Rep. No. WH 4. 17pp.

Loh, I.C., 1988, *Observed changes in the inflow salinity to Wellington Reservoir, Western Australia.* Water Authority of W.A., Rep. No. WS 34. 22pp.

Loh, I.C., 1989, *The History of Catchment and Reservoir Management on Wellington Reservoir Catchment W.A.,* in Laut, P. and Taplin B.J., *Catchment Management in Australia in the 1980s,* Divisional Report 89/3, CSIRO Division of Water Resources, Canberra, July 1989.

Luke, G.J., Burke, K.L. and O'Brien, T.M. 1988, *Evaporation data for Western Australia.* W. Aust. Dept. of Agric., Div. of Resourc. Manag., Tech. Rep. No. 65. 29pp.

MacDonald, M.G., and Harbaugh, A.W., 1988, *A modular three-dimensional finite difference groundwater flow model*, United States Geological Survey Open File Report 83-875.

Mattiske, E. M., and Havel, J. J., 1998, *Vegetation mapping in the South West of Western Australia*, Department of Conservation and Land Management.

Mauger, G.W. 1994, *Trees on farms to reduce salinity in the Clearing Control Catchments Volume 2: Wellington catchment.* Water Authority of W.A., Rep. No. Wsa48, 40pp.

Mauger, G. 1996, *Modelling dryland salinity with M.A.G.I.C. system. Water and Rivers Commission*, Rep. No. WRT7. 17pp.

Moulds, B. D. and Bari, M. A. 1995, *Wellington Reservoir Catchment Streamflow and Salinity Review.* Water Authority of W.A., Rep. No. WS 151. 78pp.

Peck, A.J. and Williamson, D.R. (Eds) 1987a, *Hydrology and salinity in the Collie River Basin, Western Australia.* J. Hydrol. (Spec. Issue), 94:1-198.

Peck, A.J. and Williamson, D.R. 1987b, *Effects of forest clearing on groundwater.* J. Hydrol. (Spec. Issue), 94:47-66.

Robinson, J., Davies, J., Van Hall, S. and Bari, M.A. 1997, *The impact of forest thinning on the hydrology of three small catchments in the south-west of Western Australia*. Water and Rivers Commission, Water Resources Tech. Series No. WRT16, 40pp.

Ruprecht, J.K. and Schofield, N.J. 1991a, *The effect of partial deforestation on hydrology and salinity in high salt storage landscapes. I. Extensive block clearing.* J. Hydrol. 129 19-38.

Ruprecht, J.K. and Schofield, N.J. 1991b, *The effect of partial deforestation on hydrology and salinity in high salt storage landscapes. II. Strip, soils and parkland clearing.* J. Hydrol. 129 39-55.

Ruprecht, J.K. and Stoneman, G.L., 1993, *Water yield issues in the jarrah forest of south Western Australia*, J. Hydrol. 150 369-391.

Ruprecht, J.K. and Bari, M.A. 1999, *Impact of forest management on water quality in south-west Western Australia.* In: Barber, C., Humphries, B. and Dixon, J. (Editors), Proceedings of the International Conference on Diffuse Pollution, International Association on Water Quality, Perth, Western Australia, 506-515pp.

Rutherford, J.L., 2000, *Hydrogeology of the Collie 1:250 000 sheet: Western Australia.* Water and Rivers Commission, Hydrogeological Map Series Explanatory Notes, Report. No HM7, 36pp.

Schofield, N. J., Ruprecht, J. K. 1989, *Regional analysis of stream salinisation in southwest Western Australia.* J. Hydrol., 112 19-39.

Schofield, N.J., Loh, I.C., Scott, P.R., Bartle, J.R., Ritson, P., Bell, R.W., Borg, H., Anson, B. and Moore, R., 1989, *Vegetation strategies to reduce stream salinities of water resource catchments in south-west Western Australia.* Water Authority of Western Australia. Rep. No WS 33.82 pp.

Sharma, M.L., Barron, R.J.W. and Williamson, D.R., 1987a, *Soil water dynamics of lateritic catchments as affected by forest clearing for pasture*. In Peck A.J., Williamson, D.R., (Editors), Hydrology and Salinity in the Collie River Basin, Western Australia. J. Hydrol., 94: 29-46.

Sharma, M.L., Barron, R.J.W. and Fernie, M.S., 1987b, *Areal distribution of infiltration parameters and some soil physical properties in lateritic catchments.* In Peck, A.J., Williamson, D.R., (Editors), Hydrology and Salinity in the Collie River Basin, Western Australia. J. Hydrol., 94: 109-127.

Sivapalan, M., Viney, N.R. and Jeevaraj, C.G., 1996, *Water and salt balance modelling to predict the effects of land-use changes in forested catchments. 3. The large catchment model*, Hydrol. Proc., 10: 429-446.

State Salinity Council, 2000, *Natural resource management in Western Australia – the salinity strategy.* Government of Western Australia, 72pp.

Steering Committee, 1987, *The impact of logging on the water resources of the southern forests, Western Australia.* Water Authority of Western Australia. Rep. No WH41, 833pp.

Stokes, R.A., Stone, R. and Loh, I.C 1980, *Summary of Soil Salt Storage Characteristics in the Northern Darling Range.* Water Resources Section, Public Works Department of W.A. Report No. 4.

Strawbridge, M., 1999, *The extent, condition and management of remnant vegetation in Water Resource Recovery catchments in south Western Australia,* Water and Rivers Commission, Rep. No. WRT15, 46pp.

Tille, P.J., 1996, *Wellington-Blackwood land resources survey*, Series No 14, Agriculture Western Australia.

Ward, D., 1977, *Tree removal and salinity in Helena Catchment, Western Australia*, Research Paper 29, Forests Department of Western Australia, Dwellingup.

Water Authority of Western Australia, 1989, *Stream salinity and its reclamation in South-West Western Australia*, Water Authority of Western Australia, Report No WS 52, 23pp, November 1989.

Williamson, D.R., Stokes, R.A. and Ruprecht, J.K., 1987, *Response of input and output of water and chloride to clearing for Agriculture*, J. Hydrol., 94, 1-28.

Wood, W.E. 1924, *Increase of salt in soil and streams following the destruction of native vegetation.* J. R. Soc. W. A., 10 35-47.

Glossary

mAHD Australian Height Datum. Height in metres above Mean Sea Level +0.026m at Fremantle.

Hectare (ha) 10 000 square metres or 2.47 acres. 100 ha=1 square kilometer

Aquifer A geological formation or group of formations able to receive, store and transmit significant quantities of water.

Kilolitre (kL) 1000 litres, 1 cubic metre or 220 gallons.

Evaporation The vaporisation of water from a free-water surface above or below ground level, normally measured in millimetres.

LAI Leaf Area Index, which is the total (one-sided) area of leaves on plants divided by the area of land occupied by the plants.

Evapo-transpiration A collective term for evaporation and transpiration.

Lowland trees Trees suitable for growing in lower slope and valley floor locations that may be subject to shallow water table or deep groundwater saline seepage.

Gigalitre (GL) 1,000,000,000 litres, 1 million cubic metres or 220 million gallons.

Piezometer A tube that is inserted in a small diameter bore drilled into an aquifer to monitor water pressure within the aquifer.

Greenness The percentage of a pixel in a Landsat image that is sunlit green leaves.

Recharge The downwards movement of water that is added to the groundwater system.

Groundwater Level An imaginary surface representing the total head of groundwater and defined by the level to which water will rise in a piezometer.

Upland commercial trees Commercial trees such as Bluegums (*Eucalyptus Globulus*) that require deep, well-drained, fertile soils normally found in upper landscape positions.

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