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SALINITY

a situation statement for Western Australia

a report to the

MINISTER FOR PRIMARY INDUSTRY

MINISTER FOR THE ENVIRONMENT

prepared by the Chief Executive Officers of

AGRICULTURE WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

WATER AND RIVERS COMMISSION

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Erosion and dying trees along a farm stream degraded by salinity.

A tree graveyard around what was once a freshwater lake.

1 Introduction

1.1 The issues

Salinisation of land and water in south-western Australia is one of the most critical environmental problems facing Western Australians.

Western Australia has over 70 per cent of Australia's reported dryland salinity (Table 1.1). An estimated 1.8 million hectares of farmland are already salt-affected to some extent and this area could double in the next 15 to 25 years and then double again before reaching an equilibrium.

As a result of the current levels of dryland salinity, more than a third (36 per cent) of the State's divertible water resources is brackish or saline and a further 16 per cent is of marginal quality. Salinity also poses a major threat to natural diversity (biological and physical), rural towns, capital infrastructure, tourism and recreation areas, and our ability to support new export industries.

1.2 Aims of this Statement

Over the past decade, there has been a range of Government and community actions to combat salinity (Appendix 8.1). There have also been several Government inquiries focussed on the salinity problem (Select Committee on Salinity, Anon 1988; Select Committee into Land Conservation, Anon 1991; Soil and Land Conservation Council and Water Resources Council, Anon 1995). This Statement updates and adds to information in these reports. The previous reports should be consulted for additional information.

This Statement provides the background material upon which the Western Australian Salinity Action Plan for Government and community action is built by:

- describing the causes, effects and implications of salinity;
- outlining options and practices for controlling and adapting to salinity.

To achieve these aims, this Statement addresses salinity caused by dryland agriculture[1]. The Statement covers all public and private land affected by, or at risk from dryland salinity in the south-west of Western Australia. After describing the causes of salinity, the Statement analyses the effects of salinity on water resources (streams, rivers and groundwaters), natural diversity (physical and biological), agricultural lands, infrastructure (roads, pipelines), rural communities (towns, homesteads), and recreation and tourism.

The Statement does not address irrigation salinity. There is a need to manage salt problems in the south-west and Ord irrigation districts. A separate review is recommended to address the current and developing problems in these areas.

Furthermore, while waterlogging, flooding, water and wind erosion, soil structure decline and eutrophication are all exacerbated by salinity, they are not specifically addressed in this Statement. The Statement does account for some of the off-site effects of salinity, but does not discuss in detail problems such as increased flood risk, sediment and nutrient movement and near-shore and off-shore changes in estuarine and marine ecosystems.

Table 1.1 Area of land reported to be affected by dryland salinity in Australia*

State	Area salt-affected in 1982 (ha)	Area salt-affected in 1996 (ha)	Potential area at equilibrium
Western Australia	264,000	1,804,000	6,109,000
South Australia	55,000	402,000	600,000
Victoria	90,000	120,000	unknown
New South Wales	unknown**	120,000	5,000,000
Tasmania	unknown**	20,000	unknown
Queensland	unknown**	10,000***	74,000
Northern Territory	unknown**	minor	unknown
Total	**na**	**2,476,000**	**>11,783,000**

* *initial estimates from Robertson (1996) and revised with assistance of National Dryland Salinity Program State representatives*

** *salinity was likely to be present but its extent had not been assessed*

*** *only severe salinity*

1 Dryland salinity is salinity which has developed following the widespread adoption of annual crops and pastures. not included are large areas of primary salinity (eg salt lakes) in the wheatbelt which pre-date settlement and agricultural use.

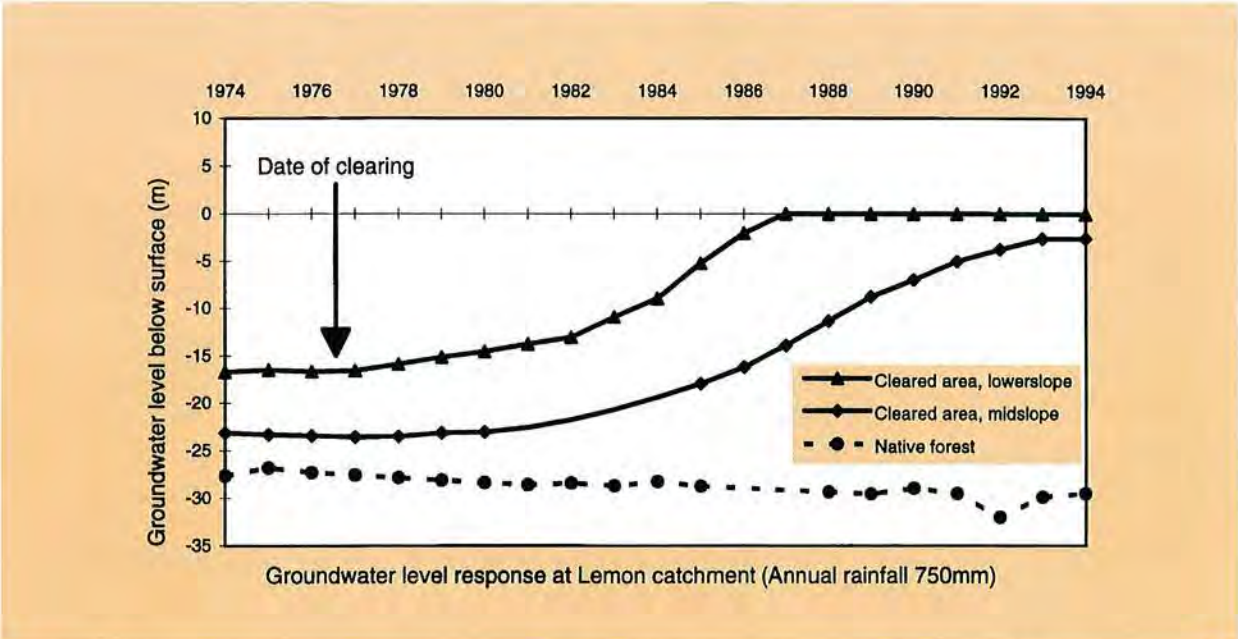


Figure 2.1: Hydrographs showing rising groundwater levels in the lower slope and mid-slope of cleared land in the Lemon catchment. The catchment was cleared in 1976. Note that water levels have fallen in forested areas in response to the low rainfalls during the period of monitoring.

2 The cause and extent of salinity

2.1 The cause of salinity

The fundamental cause of salinity is the replacement of perennial, deep-rooted native vegetation with the annual crops and pastures used in agriculture. Annual crops and pastures do not use as much of the incoming rainfall as did the native vegetation. This unused water either runs-off or infiltrates beyond the root zone and accumulates as groundwater.

Currently the annual amount of water entering groundwater systems (recharge) beneath the State's agricultural lands is estimated to be more than five billion kilolitres, or about the same volume as all the streamflows in the region. Hence groundwater systems are filling, the watertable is rising and areas of groundwater discharge and soil salinity are expanding.

As groundwaters rise, salts that have accumulated over thousands of years in the subsoil are mobilised. When groundwater comes close to the surface salt enters the plant root zone and plant vigour declines. This eventually leads to the death of species that are not salt-tolerant. Saline groundwaters also discharge at the soil surface and are concentrated by evaporation, damaging soils on-site and down slope and eventually draining into streams, rivers and lakes, degrading wetland habitat and water resources.

The salt responsible for salinity in Western Australia originated in the ocean. Salt, mainly sodium chloride, has been carried inland by the prevailing winds and deposited on the land in small amounts (20-200 kg/ha/year) in rainfall and dust (Hingston and Gailitis, 1976). Over tens of thousands of years the salt accumulated in subsoils. The amount of stored salt is least in the high rainfall areas (generally moderate relief and well drained), and highest in low rainfall areas (generally flat and poorly drained). Measurements indicate that there are between 100 and 10,000 tonnes of salt stored beneath each hectare of the State's south-west, depending on location and soil type.

Of the 25 million hectares of land in south-western Australia previously covered by native perennial vegetation almost 18 million hectares have been cleared (Table 2.1). Only 2.7 million hectares of the original vegetation remain on private land in some 350,000 small, scattered remnants (Beeston *et al.* 1994).

Table 2.1 Land use and vegetation cover in the south-west of Western Australia (Beeston *et al.* 1994)

Land use	Area (millions of ha)	% of area within the agricultural region
Agricultural region	25.3	100
Area of private land	20.8	82
Cleared land	18.0	71
Private remnant vegetation	2.8	11
Public land	4.5	18

W.E. Wood proposed clearing and agricultural land use as an explanation of the cause of Western Australia's salt problem over 70 years ago (Wood, 1924). Subsequent scientific investigations, especially over the past two decades, have confirmed and elaborated Wood's explanation. The most comprehensive investigations were conducted in the Collie River catchment as part of the program to maintain water quality in the Wellington Reservoir. Several long term catchment experiments are still being conducted in this area.

Groundwater levels in one of the experimental catchments, deliberately cleared to study the processes leading to salinity, rose dramatically after clearing (Figure 2.1). Watertables rose by as much as 20 metres in less than 20 years and reached the ground surface within 11 years of clearing. In contrast, watertable levels fell in nearby native forest due to low annual rainfall. An early study predicted that at equilibrium some ten per cent of the cleared land in this sub-catchment will become salt-affected, but recent data show that this is an underestimate.

Salinisation is a long-term process. If unmanaged, it will eventually reach a new equilibrium as recharge to groundwater systems is balanced by discharge from them. When equilibrium is reached, groundwater will stop rising and the spread of soil salinity will cease. The time required for groundwater systems to reach a new equilibrium may range from as little as ten years in the high rainfall areas to more than 200 years in the drier eastern and northern regions. However, the new equilibrium will not be benign. Salinity may affect more than 30 per cent of the land. Surface and near surface saturation will greatly enhance runoff, thus escalating erosion and flood risk, and whole valley systems will be degraded. These potential impacts are too serious to ignore.

Factors affecting the time to establish a new equilibrium include rainfall, geology, land use and time since clearing. These factors are reflected in measured rates of recharge, watertable rise and salt storage. A salinity hazard rating may be drawn by integrating these measurements. Figure 2.2 is a schematic diagram showing salinity hazard zones and variation in major factors along a transect from the coast to the edge of the agricultural region.

2.2 Critical limits of land and stream salinity

Soil salinity becomes an agricultural and ecological problem when the concentration of salts within the soil and water bodies exceed the tolerance limits of native or introduced plants. Each species has a different tolerance to salinity. Salt-affected soils may still be productive, albeit at lower yields, using salt-tolerant crops and pastures.

In agriculture, salinity is considered severe when the yield of the preferred crop or pasture is reduced by more than 50 per cent and moderate when the yields are reduced by between ten and 50 per cent. For water resources, salinity is severe if the water can no longer be diverted for beneficial use and moderate when it imposes additional costs (eg mixing of water sources, damage of infrastructure). For natural environments, salinity is significant if it modifies terrestrial or aquatic ecosystems. In its most severe form, natural plant and animal communities are either destroyed or replaced by salt-tolerant species.

The severity of salinity can be assessed using soil and water samples, visual and plant indicators, geophysical equipment and groundwater observation wells. Water considered desirable for drinking should have a total soluble salt (TSS) content of less than 500 mg/L, although the maximum permissible limit is 1500 mg/L. Salt-sensitive plants die and salt-tolerant plants become dominant when the conductivity of the root zone exceeds 100 mS/m (ECa) and the watertable is within one to two metres of the surface for most of the year. Soil is usually considered saline when the electrical conductivity of a field sample exceeds 400 mS/m (ECa) or the terrain conductivity measured in the field with geophysical instruments exceeds 50-70 mS/m (ECa).

Soils are continually gaining and losing salts as watertables rise and deliver them to the root zone, while rainfall and runoff flush them into groundwater or streams. Soils may be more saline in drier seasons (spring to autumn) and freshen after the opening rains and during winter. In addition, soils may become more saline following years of above average rains when watertables are forced close to the surface during the drier months, despite additional winter flushing. Rapid growth in the area and severity of saline lands observed after wet years are evidence of this. Similarly, farmers may report that their saline areas have decreased in extent or severity after prolonged dry seasons.

2.3 Current extent and trends

2.3.1 Agricultural land

Between 1955 and 1993 farmers estimated the extent of secondary salinity within agricultural areas in response to questions in the Australian Bureau of Statistics Agricultural Census. Over this 38-year period farmers reported that salinity increased by about 700 per cent. While this method grossly underestimated the size of the salt problem, it recognised that salinity was increasing.

Recently, Agriculture Western Australia reviewed estimates of the extent of salinity using air photo interpretation, soil and landform mapping, farm and catchment plans, satellite remote sensing, ground-based geophysics and extensive bore records to derive a best estimate of the area affected by salinity and the area at risk (Table 2.3) in the hydrologic regions shown in Figure 2.3.

Rates of spread are currently highest in the medium rainfall areas, in the central south-west and along the south coast (where extensive clearing has only recently ceased) and slower in the eastern Swan-Avon and northern regions where the rates of watertable rise are lower. The latter regions will continue to become saline as watertables rise under broad valleys.

The extent of salinity has also been mapped by CSIRO (Leeuwin Centre) in five sample areas (Figure 2.3) using satellite data obtained over several years, and other landform attributes, particularly elevation data (Table 2.4).

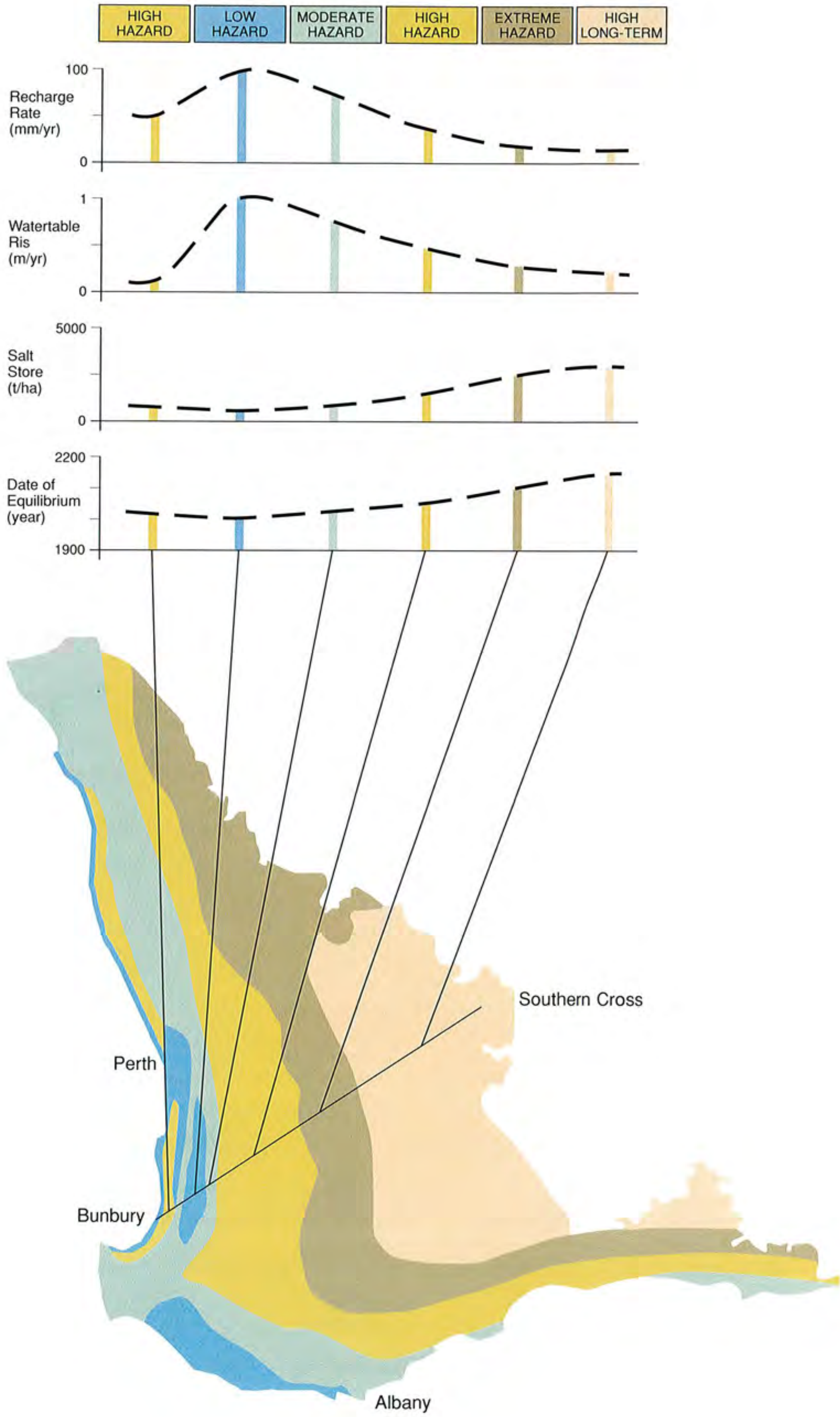


Figure 2.2: Salinity hazard zones in south-western Australia. Factors affecting salinity hazard are shown along a transect from the coast to the eastern edge of the wheatbelt. These factors change depending on land-use, geology and time since clearing, as measured by rate of water table rise, recharge rate and salt storage. It can be seen that salinity hazard ranges from high near the coast, to low in the high rainfall south-west, and from high to extreme throughout the lower rainfall regions.

Table 2.3 Estimated areas affected by secondary salinity to some extent in 1994, 2010 - 2020 (depending on rainfall) and potential at equilibrium (after Ferdowsian et al. 1996)

Hydrologic	Area cleared ha *	1994 area ha	affected %	2010/20 area ha	affected %	potential ha	area %
South coast	4,078,960	395,400	9.7	687,580	16.8	977,180	24.0
South-west	3,310,000	273,800	8.3	595,500	18.0	820,000	24.8
Swan-Avon	7,590,500	759,000	10.0	1,290,400	17.0	3,036,200	40.0
Northern	4,251,900	376,250	8.8	722,800	17.0	1,275,600	30.0
Total	19,231,360	1,804,450	9.4	3,296,280	17.1	6,108,980	31.8

* *includes some uncleared but alienated land which is also subject to salinity in highly cleared catchments*

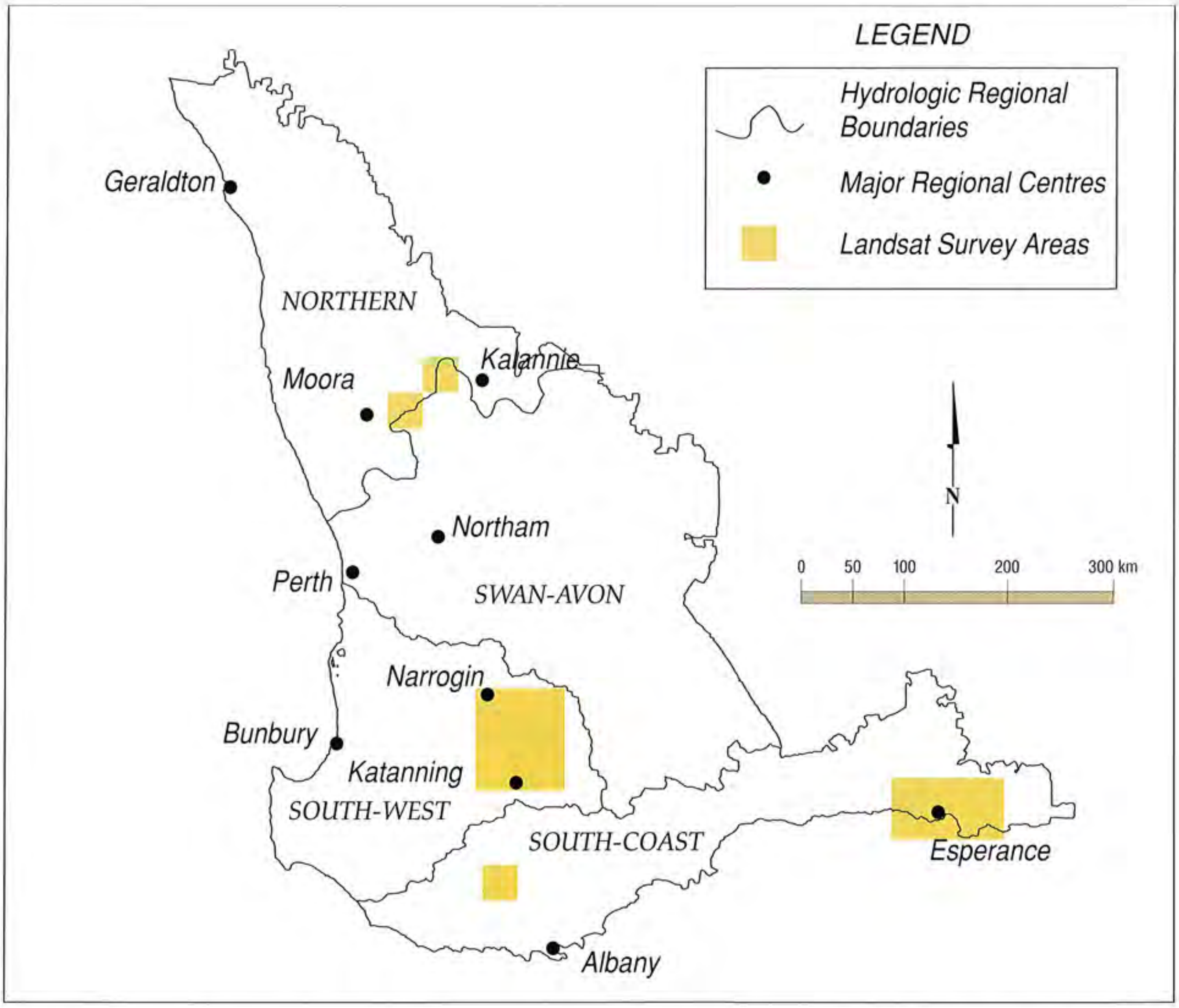


Figure 2.3: Hydrological regions used to determine the extent and predicted trends in salinity. LANDSAT survey areas, referred to in Table 2.3 are also depicted. The Upper Blackwood survey was conducted between Narrogin and Katanning, while the Upper Kent Survey took place north-west of Albany.

Table 2.4 Results of LANDSAT TM surveys showing increases in saline land between 1988 and 1994

Region/ catchment	Area surveyed (km²)	Change (%)	Increase (%)
Moora	2025	7.2 to 11.7	63
Kalannie	2025	14.2 to 22.0	55
Esperance	1580	9.2 to 14.1	53
Upper Kent	1063	6.1 to 15.3	250
Upper Blackwood	13,500	8.4 plus 4.0*	na**

* *susceptible native vegetation*

** *no change detection data at present*

From Tables 2.3 and 2.4, the best estimate of salinity is that without significant changes in land use and management, the area of salt-affected land is likely to double within the next 15 to 25 years and then double again before a new equilibrium is reached. Over 30 per cent of cleared land, and a large proportion of remnant vegetation on both private and public land, is predicted to become moderately to severely salt-affected in the long-term unless we change land management practices.

These predictions must be continually revised as new and better information becomes available.

Watertable trends

Over 2000 bores have been established throughout the agricultural area by Agriculture WA. Together with bores drilled by other State Government agencies and farmers, they are being monitored to assess trends in groundwater levels and to determine the effect of various treatments. Results from intensely monitored Agriculture WA data indicate that groundwater levels in areas away from discharge areas are rising by between:

- 0.02 and 0.30 m/year in the < 350 mm/year rainfall zone;
- 0.05 and 0.50 m/year in the 350 to 500 mm/year rainfall zone; and
- 0.15 and 1.5 m/year in the > 500 mm/year rainfall zone.

Only groundwater levels within treated areas, near discharge areas or in very high rainfall catchments appear to be nearing equilibrium or showing a falling trend. Reductions in watertables have occurred at rates between 0.1 and 0.8 metres per year beneath bluegum and pine plantations, some shelterbelts and agriforests, tagasaste plantations and some perennial pastures (lucerne). Variable reductions in water levels have also been observed very close to drains and aquifer pumping sites.

Typical groundwater hydrographs from throughout south-western Australia have been compiled (Catchment Hydrology Group, Agriculture WA, in press).

Predictive models

Estimates of the future extent of land and stream salinity and the effects of management have been made using mathematical models. This approach can be relatively inexpensive and is a quick way of assessing the likely effectiveness of management systems without the need for field trials of every new treatment. For example, modelling of the effectiveness of vegetation treatments was undertaken in the Yornaning catchment, near Narrogin. The model predicted that, without treatment, salinity would eventually affect 35 to 45 per cent of the catchment under current land uses. However, if revegetation systems were established (eg 100 trees were evenly planted on each hectare) salinity would, in time, largely disappear from the catchment (P. Raper, *pers. comm.*). While this treatment would not be routinely adopted, it indicates the magnitude of change required to achieve watertable control.

2.3.2 Water resources: streams and rural water supplies

Stream salinity

Streamflows and salinity are recorded at gauging stations on 21 major rivers, 78 tributaries and minor rivers, nine coastal rivers and 23 research catchments throughout the south-west (Schofield *et al.* 1988). Most streams from salt-affected catchments are gauged as they descend to the west and south coasts. Table 2.5 shows that the salinity in seven of the major rivers is increasing by between 13 and 93 mg/L per year. Increases are lowest in rivers with catchments which are more than 60 per cent forested (Collie, Warren, Kent and Denmark) and highest in catchments which are less than 40 per cent forested. Salt export into streams from cleared land in the 500 to 700 mm per year rainfall zone is particularly high.

Table 2.5 Stream salinity in major rivers in the south-west of Western Australia

River	Catchment area km²	Annual flow mean m³ x 106	Cleared as at 1996 %	Salinity mg/L TSS	Salinity increase mg/L/yr
Denmark	525	31	17	560	26
Collie	2830	185	24	790	24
Warren	4022	290	36	855	13
Kent	1852	84	40	1195	58
Helena	1470	50	3	360	na
Hay	1211	72	70	1800	na
Murray	6840	297	75	2260	93
Frankland	5800	179	56	2750	74
Blackwood	20500	659	85	1760	58
Swan-Avon	119000	335	75	6300	na

* *trends not available or statistically significant*

The rate of salinity increase on the Collie, Warren, Kent and Denmark Rivers has been contained by the introduction of clearing control legislation in the 1970s. These rivers were recognised as the most important long term water resources in the south-west. Most of the effect of clearing prior to the late 1970s is believed to be reflected in current stream salinity levels, although some further gradual deterioration is likely as groundwater levels continue to rise and slowly reach a new equilibrium.

The rate of salinity increase on the larger, brackish and saline rivers of the Murray, Frankland, Blackwood and Swan-Avon will continue to rise well into the next century. This is primarily a consequence of the slower responses to groundwater systems in these lower rainfall areas, and partly due to their more recent clearing histories.

Rural water supplies

Town Supplies

Most country towns are provided with water by the Water Corporation of WA from either protected supplies from vegetated catchments, sealed catchments or local groundwaters. Salinity is an issue where clearing has occurred in town catchments (eg Ravensthorpe). In many towns, salinity affects waters used for parks and gardens (eg near the south coast) at Boxwood Hills.

On-farm supplies

The increasing salinity of agricultural landscapes has increased both the cost and difficulty of establishing on-farm water resources. Farmers in wheatbelt shires have indicated that about 6.3 per cent of dams were no longer useable because of salinity (ABS, 1989). On many farms it is becoming increasingly difficult to site excavated earth dams because of shallow, saline groundwaters.

Good quality water is essential for stock that graze salt-tolerant vegetation, which is often the only possible use of saline areas. Some farms are relying on water from one remaining source. Emergency water supplies from wetlands and soaks are being lost because of salinity, a fact often only recognised when emergencies arise.

A study of the salt content of groundwater in 76 useable bores on farms in the northern wheatbelt showed an average annual increase of 80 mg/L TSS over an eight-year period between 1968/69 to 1976/77. Systems currently being developed to interrogate Water and Rivers Commission and Agriculture WA data bases are expected to show this trend is widespread in all but very high rainfall regions.

2.3.3 Natural diversity

The native flora of south-west Western Australia is internationally recognised for its diversity and uniqueness. The native fauna adds to this biological diversity and includes additional unique elements.

Our flora and fauna have been profoundly affected by a range of factors including agricultural development and the introduction of exotic plants, animals and diseases. Salinity is one of the resulting complex of threats that continues to have a detrimental effect on the State's flora and fauna. While the impacts of salinity on the biota are most obvious in the lower parts of the landscape, the relief of the wheatbelt is so low that virtually all areas may be affected. These areas may support remnant vegetation including nature reserves. For example, lower parts of the Durokoppin Nature Reserve (1000 hectares) are threatened by rising saline groundwater moving into the reserve from adjoining cleared farmland (George *et al.* 1995).

The location and area of remnant vegetation on farmland have been documented (Beeston *et al.* 1994). However, its condition and rate of decline due to salinity have not yet been assessed. George *et al.* (1995) estimate that, without remedial action, up to

80 per cent of susceptible remnants on farms and up to 50 per cent on public lands, including nature reserves, in agricultural areas could eventually be lost.

While salinity threatens our native biota across the landscape, wetlands and other low lands have borne the brunt of degradation, and this will continue. The beds and banks of 80 per cent of the region's rivers and streams are seriously degraded (L. Pen *pers. comm.*). The degradation of wetlands is well advanced but has gone largely unrecorded. Virtually all wheatbelt wetlands have been severely degraded. An oral history by Sanders (1991) has documented some of these changes.

In the late 1970s the Department of Conservation and Land Management began monitoring water and salinity levels in 52 wetlands extending from Eneabba to Esperance. During the monitoring period several wetlands in low rainfall areas, and with largely cleared catchments, have shown marked increases over the past few years (Figure 2.4). Fresh and brackish wetlands with intact native vegetation throughout their catchments have not shown significant increases in salinity.

Of the other monitored wetlands, many were already saline when monitoring began. While these have shown limited increases in salinity over the monitoring period, the gradual loss through decay of dead trees and shrubs from their floors and shores has continued. This submerged and emergent woody material provides habitat for nesting, and for aquatic invertebrates and micro-algae that contribute to biodiversity and waterbird food supplies. Therefore, without remedial action, their future as major nesting grounds for south-west waterbird populations is bleak.

It is important to recognise that although salinity adversely affects many species of wetland plants and animals, and may result in the total loss of particular wetland types, some species tolerate and even thrive in saline habitats. Thus, saline wetlands have value for nature conservation and this needs to be accounted for when considering proposals that may affect them.

In summary, salinity of wetlands and some terrestrial ecosystems is already extensive in the south-west. Without remedial action, this situation will become even worse.

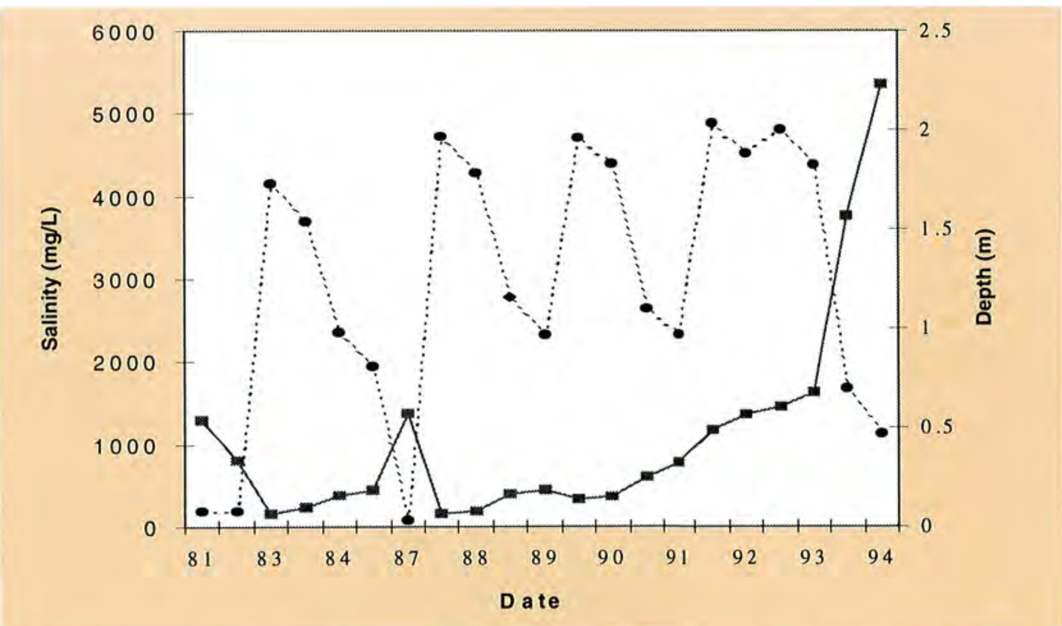
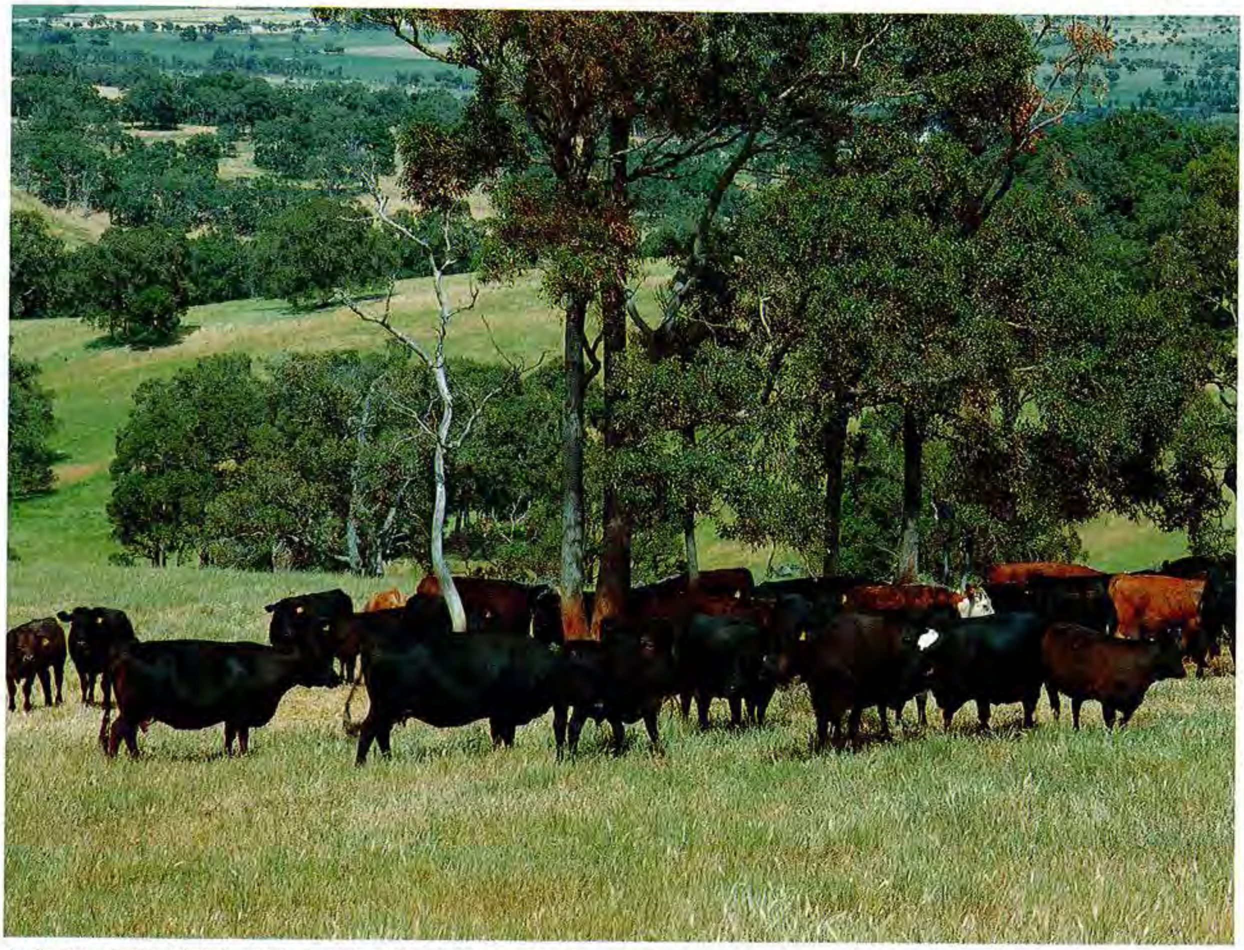


Figure 2.4: Salinity levels (dashed line) have increased substantially in Lake Bryde (40 kilometres south-east of Lake Grace Shire) since 1993 even though water level patterns (solid line) have been similar during the monitoring period.



Agriculture in the State's south-west is a $4.5 billion a year industry. Rising salinity levels increase costs for remedial action, such as the drainage shown below, or worse still, threaten to make productive land unfarmable.

3 Impact of salinity on the State

3.1 Economic implications

While salinity is a consequence of the current agricultural system, its impacts and costs are spread across many land uses.

The most recognisable effects of salinity are the impacts on farmland and the consequent loss of agricultural production. While these economic impacts are easily quantified, they make up only a small proportion of the total impact of salinity on the State. The total impact of salinity can only be measured by including off-site costs that are often overlooked such as impacts on water resources infrastructure and environmental and social costs.

3.1.1 Agricultural production

Some 1.8 million hectares of formerly productive land are already affected by salinity, with production from this land either lost or reduced. It is estimated that capital value of the land lost, which includes an opportunity cost of production lost, is in the order of $1445 million. If the current rate of salinity expansion continues, the resulting annual agricultural loss will be approximately $64 million each year until salinity reaches a new equilibrium sometime next century.

The agricultural implications of this continuing loss of productive land are twofold. Firstly, to maintain the aggregate level of production the productivity of the remaining unaffected land must be increased. These changes, with associated increases in costs, may be through innovations such as higher yielding crop and pasture varieties, more efficient agronomic management and possibly greater inputs such as fertilisers and agricultural chemicals. There are risks in this approach, including the increased likelihood that forms of land degradation other than salinity will expand.

Secondly, there are significant costs associated with undertaking works to reduce or halt the rate of salinity. When combined with increasing costs for agricultural inputs, these factors exacerbate the cost-price squeeze already being experienced by farmers. This will lead to more farm businesses becoming unviable, continued rural consolidation and further decline of rural communities. It is therefore important that private and public investment in salinity control is allocated to achieve the most effective response "in the paddock".

3.1.2 Water resources development

When the salinity of streams and reservoirs increases, the costs associated with the provision of water supplies are: (i) having to build replacement storages, (ii) using water of higher salinity, and (iii) foregoing potential sources. Where the threat of salinity is better known, there may be costs associated with preventing salt discharge into streams.

Replacement storages have been built for the Collie and Denmark Rivers in the past eight years at a cost of $43 million. In order to limit future salinity, over $46 million has already been spent on compensating farmers for not being able to clear their land, for purchasing land, and for reforestation on Clearing Control Catchments. It is expected that water from the Wellington Reservoir will supply secondary industry at Kemerton and Collie within five years. Additional capital costs to industry of using higher salinity water will be at least $15 million and shorter life of mechanical equipment can be expected.
Foregoing potential sources is equivalent to the additional cost of advancing the development of other future sources which are more expensive. The construction of a major pipeline, worth $100 million, will need to be brought forward to supply the Perth metropolitan area, because the use of nearby brackish sources has been deferred because of the expense of treatment.

3.1.3 Infrastructure, environmental and recreation costs

Waterlogged land is an unsuitable foundation for structures, and rain falling onto waterlogged land virtually all runs off. The potential four-fold expansion in waterlogged area would dramatically increase the magnitude of runoff volumes and peak flood events. Existing infrastructure has been located and designed without taking account of these risks. All infrastructures (i.e. road and rail systems, towns, farm buildings, pipelines, culverts and bridges) are vulnerable. Flooding would extend along the rivers to the coast. The maintenance and relocation costs would be a heavy financial burden especially for rural communities.

The question of risk and cost to infrastructure has not yet attracted serious investigation. However, a preliminary net present value analysis of salinity in the

Kent River catchment (1852 km^2) indicated off-site costs of $210 million (over 20 years), comprised of losses of wetlands, remnants, water resources and damage to infrastructure.

There are other environmental and social costs including loss of:

- natural biodiversity, with associated costs in terms of lost plant and animal resources for economic development. Given that the south-west has an extremely high floristic diversity, this loss is likely to be substantial;
- natural biological and physical diversity which will detrimentally affect tourism and recreation, with direct economic costs;
- natural biodiversity, particularly where it lies on major recharge or discharge areas, which will contribute to loss of agricultural production through reduced shelter benefits and further increases in saline water tables.

As with infrastructure, it is difficult to estimate these costs, but they would be a substantial burden on future generations.

3.2 Environmental implications

Salinity consists of inter-related processes of decline in the physical and biological environment. As root zones come under the influence of saline groundwater, vegetation and soil fauna decline, habitat is lost, plant and animal populations and species decline, functionally important species are diminished and the maintenance of ecosystem processes is compromised or they collapse. Biological decline is accompanied by progressive deterioration in the physical environment to produce an array of salinity-related problems such as waterlogging, bare and saline soils, erosion, sedimentation, salinity of rivers and wetlands, and increased runoff.

3.2.1 Impact on native flora

Salinity directly affects the soil biota, including those species involved in important system functions such as fixing nitrogen for use by plants. At a visible level, plants with root systems unable to tolerate increasingly saline water decline in vigour and die. As wetland and other systems become more and more saline, there is a continuing loss of populations of all but the most salt-tolerant species, and even the latter are lost where bare salt scalds appear and spread. While no individual plant is known to have become extinct as a result of salinity, this probably reflects the poor documentation of our wetland flora. Certainly, most aquatic freshwater plants have disappeared from the wheatbelt.

Eleven species of threatened flora (Declared Rare Flora) occurring in the agricultural region have at least one population considered to be at threat from salinity (D. Coates *pers. comm.*). At least one species, the hinged dragon orchid (*Drakonorchis drakeioides*), is likely to disappear unless remedial action is taken at the landscape scale to halt rising groundwater (A. Brown *pers. comm.*).

As low-lying areas continue to degrade, plant communities that specialise in growing in these areas, such as flat-topped yate (*Eucalyptus occidentalis*), salt salmon gum (*Eucalyptus salicola*) and many paperbarks (*Melaleuca* spp.) will disappear at local and regional levels. Apart from their importance for nature conservation, the value of such plants to revegetation works, amenity, and as sources of future economic worth, is very high.

3.2.2 Impact on native fauna

Most obvious has been the impact of salinity on waterbirds and fresh water invertebrates. Of the 61 more common waterbird species in south-western Australia, only 16 prefer saline (> 20,000 mg/L) or hypersaline (> 50,000 mg/L) conditions. Data from a 1981-85 survey of the south-west showed that an average of five waterbird species use hypersaline wetlands, compared with 20 in saline wetlands and 40 in fresh wetlands containing living trees and shrubs. Salinity has caused a 50 per cent decline in the number of species occurring in the better, fresh water wetlands in the south-west. If the process continues, only 16 species, plus three or four species that rely on fresh farm dams, will remain (Halse *et al.* 1993).

Salmon and York gums growing at Lake Baandee.

Data on invertebrates are scarce. A strong inverse relationship exists between salinity and species richness. Many fresh wetlands support 50 to 60 species, while now brackish lakes such as Toolibin and Walbyring contain 20 to 30 and saline lakes less than ten. Similar patterns occur in rivers. Current trends suggest the original population in agricultural regions of perhaps 200 aquatic species will be reduced to less than 50, leading to extinction of endemic species.

Other animal groups have also been badly affected. For most frogs, the effect of salinity has been to reduce markedly the habitats available to them. Some, such as the slender tree frog (*Litoria adelaidensis*) either have, or are likely to, become extinct in inland agricultural areas. Even widespread species, such as the spotted burrowing frog (*Heleioporus albopunctatus*), are considered by some research workers (eg Main 1990) to be far from secure.

For reptiles and mammals the decline and loss of habitat has had various effects. For example, in agricultural areas the long-necked swamp tortoise (*Chelodina oblonga*) has declined markedly. While adults of this species can tolerate quite high salinities, they require fresh water to breed. For mammals, such as the tammar wallaby (*Macropus eugenii*), riparian thickets and grasslands were an important habitat upon which, in some highly cleared landscapes, they were locally dependent. As these habitats disappeared, so too did the mammals. In other cases, such as the water rat (*Hydromys chrysogaster*), it was probably the loss of their prey to salinity that has largely caused their demise in agricultural areas (Sanders 1991).

The tammar wallaby has disappeared from the wheatbelt, along with the vegetation in which it lived.

3.2.3 Impact on communities

The impact on wetland systems has been to drive fresh systems brackish or saline, brackish systems saline, and saline systems, hypersaline. In addition, riparian vegetation has been devastated. Fresh and brackish systems, along with their sensitive flora and fauna, have virtually disappeared from agricultural areas. Those remaining are doomed without management. The disappearance of these wetland communities has caused such a profound change to our landscape that it is difficult to imagine the cool, well-timbered paperbark and sheoak wetlands teeming with wildlife that older farmers describe. These areas are now mostly samphire flats or bare salt pans. The significant degradation of major systems and their communities, such as the Coblinine, Beaufort, Avon and Mortlock, is striking.

Wetlands such as Toolibin Lake are the last reminders of what the landscape was like, and even this beautiful lake is partially degraded, its reed beds have vanished and its future is uncertain.

It must be emphasised that most of our wetlands, despite their degradation, still have important values. The diversity of wildlife that use even the most degraded wetlands can be surprising. However, these systems are vulnerable to complete collapse, particularly if rising groundwater is combined with, for example, a major drought or fire and grazing.

Finally, degradation of our wetlands is attracting international attention. The south-western flora is one of the most diverse Mediterranean floras in the world. If the degradation of remnant vegetation also continues higher in the landscape as forecast by George *et al.* (1995), then the losses in our native flora and fauna will be of global significance. As custodians of such a diverse biota, our responsibilities are high.

3.2.4 Implications of environmental impacts

Environmental impacts of salinity, as described in sections 3.2.1 to 3.2.3, have important implications for:

- Conservation of biodiversity. Salinity has markedly decreased biodiversity, particularly at the local and regional scales. This process will continue for many years even if practices to combat salinity are implemented immediately. Conservation of biodiversity is widely recognised as an important objective in its own right as well as for its contribution to social, cultural and economic values. The importance of biodiversity is recognised in a range of State and Federal documents, and in international treaties such as the Convention on Biodiversity, the Ramsar Convention on Wetlands of International Importance and various migratory bird agreements.

- The effects of biodiversity loss have important implications for economic (section 3.1) and recreation values (section 3.3).

- Sustainable land use. Remnant vegetation is often located where it serves a range of landcare goals including erosion control and lowering of local groundwater levels. Remnant vegetation will also play an important role in the development of new agricultural systems. For example, it provides one source of genetic material for the development of the oil mallee program and revegetation works. Using local and regional native plants in revegetation will also prevent the introduction of agricultural or environmental woody weeds.

3.3 Effects of salinity on recreation and tourism

Water attracts people. Wetlands, particularly rivers and lakes, rank with the sea as preferred locations for leisure. In agricultural areas, the decline of wetlands for swimming, water skiing and other forms of recreation is a problem that is not widely recognised by the broader community. Brackish lakes which have become highly saline or have lost most of their fringing vegetation, such as Dumbleyung Lake, have declined in popularity for leisure activities.

A survey of local residents and users of Dumbleyung Lake (G. Leaman, *pers. comm.*, 1991) produced responses from 179 residents and 52 recreational users, with the following results:

- 91 per cent of residents and 96 per cent of users rated fringing vegetation important or very important. Much of this is now lost at Dumbleyung Lake and 22 per cent of residents and 41 per cent of users were either dissatisfied or very dissatisfied with this.

- 91 per cent of residents and 90 per cent of users rated water quality as important or very important and 25 per cent of residents and 22 per cent of users were dissatisfied or very dissatisfied with water quality of the lake. Some people avoid using the lake because of its high salinity.

- When asked what other areas were used for recreation, respondents indicated that they prefer lakes, rivers, pools and dams (68 per cent). Only 31 per cent nominated non-water based recreational areas.

Scenes of tree skeletons where once woodlands stood, and glistening white lakes where once there was fresh water and thriving aquatic vegetation, have reduced the landscape's appeal to tourists. Salinity threatens local recreation resources and diminishes the inland region's tourist potential.

3.4 Effect of salinity on rural towns

Several wheatbelt towns, for example, Cranbrook, Brookton, Dowerin, Katanning, Kellerberrin, Merredin, Morawa, Perenjori, Tambellup and Wagin, have developing dryland salinity problems. Lyons (1995) made an assessment of the effects of salinity on 20 shires in the Avon catchment, representing 31 country towns. Results showed that 19 out of 20 recognised an increase in saltland areas, 13 noted seeps within the town, while over half said that waters supplies, waste management systems, vegetation, recreation facilities and buildings had been affected.

Salinity, with associated shallow watertables and waterlogging, affects the ability of many local governments to expand urban areas. For example, Katanning has extensive areas of salinity surrounding the town. Similarly, southward expansion of metropolitan Perth may be limited by shallow watertables and saline soils (eg Serpentine-Jarrahdale Shire).

4 Salinity management

Salinity management is needed if we are to maintain productivity of Western Australia's land and water resource base, conserve natural diversity and reduce economic and financial losses to individuals and the State.

Conceptually there are three approaches to salinity management:

i) substantial recovery - reverse the salinisation process and recover damaged land and water resources;
ii) contain and control - bring the process under control so that further damage is contained;
iii) live with it - adapt to the consequences of salinity and minimise the losses.

Generally the aim will be to use a mix of recovery and containment, although the task is so large in many areas we will have to live with the consequences until adequate management is introduced.

Management must focus on improving water use such that recharge and groundwater rise can be brought under control at the farm and catchment scale. Significantly increasing water use and reducing recharge will eventually lead to control, and later, substantial recovery. However, defining specific water use and recharge reduction targets is very difficult as both are difficult to measure and are highly variable, being dependent on management, soil factors, site and seasonal conditions.

Increasing water use is a prerequisite step to reducing recharge. However, as recharge varies spatially (within a paddock) and temporally (within a year or season), achieving higher water use targets may not always result in lower recharge rates. For example, "average" recharge in the eastern wheatbelt is estimated to be of the order of 20 mm/year. However, it does not follow that increasing water use by 20 mm will eliminate recharge. Much of this recharge could occur in a short period of time in mid-winter when the water use of plants is low, it could occur after summer thunderstorms when no green vegetation is present and it could occur unevenly across the landscape.

Despite this uncertainty, it is necessary to adopt targets for the reduction in recharge and consequent increase in water use. Recharge reduction targets based on estimates of annual recharge and increases in landscape water use for the salinity hazard zones in south-western Australia (Figure 2.2), are outlined in Table 4.1.

Recharge estimation is the most difficult of all hydrologic assessments. Research suggests that recharge has increased by between ten and 100 fold as a result of clearing. Reducing recharge by targeting regional increases in water use will slow the rate of watertable rise, limit the extent and spread of salinity and allow time to develop new farming systems. Where possible, recharge should be reduced to near the levels which occurred prior to clearing.

Table 4.1 Target recharge reductions by regions

Salinity hazard regions *(depicted on Figure 2.2)*	***Estimated* range of annual recharge (mm) under current agriculture**	**Target minimum reduction in recharge by increased water use (mm)**
High hazard (long term) eg eastern wheatbelt	10-40	10
Extreme hazard eg northern region	20-70	20
High hazard - inland eg eastern south-west, south coast	30-150	30
Moderate hazard eg south-west	100-200	70*
Low hazard eg mainly forested south-west and western south coast	100-300	na**
High hazard - coastal eg south-west and north coastal plains	50-300	100*

* *target reductions should consider the effects on water yield of catchments in the moderate hazard zones. In some cases drainage may be able to used, together with increased water use, to target increases in discharge*

** *target reductions are not be required in low hazard zone (>1100 mm/yr) for salinity control*

These figures are only a guide. Specific water use and recharge reduction targets will be required for each salinity management system and each land management unit.

Conventional agricultural practices are currently not achieving these water-use targets for salinity control. Increased water use of existing practices and a diverse range of new and improved practices, effectively integrated into practical agricultural systems, are therefore required. Quickly improving the water use of existing systems is a high priority. The development and implementation of new practices across the regions is also essential for long-term salinity control, even if this process take decades. Furthermore, it must be remembered that even after treatment, as groundwater systems are large and complex, the effects of treatment may be slow to become fully developed.

Practices must be appropriate to the region and to the level of control desired. However, in most regions substantial recovery cannot be achieved on a large scale because economically attractive water management practices are either not yet available or their consequences are unknown.

If the resources were available, extensive non-commercial revegetation could be undertaken to achieve substantial recovery. Farmers already do this on a small scale. It is also being done in the Collie River catchment to assist protection of a major water resource. It could be done for other high value assets such as wetlands of national importance and major infrastructure. However, the cost of this type of action is so large that it cannot be generally applied.

Hence there are three steps to take to build the capability for effective salinity management:

- increase the water use of existing practices;
- develop new and improved water management practices;
- develop the planning methods and tools for integration of water management practices into practical salinity management systems.

4.1 Water management practices

The water use by agricultural systems determines the amount of water that is available to enter and flow through the groundwater systems. There is scope to increase water use by annual and perennial plants, and to use engineering systems, to reduce the amount in groundwater systems. These water management practices can be grouped into five categories:

- increasing the range and proportion of perennial plant species used in agriculture;
- increasing water use by annual crops and pastures;
- collection, reuse and disposal of surface water;
- drainage or pumping, reuse and disposal of groundwater; and
- improved protection and management of remnant native vegetation.

4.1.1 Description of practices

Increasing the range and proportion of perennial plant species used in agriculture

The deep roots of perennial plants, especially the longer-lived woody shrubs, trees and some perennial forage species such as lucerne, have the potential to use water stored deep in the soil profile. By exploiting stored water, as well as rainfall, strategically placed trees can consume more than double the amount of water provided by rainfall. Thus they address the problem of salinity by directly controlling groundwater recharge and discharge. It is possible to use up and buffer against accumulating groundwater by manipulating the proportion and distribution of perennials, thereby controlling salinity.

Revegetation can have a wider range of benefits than just reducing groundwater recharge and controlling groundwater discharge. Examples include crop and livestock protection, wind erosion control, amenity, improved asset value and nature conservation. In some cases the full value of these benefits is only expressed intermittently, such as during windstorms when substantial erosion and reductions in crop yield can occur. Hence benefits may vary greatly from site to site and from year to year, and are difficult to encompass in a general economic analysis.

To evaluate the economics of revegetation the costs and benefits must be considered over the period of its effective life. This is commonly done by discounting the flow of costs and benefits back to the present value.

Lucerne - perennial legume.

Since the major cost of revegetation comes at establishment and the benefits come some years later, the discount rate used to give present value is a sensitive determinant of economic success. In addition, a rigorous analysis will take account of the opportunity cost of the land revegetated and will use a cautious assessment of the benefits, usually only the well quantified on-farm benefits. This type of analysis will usually show that revegetation is not an economic solution to the problems of land degradation, an economic argument that has been a major impediment to adoption of large scale tree planting by farmers.

While there are many sites that farmers will plant at their cost, without commercially attractive options, farmers and the general community will not be able to plant trees quickly enough or on the necessary scale to combat salinity. The lack of commercially attractive tree crops for the majority of dryland agricultural systems has been a major impediment to the adoption of large scale tree planting by farmers.

Commercial perennial woody crop options currently in various stages of development range from plantation and farm forestry with bluegums and pines in the higher rainfall zone (> 600 mm), maritime pine and fodder shrubs (such as tagasaste) in medium rainfall areas (> 400 mm), to oil mallees in the low rainfall wheatbelt (< 400 mm). Lucerne and perennial grasses have good potential to reduce recharge and lower watertables in the Great Southern and south coast regions.

Many more perennial species, products and markets must be developed so that there is a range of options for every land management unit in every region. These options should include perennial species for other purposes, such as land conservation and biodiversity. Where possible, the development of commercial species should be based on indigenous plants to reduce the risk of introducing weeds.

Increase water use by annual crops and pastures

There is potential to increase annual crop and pasture water use while achieving significant economic gains. For example, cropping systems in the wheatbelt are currently using about 70 per cent of the rainfall for grain production, while some grazing systems based on annual pastures in the western areas are achieving a lower water use (40 per cent of rainfall). In addition, it is possible to increase the productivity of marginal and saline lands, especially in the medium to higher rainfall zones, by the use of salt and waterlogging tolerant vegetation such as tall wheat grass, puccinellia and balansa clover.

High water use from annual species may also be achieved by improved genetic varieties, site selection, fertiliser and soil amendment (acidity, soil structure control), grazing management and systems of rotations. Increasing water use efficiency does not necessarily reduce recharge, only increasing water use does so. The wider application of high water-use crops and pastures will increase farm profitability and can have an impact on water use if developed as a part of wider management systems. The continued development of packages such as Top-Crop West and the Feed-On-Offer (FOO) programs will help increase water use. Annual plants alone, however, are not able to provide the whole solution to salinity and need to be complemented by other strategies to achieve salinity control.

Collect, reuse and dispose of surface water

Water ponded on the soil surface and waterlogging within the soil profile inhibit plant growth and may increase recharge. The number of plant species which grow well on waterlogged and inundated areas is limited, the number of economic species is even more limited. Shallow drainage can quickly and cheaply improve productivity in these circumstances. Using

Bluegums - integrating tree crops with stock.

Oil mallees - potential commercial tree crop.

shallow interceptor drains and contour banks to remove excess water can improve plant growth, increase plant water consumption, reduce erosion and recharge, and improve farm productivity. However, surface drainage alone will not prevent recharge and groundwater rise. Furthermore, the disposal of excess water requires careful planning to prevent problems being passed downstream. Reducing waterlogging on salt-affected land (eg shallow drains, mounds) is essential if significant plant growth is to be achieved on discharge areas.

In summary, this strategy indirectly addresses groundwater control through reducing the time and amount of water available to recharge groundwater. It does not provide a solution alone and must be complemented by other strategies to achieve groundwater control.

Drain or pump, reuse and dispose of groundwater

Groundwater levels can be lowered with deep drains and by groundwater pumping in areas where the soils and subsoils are relatively permeable. The spacing and depth of drains can be designed to keep groundwater below a critical depth and either tube drains or open drains may be suitable. Water pumped from aquifers may be reused if the quality is suitable, or disposed of into natural or constructed evaporation basins.

Many deep drainage methods used to date are not cost-effective. In addition, they can be environmentally unsound on grounds such as damage to downstream land and water resources. Discharge to streams can adversely affect environmental values and the prospect of damage to other properties usually makes off-site disposal unacceptable. This strategy is only likely to be applicable to rapidly protect or restore valuable assets such as towns, conservation reserves, high value agricultural systems, wetlands or infrastructure at sites where the land has suitable hydrologic properties and disposal is environmentally sound.

Improve protection and management of remnant native vegetation

Privately-owned (2.75 million hectares) and publicly-managed (4.52 million hectares) native vegetation occupies 7.27 million hectares out of over 25 million hectares in the agricultural region. While its condition varies considerably, it is particularly valued for salinity control where:

- individual remnants or reserves are large enough to affect recharge at a catchment or sub-catchment scale; or where
- smaller remnants or reserves occur on high recharge zones (deep sands and around rocky outcrops) or discharge zones (eg drainage lines, swamps and lakes).

All remnants, when combined with appropriate revegetation systems, will contribute to the local management of salinity and protect nature conservation assets. However, the current water use of remnants is often limited by poor management and their degraded condition. Privately-owned remnants are commonly exposed to grazing, often have poor natural regeneration, are subject to high watertables in the lower slopes and may be subject to extraction of timber without adequate regeneration. Recharge may occur under these remnants. Protective fencing, rehabilitation of degraded remnants, and on-going management will maintain or increase water use.

4.1.2 Relative priority of water management practices

Successful groundwater control will usually involve the integrated use of practices from each of the categories of water management. However, some categories have particular advantages and should attract priority in development and implementation.

Increased plant water use has the advantage of putting surplus water into plant growth and thereby potentially increasing the production and profitability of agriculture. Practices able to achieve better plant water use should therefore attract some priority over drainage and pumping practices where these involve disposal of water to the environment.

Woody trees and shrubs have the greatest water use potential and the development of a wide range of commercial perennial species and products is clearly a major priority in improving groundwater control. These plants can be used strategically to provide large capacity to reduce recharge. However, the fixed location and limited reach of woody perennials, even in widely dispersed planting arrangements such as alley farming, must be complemented by improved water use and management of other perennial and annual crops and pastures. The development of lucerne in both cropping (phase-cropping) and grazing systems provides a method of broadacre control which can complement revegetation, particularly in the Great Southern and south coast.

Shallow drainage is attractive in that it involves conventional technologies which, if soils and site conditions allow, may quickly improve the productivity of waterlogged and saline areas. Drainage can initially also complement the establishment of high water use practices (eg waterlogging susceptible species). In some circumstances, drainage may become less important for all but major rainfall events and in very wet years as groundwater drawdown is achieved by high water use systems. Where drainage water can be productively used, the inherent inefficiency of discarding water and the problem of disposal can be averted.

In summary, the integrated and complementary use of an array of perennial species as a protective and productive framework for high water use annual crops and pastures, augmented by carefully designed water control practices suited to the various rainfall zones, will be the foundation of groundwater control in Western Australian agriculture.

4.2 Planning tools

Planning tools are the means by which water management practices can be integrated into efficient and profitable farm management systems. The appropriate mix of water management practices will vary with the particular landscape, climate, and the objectives of the farmer, the catchment group and the State. Planning tools consist of biophysical and economic information (used to assess the local applicability of various water management options), and the techniques of farm and catchment planning (used to decide how to combine the options into a workable system). These three aspects are described in this section.

4.2.1 Biophysical information

Biophysical information is used to describe the characteristics of the land and the environment on the catchment or farm in question. The major types of biophysical information required for farm and catchment planning are:

- cadastre (land ownership)
- infrastructure (roads, rail, towns)
- climate
- topography (particularly in digital format)
- geology
- soils and/or land management units
- land use
- flora and fauna
- drainage systems including depth, flow volume and water quality
- groundwater (water levels, salinity, trends)
- multi-spectral data from satellite or airborne systems (eg LANDSAT)

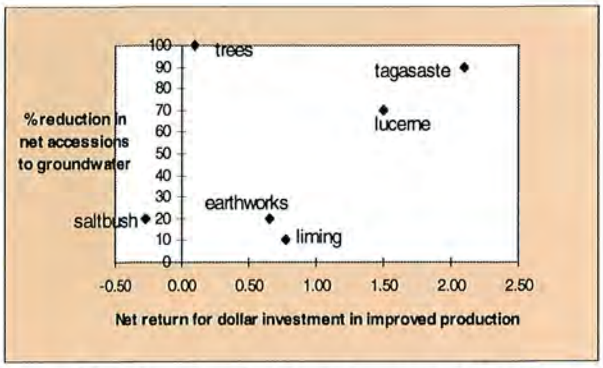


Figure 4.1: Economic and water use assessment of local control options for a medium rainfall central wheatbelt catchment.

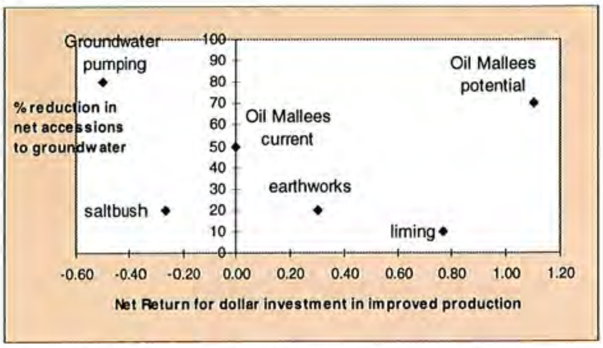


Figure 4.2: Economic and water use assessment of local control options for low rainfall eastern wheatbelt catchment.

- magnetics (ground or airborne systems)
- radiometrics (ground and airborne systems)
- electromagnetics (ground or airborne systems)

Much of this information is available and in common use but some is still in the development stage. The accuracy, scale, availability and coverage of biophysical information is variable. There is a need to better coordinate delivery of existing data and to identify and develop useful forms of packaging biophysical information. It is important that the biophysical information form the basis of "process" models of landscape behaviour or treatment. Biophysical datasets must be interpreted by experienced people if value is to be added and results converted into action plans.

4.2.2 Economic information

Farmers and their financial advisers need information on the economics of salinity control. Figures 4.1 and 4.2 present a simple framework that assesses management practices according to their water use (and therefore potential to control recharge) and economic benefit (measured by on farm production improvements) in two Western Australian regions.

Simple multi-criteria frameworks such as these can be used to assess and rank alternative practices at the farm, catchment and regional level. They highlight water management practices that are immediately available for adoption (eg tagasaste in the medium rainfall zone), as well as those that may require economic incentives or further research and development before large scale implementation becomes feasible (eg oil mallee in the low rainfall zone).

4.2.3 Farm and catchment planning

Farm and catchment planning allows the integration of a range of water management practices into efficient and profitable farm management systems. Planning combines biophysical and economic information with the farmer's and the local community's particular preferences. Planning is a complex social process. It is also a dynamic process. It inevitably involves communication, learning, changing attitudes, identifying research gaps and building commitment.

4.3 Stages of technological development

In most areas the opportunity to design effective salinity control systems is constrained by the limited selection of water management practices and planning tools. Ideally a full and balanced menu of practices and planning tools should be available. However, this will take some time to achieve. Three stages can be recognised in the development of salinity control systems.

Systems for today. Combine practices known to be locally effective and currently available for adoption. These practices consist of methods such as revegetation, farm forestry (bluegums, pines), remnant vegetation management, perennial fodder shrubs (tagasaste), perennial pastures (lucerne) along the south coast and south-west, surface drainage and some aquifer pumping systems. These practices have been shown to prevent or control the severity of salinity on the local scale. Adoption is limited to suitable regions (bluegums in high rainfall zone) but may also be constrained by poor availability of planning tools, especially biophysical and economic information.

Systems just around the corner. These will incorporate practices considered to be promising but not yet fully developed (i.e. likely to be developed within two to ten years). Practices include further advances in high water use crops and pastures (eg phase-cropping of perennials), salt-tolerant agronomic systems, farm forestry and new commercial tree crop species (eg oil mallees). In many cases the practices are emerging, but demonstration and evaluation of their performance in whole systems is lacking.

Systems for the future. These include practices which could be developed but will have a lead time of more than ten years. They include practices based on perennial woody crops (eg biofuels, extractive products), perennial legumes (in addition to lucerne) and grasses, domestication of native species, and pumping, desalination and re-use of groundwater and use of the extracted salt.

A description of each of the major salinity control practices is presented in Appendix 8.2. The list is not exhaustive, but highlights the practices and issues to be addressed.

4.4 Case studies

There are many examples of the successful use of particular water management practices. However, there are no examples of the integration of several water management practices to create successful salinity control systems on the farm or catchment scale. In this section two examples of potential systems are described, and some of the additional requirements necessary to make them effective systems are discussed.

(i) Low rainfall wheatbelt

A successful system in the low rainfall wheatbelt would include:

a) high water using crop and pasture systems;
b) introduction of deep-rooted woody perennials;
c) surface and sub-surface drainage, often combined with storage;
d) protection and enhancement of remnant vegetation.

Current management practices to reduce salinity include revegetation, sub-surface drainage of sandplain seeps to dam storages, and the management of remnant vegetation.

While these practices are valuable, they are not sufficient. Two other components are essential for an effective salinity control system.

Firstly, it is essential that improved cropping systems are more widely adopted so that potential to use water is maximised. Wheatbelt cropping systems are currently achieving an average of about 70 per cent use of rainfall for grain production. Increasing grain yields by another

300 kg/hectare has the potential to use an additional 30 mm of water for grain production. While this is the same magnitude as the long-term average recharge rate, this water did not necessarily go to recharge at the lower yield. It may have been used in growing weeds, gone as runoff or used in vegetative production that was not converted to grain yield. So annual cropping, even at high yields, will not necessarily be enough to prevent recharge and salinity. This is because much of the recharge responsible for salinity takes place in wet years, during periods of poor water uptake by plants (early and mid-winter), following out-of-season rainfall events (summer storms, floods), or on poor cropping soils. Therefore, additional management practices are necessary for an effective low rainfall wheatbelt system.

One of these practices is the use of perennial, woody vegetation. This must be present in the right proportion and arrangement to provide a back-up water use capacity to consume additional recharge that may occur. Vegetation can either be located on areas of high recharge (eg deep sands) or be widely dispersed in a way that does not obstruct large scale cropping or be vulnerable to grazing (eg alley farming). Ideally, the woody crop should generate economic return so that it can contribute to the profitability of the system.

The planting of mallee for eucalyptus oil production is one potential commercial wheatbelt tree crop now under development. Pre-commercial planting has been undertaken on full operational scale at several wheatbelt centres. The objectives are to test and develop production systems and to build up a sufficient resource for product and market development. Farmers have quickly adopted oil mallee into practical management systems and it has greatly accelerated their overall tree planting. The project presents a clear indication of the potential for adoption of commercially attractive tree crops.

(ii) Medium rainfall south-west and south coast

A successful system in the medium rainfall south-west and south coast would include:

a) higher water use annual pasture and cropping systems;
b) introduction of commercial timber crops (bluegums, pines);
c) introduction of perennials such as lucerne in selected areas;
d) surface and sub-surface drainage, often combined with surface storage for horticultural production;
e) protection and enhancement of remnant vegetation.

The introduction of these practices across the landscape would provide many of the elements of an effective salinity control system. Increasing the water use of annual crops and pastures, the appropriate use of drainage systems, and the management of remnant vegetation will reduce recharge and increase profitability in the shorter term. However, the development of commercial farm forestry and increased plantings of other perennials is essential to control salinity.

The Farm Forestry Task Force (1995) reported that the potential scale of commercial farm forestry in the wetter south-west, assuming a maximum tree planting proportion of 20 per cent, was 349,500 hectares. This includes the potential for planting *Eucalyptus globulus* (bluegums), *Pinus radiata* and *P. pinaster* (Maritime pine). Such an industry would extend from the west Midlands (40,000 hectares), through the south-west (223,000 hectares) and Great Southern (54,000 hectares), to the south-east (32,000 hectares), and would add $540 million of extra economic activity to the region, employing up to 2600 people.

A more recent assessment by CALM indicates that commercial tree farming with Maritime pine is possible on land with an annual rainfall limit of 400 mm and on sands north and south of Perth in the high rainfall zone. This means 500,000 hectares are available for planting *Pinus pinaster* alone.

These timber producing species and the industries they support provide commercially attractive farm forestry opportunities. With skilful integration into the farm these crops can provide the water use capacity to consume recharge while maintaining farm profitability.

At one site near Bridgetown evidence of successful and economic salinity management is becoming apparent. At this site watertables have been falling at rates of up to 0.7 metres/year throughout the catchment and a downslope salt-seep no longer flows during summer (Figure 4.3). This is being achieved with a planted area of 35 per cent of the cleared area arranged in a close-spaced belt configuration. This configuration markedly reduces grazing production in the second half of the production cycle. Smaller proportions of planting may result in lower but acceptable rates of watertable reduction without such a large late rotation loss of grazing.

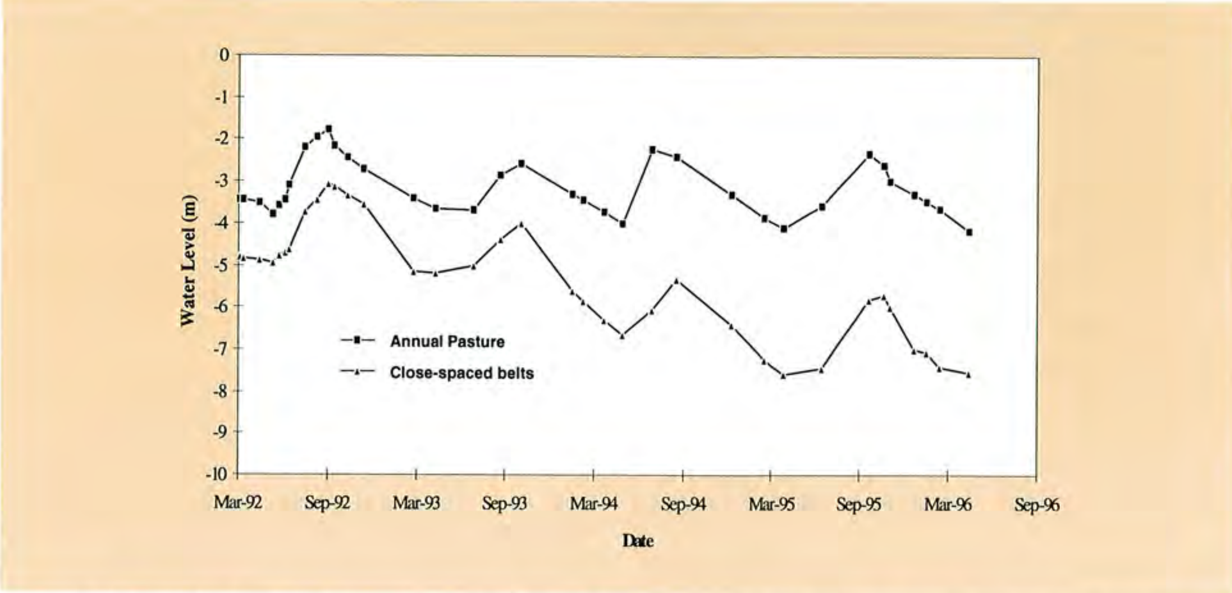


Figure 4.3: Watertables have been lowered by over 0.7 m/year by bluegums planted in a close-spaced belt farm forestry system (450 trees per hectare) relative to a control bore in adjacent annual pastures.

Further investigation is required to devise optimum proportions and patterns of distribution and for efficient integration with other water management practices.

Lucerne is a species with unrealised potential in this region. Failures prior to the 1960s were attributed to problems of grazing management, variety, pests and climate.

Evidence from groundwater monitoring at sites along the south coast have shown that if large areas are planted to lucerne, watertables will fall. Since 1990, watertables have fallen by as much as one to two metres beneath some areas of lucerne near Jerramungup. In addition, early results from experiments on a farm between Kojonup and Katanning indicate similar promise.

4.5 Management systems for high value private and public assets

The major challenge for salinity control is to develop effective and economic systems at a landscape scale for all regions. However, it will be some time before such systems are developed, adopted, and effectively controlling groundwater. In the interim it will prove necessary to implement salinity control measures at particular sites in order to protect high value assets and resources. Such sites will generally be where there is an immediate threat to towns, town water supplies, infrastructure or high value nature conservation assets. These will frequently involve a higher level of Government action, justified by the value of the asset under threat and by the potential public benefit involved.

To protect community assets specific control systems may include:

- aquifer pumping and surface water diversions (eg Toolibin Lake);
- reforestation, with specified objectives (eg Collie catchment);
- land use covenants, compulsory purchase and controlled management.

For instance, in the mid 1970s, it became clear that five water supply catchments in the south-west were in danger of being lost as potable water sources. It was recognised that the remaining tree cover in these catchments would need to be protected and additional cover established. To implement this decision, clearing controls were brought in by the Government in 1976 and farmers compensated where they were not able to clear their land. A large scale revegetation program was introduced for selected farmland.

At the Toolibin catchment, a recovery plan was developed to protect the lake from salinisation. Initial work concentrated on the construction of large earthworks for surface water control and a groundwater pumping system on the lake. However, ongoing works are focussed on catchment management, namely surface water control, revegetation (oil mallees, tagasaste) and higher water use farming systems.

5 Introduction to the Salinity Action Plan

This Situation Statement details the cause, extent and impacts of salinity on agricultural land, water resources and the natural diversity in the south-west of Western Australia. Building on this basic knowledge and understanding, the Statement examines the range of existing and potential options available to manage salinity and minimise its impact.

While a range of management options exist, and is being developed, nothing will be achieved unless there is action on the ground to implement the appropriate treatments in every salt-prone catchment in Western Australia. Managers of land in these catchments, both private and public, cannot be expected to bear the total burden of changing land use to redress salinity. It is a problem that ultimately affects the whole community both now and in the future, and therefore, the whole community must share the cost. The State Government, on behalf of the community, will support a Salinity Action Plan which will help land managers to develop and implement treatments appropriate for their catchment.

6 Acknowledgments

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8 Appendices

8.1 Previous programs for salinity

Over the past 20 to 30 years, a range of policies, investigations and programs has been developed by government and farmers to improve understanding of the processes causing salinity and to manage it. The following is a summary of the main actions.

Regulatory support for landcare

- Protecting remnant native vegetation through clearing control legislation applied to future water supply catchments, and clearing notification and control under the Soil and Land Conservation Act
- Notification of intention to drain or pump under the Soil and Land Conservation Act

Research to understand processes

- Monitoring the effects of clearing strategies in experimental catchments (eg Collie catchments)
- Regional research and monitoring in agricultural catchments
- Researching the effects of geological structures on hydrologic processes and treatments
- Developing survey techniques such as ground- and airborne-geophysics

Demonstrating treatments

- Experiments with establishing and managing trees, shrubs, crops and pastures on saline land
- Monitoring agronomic treatments on farms and experimental catchments
- Monitoring revegetation and drainage systems on farms

Monitoring salinity and setting targets for treatment

- Maintain stream flow and salinity records of major rivers
- Establishing bore networks
- Computer modeling of catchments to evaluate scenarios
- Mapping and monitoring land condition using satellite remote sensing and GIS

Reforestation

- Reclamation of the Mundaring Weir catchment by reforestation
- Partial reforestation and intensive monitoring in the Collie and other water resource catchments
- Revegetation schemes

Support for management methods

- Development of Remnant Vegetation Protection Scheme

Develop profitable forms of treatment

- Timberbelt sharefarming scheme (bluegums and pines)
- Deep-rooted perennial crops such as tagasaste and lucerne

Integrate productive forestry in agricultural systems

- Farm Forestry Unit
- Agroforestry Working Group

Improve planning at catchment and farm scales

- Network of Land Conservation District Committees and Catchment Groups
- Farmer-led projects to prepare catchment plans for salinity treatment
- ALCOA of Australia contributions to catchments (eg Swan-Avon)
- Blackwood and Swan-Avon initiatives and associated catchment coordinating groups
- South Coast Land and Water Care initiative
- Kent and Upper Denmark Integrated Catchment Management programs
- Other salinity related organisations (eg Land Management Society)

Advisory services from Agriculture WA and CALM

The above responses have been carried out in the absence of an overall plan.

8.2 Description of salinity management options

A detailed account of each of the major salinity management practices is described for each of the three development stages (today, just around the corner and the future). The practices are grouped according to the five major management systems; increased water use of annuals, development of perennials, surface water control, subsurface water control and management of remnants.

Appendix 8.2 A
Salinity management practices - options that will have a positive effect on salinity and may be adopted immediately

Salinity management practice	Element	Feasibility of practice
Agronomic (annuals)	annual pastures	Increasing water use will increase profitability in the shorter term and assist recharge reduction. Annual pastures alone are unable to manage salinity.
	new pastures	Some "high" water use annual pastures are available (eg serradella, rye-grass). Water use is a function of adaptation, nutrition and grazing management. Note that some of the proposed and existing species may become environmental weeds.
	rotations (eg lupin-wheat)	In some cases use of this system has controlled sandplain seeps in extreme hazard zone of the wheatbelt (eastern/northern).
	salt and water logging tolerant pastures	Adoption of appropriate species for land management units. Some species are already available, eg balansa clover. However, for these species to be effective in increasing water use, they should be used with a perennial (eg tall wheat grass).
	high water use pasture packages	Already available in the form of 'WoolPro' and the 'Feed-on-Offer' program Need to encourage adoption and enable farmers to asses the water use potential of their system. Linking water use to recharge reduction is a priority.
	high water use cropping package	Increase cropping of cleared lands in the low to moderate rainfall zones could increase water use and reduce recharge. Water use assessments based around projects such as 'Top-Crop West' can be developed further to include recharge assessment.
Perennial plants	sandplain tagasaste	Tagasaste has been shown to lower watertables by preventing recharge. Increased adoption of existing systems is required.
	high rainfall eucalypts and pines	Bluegums (*Eucalyptus globulus*) are a major raw material for the production of pulp wood. Other sawlog species can be developed and markets created for slower grown timbers, offering recharge reduction and diversification. Barriers to broader scale adoption include finance and marketing, parrot damage, salinity, shallow soils and need to integrate with current farm practice.

Appendix 8.2 A (cont)
Salinity management practices - options that will have a positive effect on salinity and may be adopted immediately

Salinity management practice	Element	Feasibility of practice
	medium rainfall tree crops	*Pinus pinaster* could be established as a commercial tree crop on 500,000 ha. Other tree species, such as sandalwood and eucalyptus trees with ornamental wood characteristics, could be established on a small scale (1000 ha/yr) but this has the potential to increase significantly as markets develop.
	other trees and shrubs	Species planted for biodiversity and land conservation may have a significant local impact (watertable, shelter, aesthetics etc) in or near area planted. Use of native species may assist nature conservation.
	lucerne	Lucerne is emerging as an important high water use pasture in the Great Southern, south coast and south-west regions. It has been established on over 4000 ha in the past five years. It has a proven ability to lower recharge and hence watertables. Barriers to adoption include a lack of basic research in some areas (sites) to a lack of agronomic management packages tuned to cropping and grazing systems.
	floriculture (exotic)	Small areas of exotic floriculture already exist, eg those based on proteas. Care must be taken not to over-irrigate.
	floriculture (native)	Small areas already exist, eg those based on banksias, Geraldton wax, etc. Care must be taken not to over-irrigate.
	salt bush	Development has occurred, need to integrate low input establishment systems with supplementary grasses/shrubs.
	oil mallees	A low level of sales for oil mallee products is already occurring. These are not significant at this stage, but see Appendix 8.2 B.
	fencing and firewood etc	Several small scale industries are based on cutting from remnants of native vegetation, or small plantations. In the <600 mm rainfall zone the most notable is the industry based on brown mallet at Dryandra near Narrogin.
Shallow water management	sandplain seep drainage	Locally to regionally effective and able to supply small water resources which can be channelled into on-farm supplies.

Appendix 8.2 A (cont)
Salinity management practices - options that will have a positive effect on salinity and may be adopted immediately

Salinity management practice	Element	Feasibility of practice
	intensive drainage on waterlogged and partly saline areas	Locally effective at limiting severity of salinity. Several engineering options available. Economic, and engineering design assessment required. Disposal of water often a major issue. Drains, by themselves, are not a solution to controlling salinisation.
	regional drains	Regional or catchment waterways/drains require engineering design, environment approval and economic analysis and community validation. They are not a solution to controlling salinisation by themselves.
	reverse interceptors	Profitable method of controlling waterlogging and reducing recharge. They are not a solution to controlling salinisation by themselves.
	grade banks	Conventional water management practice to reduce runoff and erosion, thereby limiting valley flooding and recharge. They are not a solution to controlling salinisation by themselves.
	water storage	End point for water conveyed by other structures to capitalise on runoff and prevent lower slope flooding and recharge.
	key lines	Systems of combining grade banks and waterways to control and harness/store runoff. Care must be taken to ensure water is moved to safe storage areas and not allowed to recharge in level banks.
	valley drainage	Small surface and near surface drains able to reduce waterlogging, recharge and affect the severity of salinity. They are not a solution to controlling salinisation by themselves.
	level banks	Used to control erosion in areas without suitable waterways. Can increase recharge if installed in leaky soils or widely used.

Appendix 8.2 A (cont)
Salinity management practices - options that will have a positive effect on salinity and may be adopted immediately

Salinity management practice	Element	Feasibility of practice
	the "catchment" drain	Large structures used in broad valleys to "safely" remove excess water and thus "control" waterlogging and salinity. However, generally not practicable as engineering is difficult, costs are high and social and ecological conditions (implied community disapproval) positive may not prevail. Note also that total recharge across the agricultural region is of the same order as the flows from the natural drainage system. Draining the agricultural region is not feasible.
Deep groundwater management	deep drains	Installed in permeable soils can be effective in lowering watertables. In low permeability soils are ineffective; require uneconomic level of design and construction costs ($/ha). Can collapse in unstable soils, liable to become silted or clogged with iron and thus made ineffective. Some of the result can be achieved by shallow drains. Disposal of water may present significant problems to downstream land managers.
	local aquifer pumping and drainage of "effluent"	Suitable in permeable aquifers with good hydraulic connection to the watertable. Expensive if electricity and conventional pumping systems are used. Effluent management required to prevent problems downstream.
	local aquifer pumping and use of evaporation basins	Disposal of effluent to evaporation basins not widely used, technically appropriate. Usually economic and practical only if high value assets are to be protected. Care must be taken to prevent leakage (recharge).
Remnant vegetation protection and management	fencing	Fencing will control grazing and permit management designed to improve vegetation cover and water use. Impact on watertable will depend on location and size of the remnant.
	expansion	Increasing the area and health of remnant vegetation increases its water use and ability to survive as an ecological unit. Management practices are known in broad terms, but need further development. Lack of adoption is an issue.

Appendix 8.2 B

Salinity management practices - options that will have a positive effect on salinity and may be adopted within ten years provided research, development and education/extension are implemented

Salinity management practice	Element	Feasibility of practice
Agronomic	pastures (exotic)	While some species are available, there is a need to develop this area further. New genetic material and better grazing management packages may increase water use. Strong requirement for industry links. Some of the proposed and existing species may become environmental weeds.
	salt and water logging tolerant pastures	While some species are available (eg balansa), there is a need to develop synergistic grazing management and site treatment systems further.
	phase cropping	Requires development of packages to manage annuals and perennials; feasible within current agronomic systems.
Perennial plants	lucerne	Lucerne is known to be able to reduce recharge and lower watertables. However, problems with persistence, acid soils and grazing management have limited its use. Breeding, development of forage management systems and community education may increase its use in medium and higher rainfall areas. Need to develop systems for lower rainfall soils.
	high rainfall eucalypts	Apart from bluegums (*Eucalyptus globulus*), there are other species of eucalypt (eg *Eucalyptus camaldulensis*) that could be developed to extend the range of sites suitable for pulpwood. A range of other sawlogs opportunities exist for many eucalypts.
	floriculture (exotic)	Priority for further development should be native floriculture where the State controls the full genetic resource, and there are multiplier effects to other land values.
	floriculture (native)	There are many species that could contribute to woody revegetation - the current small industry could be expanded, with appropriate resources, within ten years. This is a priority area for research and development under the blue sky options.

Appendix 8.2 B (cont)

Salinity management practices - options that will have a positive effect on salinity and may be adopted within ten years provided research, development and education/extension are implemented

Salinity management practice	Element	Feasibility of practice
	new fodder shrubs	Priority for development is the family *Acacia* (eg *A. saligna*), a species that is already being used for fodder. It is feasible to develop this species as a full fodder option within ten years with additional research and development.
	other grasses	Cocksfoot, phalaris etc development may produce a wider range of suitable perennials. Niche positions may develop for native grasses.
	salt bush	Development has occurred, need to integrate into new saltland grazing systems as a pioneer plant and as a source of supplementary feed.
	oil mallees	Oil mallees are currently being developed by CALM. It is important that the current development momentum with this group is maintained - they represent the best immediate option for a wheatbelt tree crop.
	melaleuca oils and other melaleuca products	Feasible, and should be developed along with the mallee oils. Melaleucas are also a resource for brush fencing and bean sticks (market gardening).
	fencing and firewood	Several small scale investigations of establishing and producing these products have begun in the wheatbelt. Consideration could be given to increasing the resources in this area. Plantation resources could be developed for either on-farm use or sale.
Shallow water management	various drainage systems	Options in this area have already been largely developed (see above, A). However, there is an urgent need to develop (including Quality Assurance) systems for; (i) engineering design and construction of systems, (ii) linked site and design selection criteria, (iii) methods to assess downstream effects. It is essential that land managers and their advisers are adequately informed of the best methods, designs and consequences of using drainage systems, and that it be placed in context with other treatments.

Appendix 8.2 B (cont)

Salinity management practices - options that will have a positive effect on salinity and may be adopted within ten years provided research, development and education/extension are implemented

Salinity management practice	Element	Feasibility of practice
Deep groundwater management	local aquifer pumping and local evaporation basins	Disposal of effluent to evaporation basins is widely used elsewhere and is technically sound, but only economically practical if high value assets are to be protected. However, some mining of the resultant salt has started in a small way, particularly in Victoria. It is important to test the feasibility and economics of salt harvesting.
	local aquifer pumping and local re-use of "effluent"	If pumped water has a low salinity it may be able to be re-used for saline pastures or aquiculture. However, re-use will create higher concentrations of saline runoff. Ultimately this may need to be combined with salt harvesting in some form.
Remnant vegetation protection and management	fencing, restoration and expansion	These management options are all technically feasible. However, better systems for establishing new areas and integrating existing remnants in farm operations need to be developed. Benefits of remnants are not widely known.

Appendix 8.2 C
Salinity management practices - that could become available, but research and development take longer than ten years

Salinity management practice	Element	Feasibility of practice
Agronomic	perennial pastures (native)	Local species, if domesticated and used, would prevent major weed problems. Potential species, such as Microlaena and Danthonia spp exist. R&D would be required to bring these on stream.
	perennial pastures/crops	Some research into the development of other perennial pastures is being undertaken. These may provide increased water use and productivity, and may have the potential to reduce recharge and salinity. The future of and for perennial crops in unknown.
Woody revegetation (fodder and other)	sandalwood	Currently research on the establishment and commercial viability of sandalwood in the wheatbelt is proceeding at a low level.
	speciality timbers for low rainfall areas	A small amount of research currently being conducted, particularly on goldfields species. Opportunities exist for hardwoods in furniture and processing timber trades. This work requires expansion.
	biomass fuels	Major problems are predicted for Australia in meeting future energy requirements. There is some scope for investigating the possible use of biomass fuels from woody revegetation in agricultural areas. Carbon balance issues should be considered.
	biosaline species	Development of extremely salt-tolerant plants may provide opportunities for the production of food and fibre.
Drainage (water and salt management)	biosaline engineering for agriculture	Opportunities exist to develop products from "waste" streams from naturally saline waterways (rivers, lakes) and man-made systems (evaporation ponds). Systems exist for the production of ceramics, energy (solar ponds) and food (some highly saline aquatic species, eg brine shrimp, bream). Solar powered energy systems may provide lower costs for energy dependant water management options (pumping). Market analysis, development of engineering systems and costs must be assessed before industries can be developed.