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AUSTRALIAN DRYLAND SALINITY ASSESSMENT 2000

National Land & Water Resources Audit

A program of the Natural Heritage Trust

A landscape of major water balance change

NATIONAL LAND AND WATER RESOURCES AUDIT

Providing nationwide assessments

The National Land and Water Resources Audit (Audit) is facilitating improved natural resource management decision making by:

Providing a clear understanding of the status of, and changes in, the nation's land, vegetation and water resources and implications for their sustainable use.

Providing an interpretation of the costs and benefits (economic, environmental and social) of land and water resource change and any remedial actions.

Developing a national information system of compatible and readily accessible land and water data.

Producing national land and water (surface and groundwater) **assessments** as integrated components of the Audit.

Ensuring integration with, **and collaboration** between, other relevant initiatives.

Providing a framework for monitoring Australia's land and water resources in an ongoing and structured way.

In partnership with Commonwealth, and State and Territory agencies and through its theme activities—Water Availability, Dryland Salinity, Vegetation, Rangelands Monitoring, Agricultural Productivity and Sustainability, Capacity for Change, Ecosystem Health and Information Management—the Audit has prepared:

Assessments of the status of and, where possible, recent changes in Australia's land, vegetation and water resources to assist decision makers achieve ecological sustainability. These assessments set a baseline or benchmark for monitoring change.

Integrated reports on the economic, environmental and social dimensions of land, and water resource management, including recommendations for management action.

Australian Natural Resources Atlas to provide internet access to integrated national, State and regional data and information on key natural resource issues.

Guidelines and protocols for assessing and monitoring the health and management of Australia's land, vegetation and water resources to meet the needs of all major stakeholders.

This report presents the key findings for Theme 2 **Dryland Salinity:**

Australian Dryland Salinity Assessment 2000: extent, impacts, processes, monitoring and management options.

AUSTRALIAN DRYLAND SALINITY ASSESSMENT 2000

Extent, impacts, processes, monitoring and management options

National Land & Water Resources Audit
A program of the Natural Heritage Trust

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The Commonwealth accepts no responsibility for the accuracy or completeness of any material contained in this report and recommends that users exercise their own skill and care with respect to its use.

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The Hon. Warren Truss MP
Minister for Agriculture, Fisheries and Forestry
Parliament House
Canberra ACT 2600

Senator, the Hon. Robert Hill
Minister for Environment and Heritage
Parliament House
Canberra ACT 2600

Dear Ministers

I have pleasure in presenting to you *Australian Dryland Salinity Assessment 2000*—a report of the National Land and Water Resources Audit (Audit).

This report is Australia's most comprehensive national assessment of dryland salinity and sets the context for tackling Australia's dryland salinity management issues. In partnership with the States and Territories, it collates and provides information on the distribution and impacts of dryland salinity.

The report promotes a catchment water balance approach for salinity management. It details a groundwater-based hydrogeological framework as the basis for planning, monitoring and evaluation of salinity management responses. The report concludes with information on salinity management options based on an understanding of the response-characteristics of Australia's groundwater systems.

Information on dryland salinity is being integrated with outputs from across the Audit to provide a comprehensive basis for natural resources management, supporting decisions at national, State and regional levels. This is achieved through the Audit's internet-based *Australian Natural Resources Atlas* (Atlas), presenting information from across Australia at the best available scales.

The Audit Advisory Council believes this report and supporting information on the Atlas provides a key input to the development and implementation of the Council of Australian Governments' National Action Plan for Salinity and Water Quality and looks forward to being able to continue to contribute to this and related natural resource management initiatives.

I am pleased to commend this report to the Natural Heritage Ministerial Board.

Yours sincerely

Roy Green
Chair
National Land and Water Resources Audit Advisory Council
15 January 2001

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PREFACE

This report is Australia's most comprehensive national assessment of dryland salinity. It provides a context for considering the dryland salinity management issues facing Australia. In collaboration with the States and Territories, it has provided information on the distribution and impacts of dryland salinity at a regional scale, and has identified a number of significant information and method limitations in our ability to evaluate the exact extent of the problem and the likely effectiveness of management interventions.

This report promotes a catchment water balance approach for salinity management. It proposes the adoption of a hydrogeological framework based on groundwater flow system characteristics to underpin planning, monitoring and evaluation of management responses.

Information on dryland salinity is being integrated with outputs from other themes in the National Land and Water Resources Audit (Audit) to provide a comprehensive base to support decisions at national and State levels. The economic aspects of dryland salinity will be reported as part of an integrated economic assessment of Australia's natural resources, their condition and management needs in the Capacity for Change theme report.

Focus on dryland salinity as a serious natural resource management issue in Australia has been building over the last decade through the activities of State governments and research including the National Dryland Salinity Program. This culminated in the Prime Minister's *National Action Plan for Salinity and Water Quality* that was endorsed by the Council of Australian Governments in November 2000. Outputs from the Audit's salinity program have assisted and will continue to assist in developing targeted national responses to dryland salinity. This report builds upon, complements and strengthens the range of assessments and directions documented within State strategies and national programs.

The Audit's dryland salinity activities have been undertaken as a component of the National Dryland Salinity Program, and relied heavily on the processes and networks established through that program.

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Salt: dominating the lower parts of the landscape

SUMMARY

Australian Dryland Salinity Assessment 2000: defining options

It has long been recognised that our land uses—including agricultural development—have significantly changed Australia's landscapes and natural systems. However, we have not always appreciated the magnitude of change in the soil, water and nutrient balances, the resultant degradation, the timeframe for these changes to be slowed or reversed, and the costs to the wider Australian community.

Changes to the Australian landscape have resulted in the widespread and rapidly growing problem of dryland salinity. Farmers were among the first to be affected, through salinisation of rivers and agricultural land. Biodiversity, as well as regional and urban infrastructure, such as water supply, roads and buildings are now also at risk.

Area at risk and impact

The National Land and Water Resources Audit's (Audit) dryland salinity assessment—Australian Dryland Salinity Assessment 2000—has, in collaboration with the States and Territories, defined the distribution and impacts of dryland salinity across Australia. The aggregate values presented below are the best available estimates within the limits of the methods and data used by the State, Territory and research agencies which undertook this risk assessment.

- Approximately 5.7 million hectares are within regions mapped to be at risk or affected by dryland salinity. It has been estimated that in 50 years' time the area of regions with a high risk may increase to 17 million hectares (three times as much as now).
- Some 20 000 km of major road and 1600 km of railways occur in regions mapped to have areas of high risk. Estimates suggest these could be 52 000 km and 3600 km respectively by the year 2050.
- Salt is transported by water. Up to 20 000 km of streams could be significantly salt affected by 2050.
- Areas of remnant native vegetation (630 000 ha) and associated ecosystems are within regions with areas mapped to be at risk. These areas are projected to increase by up to 2 000 000 ha over the next 50 years.
- Australian rural towns are not immune: over 200 towns could suffer damage to infrastructure and other community assets from dryland salinity by 2050.

Information and monitoring constraints

The State assessments have identified a number of significant information and method limitations in our ability to evaluate the exact extent of dryland salinity and the likely effectiveness of management responses. Although groundwater level and trend data are recognised as fundamental requirements in evaluating the size of the problem and the rate at which it is changing, there are major deficiencies in the design and coverage of groundwater monitoring networks. Even in Victoria, Western Australia and South Australia, where monitoring sites have been established, significant gaps limit our ability to evaluate effects of land use responses. Queensland and Tasmania have very limited formal groundwater monitoring systems suitable for assessing dryland salinity.

Groundwater: the key to understanding salinity

When changes occur in the landscape water balance—from tree clearing, loss of vigour in vegetation growth, changes in rainfall pattern—the amount of water entering the watertable (recharge) increases and the rising groundwater mobilises salt and brings it to the surface. Long response and lag times in groundwater level changes—often 100 years or more—mean that salinity is likely to increase even with immediate, widespread action.

In the face of an estimated three-fold increase in the area at risk of dryland salinity over the coming decades, the Audit's assessment concludes that the amount of change needed in the water balance, and therefore in land use, is substantial. The assessment also highlights that in some regions (e.g. northern Australia), protection and prevention management options are still available, implying that northern Australia has potential to avoid degradation from dryland salinity.

Management options in regions already affected by dryland salinity will need to take account of groundwater characteristics. These varying characteristics have been broadly grouped by groundwater flow systems during the Audit's program. Solutions will be based on engineering and innovative farming systems and productive use of saline resources. In many cases, management responses will involve trade-offs between land use patterns and water balance responses. Sometimes, the preferred option will be to 'buy time' to allow solutions to be developed. Engineering options are important and may be preferred for protection of key assets. Innovation and research need to seek new farming and land use systems that suit Australian landscapes.

A framework for action

Understanding the way in which groundwater responds to additional water seeping into it from the landscape, and the way in which this excess water is distributed within groundwater systems, provides the key to understanding the processes of salt mobilisation and the responsiveness of systems to change. This knowledge provides the basis for defining management options, so that investment is targeted, actions are appropriate and outcomes are measurable. The Audit's groundwater flow systems classification is based on geological and topographical characteristics, where similar recharge and discharge management activities are likely to lead to similar hydrogeological responses.

Case studies conducted in differing landscapes have provided examples of the use of the groundwater flow system framework across a range of scales. Analysis of the hydrogeological conditions and the modelled behaviour of groundwater flow systems to land use change in each of the case study catchments has confirmed that the concepts could be applied across Australia. In addition the results can also be extrapolated to give broad conclusions about the extent of change required to halt the spread of salinity, and about the lag times between the adoption of changes and evidence of salinity management.

Salinity management requires long-term, well-considered land use strategies underpinned by knowledge about soil, water and vegetation, and integrated with knowledge about groundwater systems so that an appropriate suite of actions may be taken to prevent or remedy impacts of dryland salinity. There is no single solution or quick fix.

The level of assessment and planning needed to develop solutions will depend on the value (not necessarily in dollar terms) of assets to be managed and protected. This assessment will also determine the most appropriate options. Dryland salinity is more than a management problem for landholders: it can only be done through inclusive regional planning with community, science, industry and government working together.

What else do we need to do to move forward?

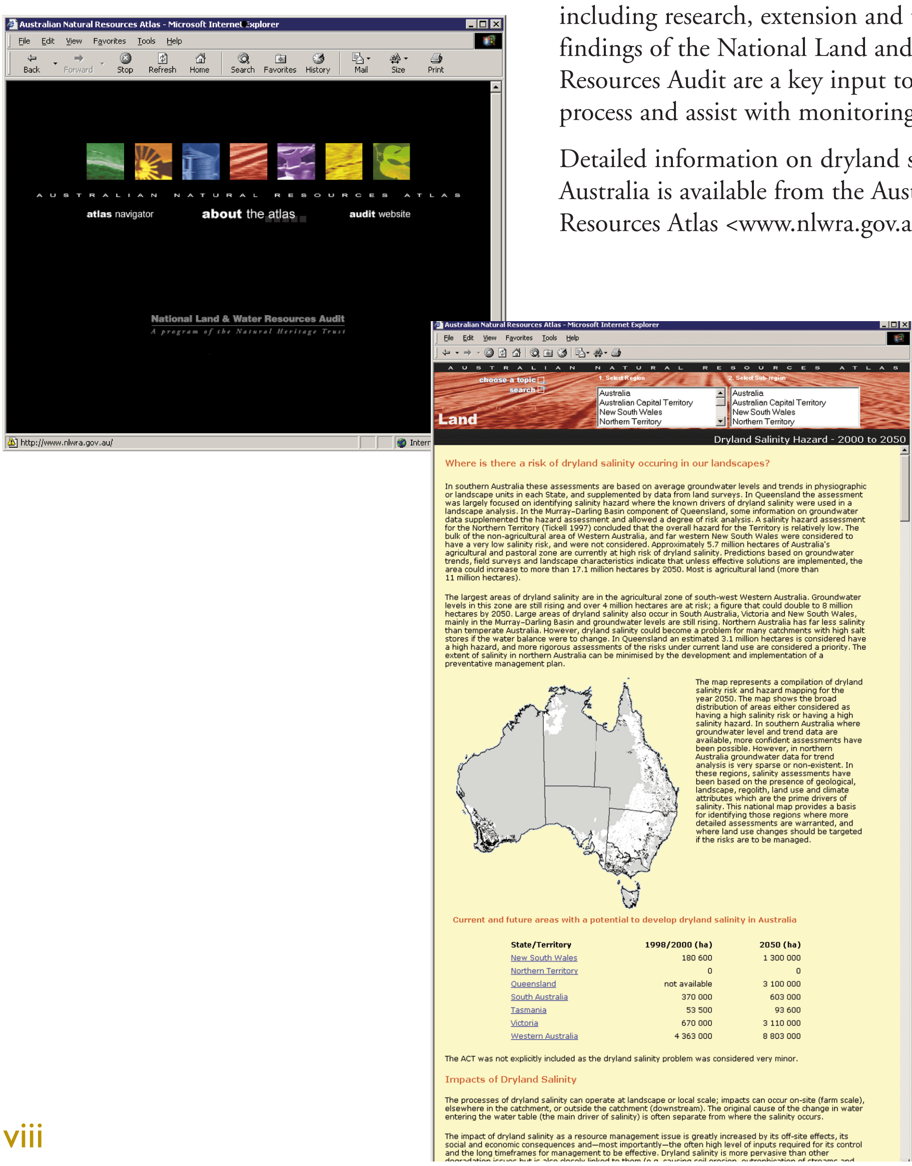
In meeting the natural resources management challenges associated with dryland salinity we need to:

- recognise that although the rate of salinisation may be able to be slowed or reversed in some areas, in others land and water resources will continue to salinise with major impacts on rural communities and terrestrial biodiversity. Consequently engineering solutions are likely to be required to protect key community assets and infrastructure;
- implement a landscape function approach to the management of on-site and off-site impacts of dryland salinity;
- support the development and use of the groundwater flow system framework both within and across States to maximise exchange of knowledge and understanding of processes, scale and type of interventions required to manage dryland salinity;
- appreciate that targets set need to be based on an understanding of biophysical processes and likely achievability;
- maintain where possible natural water balance processes;
- design new farming and land use systems that manage the salt and water balance;
- enhance existing monitoring systems to better support the assessment and evaluation of outcomes of dryland salinity management programs.

Overall, the Audit's assessment highlights the complex nature of Australia's natural resources and their response to the land use patterns we require to deliver our economic and social well-being. Dryland salinity demonstrates the integrated nature of land use and landscape, the need for our activities to be thought through in the context of Australia's biophysical assets and values, and for salinity solutions to vary, depending on the mix of community needs in any particular region.

The National Action Plan for Salinity and Water Quality agreed by the Commonwealth and States on 3 November 2000 has, as its centrepiece, community-driven action directed at salinity and water quality problems in key catchments and regions. The plan recognises the importance of knowledge and data to underpin management responses and seeks to address this through a range of capacity building activities including research, extension and training. The findings of the National Land and Water Resources Audit are a key input to inform this process and assist with monitoring outcomes.

Detailed information on dryland salinity in Australia is available from the Australian Natural Resources Atlas <www.nlwra.gov.au/atlas>.



Salt dominates the valley floors

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DRYLAND SALINITY

Two broad forms of salinity are recognised in Australia.

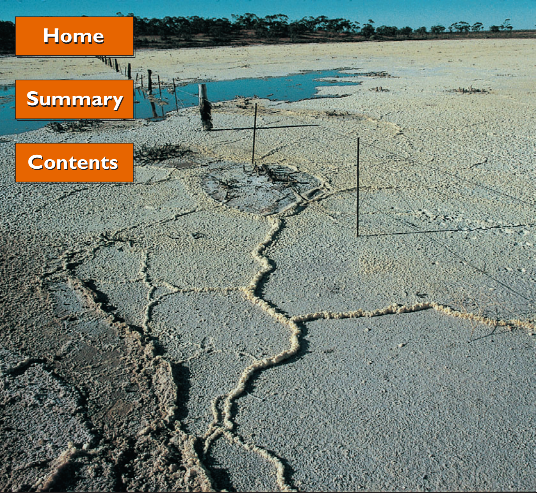
- **Primary** or naturally occurring salinity is part of the Australian landscape, and reflects the development of this landscape over time. Examples are the marine plains found around the coastline of Australia, and the salt lakes in central and western Australia.

  Salts are distributed widely across the Australian landscapes. They originate mainly from depositions of oceanic salt from rain and wind. Salt stored in the soil or groundwater is concentrated through evaporation and transpiration by plants. In a healthy catchment, salt is slowly leached downwards and stored below the root zone, or out of the system.

- **Secondary** salinity is the salinisation of land and water resources due to land use impacts by people. It includes salinity that results from watertable rises from irrigation systems—**irrigation salinity**— and from dryland management systems—**dryland salinity**. Both forms of salinity are due to accelerated rising watertables mobilising salt in the soil. There is no fundamental difference in the hydrologic process.

  Where the water balance has been altered due to changing land use (e.g. clearing of native vegetation for broad acre farming or grazing) the excess water entering the watertable mobilises salt which then rises to the land surface. Movement of water drives salinisation processes and may move the stored salt towards the soil surface or into surface water bodies.

The extent, causes and management options for irrigation salinity are well understood, and have been an important part of Murray–Darling Basin Commission activities for at least two decades. However, in most States and Territories, dryland salinity has received far less attention and resources, and has not been dealt with nationally in any systematic and coordinated manner until very recently. This report concentrates on dryland salinity in Australia.



Australian Dryland Salinity Assessment 2000 is Australia's most comprehensive dryland salinity assessment. It:

- better defines the area at risk and the impact of Australia's dryland salinity;
- projects likely increases in dryland salinity to 2050, assuming a continued rate of increase and no change to water imbalance;
- classifies hydrogeological landscapes and explains differences in responses across catchments, both in terms of developing the dryland salinity problem and the implications for salinity management;
- reports on management options and their feasibility across the differing hydrogeology of the Australian landscapes;
- highlights where trade-offs will be required between salinity management and living with salt; and
- identifies key components of a monitoring program, to track changes in salinity impact over time and evaluate effectiveness of investment in management.

The National Land and Water Audit's Australian Natural Resources Atlas—www.nlwra.gov.au/atlas—provides access to summary data and information at national and State scales as well as an access point to project documentation underpinning this summary report.

A list of contributing projects is provided in the bibliography and further information at the end of this report.

Australian Dryland Salinity Assessment 2000 was prepared in partnership with:

National Dryland Salinity Program
Supported by Land & Water Australia; Grains Research and Development Corporation; Rural Industries Research and Development Corporation; Murray–Darling Basin Commission; Agriculture, Fisheries and Forestry – Australia; National Land and Water Resources Audit; CSIRO; State Governments of New South Wales, Queensland, Victoria, Western Australia and South Australia <www.ndsp.gov.au>

New South Wales
Department of Land and Water Conservation <www.dlwc.nsw.gov.au>

Victoria
Department of Natural Resources and Environment <www.nre.vic.gov.au>

Queensland
Department of Natural Resources <www.dnr.qld.gov.au>

Western Australia
Agriculture WA <www.agric.wa.gov.au>

South Australia
Primary Industries and Resources South Australia <www.pirsa.sa.gov.au>

Tasmania
Department of Primary Industries, Water and Environment <www.dpiwe.tas.gov.au>

Northern Territory
Department of Lands, Planning and Environment <www.lpe.nt.gov.au>

Murray–Darling Basin Commission
<www.mdbc.gov.au>

Commonwealth
Bureau of Rural Sciences <www.brs.gov.au>
CSIRO Division of Land and Water <www.clw.csiro.au>

DRYLAND SALINITY IN CONTEXT

Salt concentrations in rivers affect the wildlife and vegetation

Managing dryland salinity in an integrated natural resources context

Dryland salinity is a key Australian natural resource management issue that needs to be addressed to ensure productive and sustainable land use. Dryland Salinity Assessment 2000 is a wake-up call: Australia is a vastly different continent to Europe and we need to change our European-based farming systems to work within the context of Australian soils, water resources and climate.

Dryland salinity provides us with an opportunity to integrate natural resource management into the Australian landscape and to seek new balances: in water quality and quantity, nutrients, vegetation, biodiversity, soil health, and social and economic wellbeing.

Natural resource management requires integrated solutions and therefore, integrated assessments. Australian Dryland Salinity Assessment 2000 does not just concentrate on salinity, but also contributes to the broader land and water management issues.

While this report concentrates on the area at risk of dryland salinity, there are a number of Audit themes which together explain the broader impact of dryland salinity.

Salt loads adversely affect the quality of drinking and irrigation water supplies. Excessive extraction will also reduce a river's capacity to dilute salt loads. Australia is yet to strike a balance between water available for use and water available to manage salt loads.

- The Audit's Water Availability assessment characterises and categorises Australia's water resources and provides a context for further joint management of salinity and water resources.

Salt interacts with in-stream biota, changing the ecological health of streams and estuaries.

- The condition of waterways and estuaries will be examined as part of the Audit's Ecosystems Health theme report.

Dryland salinity exacerbates soil erosion. Information about water quantity and salinity needs to be integrated with an understanding of the processes involved in sediment and nutrient movement.

- The movement of sediment and nutrients to and down Australia's river systems will be presented as part of the Audit's Agricultural Productivity and Sustainability theme report.

Salts help fine matter (e.g. suspended clay particles) to coalesce, allowing more sunlight to penetrate rivers. This, in turn, may lead to more blue–green algae blooms if suitable environmental conditions are available.

- The Audit's Australian Natural Resources Atlas details frequency of algal blooms and nutrient concentrations as part of the analysis of Australia's water quality.

Dryland salinity occurs as a result of changes in water balance following clearing of Australia's native vegetation. Protecting remaining native vegetation is a key component in any salinity management activities. The detail of pre-European vegetation gives us a basis to estimate 'natural' water balance and to select the most appropriate species for revegetation initiatives.

- The Audit's Native Vegetation Information System details the extent of remaining native vegetation and estimates vegetation type across the Australian landscape before European settlement.

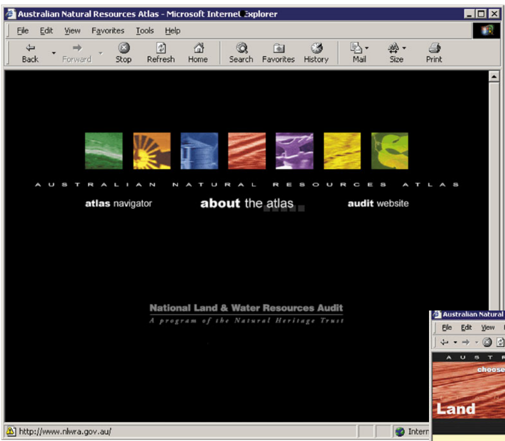
Managing dryland salinity is about changing land use and land management to re-establish the water balance. The capacity of communities to change is a key issue and will drive the rate of salinity management.

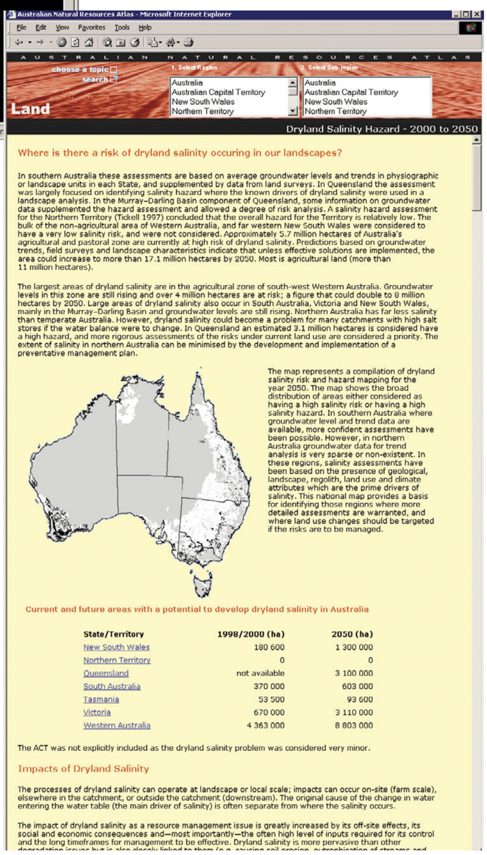
- Assessing agricultural productivity, practices and economic returns will be part of the Audit's Agricultural Productivity and Sustainability and Capacity for Change theme reports.

All natural resources management activities require sound monitoring, reporting and assessment to track progress, maximise returns on investment, and improve their application.

- Suggestions for monitoring dryland salinity within this report will be incorporated into a broader set of proposals for monitoring Australia's land and water resources in an ongoing and structured way within the Audit's Final Report, and underpinned by recommendations on database structures, maintenance and information provision and assessment within its Information Management report.

Underpinning all natural resources activities, including salinity management, is access to sound, relevant information that allows for informed debate. The Australian Natural Resources Atlas—www.nlwra.gov.au/atlas—will give Australia access to information about Australia's natural resources.





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Salt attacking house foundations

AUSTRALIA'S DRYLAND SALINITY

Although agricultural development has significantly changed Australian natural systems and landscapes, we have not always appreciated the magnitude and costs to the Australian community of this change. In 1998, the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) emphasised that dryland salinity is a particularly difficult form of degradation to manage:

> *The time scales over which salinity establishes itself, spreads, and has its effects can be long, but once established it can be very difficult or impossible to contain or reverse. As a consequence, salinity must inevitably continue to get worse in Australia as a result of land use decisions already made.*
>
> PMSEIC 1998

The consequences of dryland salinity are wide-ranging. They include impacts on soils and agricultural production, stream quality, remnant vegetation, and riparian zones and wetland areas. Salinity is degrading rural towns and infrastructure, crumbling building foundations, roads and sporting grounds. In October 2000, the Prime Minister announced a *National Action Plan for Salinity and Water Quality in Australia* (Commonwealth of Australia 2000) to be supported and implemented jointly with the States and Territories through the Council of Australian Governments process. This action plan identifies priority actions to address dryland salinity and deteriorating water quality in key catchments and regions. The plan calls for

> *… decisive salinity and water quality related action to ensure that our land and water management practices will sustain productive and profitable land and water uses as well as our natural environments.*
>
> Commonwealth of Australia 2000

Hazard/risk assessments

This report provides a synthesis of more detailed information presented in the individual State reports on areas at risk and impacts of dryland salinity. All these reports are available on the Audit Atlas website.

A collaborative program between the National Land and Water Resources Audit (Audit), and State and Territory agencies has produced assessments of extent of dryland salinity risk or hazard at the regional scale across Australia (Table 1). The assessments included information from the recent dryland salinity water resources audit carried out by the Murray–Darling Basin Commission (MDBMC 1999).

The definitions of 'hazard' and 'risk' that are most appropriate to the work carried by the Audit are:

'hazard' anything that can cause harm to an asset (e.g. salt loads in lands where groundwaters have potential to rise);

'risk' estimation of the expected amount of harm that will occur to the asset when a condition occurs (e.g. shallow saline groundwaters under cropland).

'Risk' and 'hazard' are often used as equivalent terms in common language. For ease of reading, 'risk' has been used in narrative text of this document.

Methods

Regional-scale, dryland salinity risk or hazard assessments were undertaken by State agencies using:

- information on groundwater levels and trends;
- known incidence of salinity;
- soil characteristics; and
- topography.

For those States with data on groundwater levels and trends, land units with groundwater within 2 m of surface, or within 2 to 5 m and with *well demonstrated* rising watertables (except for New South Wales) were classed as being at high risk of dryland salinity. A groundwater level of 2 m was selected in line with documentary evidence that where levels are in the 1 m to 2 m levels, salinisation of the soil occurs adversely affecting crops and native vegetation (Nulsen 1981, Talsma 1963).

The assessments used existing data held by States and were constrained by available data and financial resources, and timeframes. The assessments exposed a number of limitations in the groundwater data quality and coverage across States. Difficulties encountered in applying the same landscape analysis approach across States meant that a range of methods and scales were adopted.

Even where there were perceived to be good quality groundwater data (e.g. in Victoria, south-west Western Australia), the forecasted groundwater levels to 2020 and 2050 are based on straight-line projection of recent trends in groundwater levels. Due to inadequacies in current methods, accurate groundwater surfaces cannot be developed with the existing distributed data. This was also an outcome of the Audit's Salt Scenarios 2020 project focused on the Great Southern region of Western Australia.

Where sufficient groundwater level and trend data were available as in Western Australia, South Australia, Victoria and New South Wales, the assessments have been accepted as *risk* assessments, as the drivers of dryland salinity have been identified as operating for some time and there is confidence in the understanding of the current and future impacts of shallow water tables.

Where data on groundwater levels and trends are sparse such as in Queensland and Tasmania, assessments were based more on knowledge of land attributes and dryland salinity incidence. Groundwater data were used where available to provide extra confidence in the assessments. In these States the assessments were considered to be *hazard* assessments as there is less knowledge about the current and likely impacts of shallow watertables on dryland salinity. The existing hazard assessment of the Northern Territory was based mainly on vegetation type, aquifer attributes, landscape and depth of weathering attributes, rather than any trends in groundwater.

The Audit's assessment using groundwater data has identified areas where dryland salinity impacts from shallow groundwaters are known or expected to occur. The hazard assessments have identified those areas where dryland salinity could potentially exist given changes in land use that affect the water balance. This information should not be interpreted as actual areas affected since the assessments are likely to overestimate areal extent particularly in dissected (hilly) landscapes. Rather they identify areas or regions within which dryland salinity occurs or could occur.

Groundwater trend analysis at the scales used will only provide an overview. It is important to recognise that the risk analyses and conclusions presented in this report provide State-wide appreciations of the area at risk and impacts of dryland salinity. Trends at the local level (farm and paddock) can be ascertained from individual bores whose location with respect to landscape position and hydrogeology is well known.

Within these limitations these assessments have for the first time provided an appreciation of dryland salinity area at risk and impacts based on analysis of existing data (particularly groundwater) across all the major agricultural areas of Australia. The assessments have been presented together in Table 1 in order to give an overall picture of dryland salinity in Australia.

Area at risk

Approximately 5.7 million hectares of Australia's agricultural and pastoral zone have a high potential for developing dryland salinity through shallow watertables. Predictions based on groundwater trends, field surveys and landscape characteristics indicate that unless effective solutions are implemented, the area could increase to 17 million hectares by 2050 (Table 1, Figure 1). Most is agricultural land (more than 11 million hectares).

Dryland salinity coincides with those agricultural zones in which natural vegetation has been replaced—often many years ago—with land use systems that do not use water to the same extent as the natural vegetation.

The largest areas of dryland salinity are in the agricultural zone of south-west Western Australia. Groundwater levels in this zone are still rising and over 4 million hectares have areas at risk; an area that could double by 2050. Large areas are also at risk of dryland salinity in South Australia, Victoria and New South Wales, mainly in the Murray–Darling Basin where groundwater levels are still rising.

An existing salinity hazard assessment for the Northern Territory (Tickell 1994b) concluded that the overall hazard for the Territory is relatively low. No further assessment was carried out as part of this Audit. Also the bulk of the non-agricultural area of Western Australia, and far western New South Wales were considered to have a very low salinity risk, and were not included.

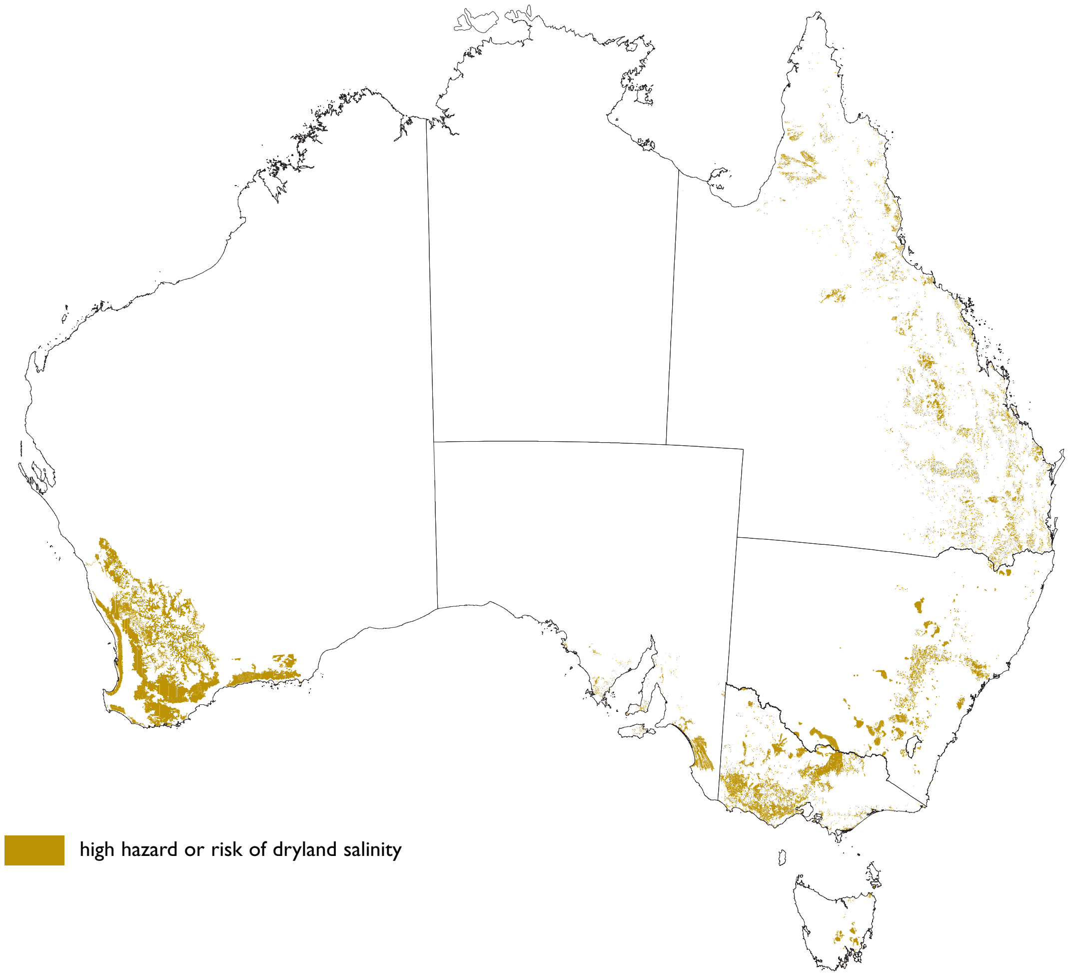
Although northern Australia has far less dryland salinity than temperate Australia, dryland salinity could become a problem for many catchments with high salt stores if water balance changes led to groundwater rises. In Queensland an estimated 3.1 million hectares is considered to have a high hazard, and more rigorous assessments of the risks under land use are a priority. The extent of salinity in northern Australia can be minimised by preventive management, maintaining water balance by protecting and ensuring vigour in native vegetation.

Table 1. Areas (ha) with a high potential to develop dryland salinity in Australia.

State/Territory*	1998/2000	2050
NSW	181 000	1 300 000
Vic	670 000	3 110 000
Qld	not assessed	3 100 000
SA	390 000	600 000
WA	4 363 000	8 800 000
Tas	54 000	90 000
Total	**5 658 000**	**17 000 000**

* The Northern Territory and the Australian Capital Territory were not included as the dryland salinity problem was considered to be very minor.

Figure 1. Forecasted areas containing land of high hazard or risk of dryland salinity in 2050.



This map represents a compilation of dryland salinity risk and hazard mapping for the year 2050. The map shows the broad distribution of areas considered as having either a high salinity risk or a high salinity hazard. In southern Australia where groundwater level and trend data are available, more confident assessments have been possible. However, in northern Australia groundwater data for trend analysis are very sparse or non-existent. In these regions, salinity assessments have been based on the presence of geological, landscape, regolith, land use and climate attributes which are the prime drivers of salinity. This national map provides a basis for identifying those regions where more detailed assessments are warranted, and where land use changes should be targeted if the risks are to be managed.

The bulk of non-agricultural areas in Western Australia, South Australia and western New South Wales were considered to have a very low salinity risk and were not assessed.

Erosion and corrosion: typical of salted landscapes

Impacts

The processes of dryland salinity can operate at landscape or local scale; impacts can occur on-site (farm scale), elsewhere in the catchment or outside the catchment (downstream). The original cause of the change in water entering the watertable (the main driver of salinity) is often distant from where the salinity occurs.

Dryland salinity as an agent of degradation

The impact of dryland salinity as a resource management issue is greatly increased by its off-site effects, its social and economic consequences and—most importantly—the often high level of inputs required and the long timeframes for management to be effective. Dryland salinity is more pervasive than other degradation issues but is also closely linked to them (e.g. causing soil erosion, eutrophication of streams and loss of riparian zone vegetation). Dryland salinity is difficult to manage because of the lasting nature of its effects on soil and water resources, and on the stability of ecosystems.

The main impact of increasing salinity at the farm level is loss of production and income. Other on-farm effects include the decline in capital value of land, damage to infrastructure, salinisation of water storage, loss of farm flora and fauna, and loss of shelter and shade. These effects are magnified at the regional level, where they have a substantial impact on public resources such as biodiversity, water supplies and infrastructure.

Some of the assets at risk as a consequences of shallow watertables are listed in Table 2, with estimates of their impact predicted to 2050.

Table 2. Summary of assets in areas at high risk from shallow watertables or with a high salinity hazard.

Asset	2000	2020	2050
Agricultural land (ha) [1]	4 650 000	6 371 000	13 660 000
Remnant and planted perennial vegetation (ha) [2, 5]	631 000	777 000	2 020 000
Length of streams and lake perimeter (km) [2]	11 800	20 000	41 300
Rail (km)[2]	1 600	2 060	5 100
Roads (km)[2]	19 900	26 600	67 400
Towns (number)[3]	68	125	219
Important wetlands (number) [1, 4]	80	81	130

1 Data from all States, Qld only for 2050.
2 Data from WA, SA, Vic and NSW, Qld only for 2050.
3 Data from WA, SA, Vic and NSW.
4 Including Ramsar wetlands.
5 Much of the remnant and perennial vegetation reported for each State occurs on agricultural lands.

Water resources at risk

The most significant off-site impact of dryland salinity is the salinisation of previously fresh rivers. This affects the supply of drinking and irrigation water, with serious economic, social and environmental consequences for rural and urban communities (e.g. in Western Australia, many of the surface water resources are already too saline for domestic use and further deterioration will challenge future supplies).

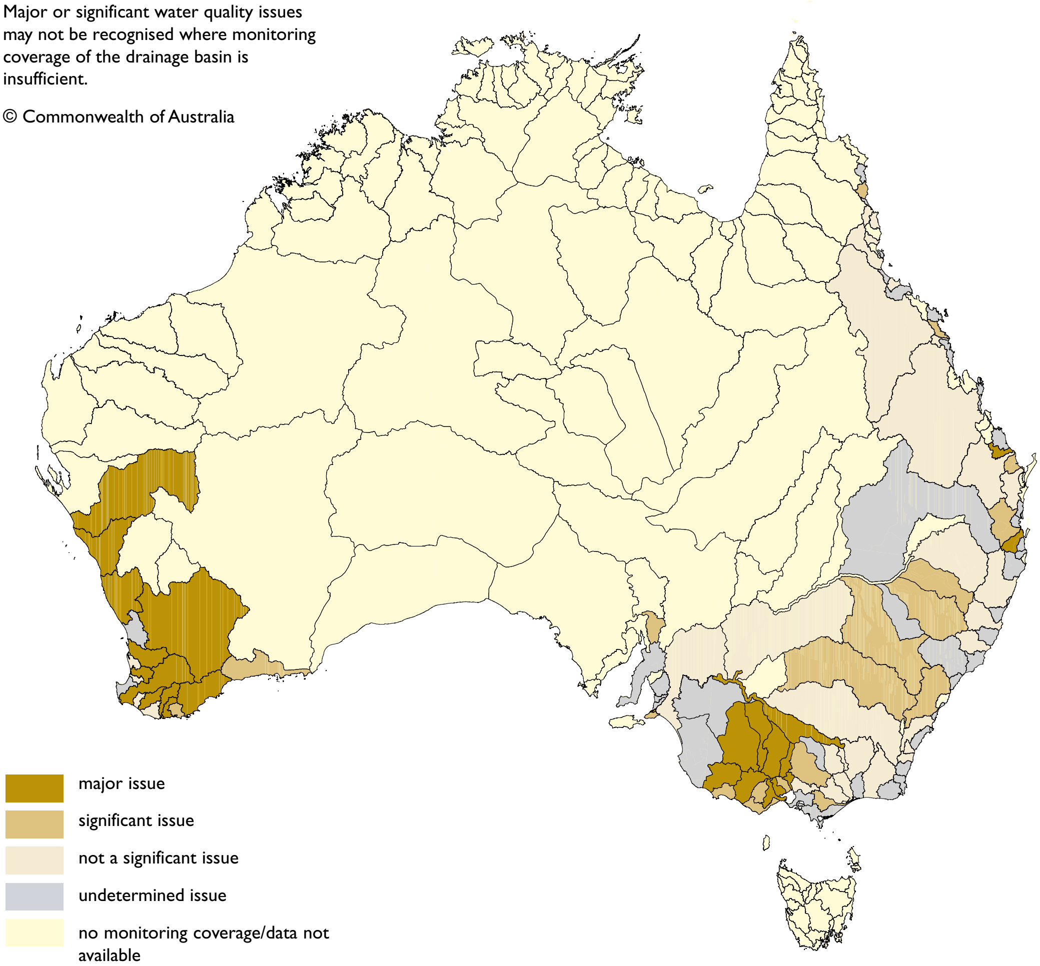
Increased salt concentrations also change the habitats of aquatic fauna in wetland, stream and riparian zone systems.

- Predictions from Western Australia show that the length of streams affected by salinity may double over the next 50 years, posing risks for riparian zones and water quality. Surface water resources in the south-west of the State are likely to become more saline.
- In Victoria, a possible three-fold increase in the length of stream or perimeter of reservoir, lake or wetland located in areas of shallow watertable is predicted over the coming 50 years. If these changes are realised, increased saline discharge could be expected into streams and surface water bodies.
- In South Australia, where water resources on the Lower Eyre Peninsula and Kangaroo Island have been degraded by salinity, there is little opportunity for increased industrial, mining or irrigation water supplies. This may have serious consequences for regional development in these areas.
- Nationally, the predicted deterioration in the quality of Murray River water indicates the magnitude of the problem. The salinity audit of the Murray–Darling Basin (MDBC 1999) suggested that in the absence of remedial action, the median salinity in the Murray River at Morgan was estimated to increase by about 25% over the next 50 years as a result of increased salt inflows from irrigation and dryland districts. Stream salinity in the Murray exceeds World Health Organization levels for potable water for about 10% of the year. Salinity levels in the Murrumbidgee River are increasing at between 0.8% and 15% each year, depending on where measurements are made.
- The Murray–Darling Basin Commission Salinity Audit also suggests that in the upper part of the Basin, the Macquarie, Namoi, Bogan, Lachlan and Castlereagh rivers will exceed the 800 µS/cm (sometimes referred to as EC units) threshold for water within the next 50 years. Some will also exceed the 1500 µS/cm threshold for irrigation within 100 years.

A high correlation between major areas of dryland salinity and areas where the water quality guidelines have been exceeded also occurs (see Figure 2).

Figure 2. Exceedance of salinity guidelines.

Major or significant water quality issues may not be recognised where monitoring coverage of the drainage basin is insufficient.



To compile an overview of surface water salinity guideline exceedances within Australia's river basins, the following definitions were used:

- 'major' issues occurred where guideline exceedances were calculated to occupy greater than a third (33%) of a basin area;
- 'significant' issues occurred where guideline exceedances were calculated to occupy greater than 5% but less than 33% of a basin area;
- 'not significant' issues occurred where monitoring coverage was greater than 50% of a basin area; and observed guideline exceedances represented less than 5% of a basin area.
- 'undetermined' issues occurred where monitoring coverage was less than 50% of a basin area; and observed guideline exceedances represented less than 5% of a basin area.

For more detailed information please refer to *Australian Water Resources Assessment 2000* (NLWRA 2001).

Road damage: a high cost reality for salinity

Agriculture

Broadacre cereal crops and traditional pasture species grown in Australia do not tolerate salt and are seriously affected when salts concentrate within the root zone. Total loss of crop and pasture production occurs where groundwaters are close enough to the surface to discharge or concentrate salts; losses may be restricted to reduced yields where groundwater is deeper.

The assessment has indicated that dryland salinity from shallow watertables potentially threatens production from 4.6 million hectares of agricultural land. Under current land use systems and climate, this is expected to at least double by 2050. These estimates also include some areas—mainly in the temperate zone—with persistent waterlogging from shallow watertables. Although salt is ubiquitous in landscapes in agricultural areas, it is acknowledged that not all of these waterlogged lands will become saline. Much of the area at risk is Australia's most productive land. The greatest impacts are in the Temperate Semi-arid Slopes and Plains agro-ecological region (Williams et al. in press) which includes the wheat–sheep belt in south-west Western Australia. Significant areas of salinity also occur in the crop–pasture zones of New South Wales, South Australia and Victoria. Major irrigation areas of the Murray–Darling Basin will be affected by the predicted increases in salt concentrations. The loss of productive lands places a burden on remaining lands. Aggregate productivity can only be maintained by increasing production from unaffected lands and/or developing integrated systems that include saltland production. Higher-yielding crops and additional agricultural inputs are seen as part of the solution but come with their own risks. Innovative land use systems are also seen as part of the solution, but these are still in very early stages of identification and development.

Infrastructure

Large decreases in the lifespan of road pavement occur when groundwater levels rise to within 2 m of the pavement surface. Salt also destroys the properties of bitumen and concrete structures. Road and bridge damage caused by shallow, saline groundwater is a major cost at all levels of government.

- Estimates are that high watertables potentially affect about 34% of State roads and 21% of national highways in south-west New South Wales, with damage costing $9 m each year for classified roads (Douglas 1997).
- Main Roads Western Australia estimated that in 1997, salinity affected 500 km of main roads and that this was likely to double within 20 years (McRobert et al. 1997).

Structures associated with communication and gas pipelines are subject to a similar fate. Wagga Wagga is one of the worst affected towns in New South Wales, experiencing salinity-induced damage to roads, footpaths, parks, sewage pipes, housing and industry (Bugden 1997). Salinity is also present in other provincial cities and towns in New South Wales and Victoria (e.g. Dubbo, Forbes, Cowra, Booroowa, Bendigo) as well as Western Sydney.

Predictions suggest that approximately 30 rural towns in Western Australia will be threatened by rising saline watertables by 2050, leading to damage to roads, recreation facilities and buildings; and difficulties with public utilities such as water supplies and waste management systems. In Victoria, predictions are that more than 60 towns will be at risk from shallow watertables.

Increased flood risks are also a consequence of shallow watertables in Western Australia (Campbell et al. 2000), and this is resulting in increased flood damage to roads, fences, dams, agricultural land and wetlands.

CASE STUDY: Merredin town site, Western Australia

Groundwater pumping and desalination project

Merredin is a regional centre in Western Australia's eastern wheat belt. Rising watertables and salinity have concerned the local community and authorities for at least 15 years. Through the State's Rural Towns Program, the Merredin town site has become the subject of detailed groundwater investigations. Recent test pumping results and computer groundwater modelling suggest that lowering the watertable by pumping would be an effective salinity control measure.

The rising saline watertable threatening the town site could be turned into a resource by desalination for drinking water. This could then be used to supplement the town water supplied from Mundaring Weir via the Kalgoorlie pipeline.

Results of groundwater investigation and modelling

Modelling has shown that to protect the whole town, nine bores each producing 50 kL/day would be required to keep groundwater levels at a safe depth.

Watertables now 2.5 to 3.0 m below ground would be lowered, effectively controlling groundwater levels and salinity under about 15 ha of the Merredin central business area. Two recently installed production bores are being used to draw 100 kL/day of moderately saline (30 000 µS/cm, or approximately half seawater quality) groundwater from under the town.

Merredin pilot project

A twelve-month joint pilot project involving Agriculture Western Australia, the Water Corporation and the Merredin Shire, and funded by the State Salinity Council's Community Support Scheme 2000 has begun.

Two hectares of evaporation ponds are to be located about 4 km west of the town centre and will dispose of the water produced by the two bores. A desalination plant adjacent to the evaporation ponds will produce potable water from 10% of the supply. This desalinated water will supplement the town supply via a Water Corporation reservoir. Discharge water from desalination will be returned to the evaporation basin.

Using some of the groundwater as it is pumped to the ponds reduces the volume for disposal by evaporation. This provides considerable economic advantages in both production of potable water and the reduction in size of the evaporation basin required.

The project is a double winner—pumping groundwater will alleviate the salinity risk, and will provide a source from which drinking quality water can be produced. Supplementing the town water supply will enable residents to reduce their dependency on water from the pipeline.

If successful, an expanded and longer-term scheme will be installed in Merredin. Similar schemes may then be employed in other salt-affected towns in Western Australia.

Macquarie Marshes: a biodiversity asset to be protected

Biodiversity

The greatest threat posed by dryland salinity to biodiversity is from the loss of habitat—both on land and in water. Dryland salinity has severely affected many areas in riparian zones because they occupy the lowest parts of the landscape where much of the saline groundwater is released to the surface. The natural vegetation of such areas has been destroyed or damaged, and this is causing major changes to the landscape and its biodiversity, including destruction of remaining natural habitat in many agricultural areas and fragmentation of wildlife corridors.

- In Western Australia, at least 1500 plant species will suffer from dryland salinity, with 450 of these possibly subject to extinction. Fauna species are likely to be reduced by 30%.

The impacts of salinity on aquatic habitats have been less well studied and are more difficult to assess than those on land-based habitat such as woodlands and riparian vegetation.

- Approximately 80 important wetlands including those of national and international significance have been affected or are at risk of damage from dryland salinity in all States. Information on the full extent and degree of impacts is very sparse. In the Murray–Darling Basin, major wetlands of the Macquarie Marshes, Great Cumbung Swamp, Avoca Marshes and Chowilla Floodplain will suffer impacts from rising salinity.

Remnant vegetation, plantation forest and areas rehabilitated to perennial vegetation in Western Australia, Victoria, South Australia and New South Wales (Table 3) are under threat due to rising watertables. The biggest threat in South Australia is to coastal lowlands of the upper south-east. In Victoria and New South Wales the threats are mainly to remnant and planted vegetation in agricultural lands.

Table 3. Remnant vegetation and plantation forest at risk (ha).

State	Current	2020	2050
NSW	7 000	32 700	81 000
Vic	6 000	11 800	24 300
Qld	n/a	n/a	92 000
SA	18 000	22 000	25 000
WA	600 000	710 000	1 800 000
Total	**631 000**	**776 500**	**2 022 300**

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Costs

The full costs of dryland salinity are extremely difficult to estimate and separate from the costs incurred from other types of degradation. Remedial and future costs of dryland salinity have been included in an economic assessment across a range of degradation issues. These will be presented as part of the Audit's Capacity for Change theme report in 2001.

Under the National Dryland Salinity Program, comprehensive guidelines for estimating costs for the range of affected stakeholders have been developed for agriculture, water and infrastructure (Wilson 1999). Estimation of costs associated with losses in biodiversity is complex and methods are not well developed. Preliminary results from a recent study for the Murray–Darling Basin Commission in eight priority catchments (Wilson 2000, Ivey ATP 2000) indicate that salinity costs to farmers, local government and government agencies are approximately $251 m a year (Table 4). Further research is being conducted by Wilson and Ivey ATP to refine these preliminary estimates, and these results should be available in March 2001.

Another recent study on financial costs to local government from dryland salinity (Spiller Gibbins Swan and SMEC 2000) for the National Dryland Salinity Program has predicted that if dryland salinity is left unchecked, it will become a major burden on local government finances. Salinity will degrade infrastructure requiring increasing proportions of rate revenue to be allocated to repair and replacement costs. Loss of land value will also reduce local government's ability to raise rate revenue.

Table 4. Total equivalent annual costs to all stakeholders in eight priority catchments in the Murray–Darling Basin (Wilson 2000b).

	Lower estimate ($m/yr)	**Upper estimate** ($m/yr)	**Best estimate** ($m/yr)
Local government	-	-	14.69
Households	41.03	139.23	90.13
Businesses	8.45	8.96	8.71
State government agencies & utilities	-	-	16.31
Environment	?	?	?
Agricultural producers	-	-	121.80
Total	**202.28**	**300.99**	**251.64**

Conclusions on the constraints to the national assessment

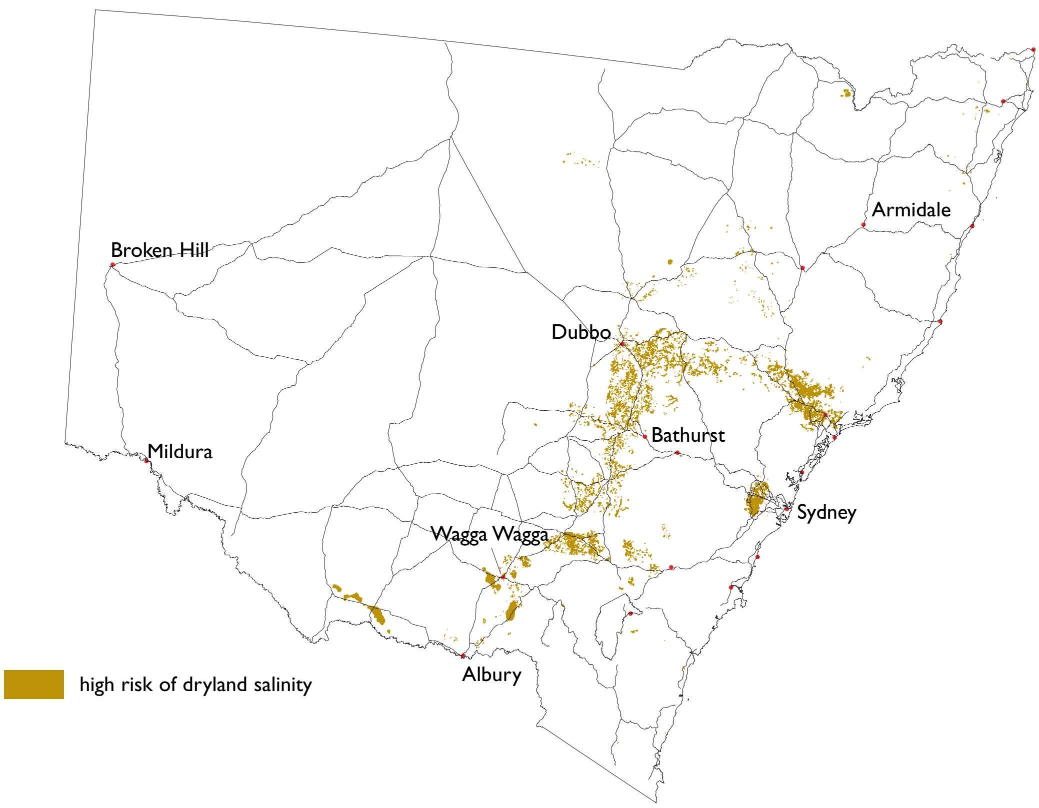
- Coverage of this assessment was constrained to the agricultural regions of Western Australia, South Australia, Victoria and Tasmania; and to the eastern regions of the Murray–Darling Basin area in New South Wales; the hazard assessment in Queensland covered the whole State.
- The issues of reporting scale, monitoring bore distribution and density, data quality and availability need to be recognised when interpreting the results of this national assessment. The assessments undertaken by the Audit provide sufficient information to target more detailed regional activities and to scope the impacts of salinity. There are insufficient data to *precisely* determine dryland salinity outbreak/incidence across Australia. Comparisons between States of 'area at risk' should not be undertaken because of the differences in assessment methods.
- The coverage of groundwater data in New South Wales, Queensland, Tasmania and South Australia is inadequate or insufficient as the prime indicator for assessing dryland salinity risk. Data gaps in other States are also significant.
- Assessment of the impacts of dryland salinity and the costs of salinity management have been constrained considerably by the data inadequacies identified in the Audit, and these need to be addressed for future audits.

NEW SOUTH WALES

Approximately 180 000 ha of land have shallow watertables or are affected by dryland salinity in New South Wales. Over 90% occurs in five catchments—the Murray, Murrumbidgee, Lachlan, Macquarie and Hunter rivers. The Hunter and Hawkesbury–Nepean river catchments have the most extensive areas of existing dryland salinity or shallow groundwaters of New South Wales in coastal catchments.

Within the Murray–Darling Basin, the area predicted to be at risk will increase from approximately 152 000 ha to 1.3 million hectares by 2050, a greater than eight-fold increase.

Figure 3. Dryland salinity risk in New South Wales 2000.



Areas of risk are based on groundwater levels and air photo interpretation. The merged data, at a nominal scale of 1:250 000, show actual areas where dryland salinity or watertables less than 2 m have been measured. For the extent map, every delineated area is underpinned by either air photo data or by one or more groundwater bores. Therefore, the area at risk is regarded as conservative due to limitations in the spatial coverage of air photo and bore data. A number of techniques to spatially extrapolate these data to infer potential areas at risk were trialled but were considered scientifically or statistically inadequate. Estimates of impacts are based on areas at risk having groundwater levels of less than 2 m. An impact assessment based on groundwater less than 5 m and rising was considered inappropriate. Total areas affected with groundwater less than 5 m and rising have been presented, but only for improved consistency with other States.

Coastal catchments are not represented in the prediction for 2050 due to the paucity of groundwater data on which to make the estimates.

Figure 4. Dryland salinity risk in New South Wales 2050.

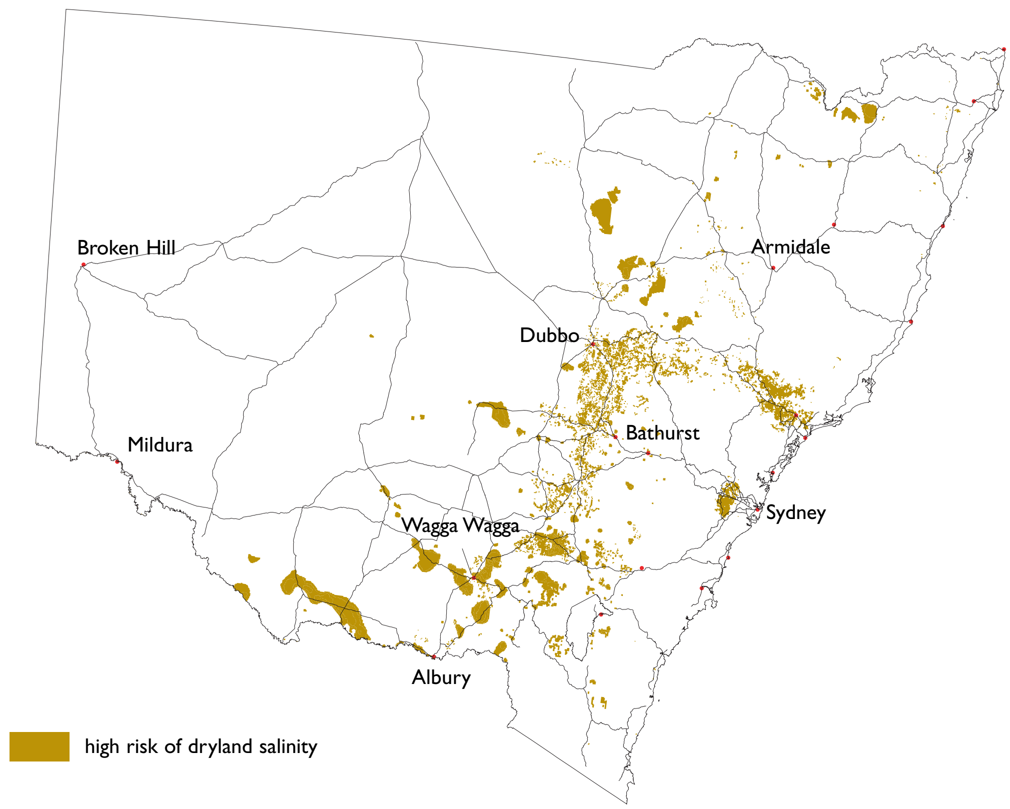


Table 5. Estimated areas (ha) with depth of watertable less than 2 m under current conditions and year 2020 and year 2050 scenarios for major catchments of the Murray–Darling Basin and coastal catchments.

Catchment	2000	2020	2050
Lake Hume	127	3 973	19 254
Murray	39 526	168 978	293 191
Murrumbidgee	58 098	286 848	469 500
Lachlan	19 793	38 845	153 264
Macintyre	3 800	25 500	67 224
Gwydir	0	0	2 973
Namoi	2 896	4 288	27 837
Castlereagh	1 197	12 005	174 666
Macquarie	25 072	36 767	90 848
Richmond	155	n/a	n/a
Clarence	91	n/a	n/a
Bellinger	27	n/a	n/a
Manning	34	n/a	n/a
Hunter	22 954	n/a	n/a
Hawkesbury–Nepean	4806	n/a	n/a
Georges–Cooks	13	n/a	n/a
Deua	11		
Total	**180 600**	**579 224**	**1 300 807**

n/a not available

Table 6. Estimated areas (ha) affected by depth to less than 5 m with a rising watertable trend for eastern Murray–Darling Basin catchments.

Catchment	2000	2020	2050
Lake Hume	3 973	12 999	37 496
Murray	168 978	227 187	293 514
Murrumbidgee	156 319	483 300	997 058
Lachlan	72 726	153 105	294 524
Macintyre	24 259	63 871	127 385
Gwydir	661	10 024	24 169
Namoi	10 244	20 427	57 528
Castlereagh	12 015	110 396	243 245
Macquarie	47 548	106 856	324 974
Total	**496 722**	**1 188 163**	**2 399 892**

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The best available estimates of rates of groundwater rise indicate that by 2020 rising watertables will occur in large areas of the Murrumbidgee and Murray catchments. By 2050, large areas of the Lachlan, Castlereagh and Macintyre catchments will also be affected (Tables 5 & 6).

Assuming no change in management and a continuation of similar climate variability to that observed during the assessment period, salt loads are predicted to increase during the next 50 years for many catchments (Table 7). The most marked increases in total salt loads for the major inland rivers in New South Wales are predicted for the Lachlan, Murrumbidgee and Namoi Rivers. The Bogan, Macquarie and Namoi catchments showed the largest increase in salinity (e.g. water salinity in the Bogan River is predicted to rise from its current level of approximately 700 µS/cm electrical conductivity to almost 2000 µS/cm in 2050; the Macquarie River rises from approximately 600 to 1700 µS/cm over the period). These predicted values exceed the World Health Organization's recommended limit for potable drinking water (800 µS/cm).

Table 7. Redistribution of salt load in the landscape by catchment.

Catchment	**Median salt load (tonnes per year)**		
	2000	2020	2050
Macintyre at Mungindi	68 000	68 000	68 000
Gwydir near Collarenebri	6 600	7 000	8 500
Namoi at Goangra	50 000	81 000	100 000
Barwon–Darling at Menindee	132 500	215 000	265 000
Castlereagh at end-of-valley	18 400	20 100	36 500
Macquarie at Carinda	32 100	65 500	89 000
Bogan at Gongolgon	24 600	48 000	63 500
Lachlan at Forbes	234 800	290 500	428 300
Murrumbidgee at Balranald	139 000	166 500	180 500

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Table 8. Key assets at risk from shallow watertables within the catchments of the Murray–Darling Basin and the coastal catchments of the Hunter and Hawkesbury–Nepean rivers*, New South Wales.

Assets	2000	2020	2050
Cropping land (ha)	28 700	114 445	223 658
Forests (ha)	540	15 348	34 507
Horticulture land (ha)	1000	1 913	4 780
Managed protection areas (ha)	130	186	744
Nature conservation areas (ha)	2400	9 450	35 502
Pasture land (ha)	132400	412 125	927 171
Remnant vegetation (ha)	5 300	17 370	46 514
Built-up areas (ha)	1 182	2 209	3 646
Towns (number)	38	82	125
Highways (km)	130	331	534
Major roads (km)	110	298	701
Minor roads (km)	700	1 959	3 615
Railways (km)	100	226	416
Bridges (number)	20	22	43
Wetlands (directly affected) (number)	9	1	2

* Data for the Hunter and Hawkesbury–Nepean only for 2000.

- Groundwater trends are dominated by rising or stable trends. No groundwater flow system under dryland agricultural systems has a significant falling trend.
- Large areas of the Western Slopes, the Hunter Valley and the Sydney Basin already have saline groundwater within 2 m of the surface.
- Within the Murray–Darling Basin, areas affected by shallow watertables will increase four-fold over the next 20 years, and eight-fold over by 2050.
- Of the 152 000 ha of land at risk from shallow groundwater within the Murray–Darling Basin, 93% is agricultural land.
- The area of agricultural land within the Murray–Darling Basin that is affected by shallow watertables will increase from the current 142 000 ha to almost 1.2 million hectares by 2050.

- Forecasted scenarios indicate that areas of conservation and remnant vegetation affected by shallow watertables will increase twelve-fold over the next 50 years.
- Areas of forest affected by shallow watertables could potentially increase seventy-fold over the next 50 years.
- In-stream saltloads are forecast to increase by at least a factor of two in most Murray–Darling Basin catchments by 2050. In some catchments, it is predicted that river EC levels will more than exceed international drinking water guidelines.
- An estimated 954 ha of built-up areas within the Murray–Darling Basin are affected by shallow watertables. This could increase to over 3600 ha by 2050.

Key issues

- Development of acceptable and achievable performance targets for major catchments contributing to dryland salinity will be a major challenge. This will require very considerable technical and process support to regional community groups.
- Development of economically viable and socially acceptable management options for many areas will be extremely difficult because of the nature of the groundwater systems controlling the salinity.

Government responses

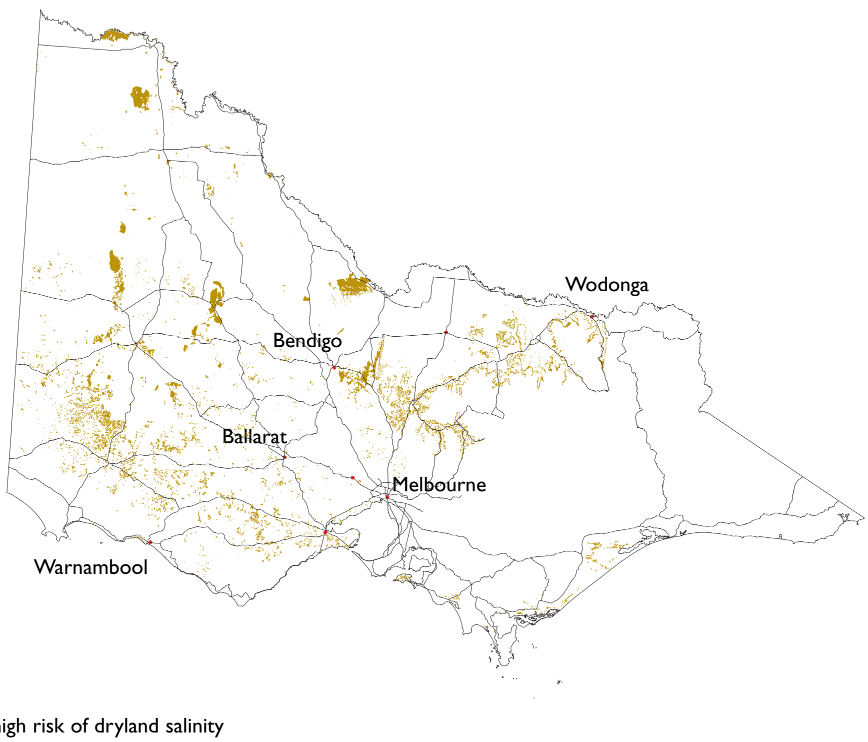
The New South Wales Government released its *State Salinity Strategy* in August 2000. The strategy provides an integrated framework for salinity management in New South Wales. It advocates a shared responsibility involving land managers, conservationists, Aboriginal communities, scientists, businesses and all levels of government. Key tools are:

- development of end-of-valley salinity targets that reflect the salinity levels the community is prepared to accept and can afford to live with;
- establishment of market-based solutions to encourage strategic investment and provide land managers with an incentive to manage their properties for specific environmental outcomes, such as reduced salinity;
- introduction of a Salinity Business Development Program to encourage emerging industries that can use saline land productively;
- better use of regulatory tools (e.g. incorporating salinity impact assessment into the clearing application approval process, water licensing and environmental planning instruments);
- improvement in the ability of front-line staff to provide advice to land managers;
- investment in upgrading data and analytical tools, and in ensuring that information is user-friendly and accessible;
- undertaking and facilitating research into land use systems that minimise recharge, use of saline-affected land and water, impacts of salinity on natural ecosystems and social and economic issues; and
- improvement of the focus of catchment management planning systems through catchment management boards to manage for change at the appropriate geographical scales.

VICTORIA

The area predicted to be at risk from shallow saline watertables is approximately 670 000 ha. This could increase to over 3 million hectares within 50 years. Between 8% and 18% of the State's agricultural land is predicted to fall into the high salinity risk category, with up to a further 47% in the moderate-risk category under the worst-case scenario. High-risk areas are concentrated in the Goulburn–Broken and North Central regions in northern Victoria and the Glenelg–Hopkins and Corangamite regions of southern Victoria (Table 9).

Figure 5. Dryland salinity risk in Victoria 2000.



Current salinity risk areas are based on mapping of land affected by dryland salinity at 1:25 000 scale and analysis of groundwater levels at a scale of approximately 1:250 000. Mapping was based on the nine-second digital elevation model for Victoria and work undertaken for the Murray–Darling Salinity Audit, for much of northern Victoria. Large contiguous areas of forest or woodland (mostly public land) were excluded from the analysis due to the lack of groundwater data and generally low threat of salinisation. Future salinity risk is based on current risk areas and analysis of groundwater trend information. Worst- and best-case trend values were calculated based on relatively wet and dry climatic sequences, respectively. Information on salinity risk and potential impact presented generally represents the worst-case trend scenario.

More specifically, the major areas of land that are either currently affected by dryland salinity and/or are predicted to have shallow watertables are:

- the Dundas tablelands of south-west Victoria;
- parts of the western Victorian basalt plains;
- the break of slope between the uplands of the Great Dividing Range and the northern Victorian riverine plain in north-eastern and north-central Victoria;
- the middle and lower reaches of the Loddon riverine plain;
- agricultural land on the eastern fringe of the Sunset Country in north-west Victoria;
- the lower Wimmera river floodplain;
- the floodplains of the Avon and Richardson rivers; and
- coastal areas of south Gippsland.

Figure 6. Dryland salinity risk in Victoria 2050.

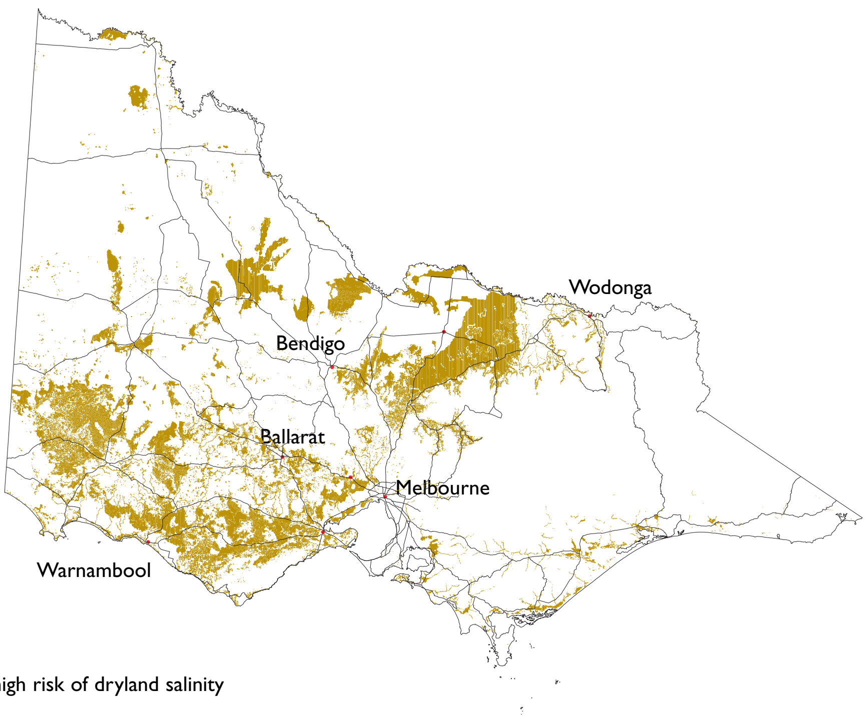


Table 9. Areas* (ha) of land predicted to have shallow watertables for catchment management authority regions in 1998, 2020 and 2050 in Victoria.

CMA Region	1998	2020 worst-case	2050 worst-case
Corangamite	51 200	213 300	499 100
East Gippsland	1 800	1 800	19 100
Glenelg–Hopkins	144 500	429 600	947 200
Goulburn–Broken	123 600	193 500	739 800
Mallee	60 700	63 500	74 400
North Central	124 300	176 500	401 400
North East	40 400	48 000	68 100
Port Phillip	8 500	43 200	134 100
West Gippsland	14 100	14 000	70 600
Wimmera	96 400	122 500	160 800
Total	**665 500**	**1 305 900**	**3 114 600**

* Area excludes irrigation and urban areas and those with substantial contiguous forest or woodland coverage.

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Table 10. Assets at high risk from salinity from shallow groundwater and under the worst-case scenario in Victoria.

Asset	Current	2020	2050
Agricultural land (ha)	555 000	1 170 000	2 800 000
Perennial vegetation (ha)	6 200	11 830	24 280
Railways (km)	131	303	952
Freeways and major roads (km)	808	1 541	3 597
Other roads (km)	3 088	6 513	17 326
Length of stream or perimeter of wetlands (km)	10 121	18 146	34 599
Towns (number)	10	21	63
Ramsar wetlands* (number)	4	5	8

* Coastal wetlands have not been included in those at risk.

- Potential future impacts on cropping land are concentrated in the North Central and Goulburn–Broken regions, while impacts on grazing land are greatest in the Glenelg–Hopkins, Goulburn–Broken and Corangamite regions of the State.
- Potential impacts of shallow watertables and dryland salinity on physical infrastructure, particularly roads and rail, are predicted to more than double by 2050. These changes, particularly for the road network, would be expected to greatly increase the maintenance costs incurred by State and local government.
- Shallow watertables are predicted to increase under more than 30 000 ha of land surrounding the Ramsar wetlands of the Western District lakes during the next 20 years.
- Wetlands in the Goulburn–Broken and Corangamite regions are expected to be the most affected, with over 40% of wetlands in each region predicted (in the worst-case scenario) to be in landscapes with shallow watertables by 2050.
- The number of rare or threatened plant and animal species whose habitat is located in shallow watertable areas is expected to increase substantially: plant species from 122 to between 196 and 346, and animal species from 269 to between 317 and 485.
- A two- to three-fold increase in the length of stream or perimeter of reservoir, lake or wetland located in areas of shallow watertable is predicted over the coming 50 years. Much of the increase is predicted for the Goulburn and North Central regions, and under the worst-case trend scenario, for the Glenelg and Corangamite regions. If realised, this change would result in increased groundwater discharge to streams, greater salt wash off and increased stream salinity and salt load.
- Stream salinity increases westwards across northern Victoria (to the Avoca River). Flow-weighted salinity (Table 11) in the lower Loddon and Avoca Rivers either already exceeds or is predicted to exceed Murray–Darling Basin Commission benchmarks for water quality (800 and 1500 µS/cm).

Table 11. Current and predicted future flow-weighted stream salinity (µS/cm) at the end of the major Murray Basin river systems in Victoria.

Location	Current	2020	2050
Goulburn River upstream of Murray River	134	136	231
Broken River upstream of Murray River	114	231	968
Campaspe River upstream of Murray River	595	600	606
Loddon River downstream of Kerang Weir	871	883	903
Avoca River downstream of Marshes	1 444	1 468	2 216
Wimmera River upstream of Lake Hindmarsh	680	684	691

- Water quality is more variable across south-west Victoria and does not have a consistent pattern of increasing salinity either westwards or downstream. Flow-weighted salinities in several of the major rivers (e.g. Barwon, Leigh, Woady Yalloak, Hopkins, Wannon) already exceed Murray–Darling Basin Commission benchmarks and are generally greater than for streams in northern Victoria.

Agricultural costs are predicted to increase from approximately $27 m each year to between $77 m and $166 m. Losses from pasture and cropping account for 95% of the current (predicted) loss in gross margin, and between 80% and 82% of the loss in predicted gross margin in 2050.

Key issues

- Management of stream salinity is perhaps the most important issue for Victoria. The issue is significant because of the State's obligations to the Murray–Darling Basin Salinity Strategy as well as potential impacts on irrigation, urban and industrial use and on aquatic ecosystems.
- Implementation targets for the catchment management authorities will require considerable technical support to integrate the latest information from the Audit and Murray–Darling Basin salinity audits, and to set up appropriate monitoring processes.

Government responses

The Victorian Salinity Program was established in 1987 with the release of *Salt Action Joint Action*. Under this program, dryland salinity management plans, strategies, or land and water management plans were prepared for major catchment areas of northern and south-west Victoria between the late 1980s and mid 1990s. They focus on dryland salinity but recognise the links to other natural resource issues. Government has accepted all plans and strategies and they are being implemented.

Catchment management authorities have been created and given responsibility for overseeing the plans, leading to further integration of salinity with other natural resource issues.

The State Government has recently prepared a revised salinity management framework for Victoria. Regional salinity management plans and strategies will be reviewed and second generation plans prepared by September 2001. Reviews will consider:

- the progress of the plans against specified targets for works;
- the progress of works towards achieving desired catchment health outcomes;
- the validity of the assumptions on which the plans were based; and
- new information that contributes to a better understanding of the dryland salinity problem.

It is expected that the reviews, particularly for the Murray Basin catchments, will recommend an approach to salinity management based on the protection of specific social, economic or environmental assets and the achievement of targets for catchment health outcomes.

QUEENSLAND

The area estimated to be affected by dryland salinity in Queensland is 48 000 ha. This area does not include all land with groundwater levels within 2 m of the surface. Affected land is distributed throughout the eastern part of the State with only minor occurrences in western Queensland.

The Condamine–Balonne and Border Rivers catchments are the only catchments in the State where sufficient data exist to determine, on a catchment-wide basis and with a moderate level of accuracy, the area with groundwater levels within 2 m of the surface (some 17 500 ha).

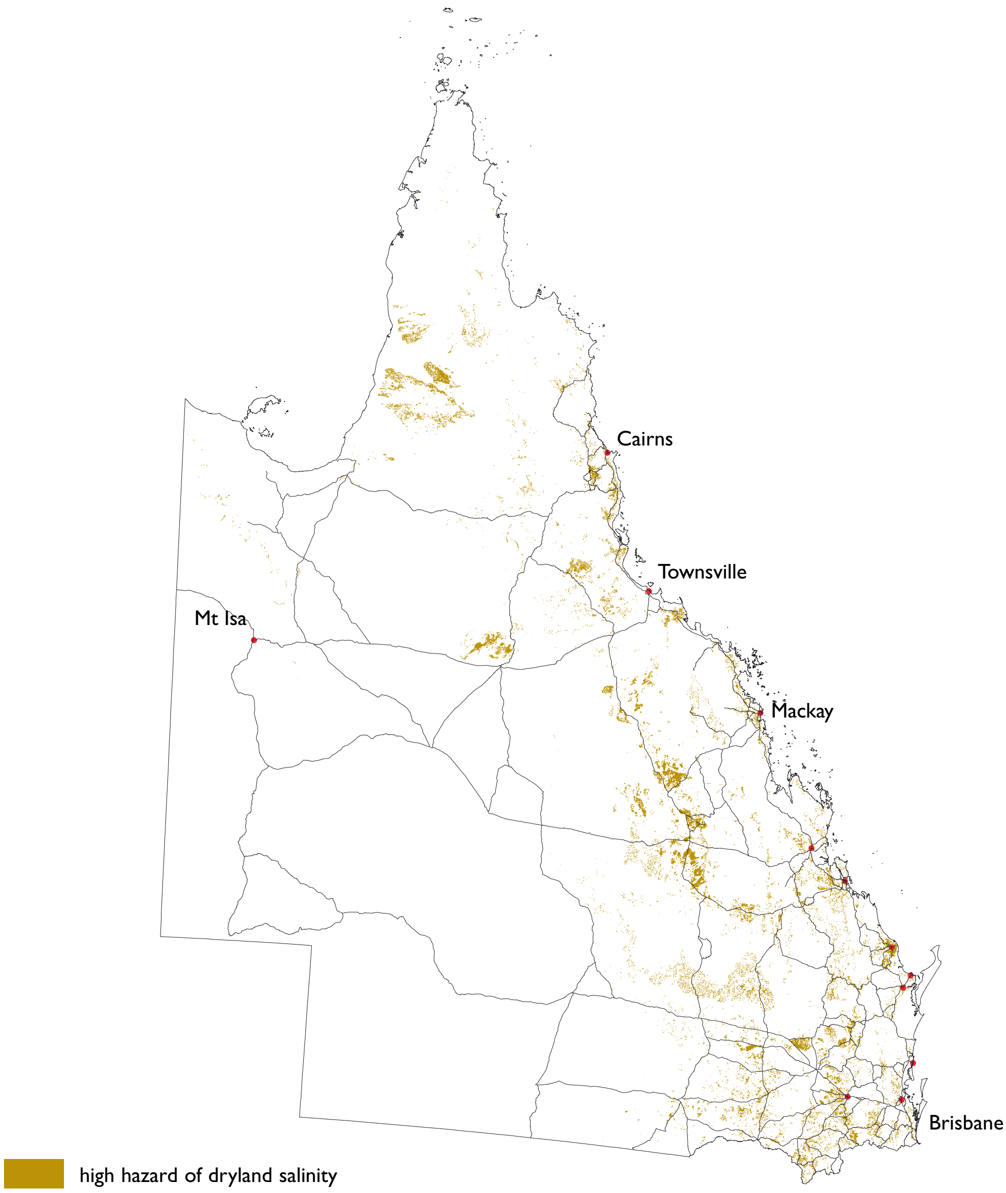
Although little data are available on which to base future water level trends over most of the State, a salinity hazard map indicating land potentially at risk of developing salinity has been produced. There is a wide distribution of land with a high salinity hazard (Table 12). Known areas of distribution are in the Murray–Darling, the Burnett and Fitzroy regions.

The hazard map was produced by collating available datasets for geology, *Atlas of Australian Soils*, elevation, land use change and potential excess rainfall. It reflects potential dryland salinity areas related to the extent of land use change. There are no State-wide data which capture salt storage in the weathered landscape zone. This factor must be taken into consideration in tropical areas where most of the salt has been flushed from the system. The index-overlay approach used to derive areas affected by dryland salinity provides an estimate of 'equilibrium' or 'worst-case' scenarios with the assumption of no change in land use or management. As a result a significant overestimation of areas at risk is likely to have been made. It should not be directly compared with 2050 predictions using the groundwater trend approach.

Table 12. Estimates of areas (ha) potentially affected by dryland salinity under current land use.

Catchment region	2050
Fitzroy	732 421
Murray–Darling	628 393
Gulf	546 412
Burdekin	476 886
North Coastal	206 534
Burnett	180 837
South-east Coastal	179 970
Central Coast	90 101
Curtis	87 399
Western	2 687
Total	**3 131 639**

Figure 7. Dryland salinity hazard in Queensland 2050.



Estimates of projected dryland salinity hazard in 2050 were based on a map overlay analysis using attributes that drive salinisation such as geology, landscape features, regolith depth and type, land use and climate. Groundwater data for assessing salinity risk in Queensland are extremely limited. Groundwater trend analysis was possible only in Condamine–Balonne and Border Rivers catchments of the Murray–Darling Basin. The estimate of area affected (48 000 ha) by dryland salinity was based on field observation in the early 1990s, and workshop-based consultations. Information has been prepared at a scale of 1:2 500 000.

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Although Queensland has an extensive groundwater monitoring network for management of groundwater extraction, the network was not designed for monitoring the shallower groundwater systems that are associated with dryland salinity processes. Hence there are very limited groundwater condition and trend monitoring data to assess and predict dryland salinity processes and impacts.

- A total of 3.1 million hectares are considered to have a high salinity hazard; and 2.6 million hectares are in agricultural lands.
- Where groundwater trend modelling was undertaken in the Condamine–Balonne and Border Rivers areas, 373 000 ha are predicted to have groundwater levels within 2 m of the surface by 2050.
- Only a very small length of roads has been specifically identified as having deteriorated as a direct result of salinity but approximately 12 000 km of roads are in the areas of high hazard.
- An increase in salinity in streams has been noted in parts of the Condamine, Lockyer Creek, the lower Mary, the South Burnett, Three Moon Creek and some tributaries of the Fitzroy.
- The Ramsar-listed wetlands in Queensland are predominantly tidal and it is expected that coastal-related processes will dominate the future health of these systems.
- No costing of the effect of salinity has been undertaken. Most outbreaks are small, localised and are not considered of serious economic consequence to agricultural land at this stage.
- Impacts on wetlands and riparian zones have not been assessed.

Table 13. Key assets located in the areas of dryland salinity hazard in Queensland.

Assets	2050
Agricultural land (ha)	2 600 000
Remnant vegetation (ha)	92 000
Length of stream (km)	1800
Roads (km)	12 000
Rail (km)	1500
Ramsar wetlands (number)	2
Ramsar wetlands (ha)	635
Important wetlands (number)	43
Important wetlands (ha)	25 600

Key issues

- Current monitoring networks do not provide a suitable framework for assessment of dryland salinity and its impacts in Queensland. There is an urgent need to establish a State-wide monitoring network of groundwater, surface water, key land use and biodiversity parameters to better inform managers of the trends and implications of dryland salinity.
- It is vital that preventive and protective action is taken in maintaining water balance for those areas where salt stores would be mobilised with the clearing of native vegetation.
- Work is required to develop and then implement farming systems that deliver sustainability and production outcomes, particularly taking into account long-term risks of watertable rise in salinity.
- The index–overlay approach generated a 'salinity hazard' map for Queensland. However, the approach does not provide an assessment of trends in dryland salinity. Based on our understanding of salinity processes and groundwater flow systems, the method does provide a sound basis for prioritisation of salinity research and development activities.
- The lack of available data limits the capacity to provide a State-wide salinity risk assessment that would underpin at fine scales regional and property planning processes for vegetation management. Nevertheless, for selected catchments in the Murray–Darling Basin where 1:25 000 scale data are available, this is possible and of priority.

Government response

This assessment has resulted in the first State-wide hazard assessment of dryland salinity in Queensland. It has identified a significant long-term risk associated with dryland salinity in Queensland and will assist in setting priorities for investigations, assessments and development of management responses on dryland salinity.

Several natural resource management initiatives have recently been implemented within Queensland and contain specific actions to minimise the future risk of dryland salinity. The Queensland Government has enacted the Vegetation Management Act 1999 (Qld) to provide controls over the clearing of remnant vegetation on freehold land to complement the Land Act 1994 (Qld) that covers leasehold land. The provisions of the Act include the preparation of regional vegetation management plans and the assessment of applications for the clearing of remnant vegetation. The accompanying policy and assessment code provides for the protection of vegetation in areas susceptible to salinisation. The Water Act 2000 (Qld) includes provisions for the preparation of property-level plans and district water use plans to address land and water management issues associated with irrigation water use including salinisation and rising groundwater levels.

Salinity outbreaks are generally localised and technical assistance is provided through government in planning control options on an individual or group basis. Numerous dryland salinity projects have been implemented with the support of Landcare and integrated catchment management groups throughout Queensland (e.g. the Balfes Creek catchment in North Queensland was a focus catchment for dryland salinity research under the National Dryland Salinity Program).

A review of the information needs for assessing and monitoring of dryland salinity has been completed in conjunction with this Audit. The review includes a work plan that will significantly increase the knowledge base on salinity and provide the technical support to underpin government policy initiatives in land and water management, and vegetation clearing. Work is being undertaken to refine salinity risk assessment in Queensland in key regions utilising the groundwater flow system approach as the framework. Implementation of the salinity work plan will be considered as part of Queensland's response to the Commonwealth's National Action Plan for Salinity and Water Quality.

The Coorong: end point for salt from the Murray–Darling river system.

SOUTH AUSTRALIA

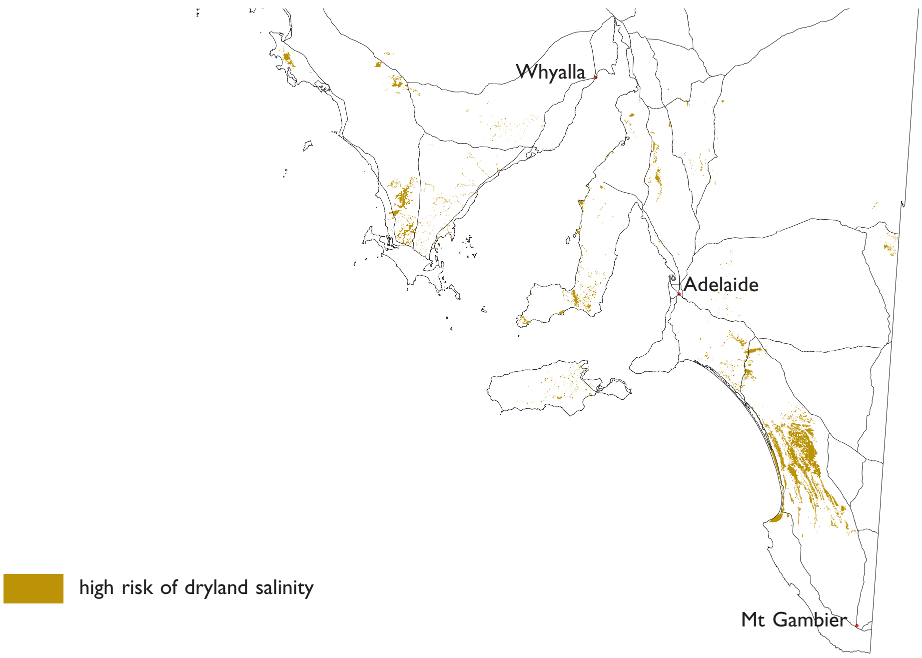
Dryland salinity affects approximately 370 000 ha of land and wetlands in South Australia, in addition to 84 000 ha of primary (or natural) salinity. Under current land use and groundwater trends this is predicted to increase by 60% in 50 years.

The largest area affected by dryland salinity in South Australia is in the Upper South East, where the rising regional watertable in the limestone aquifers of the Murray Basin is intersecting the land surface (Table 14).

Table 14. Estimates of areas (ha) affected in South Australia.

Region	2000	2020	2050
Upper South East	250 500	324 000	409 500
Murray Basin	19 800	29 600	34 000
Eyre Peninsula	20 400	24 000	27 000
Kangaroo Island	5 600	6 500	8 000
Mid North	14 800	18 000	21 000
Yorke Peninsula	13 900	17 500	20 000
Mt Lofty Ranges	1 200	1 400	1 500
Total	**326 000**	**421 000**	**521 000**

Figure 8. Dryland salinity risk in South Australia 2000.



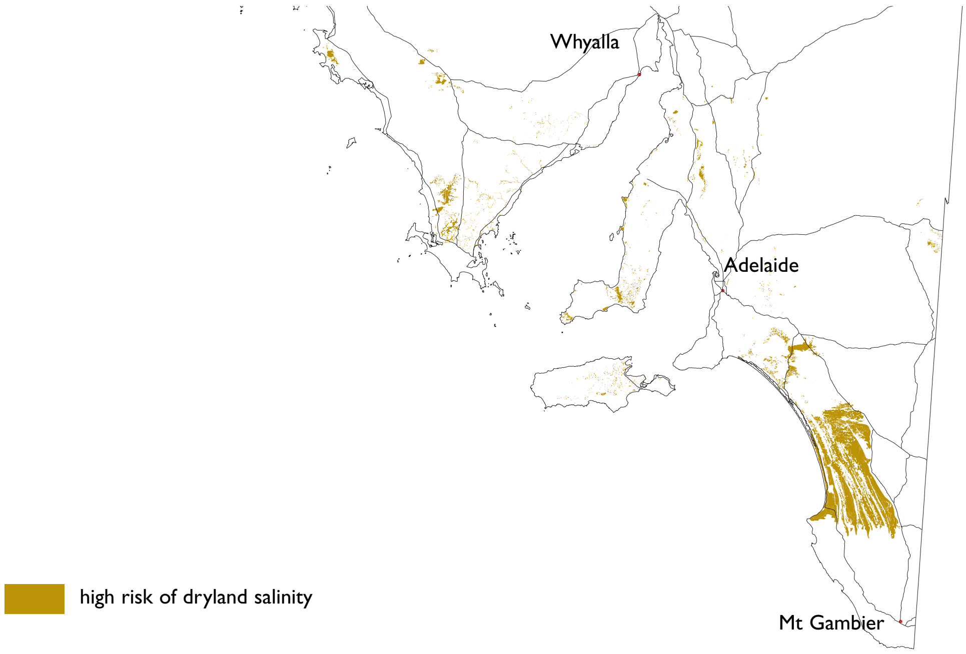
Estimate of salt-affected lands and risks was based on field survey at scale of 1:100 000. Projection for 2050 was based on extrapolation of field survey and groundwater trend data from representative catchments across the agricultural regions. The South Australian estimates of current extent cannot be compared directly to other States as they are better estimates of affected land than exist for the other States. The figures for 2050 are considered comparable to other State 2050 projections.

Findings

Table 15. Key assets at risk from dryland salinity in South Australia.

Assets	2000	2020	2050
Agricultural land (ha)	326 000	421 000	521 000
Remnant vegetation (ha)	18 000	22 000	25 000
Wetlands (ha)	45 000	52 000	57 000
Rivers ephemeral (km)	160	190	210
Roads (km)	910	1 260	1 710
Rail (km)	35	40	46
Towns (number)	0	0	2
Ramsar wetlands (number)	0	0	0
Wetlands of national significance (number)	4	4	4

Figure 9. Dryland salinity risk in South Australia 2050.



- Because most of the groundwater trends are strongly controlled by rainfall, levels have been falling throughout southern South Australia for the past two to three years due to well below average winter rainfalls with some drier catchments experiencing falling groundwater levels since 1993.
- Increasing stream salinisation is occurring in the Tod River (Eyre Peninsula) and Middle River (Kangaroo Island). Elsewhere, particularly the Mt Lofty Ranges, trends are not evident from the available data.
- Groundwater modelling suggests that vegetation clearance in the Mallee will cause salinity to increase by 115 µS/cm by 2050 at Morgan, costing consumers an additional $16.5 m each year.
- Biodiversity mapping has identified several areas at risk from rising watertables. These include extensive ti-tree shrub lands and native grasslands in the Coorong District, and seasonal wetlands and watercourses in the Upper South East. On Kangaroo Island, the viability of sedge and ti-tree ecosystems protected in conservation parks or vegetation heritage agreements are threatened by extensive areas of shallow saline aquifers, while on Lower Eyre Peninsula, native vegetation on valley floors and in seasonal swamps has been identified as being at high risk.

An interim assessment of costs (Table 16) to agricultural production represents 1–2% of the State-wide gross margin from production on all agricultural land.

Key issues

- The guarantee of good quality water into the future is the major issue for South Australia. There is very limited, often no, scope to further develop water supplies within the State. Water from the Murray is essentially the only option for improved supplies apart from the more expensive option of desalinisation of salt water. Long-term guarantees from the other States in the Murray–Darling Basin are essential for South Australia.
- Managing and preferably preventing the predicted salt inflows from the cleared Mallee region in South Australia (and to a lesser extent Victoria) will be a major challenge requiring very long time leads and integrated approaches.
- Development of industries based on saline resource will require emphasis.

Table 16. Interim total costs of dryland salinity ($m/year) in South Australia.

Impacts	2000	2020	2050
Losses in agricultural production	26.1	34.0	42.0
Road and rail maintenance	17.1	23.5	30.5
Building maintenance	1.2	1.4	1.9
Costs of increase in Murray River salinity	0	8.3	16.7
Total cost	**44.4**	**67.2**	**91.1**

Government response

A whole-of-government approach to managing the growing salinity problem in South Australia has been adopted with the formation of the State Salinity Committee, consisting of seven agency heads. This body has overseen the formulation of the overarching policy statement *Directions for Managing Salinity in South Australia* and the more specific *South Australian River Murray Salinity Strategy* and the *State Dryland Salinity Strategy* (Government of South Australia 2000a, 2000b, 2000c).

The *State Dryland Salinity Strategy* aims to reverse the trend of rising salinity and to minimise, and where possible prevent, damage to water resources, the environment and to infrastructure. Management options include:

- reducing recharge (usually with the aid of deep-rooted perennial vegetation);
- utilising discharge (usually with salt-tolerant plants or in industries that can use saline water); and
- disposal of surplus water (usually by drainage).

Key points to emerge from the strategy

- Whole-of-catchment management is required.
- Significant new investment will be needed to support individuals and communities.
- Costs of salinity are borne by the whole community and therefore managing salinity is the responsibility of everyone.

The strategy recommends:

- support for on-ground works;
- developing partnerships with affected communities;
- improving knowledge; and
- commitment to action.

Significant action is already being undertaken to combat the impacts of dryland salinity through the *Upper South East Dryland Salinity and Flood Management Plan*, (Natural Resources Council of South Australia 1993) with associated drainage, revegetation, farm redevelopment and environmental initiatives.

The *Coorong and Districts Local Action Plan* (Coorong District Local Action Plan Committee 2000) and associated on-ground works has become a national model: a local community-led implementation of significant on-ground works to increase rainfall utilisation and reduce salinity threats. Similar projects are emerging in other parts of South Australia.

A more difficult challenge is in dealing with the increased recharge from rainfall onto dryland farming areas in the Mallee region which will cause significant saline discharges into the Murray River.

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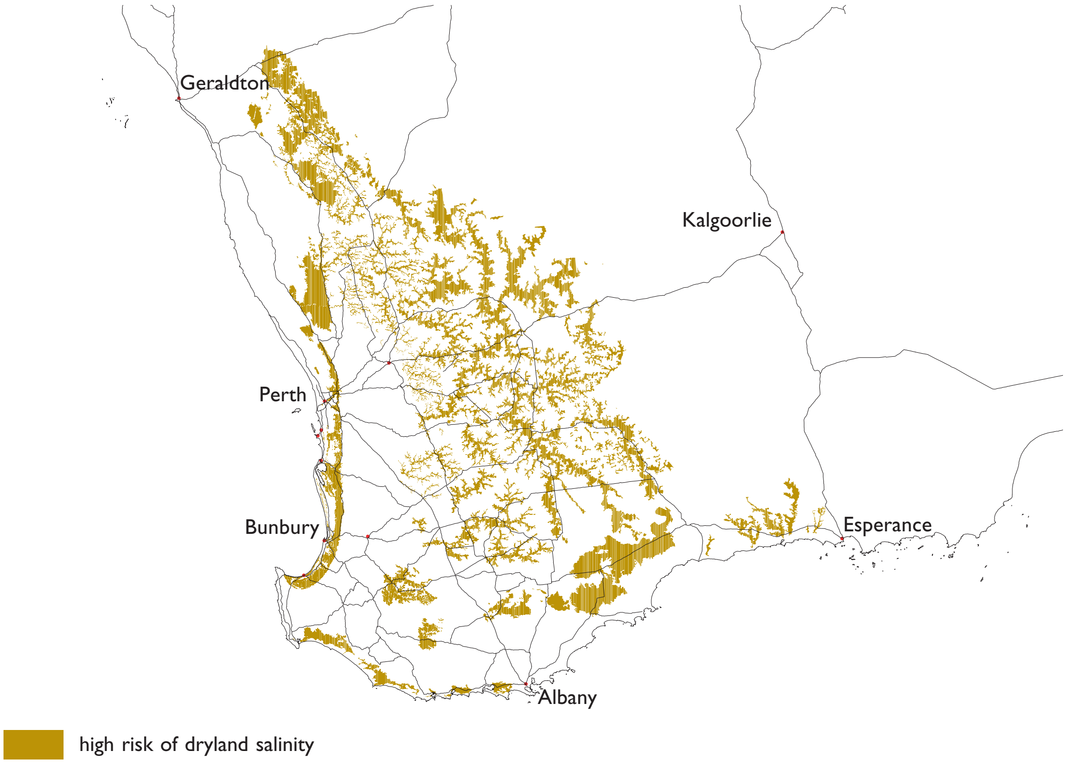
WESTERN AUSTRALIA

Western Australia has the largest area of dryland salinity in Australia and the highest risk of increased salinity in the next 50 years. An estimated 4.3 million hectares (16%) of the south-west region have a high potential of developing salinity from shallow watertables. This is predicted to rise to 8.8 million hectares (33%) by 2050.

In 2000, the risk is predominantly in the eastern wheat belt in valley floors and adjacent areas. Eastern sections of the northern wheat belt also exhibit high risk. There are some coastal areas at high risk around Bunbury and Donnybrook Sunkland. Salinity expansion by 2050 is mainly in the Great Southern and south coast regions.

Figure 10. Dryland salinity risk in south-west Western Australia 2000.



The assessment was restricted to the south-west of Western Australia where dryland salinity is widespread. All analysis was based on groundwater depth and trend and the risk of shallow watertables was derived from these two attributes. As dryland salinity is caused by shallow watertables, the risk of salinity is inferred from the risk of shallow watertables. Not all shallow watertables will be saline. Estimates and projected risk areas are based on analysis of existing groundwater levels and trends at a scale of 1:250 000 based on soil systems mapping. There are limitations in the resulting assessment due to gaps in data.

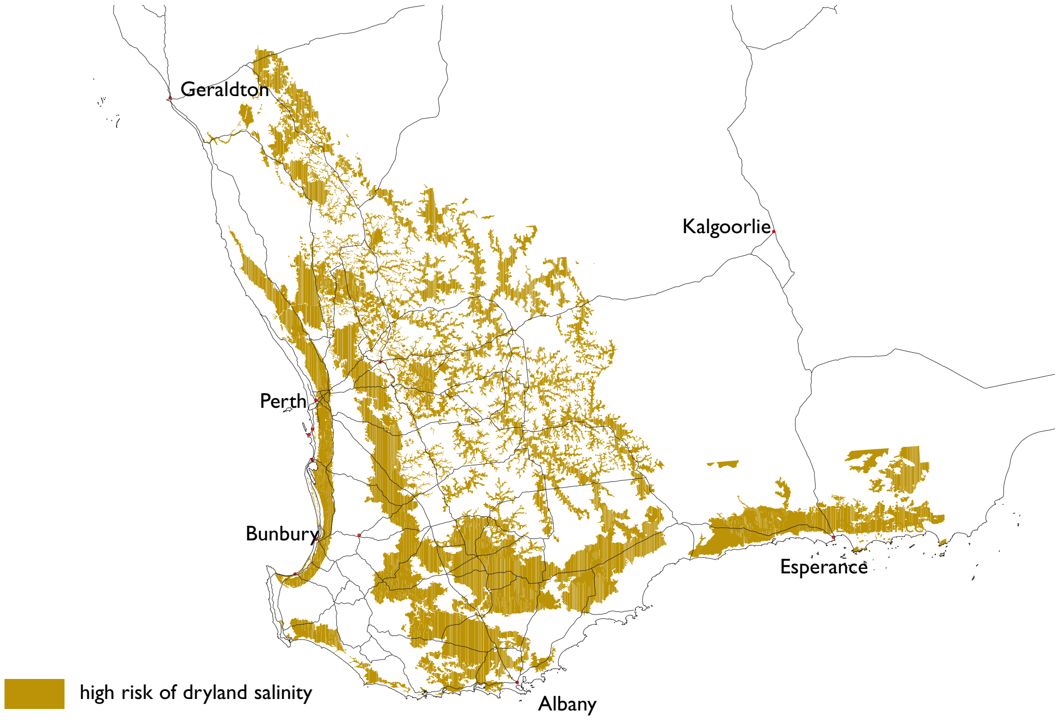
Findings

Table 17. Key assets in areas at risk from dryland salinity in Western Australia.

Assets	2000	2020*	2050*
Agricultural land (ha)	3 552 700	4 181 700	6 490 100
Perennial vegetation (ha)	600 000	710 000	1 800 000
Important wetlands (ha)	72 500	72 500	80 000
Highways (km)	720	840	1 500
Primary roads (km)	680	745	1 165
Secondary roads (km)	1 200	1 425	2 325
Minor roads (km)	11 550	13 650	22 930
Rail (km)	1 350	1 490	2 180
Stream length (km)	1 520	1 700	2 850
Towns (number)	20	22	29
Important wetlands (number)	21	21	21

* Predictions based on groundwater trends, and 'best guess' future land use.

Figure 11. Dryland salinity risk in south-west Western Australia 2050.



In south-west Western Australia:

- Groundwater level patterns are dominated by rising or stable trends. No land systems have significant falling trends.
- Of the 4.3 million hectares (16%) of the south-west region potentially at risk from shallow groundwater, 81% is agricultural land.
- Predictions based on current and perceived land uses indicate that approximately one-third of the agricultural areas may be affected by shallow watertables and salinity by 2050.
- Surface water resources in the south-west part of the State are likely to become more saline.
- Approximately 30 000 km of road and rail networks and up 30 major rural towns may potentially be affected.
- Twenty-one of the 54 wetlands located within the agricultural region are potentially at risk of shallow watertables, which may affect wetland health.
- An estimated 1500 plant species will be affected, with 450 possibly subject to extinction.
- Salinisation is likely to reduce fauna species by 30% in affected areas.
- Terrestrial animals will decline significantly (e.g. a 50% reduction in the number of water birds using wheat belt wetlands is anticipated due to the salinity-induced death of shrubs and trees).
- Species richness has already declined with the onset of salinity.

An interim assessment of the annual costs of the consequences of dryland salinity is $664 m (Table 18). This is based on 'best guess' estimates and does not include any assessment of the costs and benefits of strategies designed to combat salinity impacts on biodiversity.

Key issues

- The most important aspects of salinity investigations in Western Australia will be to determine the impact of different management strategies on groundwater trends at a catchment scale (1:10 000 to 1:25 000) as a basis for improving salinity management.
- Managing groundwater to protect rural towns and associated assets is a major challenge.

Table 18. Annual costs due to watertables/salinity ($m) in Western Australia.

	Best guess	Possible range
Agricultural land: opportunity cost of lost operating profit	80	80–261
Rural towns: annuity of a 50 year discounted present value	5	2–16
Roads: additional repair and maintenance costs	505	Not tested
Railways: additional repair and maintenance costs	11	Not tested
Vegetation: imputed cost of protection of 10% of affected areas	63	63–626
Total	**664**	

Government responses

In recognition of the magnitude of the salinity threat to agriculture, rural towns and the environment, the Western Australian Government released its first *Salinity Action Plan* in 1996 (Government of Western Australia 1996). Recently, the State Salinity Council reviewed the plan and developed a strategy that places greater emphasis on community-based programs. Goals of the strategy are:

- To reduce the rate of degradation of agricultural and public land, and where practical, recover, rehabilitate or manage salt-affected land.
- To protect and restore key water resources to ensure salinity levels are kept to a level that permits safe potable water supplies in perpetuity.
- To protect and restore high value wetlands and natural vegetation, and maintain natural (biological and physical) diversity within the region.
- To provide communities with the capacity to address salinity issues and to manage the changes brought about by salinity.
- To protect infrastructure affected by salinity.

The strategy gives priority to managing recharge and discharge, and ensuring a partnership approach between government, science and the community.

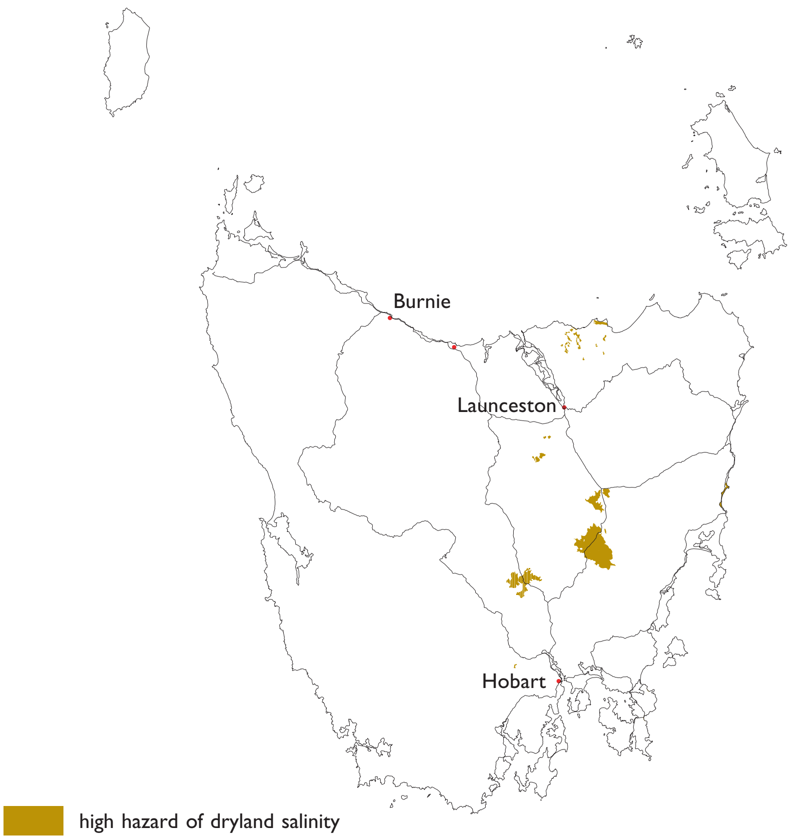
One of the major investments in salinity management in Western Australia is the Land Monitor Project. This project is a Natural Heritage Trust and Western Australian State Government initiative to map and monitor the extent of salinity through satellite imagery at the farm and catchment scale. The project aims to provide information about land condition—specifically salinity and the status of remnant vegetation—for the whole of the south-western agricultural region of Western Australia. It is a collaborative project involving Agriculture WA, CSIRO, Conservation and Land Management, Department of Land Administration, Waters and Rivers Commission, and the Department of Environmental Protection and Main Roads Western Australia.

Salinity affecting pasture on the East Coast of Tasmania February 2000

TASMANIA

The area affected by dryland salinity is estimated to be 53 000 ha. It is located mainly in the agricultural area of the midlands and northern Tasmania, King and Flinders Islands.

Figure 12. Dryland salinity hazard in Tasmania 2000.



The hazard assessment was based on field observation at the land system scale in the mid 1990s updated by expert opinion, questionnaire of Departmental and Landcare groups and limited ground truthing at a scale of 1:250 000 or greater. Groundwater data for Tasmania are extremely limited.

Findings

Table 19. Major impacts of dryland salinity in Tasmania.

Assets	2000	2020	2050
Agricultural land (ha)	53 000	69 500	93 600
Wetlands of international significance (number)	6	6	6
Wetlands of national significance (number)	44	44	44

- Tasmania's 53 000 ha affected by dryland salinity are located in agricultural land and represent 3% of the land used in Tasmania.
- The greatest threats to remnant vegetation, wetlands and fauna from dryland salinity are in the Flinders and Northern Midlands bioregions.
- In the land systems with medium to high salinity hazard there are:
  - 25 reserves;
  - 132 wetlands (six of which are of international significance);
  - 44 wetlands of national significance;
  - 44 flora species; and
  - 17 fauna species.
- There is no evidence of infrastructure damage.
- There is some evidence of damage to four golf courses and some sports ovals.

An interim assessment of cost to agriculture is $5.3 m. This is predicted to rise to approximately $9.3 m in 2050.

Key issues

- Technical understanding of the hydrogeological processes that drive dryland salinity in Tasmania is limited.
- Limited data and information have prevented adequate assessment of the extent or range of impacts from dryland salinity.
- For agriculture the most significant impact of rising salinity is considered to be the regional effect on diversification from marginal enterprises into intensive irrigated cropping (especially high value salt sensitive crops).

Government responses

As a result of the Audit-funded initiative to assess the extent and impacts of dryland salinity in Tasmania, the Environment/Resources Heads of Agencies Group has endorsed:

- the development of a state salinity management strategy; and
- for Tasmania to become a full member of the National Dryland Salinity Program.

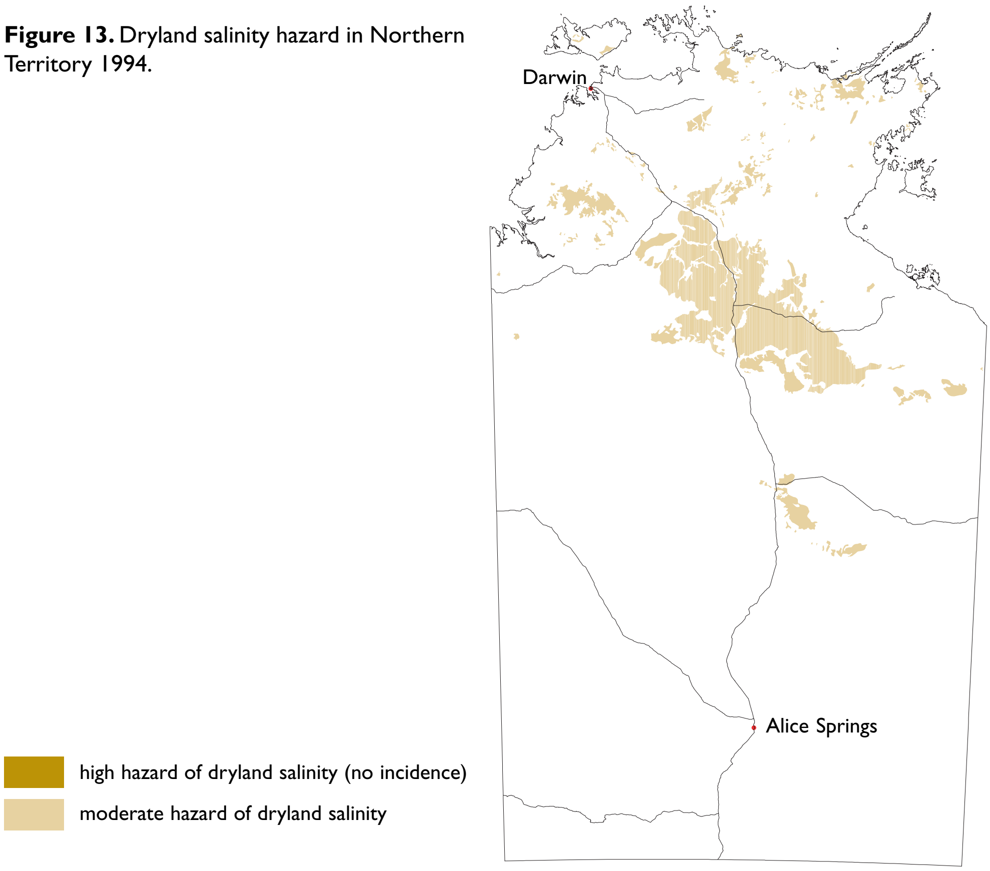
NORTHERN TERRITORY

Salinity hazard in the Northern Territory has been assessed (Tickell 1994a, 1994b, 1997) by combining information on various physical parameters that contribute toward the likelihood of dryland salinity. These parameters were then combined in a simple additive model on a geographic information system to map zones of relative hazard.

The most obvious feature of the Northern Territory salinity hazard map is the absence of any areas classified as high hazard. Approximately 6% of the total area has a *moderate hazard*, 34% is classed as low hazard and 60% as very low.

The salinity hazard of the humid north and the south of the Northern Territory show distinctly different patterns: the humid zone is classified as mainly low and moderate hazard, whereas the arid zone is predominantly very low hazard; lesser areas of low hazard are restricted to the ranges.

Figure 13. Dryland salinity hazard in Northern Territory 1994.



Five indicators used in the hazard assessment were: groundwater salinity, vegetation, median annual rainfall, aquifer yield and the presence or absence of laterite. All were given equal weightings. Each indicator was divided into a range of values and assigned a numerical rating, with the most influential having the highest rating value. A salinity hazard index of a particular area was then computed by adding the rating for each of the five indicators.

Findings

The following findings are based on Tickell 1997.

- Overall salinity hazard for the Northern Territory is relatively low.
- The greatest potential for dryland salinity is in the inland semi-arid areas (particularly on the Sturt Plateau) where conditions are marginally favourable and it would be expected to develop in isolated patches. Other susceptible areas are scattered mainly across the northern part of the Territory.
- If large areas of the Northern Territory were cleared for dryland agriculture, it is unlikely that dryland salinity would become the major problem that it is in southern and eastern Australia. This is because in higher rainfall areas, where deep-rooted vegetation is abundant, salt storages in the ground are small.
- In the more arid areas, where salt storages are often large, deep-rooted vegetation is either sparse or absent. Thus, clearing native vegetation in these areas would be unlikely to alter the water balance sufficiently to raise watertables to dangerously high levels.
- Groundwater monitoring of approximately 50 sites has shown no overall rising trends (Tickell pers. comm.)

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SALT AND THE AUSTRALIAN LANDSCAPE

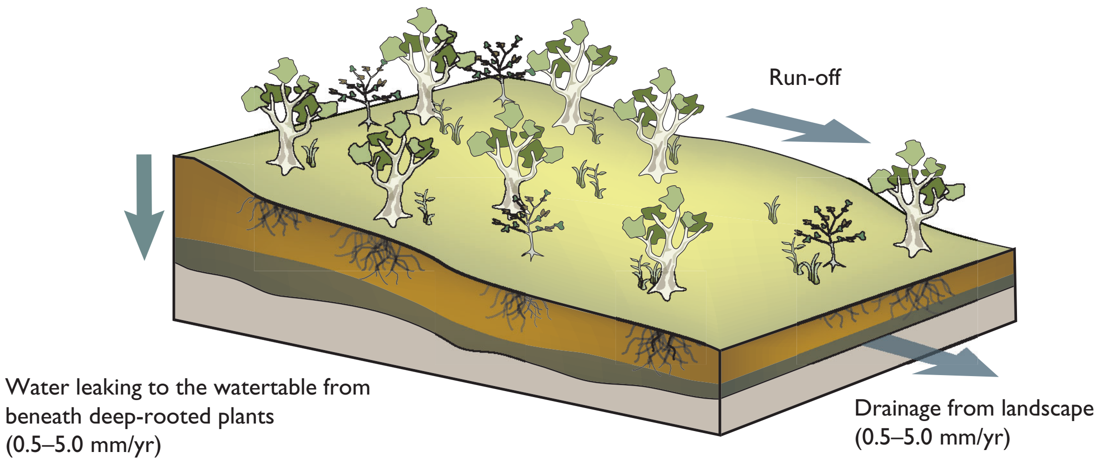
An already salty land

Australia is an ancient and flat continent that has been stable through enormous periods of geological time. Over the millennia, its land surfaces and rocks have eroded, mobilised and accumulated sediments and salts (Beckmann 1983, Holmes 1971, Isbell et al. 1983, Simpson & Herczeg 1994). Some of the salts in this landscape are released from weathering rocks (particularly marine sediments), but most are carried from the surrounding oceans in rain to be deposited in the soils, surface water and groundwater.

Salt stores have developed because there is little capacity to drain the continent of salt and water. Many clues to the saltiness of Australian landscapes can be found in accounts of the Australian bush from early European settlers and explorers. For example, Wood, a railway engineer from Western Australia, documented dryland salinity in south-west Western Australia and on the Eyre Peninsula (Wood 1924).

Salt is distributed widely across the semi-arid and arid landscapes of Australia. It occurs in patchy, complex patterns that reflect remnant features of the climate and geological events that formed the continent. These salt stores stretch in a huge arc from northern Australia, south by the Great Dividing Range, then broadening and sweeping south-west across the Murray–Darling Basin to take in the Riverina and Mallee regions of New South Wales, Victoria and South Australia. In Western Australia, massive amounts of salt are stored in an arc that sweeps south and east across the semi-arid and arid landscapes of south-western Australia (Holmes 1971).

Figure 14. Landscape in equilibrium: 'water in' equals 'water out'.



Recharge and rising salts

Australia's natural salinity has been exacerbated by changes in land use since European settlement. Native vegetation has been replaced with crops and pastures with shallower roots and different seasonal growth patterns, affecting the rate and amount of water use in the landscape. Water 'leaking' beneath the root zone and entering internal drainage and groundwater systems (known as 'recharge') has increased so that it now exceeds the capacity of the system to discharge additional water to rivers and streams. Since more water is entering the system than is leaving it, the watertable rises (Figures 14 & 15) bringing dissolved salts with it.

Deep drainage beyond the root zone does not always end up in groundwater; rather it may move laterally through the soils into surface streams. Recharge into groundwater systems can also occur from the base and banks of the streams.

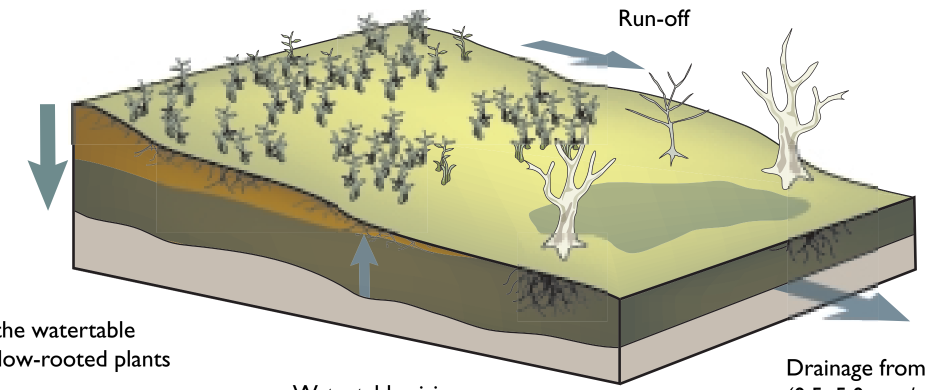
Increase in recharge beneath the root zone connects salt stored in the landscape to land surfaces, and intersects with rivers and streams causing dryland salinity on land and increased salt loads in rivers. The amount of recharge into a groundwater system depends on the climate; geology and topography; depth, water storage capacity and permeability of soils, and subsoil; and land use.

Under Australia's cropping and pasture land use patterns, excess recharge will percolate into the groundwater system at a higher rate (up to ten times) than under the natural native vegetation.

The initial recharge response may occur over relatively short time scales (30 to 50 years) or over much longer time scales (upwards of hundreds of years).

Salinisation can occur in situations controlled by local processes such as shallow groundwater on a hillslope stretching over less than a kilometre, where seepage zones develop as the slope flattens near the stream. Or salinisation can occur in extensive situations where processes operate over large areas such as regional

Figure 15. Landscape out of equilibrium: 'water in' is greater than 'water out'.



groundwater basins stretching over hundreds of kilometres, where the salt emerges on the lower parts of the basin and the floodplains.

Changes in land use and land management practices that restore water balance provide the main opportunities for intervention and remediation.

A continuing and increasing problem?

Australia has a continuing and increasing dryland salinity problem because:

- it takes time to implement the scale of land use changes necessary to alter the water balance;
- in some regions farmers do not have the practical and viable options to implement the recommended management options; and
- even where management options are implemented, there are time lags before groundwater systems show responses to the changes.

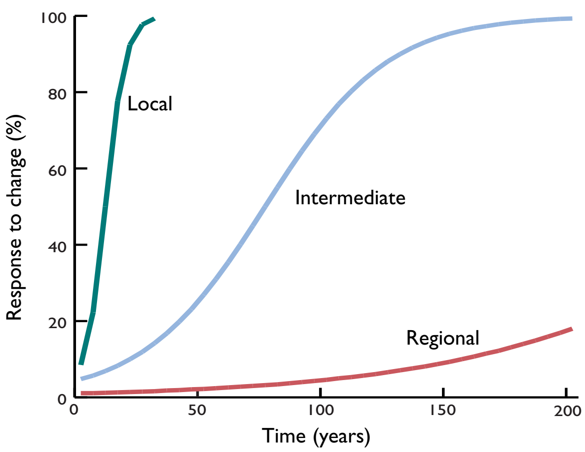
Water balance

As the groundwater system fills and eventually reaches a new equilibrium, the amount of water entering the landscape as recharge and the amount of water leaving as discharge is balanced. However there is a time lag between when changes in land use or improvement in water balance occurs and evidence of a response. It will take decades to reverse the water rise in most groundwater systems (Figure 16).

Re-establishing the water balance requires farming systems with similar water use to that of deep-rooted native vegetation. Designing and implementing such farming systems is a major challenge.

Recharge processes are generally faster than discharge processes. If it takes 30 to 50 years for our fastest groundwater system to fill with water, then it is reasonable to expect that it might take at least 30 to 50 years for it to empty back to where it was. If the system takes 100 years or more to fill, we can again expect at least a

Figure 16. Time–response characteristics of the groundwater flow systems.



similar amount of time to establish the original equilibrium. This is an important issue for management as the degree of recharge reduction and the time taken have important consequences on land use options during any adjustment period, and the degree of change sought. Beneficial effects of land use options may well occur before the system has returned to an equilibrium.

Salt balance

As more water moves through an aquifer, more salt is mobilised. Very long periods of time are needed for catchment salt stores to be reduced to the point where the amount entering the system equals the amount leaving the system, that is, to achieve a *salt balance*. The net amount of salt that exits a catchment via stream flow indicates the time it will take for the catchment to flush its store of salt, when compared with the total mass of salt stored in that catchment. In some of the more responsive groundwater flow systems, the net output of salt may take about 150 years to flush from the system. In larger catchments (e.g. the Murray groundwater basin), it may take as much as 15 000 years. This means that although management may lower the watertable and allow productive use of land, there may be ongoing salt inflow to streams via groundwater.

This makes managing stream salinity very difficult. It is very important to prevent the interception of groundwater with salt stores in regions where we still have this opportunity.

The reality

The substantial lag times for catchments to come back into water balance and change salt mobilisation mean that it is inevitable that dryland salinity will be a feature of many Australian landscapes for some time. This is true even with widespread adoption of innovative land uses that manage to turn off the recharge tap and re-establish water balance. Ultimately the decisions on the measures to be taken will be influenced by the value of the threatened assets, the capacity to manipulate the environmental processes, the economic feasibility and social acceptance of the proposed actions.

UNDERSTANDING SALINITY MANAGEMENT

Salinity: exacerbating native vegetation loss, increasing soil erosion

What do we mean by salinity management?

Salinity can be managed by prevention, treating the cause, ameliorating the symptoms, living with it, or a combination of these. It is important to specify objectives when evaluating the appropriateness of management options.

Prevention and protection:

- native vegetation retention particularly in areas of recharge on lands with a salinity risk;
- adequate resource assessment to identify areas at risk; and
- water-balance modelling to assess the impact of any proposed land use change.

Treatment of cause:

- recharge management to prevent or reduce the rate of rise of groundwater and thus, the area of land affected by salinity and the delivery of salt to water courses, wetlands and storages; and
- interception of fresh water to reduce the rate of rise of groundwater and the delivery of salt to land and water courses, wetlands and storages.

Amelioration of symptoms:

- interception and storage of salt, and reduction of groundwater level to reduce impacts of salt on assets such as water resources, infrastructure and biodiversity; or
- managing saline discharge, adapting to more saline land and water conditions and developing production systems for these saline lands and waters.

Living with salt:

- alternative use of saline land and water resources; and
- optimisation of the use of non-saline resources.

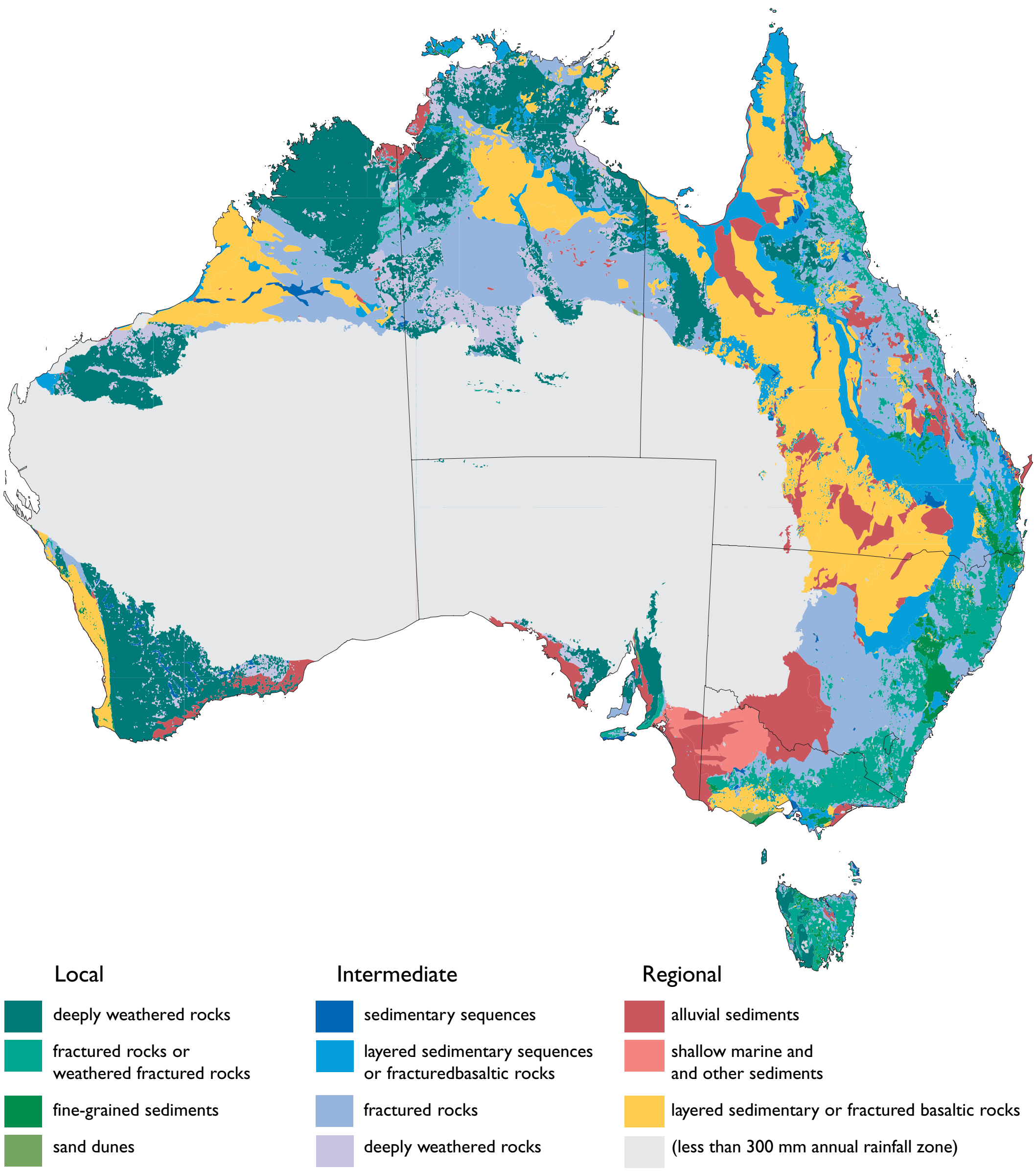
Understanding salinity

To understand salinity across the Australian landscape and through time, we need to understand how groundwater systems respond to changing recharge, and how the excess water that results from increased recharge is distributed.

Groundwater systems are not identical across all Australian landscapes and their contribution to dryland salinity also differs (Coram 1998, Coram et al. 2000, Figures 17 & 18). Lack of knowledge on these systems limited our ability to take a national view of salinity management and the effectiveness of options has been limited. Although management solutions have been identified for a few intensively studied catchments, it has not been feasible in terms of time or money to undertake similar resource intensive investigations for every catchment. This lack of information has been complicated by inappropriate extrapolation of known causes to unstudied catchments, and limited availability of information to non-specialists.

The Audit has supported the development and application of a catchment classification approach that categorises Australia's groundwater flow systems. The classification (Coram 1998) is based on recharge and flow behaviour, and uses measures such as length of flow paths through aquifers, aquifer permeability and driving pressure gradients for groundwater flow. It identifies groundwater flow systems where particular management activities will lead to similar responses and provides a framework for action. The broad distribution of groundwater flow systems in Australia (Figure 17) has been mapped using attributes such as elevation, landscape form, and geology.

Figure 17. Distribution of groundwater flow systems across Australia.



Substantiation of the flow systems

A questionnaire-based review of the groundwater flow systems approach was undertaken to test its validity. The opinions of local hydrogeologists working in the field of dryland salinity across Australia were sought to assess how accurately the groundwater flow systems approach characterised the processes driving dryland salinity at 102 sites, within constraints of existing knowledge and information. The results of the review have shown the conceptual understanding underpinning the framework to be applicable at both national and catchment scales. The groundwater flow systems framework was widely regarded to be a good description of the groundwater processes contributing to dryland salinity. The level of agreement between the local hydrogeologists' understanding and the national map differed between the groundwater flow system types, with almost universal agreement regarding the regional systems, and general agreement on most of the local and intermediate systems. More detail is provided in the report on the substantiation of the groundwater flow systems; available on the Audit Atlas website at www.nlwra.gov.au/atlas.

As in any classification system, there are limitations. More detailed groundwater flow system maps are needed for catchment scale planning using catchment scale data (geology, geomorphology, slope) to accurately locate the groundwater flow systems contributing to dryland salinity. Limited availability of appropriate scale data for geology, elevation and regolith limits the development of more accurate maps of the groundwater flow systems. The concepts of the systems can still be applied using existing data.

- At a national scale, the framework provides an excellent overview of salinity provinces and processes and it is useful for strategic policy development. The same principles applied at local and regional scales provide a sound basis for salinity planning within catchments.

The framework provides a basis for:

- defining management options; and
- ensuring that investment is targeted, actions are appropriate, and outcomes are measurable.

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Groundwater flow systems

An assessment of the 12 specific types of groundwater flow systems contributing to dryland salinity across Australia has shown that :

- groundwater processes in the deeply weathered landscapes of Western Australia are similar to those in the landscapes of the Eyre Peninsula in South Australia and the Dundas Tablelands in western Victoria;
- groundwater processes in the sedimentary deposits of the Murray–Darling Basin are similar to those in the Perth and Bremer Basins in Western Australia;
- clear similarities exist between the groundwater processes underlying salinity on the northern and western foot slopes of the Great Dividing Range in both Victoria and New South Wales.

Groundwater flow systems can be classified as local, intermediate or regional on their spatial extent and influence. The extent of the system has implications for its responsiveness to change in water balance and therefore influences the types of management options that are more appropriate for modifying the water balance.

- *Local groundwater flow systems* respond rapidly to increased groundwater recharge. Watertables rise rapidly and saline discharge typically occurs within 30 to 50 years of clearing of native vegetation for agricultural development. These systems can also respond relatively rapidly to salinity management practices, and afford opportunities to mitigate salinity at a farm scale. Examples are:

  Kamarooka catchment, Victoria (local groundwater flow system in weathered fractured rock)

  Great Southern, Western Australia (local groundwater flow system in deeply weathered rock)

- *Intermediate groundwater flow systems* have a greater storage capacity and generally higher permeability than local systems. They take longer to 'fill' following increased recharge. Increased discharge typically occurs within 50 to 100 years of clearing of native vegetation for agriculture. The extent and responsiveness of these groundwater systems present much greater challenges for dryland salinity management than local groundwater flow systems. Examples are:

  Upper Billabong Creek, New South Wales (local and intermediate groundwater flow systems in fractured rocks in connection to regional flow system in alluvial aquifers)

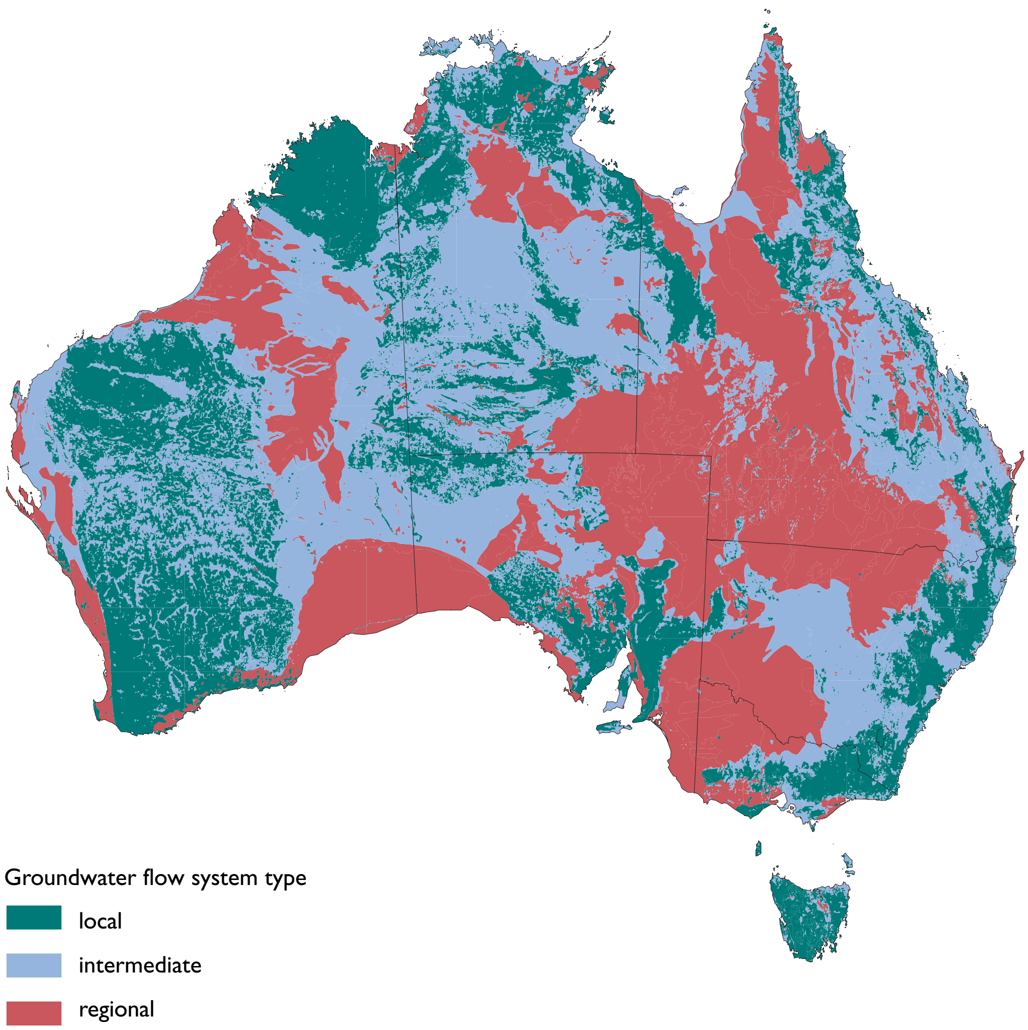
  Wanilla catchment, South Australia (local to intermediate groundwater flow system in deeply weathered rock)

- *Regional groundwater flow systems* have a high storage capacity and permeability. They take much longer to develop increased groundwater discharge than local or intermediate flow systems—probably more than 100 years after clearing the native vegetation. The full extent of change may take thousands of years. The scale of regional systems is such that farm-based catchment management options are ineffective in re-establishing an acceptable water balance. These systems will require widespread community action and major land use change to secure improvements to water balance. An example is:

  Lake Warden, Western Australia (regional groundwater flow system in alluvial sediments)

Local, intermediate and regional groundwater flow systems are distributed across Australia (Figure 18). In some areas flow systems may be superimposed or physically linked. Each system has a unique combination of attributes, but each in turn is composed of different landscapes with a degree of variability.

Figure 18. Distribution of local, intermediate and regional groundwater flow systems across Australia.



Regional systems have a large water-holding capacity and respond very slowly

The hydrogeological and topographical features associated with the groundwater flow systems provide a basis for evaluating the appropriateness of salinity management options.

The capacity of a given groundwater flow system to respond to changes in land use is driven mainly by its ability to move groundwater and is defined by:

- the groundwater gradient (water flows from a higher to a lower position in the landscape); and
- permeability of the material through which the groundwater flows (gravel, sand, clay).

If both gradient and permeability are high, the time it takes a groundwater system to respond to changes in land use is likely to be fast (a decade or so); if both are low, the response time is likely to be slow (hundreds of years). Low permeability local groundwater flow systems experiencing significant groundwater elevation within the catchment respond poorly to recharge management (alone) as a salinity management measure. This is the more general condition found throughout Australia, and the position established through the application of groundwater modelling in the Audit case studies.

Groundwater flow systems have much slower response times to changes in land use than is widely recognised. Once those changes are initiated, it takes a long time to reach a balance. Even if we manage to reduce recharge, it will take time for the excess water to flow out from the system once the groundwater system is full.

In summary:

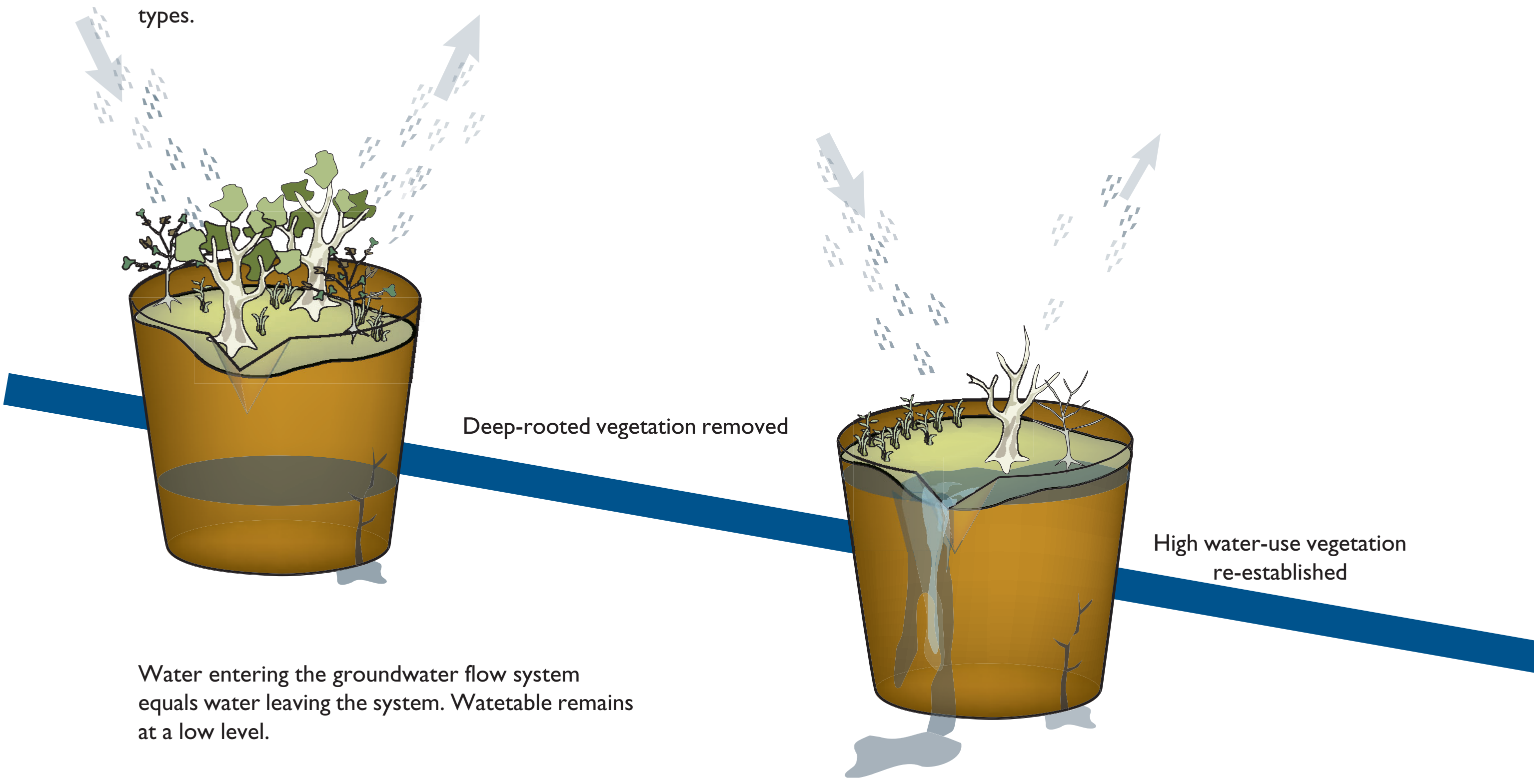
- Local flow systems have a relatively small capacity to store the additional recharge and so respond relatively rapidly to changes in land use; in many cases, they also have a relatively small discharge capacity through which to drain the excess water.
- In contrast, regional flow systems have a very large capacity to fill and subsequently respond very slowly to changes in land use, they will also take a long time to empty of excess water. Intermediate flow systems behaviour falls between local and regional systems.

Groundwater flow systems and impact on rivers

Selection of options for managing each groundwater flow system type needs to consider the way salt is mobilised out of the landscape. Salt may be mobilised as wash off from the land surface by water running into streams, as lateral sub-surface seepage or as groundwater seeping directly into streams and rivers as baseflow.

- Local flow systems are more likely to lead to landscapes where river salt is sourced mainly from wash off. Minimising wash off is achieved by minimising recharge or improving the water balance and therefore the amount of salt-laden groundwater that discharges onto the land.
- Intermediate and regional systems often have a higher level of groundwater discharging directly to streams. Intercepting groundwater can prove beneficial if the key objective is to keep salt-laden water from the stream. Knowledge of the groundwater flow systems and their variability is essential to pinpoint likely areas of high discharge and identify management options. With this knowledge, plans can be developed to intercept groundwater by engineering means such as pumping.

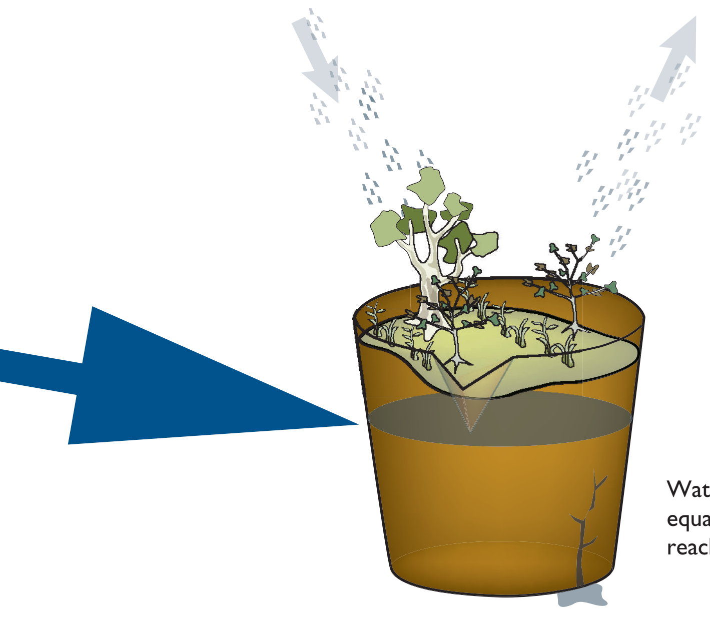
Figure 19. Groundwater flow systems respond to changes in water supply through changes in vegetation types.



A framework for action

The groundwater flow system is a useful framework to support cost-effective action in salinity management across catchments and regions. When fully implemented the framework should be able to be used to:

- apply and transfer knowledge of well-studied catchments to unstudied catchments;
- communicate that knowledge to management agencies and communities, who need to understand salinity and management options;
- identify key attributes to be monitored;
- develop cost-effective systems for monitoring; and
- prioritise investment areas for salinity management.



Water entering the groundwater flow system equals water leaving the system. Watertable reaches a new equilibrium level.

Liverpool Plains catchment

CASE STUDIES: the framework in action

Case studies were implemented in catchments in southern Australia (Table 20, Figure 20) as part of an evaluation of the groundwater flow systems and a catchment water balance approach to identify:

- areas of the catchment where changes in recharge will most affect catchment salinity;
- how much recharge reduction would be required to reduce salinity by a given percentage in an area of salt-affected land;
- land use and farming system options for reducing recharge enough to manage salinity;
- information for an economic analysis of the costs, benefits and viability of the options for change;
- constraints to achieving required change.

The concepts and principles of the groundwater flow system classification have also been applied in the Macquarie catchment (see p. 70).

Figure 20. Location of Audit case study areas.

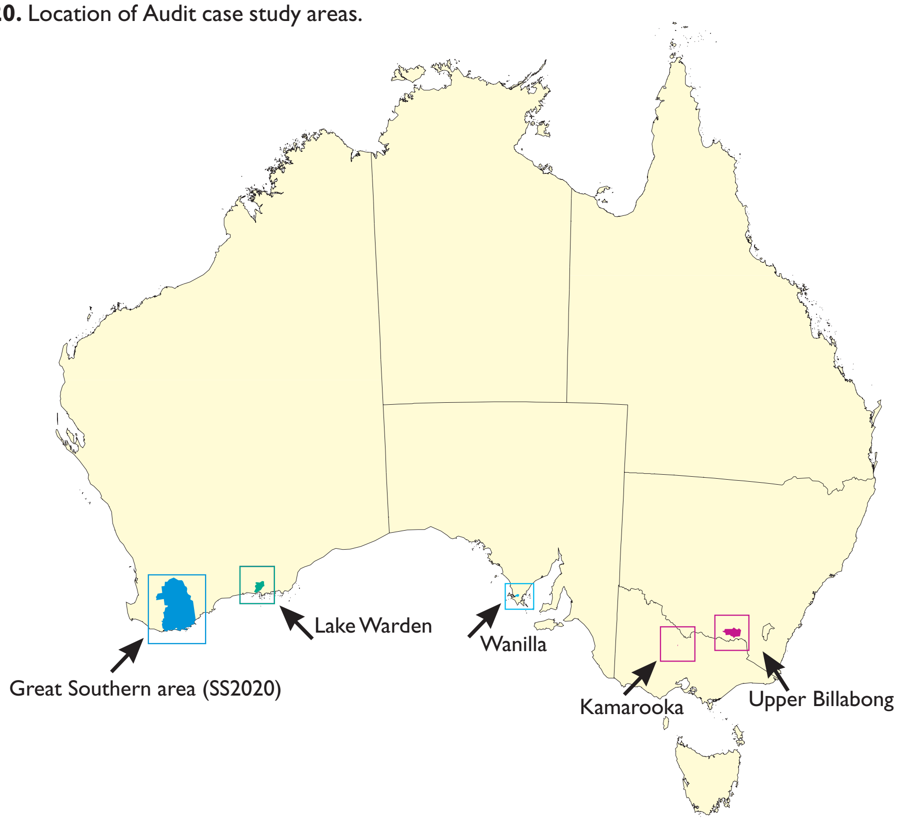


Table 20. Groundwater flow system types of the Audit case studies.

Catchment	Groundwater flow system
Kamarooka, Victoria	Local flow system in variably weathered fractured rock. Groundwater discharge at break of slope
Wanilla, South Australia	Local to intermediate flow system in deeply weathered rock. Groundwater discharge at break of slope and valley floors
Upper Billabong, New South Wales	Local and intermediate groundwater flow systems in variably weathered fractured rocks in connection to regional flow system in alluvial aquifers
Lake Warden, Western Australia	Local and regional groundwater flow system in alluvial sediments and deeply weathered rocks
Region	**Groundwater flow system**
Great Southern, Western Australia	Local and intermediate flow systems in deeply weathered rocks

An assessment was subsequently undertaken to evaluate the financial implications of implementing these changes in each case study catchment. This will be reported as part of the Capacity for Change report in 2001.

The catchments were selected on the basis of their salinity status and information availability, and because they represent the most salt-affected land types in Australia. The case studies build on the conceptual development and systems understanding gained through the National Dryland Salinity Program Phase 1 focus catchments—in particular the Liverpool Plains (New South Wales) and Loddon-Campaspe catchments (Victoria).

Results from the case study catchments confirm that the level of intervention required is far greater than generally understood:

- In many areas, we are unlikely to be able to prevent worsening dryland salinity using our current farming systems.
- We need to adopt radical changes to farming approaches (in terms of increased water use, adaptability to variable rainfall regimes) if we are to slow the advance of salinity.
- Even if we could make the massive land use changes required, in many cases groundwater systems will take a long time to respond.

These results can be used to rate the likely effectiveness of different land use options in similar catchment settings (or groundwater flow system types).

Farm-scale modelling

Farm-scale modelling is useful to rank different land use options for their effectiveness in controlling excess water in catchments. Despite a perception that water balance modelling at this scale is data intensive, the minimum data requirements can be met in most catchments. To ensure high levels of accuracy in this farm-scale modelling, improvement in the availability of data on soil water characteristics is required for most agricultural regions.

Groundwater modelling

The Flowtube catchment-scale groundwater model (Dawes et al. 2000) proved to be suitable for estimating recharge and predicting the broad-scale impacts of recharge reduction on land salinity (provided data are available for bore hydrographs, borelogs, land use and topography). This modelling approach has also been applied to several case studies in Western Australia as part of the evaluation of the long-term effects of salinity management options (Campbell et al. 2000). This approach has broad application for estimating the magnitude of recharge control that must be achieved to reduce groundwater levels, and the timeframes involved in land use options that either slow, halt or reverse dryland salinity. To do this well we need groundwater data from strategic locations in catchments. The data must reflect sites and aquifers where changes in groundwater volumes are most evident and for time periods that are appropriate for responsiveness of the groundwater flow systems. Data need to be coupled with information about stream flows and salt loads, local climatic trends, and land use changes.

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The case studies indicate the appropriateness of this tool to broadly predict the impact of land use change on dryland salinity. The case studies also identified that we lack data for making the best use of the predictive powers of this groundwater modelling tool. Its widespread use will require considerable effort to establish databases of aquifer characteristics and groundwater level trends across all major flow systems, particularly in those known to be at risk of dryland salinity.

The case studies also emphasised the difficulties in reconciling with confidence outputs from the crop and pasture water balance models with those from the groundwater models. If we are to make more detailed predictions about the effectiveness of individual farming systems on dryland salinity in systems, we need to invest in integrating the groundwater modelling tools with farming systems modelling tools. To achieve this we also require detailed data about the land-systems characteristics of those groundwater flow systems. In most catchments at risk of dryland salinity, this information is not yet available.

The following case studies present estimates of the percentage of each catchment subjected to dryland salinity or high water tables resulting from changes in recharge through time. The reductions considered were:

- no change; and
- 50, 75 and 90% reductions.

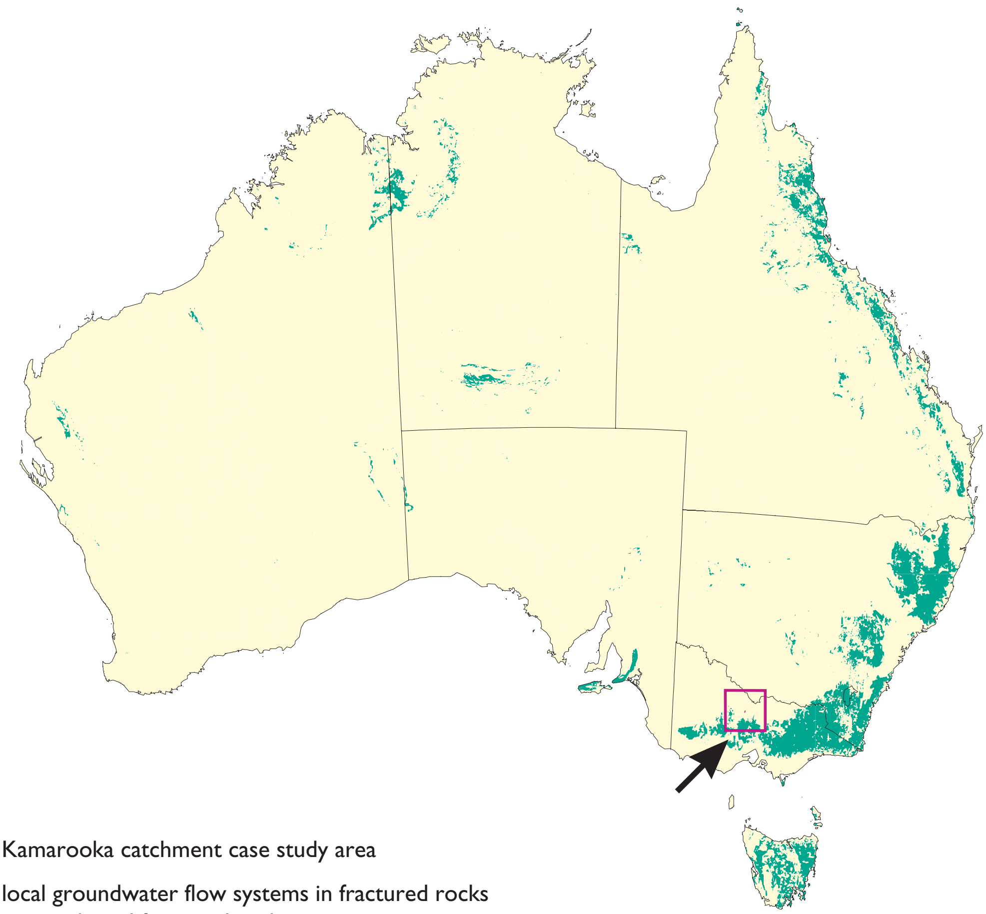
Any reduction in area at risk is based on the assumption that salinity caused as a result of high water table is **completely** reversible when the water level drops, and that any salt can be flushed from the system. In reality, there may be areas which do not recover due to changes in surface soil properties, or because drastic recharge reductions do not allow for leaching of salt from the near surface.

KAMAROOKA CATCHMENT, VICTORIA

Kamarooka is about 35 km north of Bendigo in north-central Victoria. The catchment is predominantly extensive dryland pasture for sheep grazing interspersed with cropping. It has low permeabilities and moderate to low gradients, and a low ability to move groundwater. Similar local groundwater systems are widespread in the lower slopes of the western side of the Great Dividing Range and on the Lachlan Fold Belt (New South Wales).

Approximately 800 ha of this catchment is affected by salt. Of this, 70 ha were considered to be severely affected in March 2000 (salt seeps and no plant growth).

Figure 21. Distribution of local groundwater flow systems in fractured rocks or weathered fractured rocks.



Kamarooka catchment case study area

local groundwater flow systems in fractured rocks or weathered fractured rocks

Results of groundwater investigation and modelling

- If the current land use is maintained, the area of shallow water tables (and salinity) will continue to expand laterally along the break of slope, but will not expand uphill; an extra 1% of the catchment is likely to be affected.
- If changes are made to land use in the catchment to reduce recharge by 50%, water tables can be expected to fall within 100 years, resulting in a slight reduction of the salt-affected area.
- A 40% decline in the area of land affected by shallow water tables can be expected within 50 years, and its elimination within 100 years if a 90% reduction in recharge can be achieved as a result of extensive changed land use.

Implications

- A large reduction in recharge is required to markedly reduce the area of shallow water table and salinised land, but this is expected to be achievable through a combination of revegetation and the introduction of improved farming systems.
- The main aquifer is fractured rock, which makes engineering solutions like groundwater pumping difficult to implement. Surface drainage is also likely to be unsuccessful because the fractured rock aquifer is very deep and the surface material is very clayey (low permeability).

A full technical report is available on the Audit's Atlas website at www.nlwra.gov.au/atlas.

Figure 22 and **Table 21.** Kamarooka (Victoria): change of area at risk in response to different recharge reduction rates—based on current recharge rate.

Figure 22.

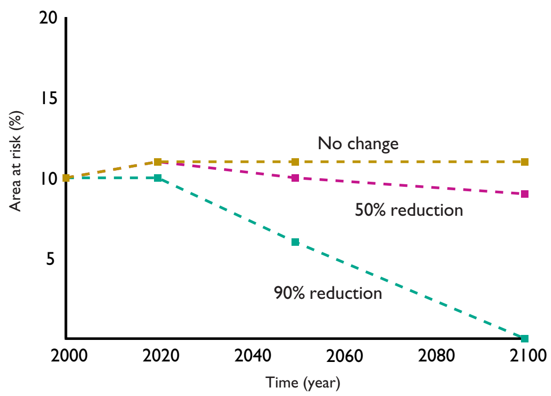


Table 21.

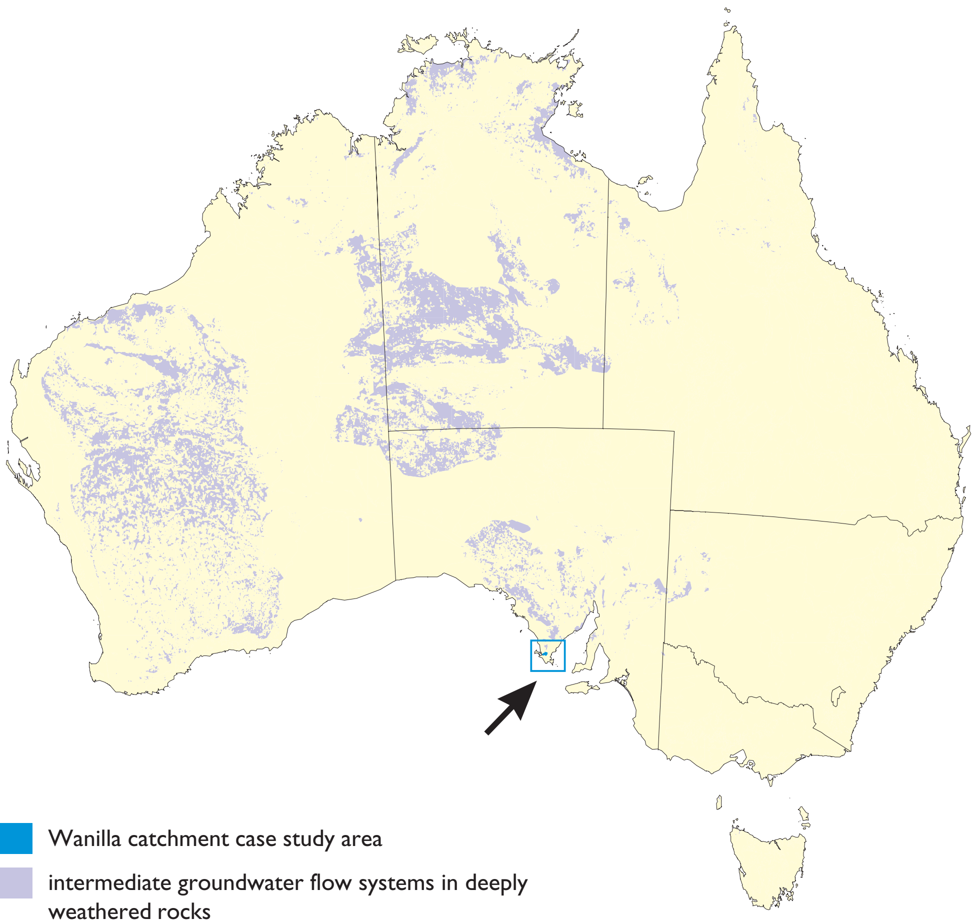
	No change (%)	Recharge reduction 50% (%)	Recharge reduction 90% (%)
2000	10	10	10
2020	11	11	10
2050	11	10	6
2100	11	9	0

WANILLA CATCHMENT, SOUTH AUSTRALIA

The Wanilla catchment is in the southern part of the Eyre Peninsula in South Australia. Some 80% of the catchment is used for cropping with pasture rotations. With its low permeabilities and groundwater gradients, the catchment has very limited ability to move groundwater. This local to intermediate groundwater flow system is widespread in Western Australia (wheat belt) and in South Australia (Eyre Peninsula).

About 8% of the catchment is salinised and land salinisation has been part of the Eyre Peninsula landscape for some considerable time. Descriptive names such as 'Salt Creek' and 'Salt Swamp' (just to the north-west of the study area) are included on a 1903 survey map. Some parts are also likely to have been groundwater seepage areas before widespread clearing of native vegetation in the early 1950s.

Figure 23. Distribution of intermediate groundwater flow systems in deeply weathered rocks.



Wanilla catchment case study area

intermediate groundwater flow systems in deeply weathered rocks

Results of groundwater investigations and modelling

The results of the groundwater investigation suggest that to a large extent, effects of land use change to pasture and cropping in the Wanilla catchment have already occurred. Groundwater levels are close to the soil surface over much of the catchment. Even immediate major changes in land use will result in only very minor reductions in the watertable over the next 20 years because of the inability of groundwater to move easily through the system.

- If the current land-use is maintained, in 20 years the area of shallow watertables will expand from 8% to 15% of the catchment and not increase significantly beyond that.
- If recharge in the catchment is reduced by 50%, the affected area will increase to around 12% of the catchment within 20 years, but not significantly beyond that point.
- Reduction in recharge of between 50% and 90%, will prevent the further increase in the area affected by shallow watertables (and salinity).

Implications

- The main aquifer is weathered bedrock rock resulting in low permeabilities and storage coefficients. Traditional engineering solutions such as groundwater pumping are difficult to implement, as demonstrated by pump tests in the Popes catchments (eastern uplands of Wanilla) and other locations on the Eyre Peninsula. Surface drainage is already being used at Wanilla because the drainage system is naturally in place and any saline seepage can be discharged to the sea.
- Given there is little scope for expansion of salinity in the cropped plains, living with the extent of salinity is the likely management option in this catchment.

A full technical report is available on the Audit's Atlas website at www.nlwra.gov.au/atlas.

Figure 24 and **Table 22.** Wanilla (South Australia): change of area at risk in response to different recharge reduction rates—based on current recharge rate.

Figure 24.

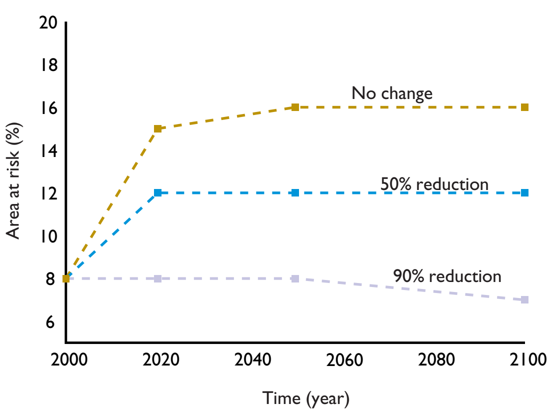


Table 22.

	No change (%)	Recharge reduction 50% (%)	90% (%)
2000	8	8	8
2020	15	12	8
2050	16	12	8
2100	16	12	7

UPPER BILLABONG CREEK, NEW SOUTH WALES

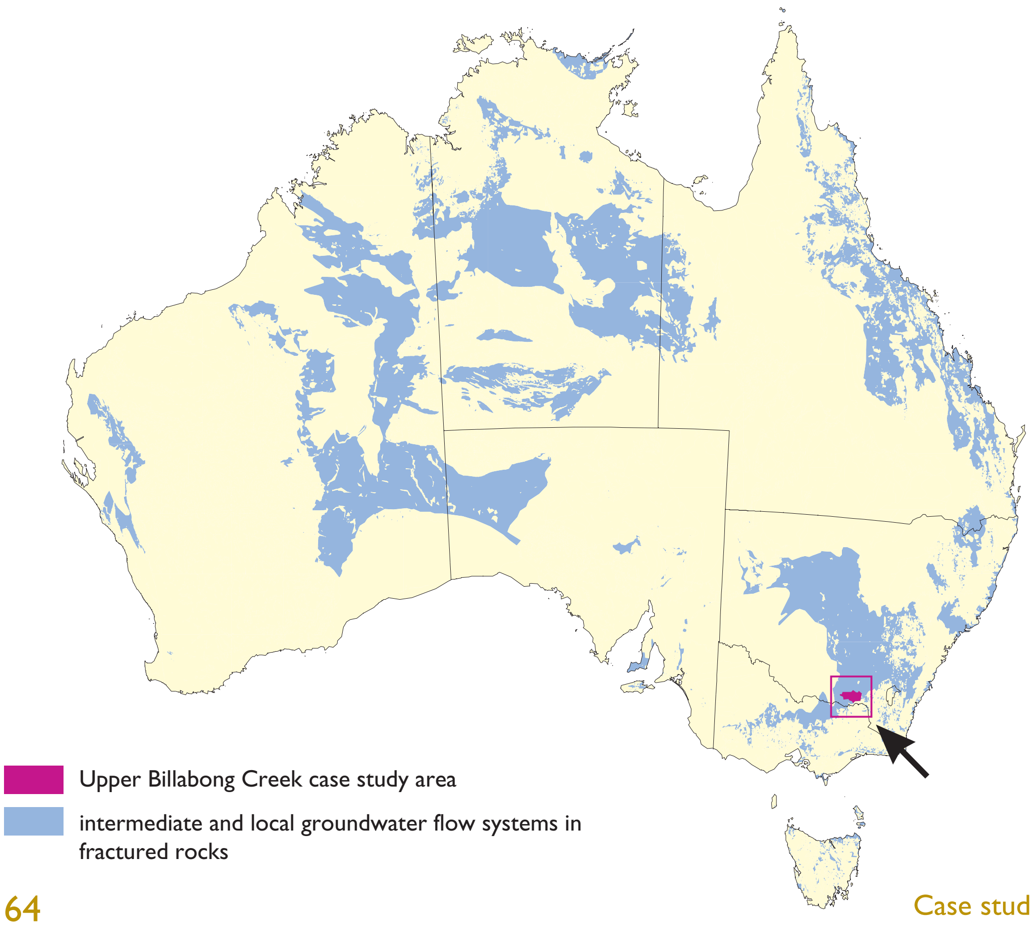
The Upper Billabong Creek catchment is in New South Wales, between the Murrumbidgee and Murray Rivers. The catchment is predominantly cleared on the lower slopes. Land use is dominated by grazing, with some cropping, particularly on the alluvial flats. Small, break-of-slope expressions of salinity are found in the local to intermediate flow systems of the Palaeozoic rocks in the upper parts of the catchment.

Despite the low permeabilities, the generally good water quality in these systems means that waterlogging rather than salinity will be the major issue. These flow systems connect to a regional alluvial system in the lower parts of the catchment where the high permeabilities and low to moderate groundwater gradients mean that the catchment has a moderate to high ability to move groundwater.

The flow system of the lower parts of the catchment is common in the Riverine Plains in NSW and Victoria.

Approximately 140 ha (or less than 1% of the catchment area) have surface expression of dryland salinity, as part of the local to intermediate flow system. There is no sign of saline discharge related to rising regional groundwater systems.

Figure 25. Distribution of intermediate and local groundwater flow systems in fractured rocks.



Results of groundwater investigations and modelling

The groundwater investigation suggests that although groundwater movement through the lower parts of the catchment is reasonably fast, its response to extensive changes in land use is expected to be slow (due to the regional scale of the flow system).

- If the current land use is maintained, groundwater levels will reach the surface at break of slope and on the plains in about 50 years; less than 2% (~5000 ha) of the catchment is predicted to be at risk from shallow watertables and salinity.
- If recharge in the catchment is reduced by 50%, the watertable will continue to rise, albeit more slowly, and affect a similar area of land as the 'do nothing' scenario after about 100 years.
- If recharge in the catchment is reduced by 90%, groundwater levels will continue to rise, but the system will stabilise before the watertables become shallow enough to cause salinity.

Implications

- In the Billabong catchment, carefully delineated recharge areas can be targeted if recharge control is part of an overall strategy.
- Strategic groundwater pumping with current levels of recharge can delay the rise of water levels by up to 50 years and reduce groundwater heads by up to 1 m compared with the 'do nothing' scenario.

A full technical report is available on the Audit's Atlas website at www.nlwra.gov.au/atlas.

Figure 26 and **Table 23.** Upper Billabong (New South Wales): change of area at risk in response to different recharge reduction rates—based on current recharge rate.

Figure 26.

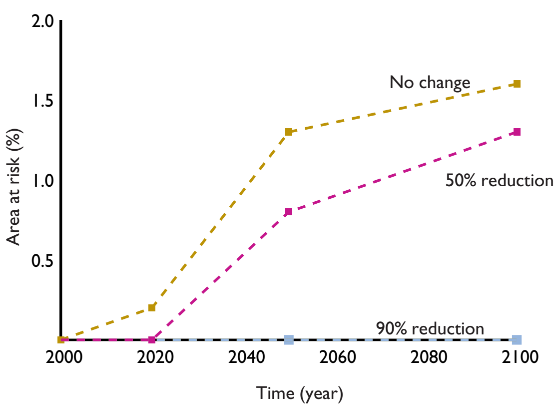


Table 23.

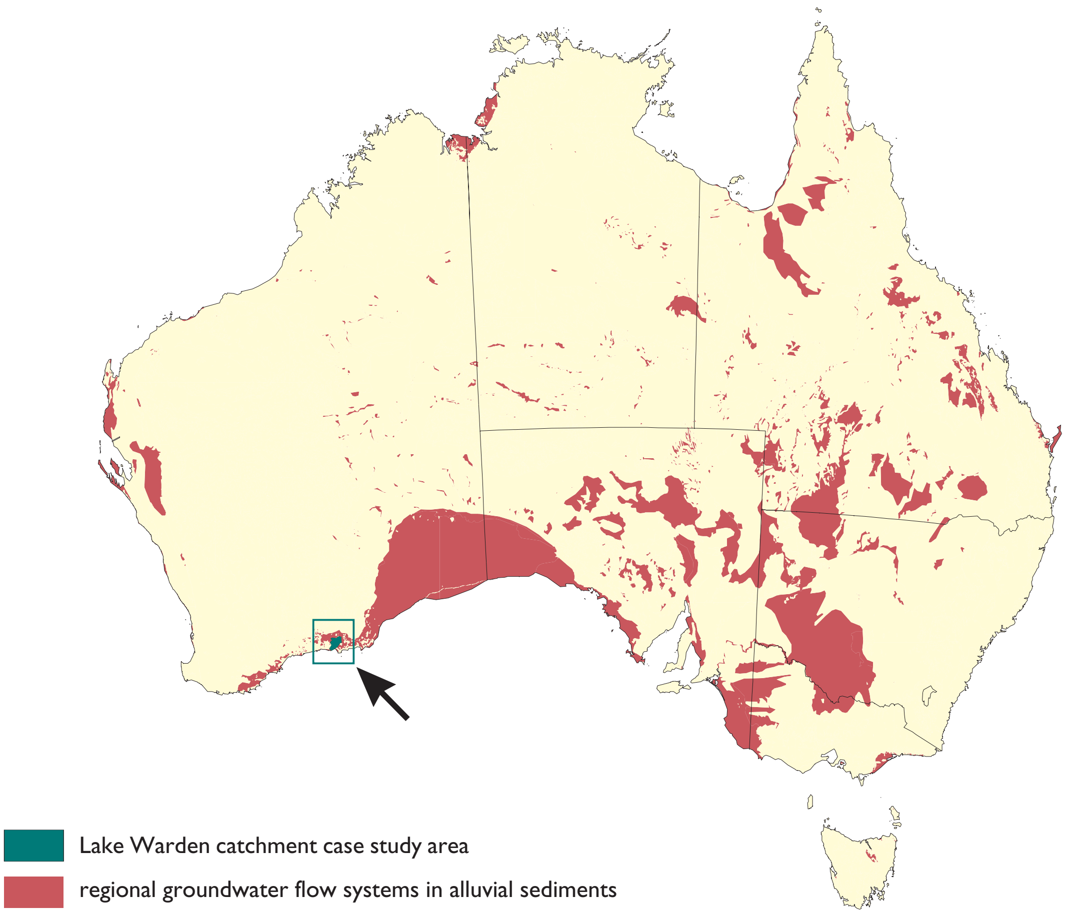
	No change (%)	Recharge reduction 50% (%)	90% (%)
2000	0.0	0.0	0.0
2020	0.2	0.0	0.0
2050	1.3	0.8	0.0
2100	1.6	1.3	0.0

LAKE WARDEN, WESTERN AUSTRALIA

Lake Warden catchment comprises four sub-catchments that feed the Lake Warden wetlands in southern Western Australia. It is dominated by annual pasture, with the remainder being cropped (approximately 33%) and perennial pasture, remnant vegetation and farm forestry (approximately 10% in total). With its low to medium permeabilities and low to moderate groundwater gradients, the catchment has a low to moderate ability to move groundwater.

It is estimated that 7.5% or 122 500 ha of cleared agricultural land in this catchment is affected by dryland salinity.

Figure 27. Distribution of regional groundwater flow systems in alluvial sediments.



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Results of groundwater investigations and modelling

The results of the groundwater investigation suggest that groundwater movements through the catchment are slow, and therefore response times to extensive changes in land use are also expected to occur very slowly.

- If current land use is maintained, watertables will reach the surface in most of the lower parts of the catchment within 40 years.
- A recharge reduction of 50% would not decrease the ultimate expanse of the area at risk of shallow watertables when compared with the status quo scenario.
- A recharge reduction of 90% would be necessary to stabilise rising groundwater level trends by 2020 and reverse the trends by 2050.

Table 24. Lake Warden (WA): change of area at different recharge reduction rates—based on current recharge rate (confined aquifer—upper catchment).

	No change (%)	Recharge reduction 50% (%)	75% (%)	90% (%)
2000	2	2	2	2
2020	9	4	3	3
2050	26	12	6	4
2100	40	23	11	5

Table 25. Lake Warden (WA): change of area at different recharge reduction rates—based on current recharge rate (unconfined aquifers).

	No change (%)	Recharge reduction 50% (%)	75% (%)	90% (%)
2000	2	2	2	2
2020	27	6	4	4
2050	45	33	7	4
2100	48	38	27	6

Implications

In Lake Warden area, recharge to the confined aquifer is taking place in well-defined areas of the upper parts of the catchment. Controlling recharge in these areas will manage the rise in artesian heads and groundwater discharge in the long term. On the other hand, recharge to the unconfined aquifers that takes place over most of the catchment will be very hard to manage.

Managing the water levels in the numerous lakes in the area through drainage needs to be investigated to assess its viability in controlling the water levels in the shallow aquifers.

A full technical report is available on the Audit's Atlas website at www.nlwra.gov.au/atlas.

Figure 28. Lake Warden (WA): change of area at different recharge reduction rates—based on current recharge rate (confined aquifer—upper catchment).

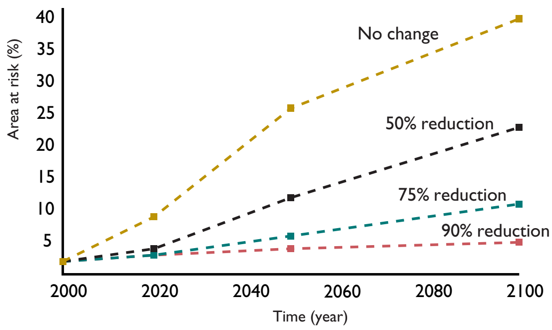
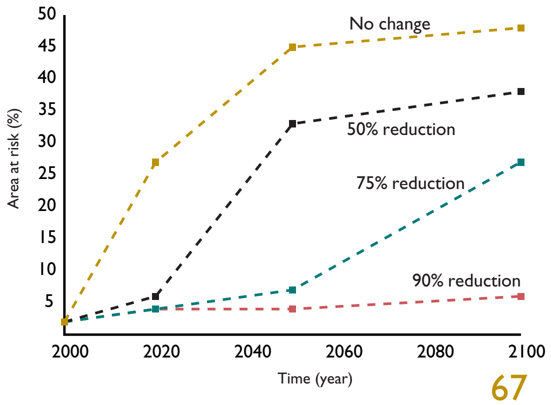


Figure 29. Lake Warden (WA): change of area at different recharge reduction rates—based on current recharge rate (unconfined aquifers).



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GREAT SOUTHERN, WESTERN AUSTRALIA

The Great Southern region is located in south-west Western Australia. Land use in the region is dominated by mixed cropping and grazing. The local and intermediate groundwater flow systems typically have low permeabilities and gradients and therefore a low ability to move groundwater. Similar local and intermediate systems are widespread in the agricultural regions of Western Australia and Eyre Peninsula of South Australia.

Salinity risk assessment

Approximately 30% of the cleared land and associated vegetation and water resources are at risk of becoming affected by salt over the next 30 years.

- Continuing current land use systems will result in larger saline areas developing.
- Most of this landscape requires large-scale intervention to change salinity risk with the exception of the steepest, wettest sites in the western portion of the region.
- Widespread adoption of low recharge farming systems may reduce the rate of groundwater rise, and the severity of the impacts, enabling communities and government to 'buy time', but it is unlikely to reduce the eventual extent of salinity.
- Although risk may be modified by engineering options, economic and environmental constraints will limit adoption other than in those areas where they are necessary to protect high value assets.

Methods

- Two new methods for analysing trends in bore hydrographs were developed. The first provides different linear trends for different segments of the data, and at the same time estimates the amplitude(s) of the seasonal response(s) in the data. The second allows gaps in the record to be inferred using rainfall data, as well as estimating long-term trends and the effect of management.
- Statistically repeatable methods for developing groundwater level maps for large regions with sparse data failed to produce a robust and reliable result.
- Previous methods for producing groundwater surfaces worked well in a local area, but the relationship could not be fitted in other regions.
- The application of the Land Monitor salinity risk maps based on predictions of shallow watertables for equilibrium conditions was useful for extrapolating expert knowledge on the ultimate extent of salinity risk and for identifying assets at risk at the regional scale.

Impacts

- For the 2.3 million hectares of area mapped for salinity risk, 1157 buildings, 3333 km of roads, 15 682 farm dams and 101 877 ha of perennial (remnant) vegetation are potentially at risk to salinity over the next 20 years.
- For three case study areas in the region that were examined in detail, the discounted value of production losses under the 'business as usual' scenario ranged between $800 and $1090 for every hectare of land that is predicted to become saline. In aggregate terms, losses for each of the two 30 000 ha case studies ranged between $4.5 and $6.1 m. The larger of the three case study areas (comprising 107 250 ha) was estimated to suffer losses of approximately $8 m. In addition to these production losses, a significant amount of new damage is expected on infrastructure and perennial vegetation.

Implications

- For all but the steepest landscapes, intervention in the form of land use change would need to be substantial and widespread.
- When alternative enterprises (e.g. trees for pulp and timber production) are limited to only the most appropriate soils, the ultimate extent of salinity does not radically change, although the impact is delayed.
- Since salinity risk abatement associated with low-recharge land use systems largely benefits the land they are planted on, these alternative farming systems must be profitable in their own right.
- The non-farm assets at risk require large-scale, local, mainly non-economically-driven intervention.
- Given the scale of revegetation required to substantially change the ultimate extent of salinity, it does not appear feasible with available low-recharge farming systems and tools to make up the gap in farm profitability associated with alternative, low-recharge farming systems.
- While 'low recharge high water use' farming will ultimately leave almost as much land at risk to salinity as current practice, the possibility that decades might elapse before the full impact of salinity is realised has considerable social and economic value. If nothing else, it gives families and government more time to adapt to a salinised landscape and possibly for some innovative solutions to be developed.
- Since bore hydrographic monitoring is essential for evaluating the effectiveness of treatments, monitoring systems must be substantially improved in aspects such as geo-referencing, surveying of elevation and spatial coverage of bores.
- Hydrogeological modelling in selected catchments suggests that most remediation strategies do not offer a great deal of off-site groundwater control. Most of the benefits of remediation strategies are local and prevent land from becoming saline because of a treatment planted on that land. This means that with no external subsidies for on-farm costs, treatments should be commercially profitable in their own right if they are to be attractive to farmers and the wider community. This is a key finding and indicates very clearly that farm-based solutions are an important tool and deliver local salinity mitigation benefits.

A full technical report is available on the Audit's Atlas website at www.nlwra.gov.au/atlas.

CASE STUDY: application of groundwater flow systems across geographic scales

Australian groundwater flow systems have been classified as local, intermediate or regional. Each system has a unique combination of attributes, but each in turn is composed of different landscapes with a degree of variability. At the national scale, the variability within each groundwater flow system is minor compared with the differences between groundwater flow systems. However, at finer scales, this variability becomes important, and so it is necessary to undertake more detailed analysis to ensure that the framework and concepts developed at the national level can be applied at the catchment scale.

In one sense classifying landscapes into their groundwater flow systems is an approach to standardising all of our knowledge of those landscapes. This enables us to use the groundwater flow system classification principles to define discrete catchments/regions that have common groundwater and salinity processes, common responses to land management, and a common range of salinity management options. The principles as established are based upon local knowledge and as such are more easily applied at the local level, than they are at the national level.

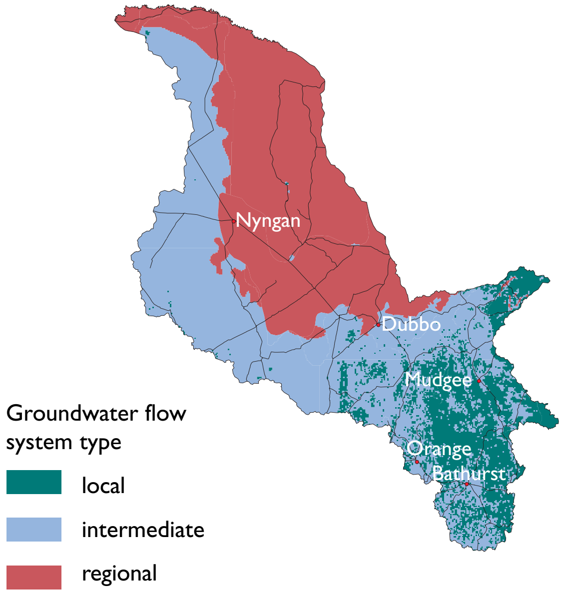
This finer scale of detailed analysis has already been accomplished in some catchments (see examples given below).

The Macquarie Catchment, Central New South Wales

The Macquarie Catchment is a large catchment in Central West New South Wales that drains to the north-west into the Darling River. Its upper reaches are the higher relief landscapes in the Bathurst–Orange district, flowing down basin through Wellington and Dubbo, and finally across the flat alluvial plains before reaching the Darling.

The national groundwater flow systems classification defined the catchments as having a complex distribution of local and intermediate flow systems in the headwaters (Figure 30), moving to a predominantly intermediate system in the middle reaches. The flow system then changes to a regional flow system based on the Great Artesian Basin recharge beds, and finally a regional alluvial sediments flow system underlying the Riverine Plain to the north-west.

Figure 30. Australian groundwater flow systems: Macquarie catchment, New South Wales.



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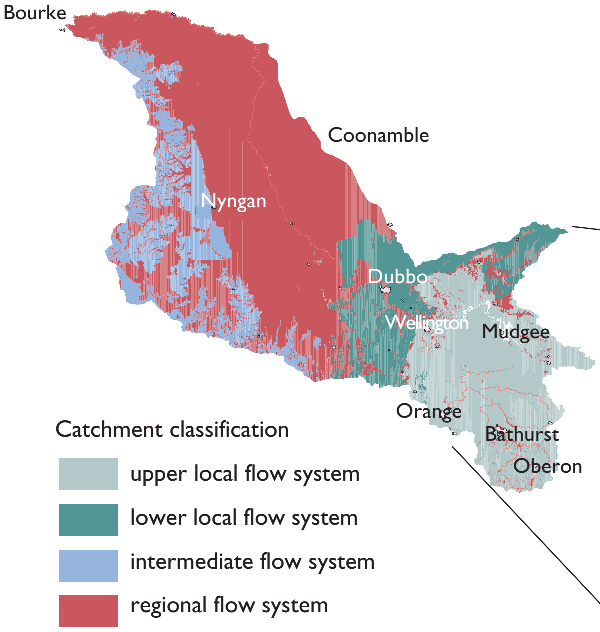
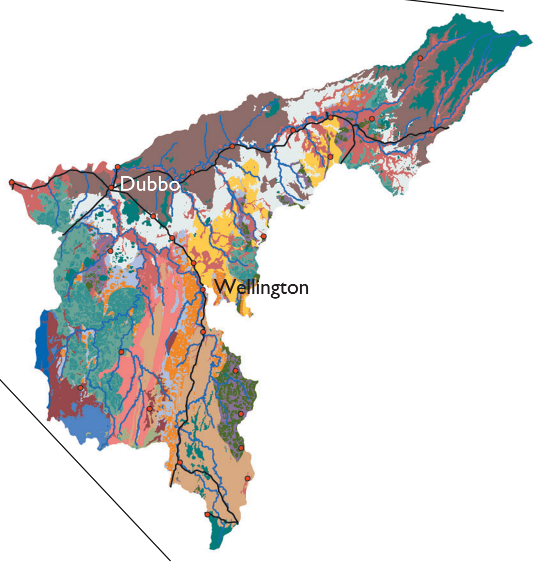
Two separate catchment classification exercises have been completed in the catchment. The first, as part of a modelling exercise carried out by Australian Bureau of Agriculture and Resource Economics/CSIRO to determine whole-of-catchment responses to land use change, used the mapping rules devised for the national groundwater flow systems map, but applied them to more detailed data coverage available for the catchment. This had the effect of not only increasing the level of detail that described the catchment, but also finetuning the classification in some areas in response to the better data (Figure 31).

Figure 31. Groundwater flow systems of the Macquarie–Bogan catchment (enhanced data inputs).



A second classification was undertaken in a study of the mid-Macquarie catchment aimed at providing a framework for catchment management. This classification used a new dataset based on more detailed geological data, together with more detailed elevation data. The key to the new classification was the reformulation of conceptual models based on knowledge from local salinity experts. This enabled a new set of rules to be developed that generated a more detailed set of flow systems and mapped as a set of Land Management Units (Figure 32). The new set of units is at a finer scale than the groundwater flow system classification and will form the basis for definition of a range of management options for discussion with the local community.

Figure 32. Seventeen Land Management Units were defined by the classification procedure (enhanced data and mapping rules).

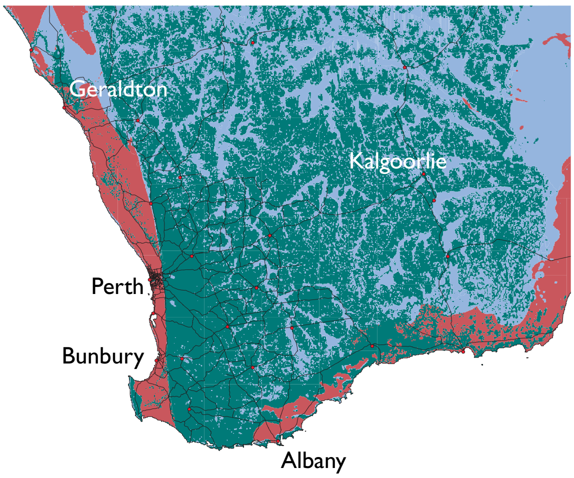


South-west of Western Australia

The groundwater flow system classification project had defined a large area of south-west Western Australia as a series of local flow systems. Again, at the national scale this was sufficient to demonstrate the differences between this region and others across Australia. It was of limited use in defining the response and applicability of management options.

More detailed work shows that local flow systems behave differently. Work by Agriculture WA and CSIRO Land and Water (George et al. in press) was aimed at simulating groundwater responses in several catchments to a variety of land use change and engineering interventions. Results show that watertables, and hence the long-term salinity risk, in relatively flat catchments in the low to medium rainfall areas (representing much of the agricultural area) respond only to significant (greater than 50%) reductions in recharge. Lower levels (less than 50%) of intervention may buy significant (greater than 40 years in the modelled cases) time before salinity impacts are fully realised in catchments with a deep (10–20 m) watertable.

Figure 33. Australian groundwater flow systems: south-west Western Australia.



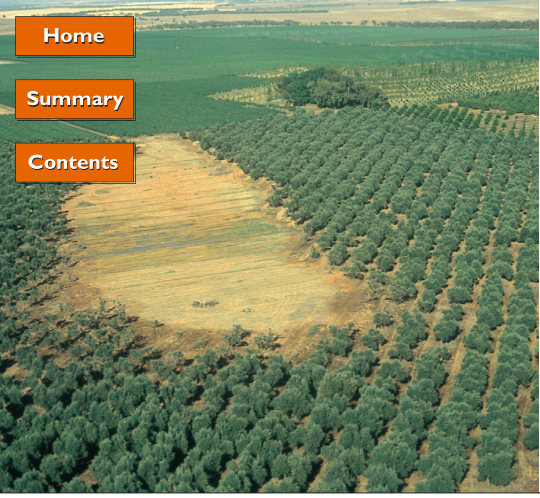
In the very long term, they do not significantly alter outcomes. By contrast, modelling suggests that catchments in undulating landscapes respond to the recharge reductions relatively quickly. In these areas, groundwater and salinity levels may decline (in upper and mid-slopes) within 10–20 years. However, the likelihood of the majority of the treatment options modelled being adopted is low; these treatment options are not well developed, and are not as economically attractive as current farming systems. This Western Australian work has focused on simulating the response for an area of high watertables, and does not make predictions about changes in salt loads in rivers and streams.

The work also concluded that some catchments within the flatter regions would develop significant areas with a shallow watertable as a result of their geomorphology. Evidence suggested convex or complex shaped land systems have a lower risk of salinity. Local topographic variations will also have a large impact on the area that actually becomes saline. As potential evaporation rates are very high (greater than 2000 mm per year), and discharge rates low (less than 100 mm per year), relatively small areas of the low gradient, high watertable areas need to discharge groundwater.

Conclusions

These conclusions highlight the fundamental characteristics of landscapes that operate at the finest, or paddock, scale. The national groundwater flow systems classification provides context and direction for these finer scale investigations.

The national groundwater flow systems map is a strategic planning tool. It is based on regional-scale information. It forms the technical base to consider regional salinity management options in the context of groundwater processes and the responsiveness of aquifers to changes in land use. Finer-scale analysis, building on these concepts and process understandings (such as the two-dimensional models from Western Australia), provides a tactical planning base at the local scale.



Deep-rooted perennial vegetation, one solution to recharge management

WAYS FORWARD: implications of Audit findings for salinity management

Australian Dryland Salinity Assessment 2000 has focused on developing an understanding of how the major groundwater systems across Australia function and, from this basis, an analysis of management options to control dryland salinity.

The improved understanding of groundwater processes and types provides information on:

- the extent of land use change and recharge reduction required to halt, and maybe reverse, the spread of rising watertables and salinised lands.
- the lag times between adopting recharge reduction or interception of saline groundwater and consequent responses in groundwater levels, area of land salinised and/or salt delivery to streams.

Local groundwater flow systems

Australia has close to 25 million hectares of local groundwater flow systems. Approximately 3% of these are considered to be at risk of developing some dryland salinity. These systems are commonly deeply weathered, low permeability systems that are already almost full and occur in cleared areas of temperate Australia.

These areas are likely to exhibit a lag of three to ten years or more between changes in the water balance and the initial occurrence of salinity. For these systems there is a probable lag of several decades before hydrogeological balance is reached. Consistent with these relatively small systems, changes in land use to effect significant reduction in recharge are needed on a local scale for each system.

Based on a conservative assumption that changes are required over half of each catchment area, approximately 12 million hectares in temperate Australia could require treatment to reduce recharge and restore hydrogeological balance. If these treatments are undertaken the area of salinised land will reduce fairly rapidly, probably within 10 to 15 years and in some cases much less time. However, low discharge capacity of many of these systems means that it is likely to be decades before salt delivery to water resources is significantly reduced. Biophysical options are appropriate for these systems. **Recognising that lag times to improve land will be much less than those to improve water resources, application of recharge management will depend on whether the main objective is land or water rehabilitation.**

Intermediate groundwater flow systems

Australia has around 40 million hectares of intermediate groundwater flow systems. Approximately 5% of these systems are considered to have a high risk of developing dryland salinity. They are mostly (75%) deeply weathered, low permeability systems. They are already close to full and occur in cleared areas of temperate Australia. These systems also include some high permeability, buried river channel systems.

These areas are likely to exhibit a lag of several decades or more between changes in water balance and the initial occurrence of salinity, and 50 years or more before hydrogeological balance is reached. To rehabilitate land and waters, changes in land use / water balance are needed over a significant proportion of each catchment. Based on a conservative assumption that land use changes to reduce recharge are required over half of each catchment this would amount to an area of approximately 20 million hectares. In most intermediate flow systems, the low discharge capacity means that it is likely to be decades before the effects of such changes become evident on land. In the higher permeability flow systems the effects of changes in land use are likely to become evident within a shorter period, possibly with similar response times to the local systems.

Regional groundwater flow systems

Australia has around 45 million hectares of regional groundwater flow systems. Approximately 6% of this land is considered to be at high risk of salinity in the next 100 years. These systems are characterised by broad plains and deep sedimentary sequences. They are likely to exhibit a lag of over 100 years between changes in water balance and the initial occurrence of salinity, and probably over 1000 years before hydrogeological balance is reached. Consistent with these extensive systems and very slow response times, it is likely to be many decades before the effects of recharge management become evident in groundwater levels. Improvements in salt loads to streams as a result of recharge management may not be detected within our natural resources management planning horizon of 50 years.

Table 26. Changes in recharge (mm/year) following conversion to crops or pastures (Williamson 1998).

Land use change	State	Average rainfall (mm/yr)	Recharge increase (mm/yr)	Recharge increase to rainfall ratio
Mallee to agriculture	SA	340	17	0.05
Mallee to agriculture	SA	370	27	0.07
Woodland to cropping	WA	500	36	0.07
Shrubland to cropping	WA	500	26	0.05
Forest to crop/pasture	Vic	620	20	0.03
Forest to crop/pasture	Vic	650	17	0.03
Forest to crop/pasture	WA	720	30	0.04
Sclerophyll forest to cropping	WA	730	24	0.03
Pine to pasture	SA	750	64	0.09
Forest to cropping	WA	910	65	0.07
Forest to pasture	Vic	990	80	0.08
Forest to pasture	WA	1010	60	0.06
Forest to pasture	WA	1150	52	0.05

Further information on the advantages and limitations of a range of salinity management measures is provided in the **fact sheets** at the end of this document.

Waterlogging in a saline area

WAYS FORWARD: management options for dryland salinity

Once salt has been mobilised, it will continue to move to the discharge areas in the lower regions of the landscape including streams, rivers and wetlands. Slowing or halting salt transport will require recharge control. Salt will continue to have an effect until its store is exhausted. Recognition of the central role of recharge control for managing salinity must be central to our strategic planning. It is sobering to extrapolate the results of the Audit case studies across Australia. Both the extent of land use change required and the likely lag times to treat the cause of salinity are far greater than generally recognised at either the policy level or in regional communities striving to control salinity.

If and where recharge control is not possible or feasible then we are dependent on engineering solutions that can effectively intercept the salt and store it safely in the landscape.

In other cases, particularly if land rather than water is the main assset at risk, adapting to salinity may well be the best option—there are many beneficial uses of salinised land and water resources.

Landowners, individually or as part of a catchment, must be confident that there will be a positive result before undertaking any salinity work based on recharge management. To meet this need, scientists must continue to develop, test and revise recharge management techniques in the context of the time taken and efficiency of the technique to improve groundwater levels.

The ways forward in salinity management are many and varied depending on objectives and the local biophysical environment. A combination of approaches that considers both individual farm and whole catchment factors is likely to be the best option.

Options for recharge management

Recharge reduction options include changing land use and farming practices, intercepting fresh water using engineering methods; retaining, re-establishing and managing remnant native vegetation, or a combination of these.

Substantial land use change will be required to significantly reduce recharge, by introducing high water-use farming systems in cropping areas, high water-use pasture systems and by revegetating with trees or agro-forestry systems.

Engineering methods that intercept surface water through banks or shallow drains are used for recharge control. Good quality water harvested by pumping or water diversion can be reused elsewhere on a property for irrigation or stock watering, by making productive use of water that may otherwise be a problem once it intercepts salt in the landscape.

Native vegetation over a substantial part of a catchment provides optimum recharge control as most salinisation is the consequence of water balance change that followed tree clearing. Management and protection of remnant native vegetation is the first step in working towards a higher water-using landscape. The scale of change in recharge following conversion of native vegetation to crops and pastures varies between 3% and 9% (Table 26) of the average rainfall (Williamson 1998). As recharge processes are generally faster than discharge processes, measures required to re-establish the water balance are substantial.

Saltbush: a key plant in making saline lands productive

Stirzaker et al. (2000) and others suggest a revolution in land use and farming systems including:

- opportunity cropping (rotations of winter and summer crops that are sensitive to soil water);
- phase farming (alternating phases of crops and lucerne);
- companion farming (over-sowing annual cereals into perennial forages/pastures);
- new agricultural plants;
- perennial pasture;
- high rainfall tree products;
- low rainfall tree products and revegetation with native woodlands and forests; and
- agroforestry.

Some of these options are more beneficial than others in controlling 'leakage'; some are available now, while others require additional research. Further research is also needed to determine which tree–crop–pasture mixes can reduce 'leakage' to acceptable levels and continue to generate attractive farm and community wealth. The appropriate siting of two or more of the above options within a catchment (taking account of soil type and landscape position) may have a beneficial multiplier effect for salinity management.

Significant changes in land use over a smaller proportion of catchment areas may not ultimately reduce the extent or severity of salinity, but may reduce the rate of salinisation in systems that are not yet full (particularly regional systems). Modelling the benefits of adopting land uses that partially reduce recharge levels indicates that it may be possible to delay the onset of salinisation for several decades. Partial changes in land use may be the realistic option, while more long-term options are researched, developed or evaluated (Stirzaker et al. 2000).

By overlaying our understanding of the geophysical characteristics of a catchment with the knowledge acquired from modelling of groundwater and farming systems, we can develop principles about the effectiveness of land use options. These principles will allow regional groups to make informed judgements about the likely performance of catchments under a range of land use options.

The flow systems where farming systems might be expected to deliver whole-of-catchment/end-of-catchment salinity benefits within an acceptable timeframe are those made up of responsive permeable aquifers in either local, or perhaps some intermediate flow systems. These are not extensive in the Australian landscape and are found mainly in some fractured rock aquifers in eastern Australia. Farm planning that integrates production and recharge management options is likely to be a necessity if catchment groups/authorities are to meet the types of water management targets being considered in catchment management plans in southern Australia.

As it is difficult to make generalisations about what will be effective for a particular catchment it is important to consider each option within the context of local catchment and farm conditions.

The sobering reality for most groundwater flow systems is that while recharge reduction may restrict the expansion of saline land, and may even reduce its area in some cases, it is unlikely to be successful in reducing the delivery of salt to the streams, rivers and wetlands. The salinisation of the water resources in these systems will continue unless engineering interventions to intercept the salt are put in place.

Engineering options for recharge and discharge management

Engineering options fall into two broad groups: the fairly simple, largely on paddock surface water management measures (e.g. banks, drains) and the more expensive, often larger area measures (e.g. deep drains, sub surface drains, pumps, interception and diversion systems).

Surface water management to control flows for erosion, waterlogging and harvesting water on farms has been a common feature of many regions, and offers opportunities for removing surface water before it can infiltrate and contribute to recharge. These measures along with more innovative measures such as raised bed farming will be a feature of farming systems particularly in Western Australia.

The more classical engineering options using groundwater pumps, deep drains and interception and storage/disposal structures have been limited mainly to irrigation areas or areas where water resources are being threatened. The high cost of establishing and operating these technologies mean that they are applicable either to protecting high value assets, or where it is necessary and economically viable, to extracting groundwater for industry development. Where groundwater is 'fresh', it might be used to support industries such as intensive horticulture; where saline, it might be used as the resource base for new and emerging saline industries.

In general, the application of these engineering options is limited by the permeability of the groundwater flow system being pumped or drained, although where high-value assets need protecting, it will usually be technically feasible, although sometimes costly, to implement these options. The pilot investigation at Merredin (see p. 12) in Western Australia is an example.

Productive uses of saline land and water

The productive uses of saline land and water include: halophytic vegetation and salt-tolerant grasses for stock fodder; salt-tolerant trees and horticulture; saline aquaculture; and nature conservation areas for biodiversity protection, greenhouse credits and recreational values. Chemical extraction and desalinisation of water are further options, more likely to be used to defray some of the costs of protecting high value assets.

These measures are limited to discharge areas, and their suitability is determined by the quantity and quality of groundwater, and varies between groundwater flow systems. The demand for saltland production systems will become more widespread as the extent of salinity increases.

Applicability of options

No one option is likely to work in isolation and most situations will require a suite of 'tools' for effective salinity management.

Current farming systems options for combating dryland salinity are limited by their ability to achieve sufficient recharge reductions in many situations; the scale at which they would need to be applied; and the lag times in influencing intermediate, regional and many local groundwater flow systems. Farming systems will also have to demonstrate economic benefits in their own right if they are to be adopted at the scale required.

In most systems it will be technically feasible to apply engineering options to protect major assets. It will also be possible to extract groundwater where salinity mitigation might be used in conjunction with industry or regional development. Costs and benefits relating to asset protection and industry development will determine the level of application of engineering technologies.

In most instances we can also apply a range of productive uses to the management of saline land and saline water resources.

An important determinant of options selected will be the benefit–cost analysis irrespective of the scale. Not only will new farming and land use systems that suit Australian environments be required, but innovative and inclusive approaches that permit fair comparison of market and non-market values will need to be developed.

Overall conclusions

- Different groundwater flow systems require substantially different combinations of management options.
- Holistic approaches to salinity that take account of the groundwater flow systems and the objectives of management are essential.
- In most instances there will be no single solution to the problem, and the combination of approaches will differ across temperate Australia.
- Adaptive management and innovation have a significant role to play in maintaining productivity and profitability. Strategic investment in management measures and mitigation may provide options to live with the current and rising levels of salinity.
- Intervention needs to be driven by asset protection plans for infrastructure, biodiversity, productive soils, water resources and combinations of these assets, with realistic targets set in terms of the level of salinity management that is feasible.

NORTHERN AUSTRALIA: a special case

Prevention and protection: opportunities in northern Australia

Treating the cause of salinity through recharge reduction may be effective in reversing salinisation in only a few responsive groundwater systems. Once the salinisation process is under way it is extremely difficult to slow, halt or reverse in order to protect water and land resources. Prevention is a far better investment than any attempt at control or management.

Northern Australia presents opportunities to avoid the dryland salinity problems of temperate Australia. Broad-scale clearing without recognition of salt stores and the resulting change in water balance is a recipe for problems, whether it is in 20 or 100 years. Wise management now to protect the landscape and prevent dryland salinity will prove far more cost-effective than any attempts to solve the problem once it occurs.

While salinity analysis has focused on southern Australia, sound scientific evidence (Bui et al. 1996, Williams et al. 1997, Bui 2000, Gordon et al. 2000, Gunn1967, Shaw et al. 1994) shows that all the factors that contribute to salinity hazard also exist over large areas of the semi-arid zones of northern Australia. Two factors that must be present for a salinity hazard to exist after clearing or change in vegetation cover are :

- presence of stored salt in the soil, regolith or groundwater systems, and
- an increase in the water draining beneath the root zone following tree clearing or vegetation change.

Hazard assessments have been carried out in Queensland as part of the Audit program and previously for the Northern Territory (Tickell 1994a, 1994b) .

An assessment is yet to take place for northern regions of Western Australia.

Northern Australia has seasonal patterns of high evaporation and summer rainfall. A common misconception is that these patterns mean that land clearing and other vegetation management cannot increase the amount of water draining below the root zone to intercept the salt and move it to lower positions in the landscape and to rivers, streams and wetlands.

Hydrogeological evidence does not support this perception. The summer wet season rainfall pattern in northern Australia is concentrated between December and April. These rainfall patterns respond to vegetation change (particularly the removal of deep-rooted perennial species) in a similar way and extent to the winter-dominant rainfall patterns of southern Australia where salinity is widespread (Williams et al. 1997, Gordon et al. 2000, Stirzaker et al. 2000). A change in vegetation can significantly increase the water that drains (deep drainage) beneath the root zone in northern and central Queensland. It is important to conduct water balance analysis over periods of a day or so, to see evidence of increased deep drainage following clearing. Coarse, monthly analysis of water balance can be misleading and is the basis for current misconceptions.

Key messages

- Hazard assessment has confirmed that large areas of the tropics and subtropics have a potential salinity problem if clearing occurs.
- Broad-scale land clearing with little or no regard for the salinity hazard is a recipe to repeat the problems of temperate Australia.
- Assessment of areas identified as having a hazard, particularly areas of extensive clearing in central and southern Queensland, is essential and would underpin the development and implementation of vegetation management policies and guidelines.
- Opportunity exists for a major national, well-focused investment in preventive action in northern Australia.

WAYS FORWARD: regional approaches essential

Cooperative community solutions

Dryland salinity is a reality for thousands of rural landholders and urban householders dealing with salinised land and facing crumbling foundations and diminishing water quality. Salinity will continue to worsen because the processes that control it operate over large areas and responses in groundwater levels to changes in the water balance are slow. Realistic options for its management are limited, and substantial changes in our land use patterns may be required in many areas before groundwater levels begin to fall.

Our requirement to manage recharge is a consequence of changes in the hydrogeological balance imposed over the past one hundred and fifty years; continuing or increasing salinity problems are a measure of the limited responsiveness of groundwater systems to management efforts. Given that many groundwater systems are slow to change—and that it is unlikely that they will respond within timeframes acceptable to contemporary stakeholders—we need to be more selective in the use of biologically-based salinity management programs.

Biological approaches (e.g. adoption of perennial vegetation, such as perennial pastures, woody vegetation and reforestation) do give us the opportunity to slow salinisation sufficiently to 'buy time' and to limit the ultimate size of the problem. In some cases they may also lessen the amount of groundwater that needs to be managed (e.g. where engineering options are applied to protect important assets or where they afford positive benefits in concert with options for managing saltland productively). In other circumstances, potential increases in farm productivity resulting from the more efficient use of water will be an essential part of the overall suite of required responses. They are likely to work best when combined with surface water management or other engineering options.

Given that we face a three-fold increase in salinity over the coming decades:

- We need to recognise that there is no quick fix. Salinity can be managed by prevention, treating the cause, ameliorating the symptoms, living with it or a combination of these.
- Salinity management requires knowledge about soil, salt, water and vegetation; integrated with knowledge about groundwater flow systems.
- We need to implement a landscape function approach to the management of on-site and off-site impacts of dryland salinity. In some areas this may require a mix of biological, engineering and industrial responses in accordance with biophysical and hydrogeological systems.
- We need to enhance monitoring systems to allow evaluation of the effectiveness of management responses and to build on our understanding of landscape processes.

Options for managing dryland salinity will vary across Australia in response to environmental conditions and social and economic aspirations for the catchment. These communities will need to identify the level of salinity management they wish to achieve in conjunction with their other objectives.

The National Action Plan for Salinity and Water Quality agreed by the Commonwealth and States on 3 November 2000 has, as its centrepiece, community-driven action directed at salinity and water quality problems in key catchments and regions. The plan recognises the importance of knowledge and data to underpin management responses and seeks to address this through a range of capacity building activities including research, extension and training. These activities will include mapping of salinity risk using airborne electromagnetic methods and ground truthing.

The Commonwealth has been extensively involved in the development of the mapping technology. Mapping in a number of regions is to commence during the first half of 2001.

The salinity-risk mapping and support of community actions are intended to assist communities to ensure that their actions are cost-effective and well targeted. The findings of the National Land and Water Resources Audit are a key input to inform this process and assist with monitoring outcomes.

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Electromagnetic monitoring: collecting information required for paddock management

Assessment and monitoring—current capability

This assessment is the first rigorous scientific attempt to present a national perspective of salinity. It has built on recent assessments in Western Australia and the Murray–Darling Basin, and provided an opportunity to assess the adequacy of data and information and to identify the elements of better collection, analysis and reporting systems.

The groundwater rise projections and scenario modelling summarised in this report have been based on available data in each State and Territory. It is clear from the studies undertaken as part of this Audit that monitoring and assessment systems for dryland salinity are incomplete for determining the current and future extent of salinity across the continent, or for assessing the effects of any remedial or preventative management responses. We have limited capability to predict salinity trends with confidence even in catchments that are supposedly well instrumented, such as those chosen for the Audit's case studies.

Assessment and monitoring capabilities

- There is no consistent national approach to monitoring the extent of and trends in dryland salinity.
- Surface water monitoring systems in most States have not been specifically designed to enable monitoring of salt loads. This limits the ability to assess the effectiveness of land and water management options in managing salt export out of catchments.
- Although groundwater level and trend data are recognised as a fundamental requirement in evaluating the size of the problem and the rates at which it is changing, there are major deficiencies in the design and coverage of groundwater monitoring networks. Even in Victoria, South Australia and Western Australia, where monitoring sites have been established, there are significant gaps in coverage or design, that limit the ability to evaluate effects of land use systems. Queensland and Tasmania have very limited formal groundwater monitoring systems suitable for assessing dryland salinity.
- Data on groundwater trends have been used in Victoria and Western Australia to supplement field survey or remote sensing. Groundwater monitoring in these States has been developed by State and community groups largely on a project-by-project basis.
- In Western Australia, 'Land Monitor' based on the use of multi-temporal Landsat imagery is the main form of monitoring the extent of area affected by dryland salinity. This approach has yet to be fully developed and accepted in the eastern States. Recent work in the Great Southern region of Western Australia, as part of the Audit salinity theme, has identified a number of constraints to integrating the groundwater information with the Land Monitor data to improve the confidence in assessing the extent and risks of dryland salinity (Campbell et al. 2000).
- Many groundwater monitoring sites are neither georeferenced nor related to an elevation datum.
- Monitoring sites are often not strategically placed in the landscape, nor is there adequate knowledge about the groundwater flow systems being monitored, and hence we have a limited ability to evaluate impacts of land use on dryland salinity.

- Where data on surface water or groundwater have been collected, there are major gaps in the length and frequencies of measurements, and inconsistencies in chemical analyses carried out. This limits the interpretations that can be made of salt load and salt concentration trends through time.
- Lack of formal design in biophysical monitoring systems then limits our ability to develop an economic evaluation of impacts.
- No formal monitoring system exists for changes in land use / land management and therefore tracking changes to water balance.

Most States have highlighted the need for improved monitoring systems for evaluating salinity management responses in the future. Improvements include better design and performance indicators appropriate to the questions being asked and the scale being considered. Because timeframes for measuring responses for some indicators such as salt trends in streams are long, surrogate measures (such as changes in the levels of perennial vegetation) will be required to assess impacts of land use changes/management responses in the short term.

Details of the framework and guidelines proposed by the Audit for monitoring dryland salinity have been prepared and are available on the Australian Natural Resources Atlas www.nlwra.gov.au/atlas.

Designing a monitoring system for Australia

If we are to make informed decisions about how to prioritise our investment in salinity, and how to assess the effectiveness of investments, we need to be equipped with sufficient, good quality data that enable us to answer some fundamental questions at the catchment scale.

- How effective have management activities been?
- What is the likely future extent/severity/ impact of salinity?
- What is the contribution to improving groundwater level of any salinity management investment?
- What investments are likely to deliver the most effective changes to water balance and over what time frame?
- How are systems—such as in-stream water quality, wetlands and soils—responding to improvements in groundwater level?
- What are the minimum components for an effective Australia-wide dryland salinity assessment and monitoring program?

We need:

- an analytical framework based on our understanding of hydrogeological processes controlling salinity, including timescales and spatial extents;
- evaluation methods and appropriate data (including indirect and surrogate indicators) that allow continuing evaluation of land management responses; the methods must enable the linking of biophysical, social and economic dimensions;
- consistent design and standards for data collection; and
- a capability to collect and manage data, and to produce information and assessments from this data.

The conceptual framework of groundwater flow systems provides the biophysical understanding to ensure that monitoring systems at the catchment scale:

- are consistent with the physical characteristics of areas at risk of salinity;
- are cognisant of the differing time periods of salinity development and specify the frequency and minimum duration of activities;
- allow comparison of like areas irrespective of State/Territory boundaries;
- concentrate on measuring change at a minimum number of locations, representative of that region and for the groundwater system type;
- can be aligned with other key aspects of monitoring (e.g. stream flow salinities) where these are compatible with strategic salinity monitoring; and
- are based on key agents of change for groundwater in a particular groundwater system (e.g. land use changes that impact on water balance).

Core data requirements of any monitoring program

- Extent of land salinisation.
- Trends in groundwater levels, stream salinities and salt loads.
- Land use/land cover (including native vegetation).
- Aquifer characteristics of major flow system types.
- Soil–water characteristics and parameters for crop–pasture–tree–water balance models.
- Crop and pasture production data (costs and returns).

An essential requirement for any monitoring system is long-term funding security and clearly defined roles for those with responsibilities in evaluating dryland salinity management activities.

Coordinating activities across Australia in designing systems, developing methods and reporting regular assessments would promote information sharing and improve both systems capability and return on dryland salinity management investments. This will require a national sponsor to ensure that the benefits of coordination are realised.

Hand-held electromagnetic instruments

Future knowledge requirements

Land use solutions to control recharge

There is an urgent need for land use solutions to control recharge and to achieve reductions to levels equivalent to the discharge capacity of the catchments. Stirzaker et al. (2000) set out some prospects but research, development and innovation to build these new industries is essential.

We also need to know more about how changing land use affects the landscape, so we can predict downstream impacts more confidently. We need to invest in development of specific tools, such as techniques that link surface water balance models and groundwater models to improve estimates of salt flows through the landscape.

Land use solution for salinised land and water

It is clear that despite best efforts, increasing areas of salinised land and salinised rivers and wetlands will need to be used for production. Salt-tolerant crops and pastures will be required where (from an economic point of view) 'living with salt' is the only feasible alternative.

Improved knowledge of Australian groundwater flow systems

We lack detailed knowledge about the groundwater processes that lead to dryland salinity for many parts of Australia. This is due to a lack of data and inability to transfer knowledge from well-studied areas to less familiar parts of the country.

Further development of the groundwater flow systems framework at the catchment scale is warranted to improve our understanding of individual flow systems and their responses to changes. If the full benefits of the application of the groundwater flow systems in tactical planning at the catchment scale are to be achieved, investment in catchment-scale data to support the assessments is required.

WAYS FORWARD: key implications for policy makers

Implications of long response times in groundwater flow systems to remedial measures

- A central feature of policy making on dryland salinity is that decisions are going to be made in the context of considerable uncertainty about outcomes, and trade-offs in targeting investments will be inevitable. Regional bodies that are to develop integrated regional/catchment strategies for salinity and water quality under the National Action Plan will need to be conscious—while setting targets and regional outcomes and assessing the trade-offs—of the level of temporal and spatial uncertainty, and lags in management actions.
- Evaluation of the effectiveness of management responses will be difficult or imprecise, and surrogate performance indicators will be required. These will need to be well understood by those involved in monitoring the effectiveness of investments.

Implications of the limited responsiveness of some groundwater flow systems to biological management options

- Surface water and groundwater resources will continue to salinise, with major impacts on rural communities and aquatic ecosystems.
- Although the rate of salinisation may be able to be slowed or reversed in some areas, in others land resources will continue to salinise, with major impacts on rural communities and terrestrial biodiversity.

Where salinisation can be halted or reversed, innovative land use systems will be required to produce the required reduction in recharge.

- Alternative industries using saline resources may be required in large areas of Australia.
- Existing pasture and crop species will require specific genetic improvement to tolerate saline conditions if existing production systems are to be maintained in areas of major salinisation.
- The development of new industries and land uses based on deep-rooted perennial plants, that are commercially viable and control the leakage beneath the root zone at levels similar to native vegetation, will require a long-term, well-focused and funded strategy of research, development, adoption and enterprise innovation.

Implications of the inadequate land and water monitoring and assessment systems

- There is a lack of comparability of assessment data across States and Territories. Some have capacity to report risks while others are limited to hazard. Methods and data constraints can lead to over estimates or underestimates.
- Lack of design and purpose in the groundwater monitoring networks limits our capability to assess change, evaluate the effectiveness of management programs and prioritise activities.
- Design of salinity management responses for nature conservation assets is severely compromised by inadequate knowledge on our biodiversity and the impacts of salinity.

POLICY DIRECTION

The Prime Minister, Premiers and Chief Ministers agreed on 3 November 2000 to a new National Action Plan for Salinity and Water Quality that sets policy direction for addressing dryland salinity and the deterioration of water quality. Core elements of the plan are:

- Setting targets and standards for natural resource management, particularly for water quality and salinity. Targets and standards will cover salinity, water quality and associated water flows, and stream and terrestrial biodiversity based on good science and economics.
- Integrated catchment and regional management plans developed by communities, in all highly affected catchments and regions where immediate action will result in substantial progress towards meeting State, Territory and basin-wide targets to reverse the spread of dryland salinity and improve water quality. The Commonwealth, States and Territories will need to agree on targets and outcomes for each integrated catchment or region management plan, in partnership with communities. Each plan will need to be accredited for its strategic content, proposed targets and outcomes, accountability, performance monitoring and reporting.
- Capacity building for communities and landholders to assist them develop and implement integrated catchment and region plans, together with the provision of technical and scientific support, and engineering innovations. It will include: research and development of new production systems attuned to Australian conditions, extension of information/data from the Audit to communities, provision of technical support through 'salinity response teams', and salinity mapping and training support.
- An improved governance framework to secure the Commonwealth–State/Territory investments and community action in the long term. This would include property rights, pricing and regulatory reforms for water and land use; placing caps for all surface and groundwater systems identified as over-allocated or approaching full allocation; prohibition of land clearing in areas where it would lead to unacceptable land or water degradation; and development of market-based incentives for adoption of best land and water management practices.
- Clearly articulated roles for the Commonwealth, State and Territory, local government, and community to replace the current disjointed Commonwealth–State/Territory frameworks for natural resource management. This would provide an effective, integrated and coherent framework to deliver and monitor implementation of the action plan.
- A public communication program to support widespread understanding of all aspects of the action plan to promote behavioural change and community support.

The action plan recognises the importance of knowledge to underpin management change. The work of the Audit on dryland salinity will provide valuable support in this and in implementation of the action plan, by informing regional communities and landholders of the regional and local natural resource condition: so that they are better able to plan regional and catchment salinity and water management strategies, and to monitor the performance of their actions.

The action plan also recognises the importance of on-going evaluation and monitoring of the natural resource base.

Riparian and wetland areas: major losses of these key wildlife habitats

GLOSSARY

Agronomy
The applied aspects of both soil science and the several plant sciences, often limited to applied plant sciences dealing with crops.

Alluvial
Deposited by rivers in low-lying areas and flood plains.

Annuals
Plants that live for one growing season.

Aquifer
A layer of rock which holds and allows water to move through it, and from which water can be extracted. Confined aquifers have a layer of rock above them which are impermeable to water.

Bedrock
Unweathered hard rock at the base of a soil profile.

Biophysical
Relating to biological and physical processes.

Bore
A hole of uniform diameter (usually 150 mm to 160 mm) drilled vertically into the ground to tap an aquifer. It contains a pipe through which groundwater can be pumped or can flow to the surface by artesian pressure (see also pressure and hydraulic pressure).

Break of slope
The line across a landscape at which the surface slope is reduced and where the hydraulic conductivity of the underlying material or the hydraulic gradient decreases.

Catchment
The area of land from which rainwater or snow melt drains into a reservoir, pond, lake or stream.

Colluvial (deposits)
Deposits of loose material that have been carried by gravity and are usually found at the foot of slopes or cliff lines.

Deep drainage
Where water drains from below the root-zone into underlying aquifer systems.

Discharge
Flow of groundwater from the saturated zone to the earth surface.

Discharge area
The area in which there is upward movement of groundwater and where groundwater is discharged from the soil surface. Groundwater escapes via springs, evaporation, transpiration and surface drainage (see also recharge area).

Drain
A channel for the purpose of interception and removal of excess surface or sub-surface water to a stable outlet.

Ecosystem
A community of organisms, interacting with each other, plus the environment in which they live and with which they also interact such as a pond or forest.

Electrical conductivity
Ability of a substance to conduct electricity.

Episodic recharge
Where recharge occurs as a result of a small number of intense or prolonged rainfall events, rather than steadily over a long period.

Evaporation
The process of water changing from a liquid to a vapour.

Extrapolate
To estimate a quantity which depends on one or more variables by extending the variable/s beyond their established ranges.

Fallowing
The land management practice of leaving land without vegetative cover for a period of time before sowing another crop. Its purpose is to allow nutrients and water to accumulate in the soil.

Flowtube model
A catchment-scale groundwater model.

Geology/geologic
Science of learning about the earth: its origin, structures, composition, historical changes and processes.

Geomorphology
Science of describing and interpreting landform patterns and processes of landscape formation.

Geophysics
The science of studying the earth's physical properties such as magnetism, conductivity and density.

Groundwater
All free water below the surface in the layers of the Earth's crust.

Hazard
Anything that can cause harm to an asset.

Hydraulic conductivity
The physical property of the aquifer which determines the rate of movement of water.

Hydraulic gradient
The slope on the watertable (change in hydraulic pressure over distance in the direction of flow) which determines the rate of movement of groundwater.

Hydraulic pressure
The pressure exerted by water over an area, usually causing some movement or flow of water from one area to another.

Hydrogeology
The study of groundwater movement.

Hypersaline
More saline than seawater.

Inundation
Flooding, overflowing or deluge.

Non-market value
Value placed on environmental changes which are usually not valued through market transactions. An attempt is made to estimate in dollar terms the loss suffered by the community by such changes.

Perched aquifer/watertable
A watertable above the main watertable level where impermeable soil or rock prevents the water from percolating through to the main groundwater body.

Permeability
The capacity of a substance (for example, soil or rock) to allow water to pass through it. Sand, for example, is said to have high permeability.

Perennial
Plant that lives for several years (annuals live for only one growing season).

Pressure
In confined aquifers (those under a confining layer), the groundwater is stored under pressure. When it is intercepted (e.g. by a bore), the groundwater rises under pressure to a level above the top of the aquifer.

Recharge
A component of rainfall that drains below the root zone of vegetation and joins the groundwater.

Recharge area
The area where water can enter and move downward to the groundwater. Recharge areas are usually permeable in the upper slopes and are often on shallow soils.

Regolith
Weathered or sedimentary material that is over bedrock.

Remnant vegetation
Vegetation remaining after an area has been cleared.

Risk
An estimation of the expected amount of harm that will occur to an asset.

Root zone
Near-surface part of a soil profile where roots are active.

Seeps/seepage
Where there is permanent or seasonal appearance of water at the soil surface causing soil salinity either directly through saline water or by evaporative concentration. Non-saline seepages also occur.

Spectra/spectrum
A continuous range of frequencies within which waves have some specified common characteristics (as in radio-frequency spectrum, visible spectrum).

Topography
The detailed description and analysis of the features of a relatively small area, district or locality.

Transpiration
The process by which water is extracted from the soil, transmitted through plants, and evaporated from the leaves.

Water balance
A state of equilibrium when rainfall or irrigation water in a landscape is accounted for by the sum of run-off, plant water use, evaporation, recharge and changes in soil moisture content.

Waterlogging
Waterlogging occurs when the watertable rises into the root zone. It results in anaerobic (absence of free oxygen) conditions which reduce plant growth and may kill plants.

Watertable
The watertable is the upper surface of groundwater. The soil profile is fully saturated below the watertable and unsaturated above it.

Weathering
Chemical, physical and biological decomposition of rocks. This can result in the formation of a soil profile.

Piezometers: a monitoring tool

REFERENCES AND FURTHER INFORMATION

Australian Natural Resources Atlas: presents the results of all State investigations spatially, including an on-line mapping function to link dryland salinity to other natural resource information—including soil, water, infrastructure and production information. The atlas also provides links to all technical reports prepared by States and consultants as part of the Audit's investigations. The atlas can be found at www.nlwra.gov.au/atlas.

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Peter Richardson	inside cover, pages ix, 48, 56, 75
Mirko Stauffacher	pages 60, 62, 64
Baden Williams	pages v, 44, 82, 91

GROUNDWATER FLOW SYSTEM FACT SHEETS

Background

Australian groundwater flow systems define hydrogeological provinces with similar geological and geomorphic characteristics and landscape processes that give rise to the incidence of dryland salinity.

Hydrogeological processes determine the responsiveness of the groundwater systems to change and therefore govern the extent, scale and mix of interventions required to manage dryland salinity. The mix of options that might be reasonably considered to manage salinity will vary considerably (e.g. local groundwater flow systems in deeply weathered terrain will need different solutions to large regional groundwater flow systems comprising alluvial aquifers operating at the scale of river basins).

Context for action

The responsiveness of groundwater systems to change will dictate what can be effectively achieved through groundwater recharge and discharge management within reasonable timeframes.

Attributes of groundwater systems that determine their capacity to transmit groundwater exert considerable influence over the capacity to manage salinity either through biological options for managing recharge, engineering options for managing watertables, or options for developing saline industries. Highly transmissive local flow systems might be expected to respond to most salinity management options far more readily than very sluggish local flow, or perhaps regional flow systems operating over hundreds of kilometres.

Biological options that promise to reduce recharge by 50% might be seen in a very positive light, particularly if they achieve increased productivity of farming systems through greater water use efficiency. However, the underlying groundwater system could take a long time to change because of:

- the sluggish nature of the aquifer;
- its regional extent; or
- strong convergence upon a lower discharge site.

Therefore salinity benefits might not be evident for some 15 to 60 years, or indeed much longer (depending on the groundwater flow system).

Engineering options will be required in very sluggish groundwater flow systems because of difficulties in extracting groundwater from slowly permeable materials. The ability to reliably harvest saline groundwater from slowly permeable landscapes also influences the range and efficacy of many commercial options that might be considered in the quest for saline industries such as salt harvesting or saline agriculture or aquaculture.

Acknowledgment: Much of the background material presented below on recharge management options has been taken from the National Dryland Salinity Program publication *Assessing the causes, impacts, costs and management of dryland salinity*, L. Martin & J. Metcalfe, LWRRDC Occasional Paper 20/98 Revision Number One.

Biological options for managing groundwater recharge

Biological systems for managing groundwater recharge most commonly involve the widespread reintroduction of perennial vegetation in the landscape, either in the form of deep-rooted high-water-using perennial pastures, cropping practices which afford improved water use efficiency in croplands, or the adoption of of woody vegetation ranging from fodder shrubs to plantation forestry.

Each of these biological systems varies in its capacity to control groundwater recharge. This variance has been taken into account in rating the efficacy of each salinity management option. Broad judgments are made, largely on the basis of woody vegetation being more effective in recharge management than perennial pastures, which are in turn considered more effective than cropland management. In the overall assessment, however, the means of controlling recharge is considered much less important than consideration of the timeframes in which recharge reduction options translate into salinity benefits through groundwater responses.

Maintenance of remnant native vegetation

It is easier and more economic to maintain existing native vegetation than to replace it once it has been disturbed or cleared.

However, in order to maintain the vegetation in good condition it is necessary to adopt a management regime that will ensure its long-term viability. The main management practices required to maintain and, where necessary, rehabilitate native vegetation involve:

- fencing remnant vegetation to control grazing stock;
- eradicating rabbits and controlling weeds;
- maintaining fire breaks;
- minimising pesticide drift into native vegetation;
- confining recreational activities to specified areas; and
- re-establishing plant species that are absent from the ecosystem.

Advantages

- Saving remnant vegetation helps in recharge control.
- Preserved areas help to set recharge control targets.
- Areas of remnant native vegetation that remain are the most important systems in terms of biodiversity outside tropical rainforests.
- High heritage and conservation values are maintained.

Limitations

- Due to the limited amounts of remnant native vegetation left to protect there may only be modest benefits to catchment-scale recharge control.
- There is evidence that degraded remnant vegetation provides incomplete recharge control.
- Much of the existing remnant vegetation is not self-sustaining since it is too scattered to regenerate effectively.
- It may not be possible to do enough to save downstream systems due to rising watertables and existing damage may be irreversible.
- The time it takes for recharge control to reduce saline discharge may be very long (hundreds to thousands of years in some places).
- Native vegetation can harbour pest plants and animals, and therefore requires ongoing management.

Annual crops and pastures

There are a number of ways that water use can be increased in conventional crops and pastures. Although many are relatively simple measures, greater effort may be required in planning and management (particularly with pastures) if they are to be effective for reducing recharge. The following measures increase water use by annual crops.

Improving agronomy

- Lifting yields of cereal and legume crops though improved management, better crop rotations and improved pasture management (during the pasture phase) may improve the water use efficiency of crops.

Removing impediments to root growth/ reduced tillage

- In some cases tillage to enable better root growth will aid in reducing recharge, while in others, reducing tillage will help decrease recharge rates. Determining whether or not it is appropriate to till serves to highlight the complexity of salinity management and how options are very specific to local conditions.

Eliminating fallow periods

- Fallow periods have been used traditionally to allow water stores to increase, and therefore improve productivity. However, recharge is increased and can lead to more rapid degradation than if fields are continuously under vegetation cover.

Opportunity or response cropping

- This occurs when favourable conditions such as suitable soil moisture levels are used to determine when to plant.

Phase cropping

- Phase cropping involves the rotation of annual cropping systems with perennial pasture systems (e.g. following 5–7 years of a continuous cropping phase with 5–7 years of lucerne. The lucerne helps to remove water that has escaped past the root zone of shallow rooted crops in previous years).

Alley cropping

- Annual crops are planted in alleys among belts of perennial plants which provide shelter, increased water use and, depending on the species used, possibly grazing, timber and/or habitat.

<u>Advantages</u>

- In cropped areas there is the potential for a high rate of adoption of this solution, particularly when there is the possibility of higher economic return.
- Costs can be kept to a minimum, and may be offset by productivity increases.
- This solution doesn't require substantial land use change.
- Productivity is likely to increase.

<u>Limitations</u>

- Although there is room to improve farming practices so that water use is maximised, it is difficult to significantly reduce recharge under annual crops and pastures (and almost impossible in wet years); increased plant water use and productivity may come from reduced soil evaporation and hence may not significantly reduce recharge.
- Skilful management and widespread commitment on every farm in a catchment is required to consistently achieve high water use.
- Increasing the water use by annual plants is unlikely to prevent salinisation on its own.
- Annuals do not use water that falls in intense or prolonged rainfall events, or that falls when plants are not growing.
- Reducing recharge under annuals is a problem in well-drained (e.g. deep sands), low-fertility and waterlogged soils and on heavily grazed pastures.
- When annual rainfall exceeds 600 mm the scope for recharge control by modified agronomic practices in cropped areas is limited.
- Continuous cropping practices may be unsustainable where there is soil structure decline, acidification, and herbicide resistance.

Traditional perennial species

The deeper roots of trees, shrubs and some perennial pasture species give greater water-use potential than annual, shallow-rooted plants. Perennial pasture systems have repeatedly been shown to be superior to annual systems for controlling deep drainage. Lucerne has attracted particular interest for its ability to substantially reduce recharge.

Advantages of using perennial pasture system

- Land use is complementary (e.g. in crop/pasture rotations shallow-rooted species are replaced with deeper-rooted more water efficient species).
- Adoption rates are likely to be higher than for more substantial land use change strategies.
- Gives a cash flow if well managed.
- Water use will increase and make some difference to recharge.

Limitations

- When changing from annual to perennial pasture species, better management is required (e.g. restricted grazing).
- May only deliver marginal benefits in terms of recharge.

Changing to new perennial species

There is potential for reducing recharge by changing to new deep-rooted perennial woody plant crops such as jojoba, oil mallee species and broom brush. These may provide some of the economic returns required to finance the scale of revegetation that is required to make a difference to salinity problems. Such woody plants may also be important in agroforestry and alley farming options (e.g. the *State Salinity Strategy* for Western Australia indicates the need for 3 million hectares of revegetation over the next 30 years. Governments cannot finance this scale and rate of planting, but could provide commercial incentives to increase farmer motivation to adopt revegetation as part of agricultural practice and farm business).

Alternatively, sustainable agriculture utilising commercially motivated revegetation can be seen as complementary to biodiversity conservation. Biodiversity conservation may require woody plant crops as they have the potential to provide commercially viable industries while at the same time addressing the salinity problem.

Advantages

- These crops may prove effective for controlling recharge and re-establishing water balance in low rainfall areas.
- Perennial species may provide economically viable alternatives to traditional crops (e.g. oil mallee in the wheat belt of Western Australia).
- Evidence is emerging that mixtures of trees/woody plant crops and annual plant crops may be more productive than monocultures of either.

Disadvantages

- Uncertainty about market prospects for the crops if there is insufficient planning and economic analysis.
- Time lag involved in establishing crops can place additional financial strains on already struggling enterprises.
- Cultural change required for their cultivation may be a disincentive.
- Deep-rooted perennials which thrive in a new environment will always have the potential to invade remnant native vegetation. Native non-local plants can be as great a weed threat as exotics.

Trees

Under favourable conditions, trees can extract large quantities of water from the soil by transpiration, and can directly intercept and evaporate rainfall. They use more water to a greater depth in the root zone than shallower-rooted species, reducing deep drainage.

Trees actively use water for a greater part of the year than most crops and pastures and are the only generally effective way of lowering watertables in the absence of massive engineering. Trees are particularly useful for reducing recharge in higher rainfall areas (greater than 500 mm/year) and can minimise recharge even given large episodic rainfall events. Other types of vegetative land cover are unable to provide effective recharge reduction when rainfall events are episodic.

Situations most suited to using trees to manage salinity include those where:

- there are shallow soils (less than 5 m) over weathered and fractured rock;
- the soils are deep sandy or permeable (less than 5 m);
- the country is steep and broken;
- timber processing industries are situated nearby;
- shade or windbreaks are needed;
- the region was naturally treed prior to settlement;
- wildlife protection is desired; and
- groundwater is close and fresh (less than 5 m).

Advantages

Few would argue with the contention that planting trees can reverse land degradation if revegetation is extensive and strategically placed. In addition to effective recharge control through higher water use and consequent lowering of watertables, planting trees confers other important advantages:

- enhancement of regional biodiversity by providing habitat for other plant and animal species;
- aesthetic improvements to the appearance of the land;
- returns for both landowners and the community;
- erosion and wind control;
- windbreaks for stock;
- biological weed and pest controls;
- increased production (see alley farming); and
- potentially sustainable income sources.

Impediments

Establishment of trees is expensive. Using them to manage salinity or provide income is a long-term strategy. After the trees are planted, it will be some years before watertable levels start to be affected and many more years before the trees reach maturity and provide other desired benefits.

Another major obstacle is that for effective reduction in recharge there may need to be 30–50% reforestation in a catchment (and even more if trees are to be harvested). This is a particular issue for those landowners in recharge areas who do not themselves experience salinity problems. These landowners are unlikely to see the value in losing large areas of their land at high cost when they are not personally impacted by the salinity itself.

Impediments associated with planting trees to manage recharge include:

- costs: initial planting costs are high and unless there is a perception of a solid economic return it can be difficult to convince farmers to plant trees;
- cash flow: if growing trees for harvest, it may be 25 years before there is an economic return;
- difficulties with integrating trees into farming systems;
- lack of species and systems suitable for lower rainfall areas;
- need for infrastructure to support agroforestry enterprises, such as sawmills and markets;
- risk of fire;
- loss of productive land with non-commercial tree planting (at least in the short term);
- the need to harvest trees for a return on investment, which means plantings will need to be staged to ensure recharge control;
- the time lag before trees begin to have an effect on recharge.

Engineering options for managing watertables

Engineering strategies to reduce recharge include drainage to intercept and redirect surface and groundwater, and groundwater pumping of fresh water. These strategies can be costly to implement and are hence usually only used in urban areas. Deep subsurface drainage and pumping have been shown to be cost-effective only in situations where:

- the land is very valuable (towns, nature reserves, infrastructure);
- the soils and aquifers are permeable and in hydraulic connection (water flow is connected); and
- there is a safe option for effluent disposal.

Engineering strategies are often combined with vegetation strategies to increase the effectiveness of salinity management plans.

In areas prone to flooding, inundation (water ponding at the soil surface), waterlogging (excess water in the root zone of plants) and where agronomic solutions are inadequate, drainage is often a solution. Areas with excess surface water contribute salt, sediment, nutrients, and pesticides to streams, rivers, wetlands and estuaries. Collection and storage for later re-use of these surface waters can increase plant growth and water use and reduce recharge.

Advantages

Surface drains

- Low cost measures which are cheaper to construct and maintain than it is to take land out of production.
- Cause minimal disruption to land use.

Subsurface drains

- Effective for removal of groundwater from waterlogged areas.
- Can lower watertables sufficiently to enable productive use of affected land.

Groundwater drains

- Interception trenches are a relatively cheap water interception and storage strategy.
- Can lower watertables.
- Enable unusable land to be reclaimed for production.

Groundwater pumps

- If pumping works, salinisation problems can be minimised and production of conventional agricultural systems boosted at the same time.
- Capital assets in towns can be protected by removing the problems associated with salinity and waterlogging

Limitations

Surface drains

- Value for controlling waterlogging may be limited in some areas.
- Effluent may cause problems off-site (salts, nutrients).
- Cannot be built in sodic soils.

Subsurface drains

- Much more costly than surface drainage measures.
- Storage or disposal of collected water can be costly.

Groundwater drains

- Deep drains are costly to build.
- Storage and disposal of collected water can be costly unless it has a beneficial use.

Groundwater pumps

- Capital cost is high; can be expensive to set up and maintain.
- Applicable areas are limited to high yielding aquifers.
- Only treats the symptoms.
- Limited area of influence in most systems.
- If using water for irrigation it must be carefully managed.
- Water storage systems that leak can recharge the system.
- Industry infrastructure is required for the irrigated crops.
- Disposal of water to the environment.

Saline industries

It is apparent that throughout much of Australia salinity will continue to expand over coming decades in spite of our best efforts to contain it. In many instances there will be little choice other than to adapt to more saline conditions by further developing the range of saline industries.

How difficult it is to develop these new industries depends upon the nature of biophysical and landscape processes operative within each groundwater flow system. Options that require large amounts of saline groundwater (e.g. salt harvesting) will be established with greater ease where the landscape is made up of highly transmissive regional aquifers. Industries based upon the grazing of salt-tolerant grasses may find greater application in the more humid regions within upland regions made up of fractured rock aquifers.

The fact sheets

The following fact sheets describe each hydrogeological province in terms of the biophysical and landscape context in which salinity occurs, the attributes that determine groundwater responsiveness, and the processes that operate in the landscape to affect salinity. The likely efficacy of salinity management options has been rated. The ratings are based on a set of mainly quantitative criteria and expert judgement (Table 27).

The evaluation process

Listing the attributes of each salinity/ groundwater flow system provides a common basis for defining hydrogeological performance in terms readily appreciated by the Australian salinity and groundwater specialists, and a common basis for considering the responsiveness of each system. Specifying the biophysical and landscape determinants of each system has allowed the experience and knowledge gained over many decades of salinity research to be considered, in addition to more recent hydrogeological modelling, particularly that achieved within the case studies of the Audit. In this sense the fact sheets represent the outcome of an 'expert' decision making process.

Fact sheets: version 1

The information in each fact sheet illustrates our knowledge and understanding of the general salinity and groundwater processes that prevail in Australian groundwater flow systems. The discussion of management options presented under each of the groundwater flow systems is intentionally generic. Readers should use these comments as a starting point for the consideration of options at a catchment level and refine with more detailed local information. It is anticipated that over time this material will be revised as new information becomes available.

Table 27. Definitions of the relative ratings that apply to the attributes of groundwater flow system as listed within fact sheets.

Attributes	Rating	Meaning/value
Scale (of groundwater processes)	Local	Groundwater flows over distances less than 5 km within the confines of sub-catchments
	Intermediate	Groundwater flow over distances of 5 to 30 km and may occur across sub-catchment boundaries
	Regional	Groundwater flow occurs over distances exceeding 50 km at the scale of river basins
Aquifer transmissivity	Low	Less that 2 m^2/day
(ability to transmit groundwater	Moderate	2 m^2/day to 100 m^2/day
through the aquifer)	High	Greater than 100 m^2/day
Groundwater salinity	Low	Less than 2000 mg/l
	Moderate	Ranging from 2000 mg/l to 10 000 mg/l
	High	Greater than 10 000 mg/l
Catchment size	Small	Less than 10 km^2
	Moderate	Ranging from 10 km^2 to 500 km^2
	Large	Greater than 500 km^2
Annual rainfall	Low	Less than 400 mm
	Moderate	Ranging from 400 mm to 800 mm
	High	Greater than 800 mm
Salinity rating	S1	Loss of production
	S2	Saline land covered with salt-tolerant volunteer species
	S3	Barren saline soils, typically eroded with exposed sub-soils
Responsiveness to land management	Low	Salinity benefits accrue over timeframes that exceed 50 years
	Moderate	Salinity benefits accrue over timeframes ranging from 30 to 50 years
	High	Salinity benefits accrue over timeframes less than 30 years

FACT SHEET 1. LOCAL FLOW SYSTEMS IN DEEPLY WEATHERED ROCKS

Regions

Local flow systems in deeply weathered rocks are found in south-west Western Australia; Eyre Peninsula, South Australia; and Dundas Tablelands, Victoria.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Gently undulating
Aquifer	Saprolite
Aquifer transmissivity	Low
Groundwater salinity	Moderate – high
Land use	Grazing and cropping
Catchment size	Small – moderate
Annual rainfall	Moderate
Salinity manifestation	Break of slope and valley floor
Salinity rating	S2, S3
Temporal distribution of recharge	Seasonal
Spatial distribution of recharge	Catchment

Type areas:

Discussion

These groundwater systems typically occur within ancient landscapes. They are formed through deep weathering in early Tertiary times. They occur most commonly where deep chemical alteration of the upper regolith of granitic terrain has resulted in extensive zones of pallid clay and silt; a very effective medium for storing salts introduced as aerosols through rainfall and concentrated in the saprolite through evapotranspiration. In these simple systems, groundwater recharge generally occurs on the slopes of catchments. Vertical movement dominates groundwater hydrogeology, and is compounded by lateral convergence on the lower landscape, causing rising watertables and ultimately saline groundwater discharge at breaks of slope or valley floors. In these systems the timeframe between clearing land of native vegetation and the onset of groundwater discharge is short, on average 20 years. Once full and without intervention, the time for the groundwater systems to empty out excess water is likely to be much longer, due to the low permeability of the rock material. The critical attributes of this groundwater flow system for salinity management are the low permeability of the aquifers and the relatively high groundwater salinity levels.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Recharge may be managed (in part) by pastures but the sluggish nature of groundwater flow together with contemporary elevated groundwater conditions mitigate the opportunity to manage salinity within a timeframe acceptable to most stakeholders.

Cropland agronomy
As above. Biological management of recharge in these systems is unlikely to deliver salinity benefits within an acceptable timeframe. Adopting cropping systems and rotations that incorporate lucerne and woody vegetation may reduce recharge, but watertable reductions are unlikely to be realised within the short term.

Woody perennial vegetation
As above. The behaviour of these systems is controlled by their inherent low permeability, and accordingly their slow responsiveness to land management. This option may be effective in the long term.

Plantation forestry
Provides effective recharge management, and may be effective in managing salinity in the medium to long term.

Engineering watertable management

Surface drainage
Drainage may reduce run-off flowing onto or ponding on saline land. This may in turn limit salt wash-off to streams, minimise erosion of saline soils and increase agricultural productivity.

Sub-surface drainage
This is a technically feasible option, but limited permeability together with a high cost factor makes it unacceptable in most regions unless high value assets require protection.

Groundwater pumping
Limited application because of the poorly permeable nature of the weathered rock material and high cost factor.

Managing saline resources

Halophytic vegetation
Generally applicable where diffuse saline groundwater discharge within semi-arid slowly permeable landscapes affects extensive soil salinity.

Salt-tolerant grasses/clovers
Widespread application, increased productivity and protect saline land from soil erosion.

Saline horticulture & silviculture
Where it is economically feasible, saline horticulture and silviculture may have application, particularly in marginal to salt-affected land.

Salt harvesting
Lack of pumpable aquifers and higher rainfall/evaporation ratios mitigate against salt harvesting.

Saline aquaculture
Lack of pumpable aquifers limits the availability of saline groundwater resources, nevertheless saline farm dams provide some opportunities.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 2. INTERMEDIATE FLOW SYSTEMS WITHIN SEDIMENTARY SEQUENCES INFILLING LARGE VALLEYS

Regions

Intermediate flow systems within sedimentary sequences infilling large valleys are found in the wheat belt of Western Australia.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Intermediate
Landform	Alluvial plains within broad valleys
Aquifer	Alluvial sediments
Aquifer transmissivity	Low – high
Groundwater salinity	High
Land use	Cereal cropping
Catchment size	Large
Annual rainfall	Low
Salinity manifestation	Expansive areas in valley floors
Salinity rating	S3
Temporal distribution of recharge	Seasonal with strong episodic overprinting
Spatial distribution of recharge	General catchment
Type areas:	Toolibin, eastern wheat belt of Western Australia

Discussion

This groundwater flow system is made up of ancient valleys that once formed an integrated river basin draining the south-west of Western Australia. The old valleys were extensively disrupted by tectonic activity during Tertiary times, and have been infilled with both coarse and fine-grained alluvium. Each ancient river basin now forms a series of discrete, elongate linear groundwater basins that may be contiguous over distances of 10 to 20 km or more. The alluvial fill in the valleys forms the main aquifer and the groundwater it contains is extremely saline. Groundwater recharged on the slopes of the broad valleys converges on these unconfined/semi-confined transmissive aquifers in the plains of the valley floors. Salinity is manifest as expansive areas of saline groundwater discharge within these linear plains. The diffuse and episodic nature of recharge means that it is extremely difficult to manage recharge rates using conventional farming systems. Although transmissivity rates are variable in these aquifers, engineering options are theoretically feasible, but the high salinity of groundwaters controls the potential uses for extracted groundwaters.

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Recharge management

Pasture agronomy
These groundwater systems are not responsive to recharge management due to the diffuse and episodic nature of recharge, but benefits can be achieved at the farm or sub-catchment scale.

Cropland agronomy
As above.

Woody perennial vegetation
As above.

Plantation forestry
As above.

Engineering watertable management

Surface drainage
May be appropriate in areas where it can be used to avoid waterlogging and exacerbation of salinity.

Sub-surface drainage
Technically feasible and appropriate, particularly where there are important high value assets that must be protected. The high salinities of groundwaters must be taken into account in disposal/utilisation options.

Groundwater pumping
As above.

Managing saline resources

Halophytic vegetation
Technically feasible and appropriate in semi-arid environs. Also used as a pioneer species to assist establishment of less salt-tolerant pastures.

Salt-tolerant grasses/clovers
Poor application in areas with high salinity and aridity (unless used as above).

Saline horticulture & silviculture
Generally excessively saline conditions.

Salt harvesting, saline aquaculture
Technically feasible, but largely dependant upon economic circumstances.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 3. LOCAL FLOW SYSTEMS IN FRACTURED ROCKS

Regions

Local flow systems in fractured rocks are found in the central highlands of Victoria and the Great Dividing Range of New South Wales.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Hills, rolling hills
Aquifer	Fractured rocks
Aquifer transmissivity	Moderate
Groundwater salinity	Low – moderate
Land use	Grazing
Catchment size	Small
Annual rainfall	Moderate – high
Salinity manifestation	Discharge zones associated with break of slope and valley floors; some structural control
Salinity rating	S1, S2
Temporal distribution of recharge	Seasonal
Spatial distribution of recharge	Diffuse, highest within areas of skeletal soils—usually in upper parts of catchments
Type areas:	Boorowa River catchment, New South Wales

Discussion

Groundwater recharge in all parts of the landscape causes saline groundwater discharge both to land and streams. This mainly occurs where the hydraulic gradient reduces with slope and bedrock variation. Groundwater flow systems are characterised by a large number of small local flow systems correlating very closely with topographic catchments. Recharge, occurring in phase with seasonal rainfall patterns and in areas high in the landscape, produces a distinctive filling and draining response. This response pattern is more attenuated lower in the landscape. Rocks are usually only superficially weathered, with groundwater flow generally converging on the downslope regions. Ephemeral and perennial stream networks receive groundwater discharge as baseflow. Salt storage in the catchments is usually low, but off-site impacts are caused by the volumes of saline stream water exported from the system. Response times to changed groundwater conditions can be rapid (one or two decades), with equilibrium conditions taking significantly longer to establish. The main management issue is the need to consider off-site impacts, whether these relate to the impact of increased vegetation on reducing run-off, and thus increasing stream salinity levels; or the impacts of extracted/drained groundwater on stream salinity levels.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Likely to have low effectiveness if applied over the entire area, but moderate effectiveness if deep-rooted pastures are widely applied over lower slopes in conjunction with more radical land use change (woody vegetation/plantation forestry) over higher slopes. A major impediment to perennial pasture establishment is pervasive low soil acidity.

Cropland agronomy (usually poor cropping country)
Likely to have low effectiveness. Only benefit will be in returning higher gross margins. Will also promote higher levels of erosion.

Woody perennial vegetation
Likely to be effective in reducing recharge only if implemented over large areas, and particularly important in high recharge areas.

Plantation forestry
Likely to be effective in reducing recharge over much of the area, and particularly important in high recharge areas.

Engineering watertable management

Surface drainage
The main issue limiting the use of surface drainage is that of salt export, as well as the economics of implementation.

Sub-surface drainage
Subsurface drainage is not a feasible option due to the extent of drains required. Issues of salt export and economics of implementation limit the use of subsurface drainage.

Groundwater pumping
Groundwater pumping is technically viable using low capacity technology. Although low salinity of groundwater in this region makes this option suitable for irrigation-based activities, yield restrictions will introduce complications. The main issue is that while groundwater salinities are low, the total volume required to be pumped to balance recharge is large and salt disposal issues arise. Any groundwater pumping option will need to be integrated into a total water management plan.

Managing saline resources

Halophytic vegetation
Salinities are low, and the area of land with high salinity is minimal. Cold climate halophytes will be required.

Salt-tolerant grasses
Salt-tolerant species are likely to be an important land management option, where saline land is a reality but where groundwater levels permit the establishment of grasses.

Saline horticulture & silviculture
The area of land with high salinities is restricted.

Salt harvesting
Minimal salinity at levels required.

Saline aquaculture
Minimal salinity at levels required.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 4. LOCAL FLOW SYSTEMS IN DEEPLY WEATHERED FRACTURED ROCKS

Regions

Local flow systems in deeply weathered fractured rocks are found in the foothills of the Great Dividing Range in Victoria, New South Wales and Queensland, and in the foothills of the Lofty Ranges in South Australia.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Gently undulating
Aquifer upper parts catchments	Saprolite & fractured rock
Aquifer transmissivity	Moderate (higher in the upper parts of catchments; low in the lower parts)
Groundwater salinity	Moderate – high
Land use	Cropping and grazing
Catchment size	Small
Annual rainfall	Moderate
Salinity manifestation	Break of slope & valley floor
Salinity rating	S2, S3
Temporal distribution of recharge	Seasonal with episodic overprinting
Spatial distribution of recharge	General catchment, higher on upper slopes and crests
Type areas:	Kamarooka catchment, north central Victoria

Discussion

Local groundwater flow systems in deeply weathered fractured rock terrain cause extensive areas of dryland salinity along the foothills of the northern and western slopes of the Dividing Ranges of eastern Australia. These regions are made up of the remnants of early Tertiary land surfaces that have been extensively and variably dissected and eroded. They are typically made up of fractured rock aquifers exposed in the upper slopes and crests of the catchments, which are overlain by remnant clay and weathered bedrock surfaces on the mid and lower slopes. Groundwater recharge is higher on the upper slopes and crests, and lower on the mid and lower slopes. Groundwater migrates from the slopes of catchments toward adjacent valley floors, and is transmitted largely by the underlying fractured rock. Groundwater discharge and salinity typically occur in valley floors and at breaks of slope, and coincident with artesian groundwater pressures caused by reduced hydraulic gradients. In southern Australia these systems occur in landscapes with very high salt stores. Saline groundwater discharges typically cause expansive areas of severe salinity. The issues for managing salinity in these systems are the low permeabilities of aquifers in the lower parts of catchments (and thus the timeframes involved in draining the aquifers sufficiently to lower groundwater levels), the difficulty of locating sustainable groundwater supplies in a hydraulically variable aquifer, and the relatively high groundwater salinity levels.

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Recharge management

Pasture agronomy
Opportunities for recharge reduction, however salinity benefits unlikely to accrue in less than 50 to 100 years.

Cropland agronomy
As above. Some opportunities to incorporate dryland lucerne into cropping rotations, but salinity benefits will not be realised in timeframes of less than 50 to 100 years.

Woody perennial vegetation
As above.

Plantation forestry
Technically feasible, but poor application because of low rainfall.

Engineering watertable management

Surface drainage
May assist with the management of saline soils by controlling run-off and erosion, may also be useful in avoiding salt wash-off from saline soils.

Sub-surface drainage
Technically feasible, but only economically sound where there is the need to protect high value assets.

Groundwater pumping
As above.

Managing saline resources

Halophytic vegetation
Technically suited to high salinity, lower rainfall environs. Sometimes used as pioneer species to assist establishment of less salt-tolerant pastures.

Salt-tolerant grasses/clovers
Largely restricted to less saline lands.

Saline horticulture & silviculture
Poorly suited to high salinity poorly drained soils.

Salt harvesting
Technically feasible but limited somewhat by the difficulty in locating suitable groundwater yields.

Saline aquaculture
Technically feasible where the economic environment is favourable.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 5. LOCAL FLOW SYSTEMS ASSOCIATED WITH COLLUVIAL FANS

Regions

Local flow systems associated with colluvial fans are found in the coarser sediments in shallower terrain of the footslopes of the Dividing Ranges, Victoria, New South Wales and Queensland; and the Lofty Ranges of South Australia.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Colluvial fan (footslope terrain)
Aquifer	Unconsolidated colluvial sediments
Aquifer transmissivity	Low – moderate
Groundwater salinity	Low
Land use	Grazing
Catchment size	Small
Annual rainfall	Moderate – high
Salinity manifestation	Break of slope seeps
Salinity rating	S2, S3
Temporal distribution of recharge	Seasonal with episodic overprinting
Spatial distribution of recharge	Upper slopes and crests
Type areas:	Warrenbayne, Victoria

Discussion

These groundwater systems typically occur where coarse colluvial slope wash material overlies a massive, unjointed bedrock. This leads to a contrast in hydraulic conductivity between the permeable slope wash and the relatively impermeable underlying rock. Most groundwater flows down slope via the colluvial material, which is usually 1–10 m thick on the highest slopes, and up to 20 m thick in the valley floors. Groundwater salinity concentrations are low. Discharge is usually at the break of slope where the colluvial material becomes finer, and where hydraulic gradients flatten. This provides potential for groundwater utilisation upslope of discharge zones, and means that the timeframes for management of salinity are relatively brief, with positive benefits from effective recharge management possible within a decade or so of their application. The relatively high rainfall of many of these systems and relatively high soil fertility mean that water efficient biological options are feasible for controlling salinity.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Existing pasture options are unlikely to be able to reduce recharge sufficiently to prevent these systems filling up, although they may provide some scope to slow groundwater level rises.

Cropland agronomy (poor cropping land due to slopes)
Existing cropping options are unlikely to be able to reduce recharge sufficiently to prevent these systems filling up or to provide a substantial decrease in rates of groundwater level rise.

Woody perennial vegetation
Woody perennial vegetation offers considerable potential for reducing recharge to levels necessary for controlling salinity.

Plantation forestry
Plantation forestry that extracts groundwater directly from the aquifer at break of slope positions provides potential for reducing recharge to levels necessary to controlling salinity and in some instances providing economic returns.

Engineering watertable management

Surface drainage
Surface drainage on the slopes of colluvial fans is unlikely to provide a reasonable salinity benefit, although under some circumstances it may be possible to divert water that would otherwise have the opportunity of contributing to groundwater recharge.

Sub-surface drainage
Sub-surface drainage may provide opportunities where deeper drainage lateral to the slope has the opportunity to intercept fresher groundwater before it moves down-slope. It is equally true, however, that low-yielding groundwater pumping may afford the same result in a more cost-effective manner.

Groundwater pumping
The transmissive nature of these aquifers means that low-yield groundwater pumping is technically feasible, and the relatively low salinity of much of the groundwater means that in many cases the pumped water can have productive uses.

Managing saline resources

Halophytic vegetation
Halophytic vegetation is more suited to semi-arid, high salinity lands.

Salt-tolerant grasses/clovers
Establishment of salt-tolerant grasses is an appropriate response to saline seeps in these low salinity systems.

Saline horticulture & silviculture
This option is appropriate given that in some regions there are opportunities for small scale developments based on limited groundwater pumping. It may be restricted due to the low salinities encountered.

Salt harvesting
The relatively low salinities and low yield of these systems mean that salt harvesting is not a viable option.

Saline aquaculture
The low yield of these systems provides little opportunity for saline aquaculture.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 6. INTERMEDIATE FLOW SYSTEMS IN FRACTURED ROCK AQUIFERS

Regions

Intermediate flow systems in fractured rock aquifers are found in more gentle hilly terrain of the uplands of the Great Dividing Ranges in eastern Australia.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Intermediate
Landform	Hilly uplands of south-east Australia
Aquifer	Fractured rock
Aquifer transmissivity	Moderate
Groundwater salinity	Low – moderate
Land use	Grazing
Catchment size	Moderate
Annual rainfall	Moderate
Salinity manifestation	Regional break of slope
Salinity rating	S2
Temporal distribution of recharge	Seasonal with episodic overprinting
Spatial distribution of recharge	High recharge in areas of aquifer outcrop, typically within catchment headwaters
Type areas:	Axe Creek catchment, central Victoria

Discussion

Fractured rock aquifers commonly influence dryland salinity in the Great Dividing Range of eastern Australia. These intermediate groundwater flow systems occur where the slopes of the land are not excessive, and where local relief is generally less than 20–30 m. Under these circumstances groundwaters may flow across catchment boundaries. Groundwater recharge typically occurs in regions where fractured rock outcrops occur in catchment headwaters. Groundwater flows down basin over distances of 20–30 km or more, and discharges where there is a reduction in the hydraulic gradient consistent with major changes in slope of the land. This commonly occurs immediately below catchment headwaters. Salinity frequently occurs within the mid to upper catchment regions. Groundwater discharge most commonly occurs through baseflow to streams, often contributing as much as 600 kg of salt per hectare of catchment to downstream rivers. The issues for managing these systems relate to the scale at which options must be applied; the moderate groundwater salinity levels (2000–6000 mg/L); and the timeframes required for aquifers to drain sufficiently to lower groundwater levels.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy

Deeper-rooted pastures may reduce recharge, but it is unlikely that recharge can be reduced to the levels required to restore pre-development rates by this means alone (especially in the more winter-dominated regions). In addition, the groundwater systems are highly buffered against groundwater level change by the large dimension of the aquifer.

Cropland agronomy

Little cropping is practised in this terrain, and groundwater flow is strongly buffered by existing conditions.

Woody perennial vegetation

Applications may be useful in reducing recharge but groundwater systems are strongly buffered against change.

Plantation forestry

Plantation forestry is effective in reducing recharge, but strongly buffered groundwater systems will militate against short-term salinity benefits. Reduction in surface water run-off as a consequence of plantation developments is also likely to exacerbate stream salinity in the short to medium term.

Engineering watertable management

Surface drainage

May be beneficial in reducing surface water moving over salt-affected soils, thus protecting saline soils from soil erosion.

Sub-surface drainage

May be used to protect high value assets, but groundwater pumping will usually provide greater benefits and be more cost-effective.

Groundwater pumping

Technically feasible where high value assets must be protected, or where moderately saline groundwater might be used as an industry resource.

Managing saline resources

Halophytic vegetation

Higher annual rainfall and ephemeral waterlogging are not generally conducive to halophytic vegetation.

Salt-tolerant grasses/clovers

Salt-tolerant grasses have widespread application for maintaining vegetative cover and a measure of agricultural productivity on saline soils within upland areas.

Saline horticulture & silviculture

A limited range of productive species can be grown on saline land in upland areas.

Salt harvesting

Low to moderate salinity groundwater and higher ratios of precipitation/evaporation generally make this option less feasible.

Saline aquaculture

Considerable potential exists for low to moderate salinity groundwater to be used in commercial aquaculture, as long as appropriate means of managing salt and nutrient disposal can be secured.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 7. LOCAL FLOW SYSTEMS IN FINE GRAINED UNCONSOLIDATED SEDIMENTS

Regions

Local flow systems in fine grained unconsolidated sediments are found in south-west Victoria.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Dissected clay plateaus
Aquifer	Clay deposits
Aquifer transmissivity	Low
Groundwater salinity	Low – moderate
Land use	Grazing
Catchment size	Small
Annual rainfall	Moderate
Salinity manifestation	Break of slope and valley floor
Salinity rating	S1, S2
Temporal distribution of recharge	Seasonal
Spatial distribution of recharge	Recharge occurs diffusely over the entire catchment
Type areas:	Barwon Downs & Heytsbury, Victoria

Discussion

Dryland salinity is particularly common in these low permeability landscapes that have a moderate to high salt store, particularly where the climate imposes cold wet winters and hot dry summers. These conditions are found in landscapes made up of marine clay deposits within the Heytsbury–Barwon Downs region of south-west Victoria. Local flow systems develop in the low permeability clays as a consequence of recharge on the slopes and crests of a catchment. Groundwater discharge occurs at breaks of slope or on adjacent valley floors. The main issue for managing dryland salinity in these systems relates to the low permeability of the aquifers, and thus their limited ability to drain sufficiently to lower groundwater levels.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Elevated groundwater and poorly responsive aquifers will sustain groundwater convergence on saline areas long after recharge management is applied.

Cropland agronomy
Poor aquifer responsiveness and little ability to manipulate recharge within cropland management.

Woody perennial vegetation
Poorly responsive aquifers and large areas of farmland needed for effective recharge management.

Plantation forestry
Opportunities for recharge management, but unlikely to yield significant salinity benefits within the short to medium term because of poorly responsive aquifers. Plantation forestry would also compete with high value agricultural lands.

Engineering watertable management

Surface drainage
Surface drainage does provide some opportunities to remove surface water before it has the opportunity to become recharge. The practice is unlikely to yield salinity benefits within the short to medium timeframes.

Sub-surface drainage
Low permeability landscapes make this option more difficult to apply. It will generally be applicable only in those regions where it is essential to protect high value assets.

Groundwater pumping
Low permeability landscapes provide little opportunity for groundwater pumping, although it may be technically feasible where it necessary to protect high value assets.

Managing saline resources

Halophytic vegetation
Halophytic vegetation is more suited to semi-arid regions less prone to cold wet winters and waterlogged soils.

Salt-tolerant grasses/clovers
Salt-tolerant grasses are well suited to saline soils within these groundwater flow systems.

Saline horticulture & silviculture
Horticulture is generally less suitable due to heavy soils prone to waterlogging. There may be opportunities for saline silviculture where native species can be utilised.

Salt harvesting
Groundwaters are generally too fresh for salt harvesting to be an economic proposition.

Saline aquaculture
Insufficient groundwater to make saline aquaculture technically feasible.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 8. REGIONAL FLOW SYSTEMS IN ALLUVIAL AQUIFERS

Regions

Regional flow systems in alluvial aquifers are found on the riverine plains of Victoria and New South Wales.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Regional
Landform	Plains
Aquifer	Buried alluvial sands and gravels
Aquifer transmissivity	Very high
Groundwater salinity	Low – moderate
Land use	Cereal cropping, grazing
Catchment size	Very large
Annual rainfall	Moderate
Salinity manifestation	Saline depressions and wetlands, vegetation death along stream courses, river salinity increases
Salinity rating	S2, S3
Temporal distribution of recharge	Seasonal and episodic
Spatial distribution of recharge	General catchment but greater within alluvial fans at the highland front
Type areas:	Loddon Plains, north-central Victoria

Discussion

This groundwater flow system typically occurs within many inland alluvial sedimentary sequences (e.g. the Riverine Plain of the southern Murray–Darling Basin, and the Plains of the northern rivers of NSW and southern Queensland). The flow system is also recognised in sedimentary basins such as the Perth and Bremer Basins of Western Australia. Groundwater in the Riverine Plains, Murray–Darling Basin, is transmitted from upland valleys to the lower plains via very large regional gravel aquifers that lie buried within ancient valleys beneath the sand and clay sediments that make up the Riverine Plains. The regional aquifers are recharged during episodes of sheet flooding on the plains, and through leakage from regional river systems. Recharge is highest within alluvial fans formed near the upland front. Increased recharge, following agricultural development in the down-basin sectors of the plain, results in regional groundwater discharge. Due to the long history of agricultural land use in the southern and wetter regions, groundwater levels have already risen in the upper parts of the catchments, although widespread dryland salinity is yet to be manifest (in the lower parts of the catchments). Rising groundwater levels are yet to be measured in the more arid parts of the flow system. In areas where the groundwater has already been extensively developed, rising groundwater level trends have started to slow. Pertinent management issues for these groundwater flow systems include the:

- existing volume of groundwater due to already increased recharge;
- vast extent across which options must be applied to produce change;

- significant contribution episodic events make to recharge volumes;
- transmissive nature of the aquifers, and the moderate salinity levels of groundwaters.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Increased regional groundwater flows are already established through elevated recharge, and will be sustained for a considerable time irrespective of biological management of recharge. Moreover, pasture management will not mitigate recharge produced by sheet flooding episodes nor leakage from regional rivers.

Cropland agronomy
As above.

Woody perennial vegetation
As above.

Plantation forestry
As above, except where plantations are irrigated with water pumped from the regional aquifers.

Engineering watertable management

Surface drainage
Drainage may provide some opportunities to remove surface water before it has the opportunity to contribute to recharge, but it is unlikely to manage major recharge events that occur during episodes of sheet flooding.

Sub-surface drainage
Sub-surface drainage is technically feasible but only likely to be attractive where there is a need to protect valuable assets. Under these conditions groundwater pumping may also prove to be a more cost effective solution.

Groundwater pumping
Groundwater pumping provides considerable opportunities where rising groundwaters are fresh, and capable of being used for small-scale irrigation development. Pumping the more saline groundwaters may also provide significant opportunities for the development of saline industries including saline aquaculture.

Managing saline resources

Halophytic vegetation
Halophytic vegetation may prove useful as a means of gaining production from saline soils, particularly in the more westerly regions of the plains where groundwater salinity is higher and the climate is more arid.

Salt-tolerant grasses/clovers
Salt-tolerant grasses may have a role in the easterly sections of the plains where salinity effected by groundwater discharge might be less extreme because of lower salinity groundwaters.

Saline horticulture & silviculture
Both saline horticulture and silviculture have potential in the Riverine Plains, particularly where they might be irrigated with low to moderate salinity groundwater.

Salt harvesting
The high transmissivities of these aquifers means that salt harvesting is technically possible, and will be most suited to those regions where groundwater salinity is highest.

Saline aquaculture
Significant opportunities exist, in a technical sense, to extract low to moderate salinity groundwater for the purposes of saline aquaculture.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 9. REGIONAL FLOW SYSTEMS WITHIN UNCONFINED SEDIMENTS

Regions

Regional flow systems within unconfined sediments are found on the mallee plains of Victoria.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Regional
Landform	Aeolian plains
Aquifer	Unconsolidated sands
Aquifer transmissivity	Moderate
Groundwater salinity	High
Land use	Cropping and grazing
Catchment size	Large
Annual rainfall	Low
Salinity manifestation	Expansive salinas
Salinity rating	S3
Temporal distribution of recharge	Episodic
Spatial distribution of recharge	Diffuse across the region
Type areas:	Mallee plains, Victoria & South Australia

Discussion

This groundwater system typically occurs within unconsolidated sediments, usually sands and silts, related to large-scale Aeolian landscapes. The system covers extremely large and flat areas, is regionally unconfined and rarely reaches great thickness. In the Mallee Region of Victoria, saline discharge and the presence of saline areas were characteristic components of the landscape prior to widespread land use change. This has also increased since European settlement. The groundwater system is characterised by high salinity, a relatively permeable and extensive aquifer, very low hydraulic gradients, and episodic recharge that occurs diffusely across the plains. Groundwater salinity is controlled by evaporative concentration in the subsurface and discharge of water from hypersaline lakes. The region is also characterised by low soil fertility. Due to the long history of agricultural land use in this region, groundwater levels have already risen across the catchments, although these are yet to translate into major regional lateral flow out of the aquifer due to the continued flat hydraulic gradients and lower transmissivities. These characteristics mean that the scale of land use change that must be adopted to reduce recharge to the system is considerable. It must:

- be able to intercept irregular and extreme recharge pulses; and
- deal with already increased groundwater volumes moving through the system.

Salinity is always likely to be a component of the landscape. Viable options for dealing with dryland salinity must therefore focus on either using the saline water as a resource, or managing saline land for its conservation and recreational values.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
Likely to have low effectiveness even if applied over the entire area, due to the inability of shallow-rooted systems to intercept episodic recharge, and the lengthy time required for groundwater to recede to where salinity benefits might accrue.

Cropland agronomy
As above.

Woody perennial vegetation
While woody perennial vegetation provides the opportunity to manage groundwater recharge, and perhaps even episodic recharge, it is unrealistic to expect that it might be adopted on a scale sufficient to influence salinity within a super-regional groundwater flow system in semi-arid terrain. Even if regional recharge management could be achieved, the groundwater system would remain strongly buffered against change, and the length of time required for groundwater to recede would be excessive.

Plantation forestry
It is technically feasible to manage groundwater recharge with plantation forestry within this groundwater flow system. Given that the region has a semi-arid climate, it is unlikely that this option will ever be adopted on a scale sufficient to influence dryland salinity. Even if large scale forestry were practised, the strongly buffered regional groundwater system would not recede within a timeframe acceptable to most stakeholders.

Engineering watertable management

Surface drainage
The main issue limiting the use of surface drainage is that when recharge to these systems does occur, it is highly diffuse and infiltrates through the relatively permeable soils before a surface drainage system is likely to be able to divert it.

Sub-surface drainage
Sub-surface drainage may be a viable option where watertables must be artificially lowered to protect high value assets. Under most circumstances, groundwater pumping will provide a more cost-effective solution.

Groundwater pumping
Groundwater pumping is technically viable from these relatively transmissive aquifers, and the option has application in situations where high value assets need to be protected, or where there is potential for industries that rely on a supply of saline groundwater (see below). Alternatively, diversion of pumped groundwater to natural depressions in the land surface which act as evaporation basins may provide some opportunities for protecting high value assets.

Managing saline resources

Halophytic vegetation
Halophytic vegetation is well-suited to high salinity areas and the semi-arid climate.

Salt-tolerant grasses/clovers
Salt-tolerant grasses are less suited to the high salinity, high aridity areas.

Saline horticulture & silviculture
Most salt-tolerant horticultural/tree crops will be poorly productive under conditions of extreme salinity and aridity.

Salt harvesting
The high salinities and relatively high transmissivities of these systems mean that salt harvesting from either pumped or discharged groundwater is likely to be a technically viable option.

Saline aquaculture
The ability to pump saline groundwater from regional aquifers presents opportunities to cultivate a range of otherwise marine products in inland areas.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 10. LOCAL FLOW SYSTEMS ASSOCIATED WITH SAND DUNES

Regions

Local flow systems associated with sand dunes are found on the sand dunes of the eastern wheat belt sandplains in Western Australia and in the mallee in Victoria.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local
Landform	Sand dunes on extensive plains
Aquifer	Aeolian sediments
Aquifer transmissivity	Moderate – high
Groundwater salinity	Low – moderate
Land use	Grazing and cropping
Catchment size	Small
Annual rainfall	Low
Salinity manifestation	Seeps at the base of dunes
Salinity rating	S2, S3
Temporal distribution of recharge	Highly seasonal but also very sensitive to episodic extremes
Spatial distribution of recharge	Dune slopes and crests
Type areas:	East Belka catchment, Western Australia; mallee dunes, Victoria

Discussion

This groundwater flow system type develops in highly permeable sand dunes. It is characterised by ephemeral perched groundwater flow occurring in response to seasonal 'filling up' that discontinues once the system has drained of the seasonal pulse. This means that management timeframes for the system are relatively brief, and that positive benefits from recharge management can be expected within years of their application. However, the highly permeable nature of the surface material, and the episodic nature of recharge, means that salinity management options must be particularly effective in intercepting considerable and highly variable volumes of water, and at other times existing through long periods with little moisture. This considerably limits the options that are likely to be appropriate to this groundwater flow system.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy

Existing pasture options may be able to reduce recharge sufficiently to prevent these systems filling up seasonally and also to respond to the longer-term variability of rainfall patterns.

Cropland agronomy

Existing cropping options are unlikely to be able to reduce recharge sufficiently to prevent these systems filling up seasonally and certainly not able to prevent episodic recharge in years of excessive rainfall.

Woody perennial vegetation

Woody perennial vegetation offers considerable potential for reducing recharge to levels necessary for controlling salinity, particularly where species mixes can opportunistically use episodic rainfall when it occurs.

Plantation forestry

Plantation forestry would be technically effective in reducing recharge to levels necessary for controlling salinity. The low rainfall of these regions means that most tree species are unlikely to be successfully established. There is some potential to use mallee species that are adapted to low rainfall regimes and using episodic rainfall when it occurs.

Engineering watertable management

Surface drainage

The high permeability and diffuse, episodic recharge characteristics of these landscapes mean that surface drainage generally has limited application. It is likely to be appropriate in conjunction with land use options that can efficiently use the drained water before it infiltrates back to the groundwater system.

Sub-surface drainage

The permeability of these landscapes and diffuse, episodic recharge characteristics mean that sub-surface drainage generally has limited effectiveness. It is likely to be appropriate in conjunction with land use options that can efficiently use the drained water before it infiltrates back to the groundwater system.

Groundwater pumping

The transmissive nature of these aquifers means that groundwater pumping is technically feasible, although its appropriateness is likely to be limited by high groundwater salinity and whether there are productive uses for it.

Managing saline resources

Halophytic vegetation

The high salinity and semi-arid area of dune seepages are well suited to the establishment of halophytic vegetation.

Salt-tolerant grasses/clovers

Salt-tolerant grasses have potential for establishing a vegetative cover and some production from seepages in regions with othrewise excessive soil salinity and aridity.

Saline horticulture & silviculture

Some opportunities exist for specialist horticultural and tree products useful in gaining production from saline seepages associated with dunes in semi-arid areas.

Salt harvesting

The relatively low salinities and low groundwater volumes associated with dune systems mean that salt harvesting is unlikely to be a viable option.

Saline aquaculture

Saline aquaculture may be technically viable, but gaining sufficient groundwater from the low volume aquifers is likely to be an issue.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 11. REGIONAL AND INTERMEDIATE FLOW SYSTEMS WITHIN FRACTURED BASALTIC ROCKS

Regions

Regional and intermediate flow systems within fractured basaltic rocks are found in the basalt plains of western Victoria.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Regional
Landform	Plains
Aquifer	Fractured volcanic rocks comprising numerous individual lava flows
Aquifer transmissivity	Moderate – high
Groundwater salinity	Low – high
Land use	Grazing
Catchment size	Large
Annual rainfall	Moderate – high
Salinity manifestation	Discharge zones associated with low lying land and lakes
Salinity rating	S1, S2
Temporal distribution of recharge	Seasonal with episodic overprinting
Spatial distribution of recharge	Diffuse, highest within higher permeability basalts ('stoney rises')
Type areas:	Lough Calvert area, Victoria

Discussion

Typically this groundwater flow system occurs in extensive basalt landscapes that are relatively flat. Groundwater is free to migrate through the permeable fractured rock aquifer across sub-catchment boundaries. Saline discharge was a component of this landscape prior to widespread land use change, and this has increased since European settlement. The groundwater system is characterised by a relatively permeable aquifer, low hydraulic gradients, and diffuse recharge that is dominated by distinct, but large areas where recharge occurs particularly rapidly. Groundwater salinity is controlled by interactions with other sources, either from discharge of saline water from other aquifers or from saline lakes, or from recharge of fresh water from higher permeability basalts. Recharge is greatest during the cooler months, when plant growth is at a minimum. Due to the long history of agricultural land use in these regions, groundwater levels have already risen across the catchment. These attributes mean that while the scale of land use change that must be adopted is considerable, there are some viable options for reducing dryland salinity. These must focus on either reducing recharge through land use alternatives such as plantations, re-establishment of native vegetation; or pumping of less saline groundwater for horticultural or other purposes. Surface drainage is also an option, although as the region drains internally, the issue of disposal of saline water is substantial. Historically, drains have fed existing lakes within surface depressions. The timeframes involved in reducing existing salinity using many of these options are considerable, given the already elevated groundwater levels.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy

While it may be possible to manage groundwater recharge locally with the aid of high water-use pasture systems, it will be difficult to realise a regional salinity benefit from these practices. Groundwater is free to migrate through the permeable fractured rock aquifer across sub-catchment boundaries. This means that very large areas would have to be treated to achieve effective recharge reduction in proportion to the scale of the groundwater processes. Watertables are already well established at elevated positions in the landscape, and the flow system is, thus, strongly buffered against changes imposed by biological intervention.

Cropland agronomy

Cropping systems in this region may enhance groundwater recharge and few biological options that will lessen the impact appear to exist.

Woody perennial vegetation

Woody vegetation may be effective in local recharge management and important in localised high recharge areas such as 'stoney rises' and scoria cones. Where such vegetation is used locally for these purposes, it cannot be expected to deliver benefits in terms of the management of regional salinity issues. Even widespread adoption of woody vegetation across the plains is unlikely to deliver salinity benefits within an acceptable timeframe because of the existence of elevated groundwaters.

Plantation forestry

Plantation forestry may provide a medium-term salinity benefit where it is practised over very large areas. In the short to medium terms, the reduction in runoff experienced as a consequence of higher water use may result in increased stream salinity (reflecting the reduction in dilution flows).

Engineering watertable management

Surface drainage

Surface drainage may provide a level of recharge management, since under some circumstances it may remove surface water that would otherwise become groundwater recharge. It is most unlikely however, that localised drainage will deliver salinity benefits through mitigation of watertables associated with the regional aquifer. Surface drainage may help manage localised soil salinity by lessening runoff from affected areas and reducing potential for soil erosion.

Sub-surface drainage

While it may be technically feasible to apply sub-surface drainage to the management of watertables, this activity would under most circumstances only be economically viable where high value assets must be protected.

Groundwater pumping

Groundwater pumping is technically viable where there are highly transmissive aquifers. In some areas low salinity groundwater makes this option suitable for limited irrigation-based activities. These practices, however, require careful management to avoid inflows of saline groundwater from more saline aquifers. Groundwater pumping is technically feasible where it is necessary to protect high value assets.

Managing saline resources

Halophytic vegetation

Halophytic vegetation is more suited to the semi-arid lands where salinity is higher and the landscape less prone to waterlogging.

Salt-tolerant grasses/clovers

Salt-tolerant species are likely to be an important land management option within the cooler and wetter lands common to the basalt plains.

Saline horticulture & silviculture

Salt-tolerant crops are likely to be an important land management option in saline areas, particularly where groundwater salinity is low to moderate.

Salt harvesting

Salt harvesting from some saline lakes has been practised in the past, and may provide some local opportunities for saline industries.

Saline aquaculture

Existing saline lakes may lend themselves to the establishment of saline aquaculture; and recreational fishing is already practised. The throughflow nature of this highly transmissive system enables some flushing of such lakes.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

FACT SHEET 12. INTERMEDIATE AND LOCAL FLOW SYSTEMS IN FRACTURED BASALTIC ROCKS AND LAYERED SEDIMENTARY ROCKS

Regions

Intermediate and local flow systems in fractured basaltic rocks and layered sedimentary rocks are found in basalt flows and layered sediments of New South Wales, Queensland and South Australia.

Critical attributes that determine groundwater behaviour in response to land management

Scale	Local and intermediate
Landform	Plains and undulating terrain
Aquifer	Fractured basalt; layered sediments—either weathered or fractured
Aquifer transmissivity	Low – moderate
Groundwater salinity	Low – high
Land use	Grazing and/or cropping
Catchment size	Moderate
Annual rainfall	Moderate
Salinity manifestation	Drainage depressions
Salinity rating	S21, S2
Temporal distribution of recharge	Seasonal with episodic overprinting
Spatial distribution of recharge	General catchment, higher on upper slopes and crests
Type areas:	Piliga, New South Wales

Discussion

This flow system can be found in either extensive, fractured basaltic materials, or in widespread, sedimentary sequences. In both cases, the characteristic attribute is the layered nature of the system, with higher permeability layers interspersed with layers that restrict groundwater flow. Landscape relief is usually subdued with some regions exhibiting intermediate flow behaviour (i.e. flow passing across catchment boundaries). In other regions flow is more constrained within catchments. Groundwater flow occurs via fractures in basaltic rocks and layered sedimentary rocks. In steeper terrain, groundwater simply flows from individual hills and discharges where the hydraulic gradient reduces in the footslopes. In less steep terrain, groundwater flow may occur over much larger distances, measured in tens of kilometres. Flow may also occur across sub-catchment boundaries. Groundwater discharge and salinity typically occurs where higher permeability fractured rocks rest over less permeable materials, causing groundwater seepages where the interface is exposed in erosional surfaces. Recharge is highest in systems where the fractured rocks outcrop or have minimal soil cover. This form of salinity is particularly common in southern Queensland. The groundwater flow system is not well understood, and further work is needed to identify the most appropriate management options.

Potential options and their suitability for salinity management

Recharge management

Pasture agronomy
It is thought that some of these systems are responsive to recharge management, and that this might be achieved through pasture management. Further work is needed to substantiate this position.

Cropland agronomy
It is doubtful that manipulation of cropping systems will realise a salinity benefit through recharge reduction.

Woody perennial vegetation
(as for pasture management) Woody vegetation may provide a means of managing recharge and realising salinity benefits. Further work is needed for substantiation.

Plantation forestry
Rainfall is generally lower than that required for commercial forestry.

Engineering watertable management

Surface drainage
Surface drainage may remove water from the landscape that would otherwise become recharge. Further work is needed for substantiation.

Sub-surface drainage
Only applicable where circumstances demand the protection of high value assets.

Groundwater pumping
Technically feasible and suitable where there is a need to protect high value assets, or where the groundwater is of low or moderate salinity and there are opportunities for its use through small lot irrigation or saline industries.

Managing saline resources

Halophytic vegetation
Halophytic vegetation may be suitable in the more arid regions where salinity is higher.

Salt-tolerant grasses/clovers
Suited to the higher rainfall regions, where groundwater salinities are lower, and the land is prone to periodic waterlogging.

Saline horticulture & silviculture
Opportunities exist for saline horticulture and silviculture, particularly where developments can be irrigated with low to moderate salinity groundwaters.

Salt harvesting
Groundwaters are generally not sufficiently saline to make salt harvesting an economic proposition.

Saline aquaculture
It is technically feasible in many areas to establish small lot developments for saline aquaculture through groundwater pumping.

Combining options

The use of two or more of the above options (appropriate to the prevailing climate, soil type and landscape position) typically may have a beneficial salinity management effect.

NATIONAL LAND AND WATER RESOURCES AUDIT

Who is the Audit responsible to?

The Minister for Agriculture, Fisheries and Forestry has overall responsibility for the Audit as a program of the Natural Heritage Trust. The Audit reports through Minister Truss to the Natural Heritage Board comprising both Minister Truss and Senator the Hon. Robert Hill, Minister for the Environment and Heritage.

How is the Audit managed?

An Advisory Council manages the implementation of the Audit. Dr Roy Green, with a background in research, science policy and management chairs the Advisory Council. Members of the Advisory Council and the organisations they represent are: Alex Campbell (L&WA), Geoff Gorrie (AFFA), Stephen Hunter (EA), Bryan Jenkins (SCEP), John Radcliffe (CSIRO), Peter Sutherland (SCARM), Jon Womersley (SCC), Roger Wickes (SCARM) and Colin Creighton (Audit).

What is the role of the Audit Management Unit?

The Audit Management Unit's role has evolved over its five-year life. Phases of activity include:

Phase 1: Strategic planning and work plan formulation—specifying (in partnership with Commonwealth, States and Territories, industry and community) the activities and outputs of the Audit—completed in 1998–99.

Phase 2: Project management—letting contracts, negotiating partnerships and then managing all the component projects and consultancies that will deliver Audit outputs—a major component of Unit activities from 1998–99 onwards.

Phase 3: Reporting—combining outputs from projects in each theme to detail Audit findings and formulate recommendations—an increasingly important task in 2000–01 and the early part of 2001–02.

Phase 4: Integration and implementation—combining theme outputs in a final report, working towards the implementation of recommendations across government, industry and community, and the application of information products as tools to improve natural resources management—the major focus for 2001–02.

Phase 5: Developing long term arrangements for continuing Audit-type activities—developing and advocating a strategic approach for the continuation of Audit-type activities—complete in 2001–02.

The Audit Management Unit has been maintained over the Audit's period of operations as a eight-person multi-disciplinary team. This team as at January 2001 comprises Colin Creighton, Warwick McDonald, Stewart Noble, Maria Cofinas, Jim Tait, Rochelle Lawson, Sylvia Graham and Drusilla Patkin.

How are Audit activities undertaken?

As work plans were agreed by clients and approved by the Advisory Council, component projects in these work plans are contracted out. Contracting involves negotiation by the Audit to develop partnerships with key clients or a competitive tender process.

Facts and figures

• Total Audit worth, including all partnerships – in excess of	$52 m
• Audit allocation from Natural Heritage Trust	$34.19 m
• Percent of funds allocated to contracts	~ 92%
• Total number of contracts	130

Natural Heritage Trust

Helping Communities Helping Australia

A Commonwealth Government Initiative

National Land & Water Resources Audit

A program of the Natural Heritage Trust

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