An Evaluation Framework for Dryland Salinity

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The Bureau of Rural Sciences (BRS) is the scientific bureau within the Department of Agriculture, Fisheries and Forestry – Australia (AFFA). Its role is to deliver effective, timely, policy-relevant scientific advice, assessments and tools for decision-making on profitable, competitive and sustainable Australian industries and their supporting communities.

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Foreword

The National Land and Water Resources Audit estimates a three fold increase in the area at risk from dryland salinity in Australia, over the next fifty years – from about 6 million to 17 million hectares. The Audit’s estimates also suggest that by 2050 20,000 kilometres of streams may be affected by salinity; 52,000 kilometres of roads will be at risk of salinity damage; and more than 200 towns could suffer infrastructure damage.

The Prime Minister, Premiers and Chief Ministers have agreed to a National Action Plan for Salinity and Water Quality that sets policy direction for addressing dryland salinity and deteriorating water quality. The plan recognises the need for regional communities and landholders to have the information they need on the state of their natural resources, to be able to assess environmental change and thereby evaluate the effectiveness of management interventions.

In response to these needs, National Land and Water Resources Audit, National Dryland Salinity Program and Bureau of Rural Sciences produced a technical report providing an evaluation framework to assist regional groups to monitor and evaluate the effectiveness and efficiency of management activities. This report provides guidelines for mapping, monitoring and modelling of key biophysical attributes within a groundwater flow system technical framework and natural resource management decision-making context. The report provides a comprehensive summary of the current situation regarding monitoring of dryland salinity at a Commonwealth, State and Territory level.

This report provides the basis for developing an Australia-wide approach to dryland salinity evaluation and reporting. The report also helps regional groups develop dryland salinity management strategies and to monitor the effectiveness of these strategies using the groundwater flow systems framework.

The Bureau of Rural Sciences has pleasure in publishing this important contribution to dryland salinity management in Australia on behalf of the National Land and Water Resources Audit and National Dryland Salinity Program.

Dr Peter O’Brien
Executive Director,
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Executive summary

Monitoring and evaluating the effectiveness and efficiency of dryland salinity management activities

There is a compelling need for a systematic approach to decision-making in dryland salinity management. At the national scale, science needs to support regional groups as they determine the most effective management response for salinity-affected areas to maximise the return for limited available investment. As regional groups review their performance they will need to be able to monitor and evaluate the effectiveness and efficiency of management activities.

In the context of a five-stage, systematic decision-making approach to dryland salinity management, this report provides a comprehensive evaluation framework that includes guidelines for combining mapping, monitoring and modelling. These guidelines provide details for the key underpinning information sets to help decision-making in developing regional management strategies and monitoring.

The dryland salinity evaluation approach proposed here involves:

- defining the scope of the problem and identifying feasible management options (problem definition);
- understanding the physical drivers of dryland salinity (knowledge generation);
- formulating policy responses to the problem (policy formulation);
- implementing activities to address the problem in accordance with the policy responses (implementation);
- and
- assessing the effectiveness of management activities (evaluation).

A five stage systematic decision-making approach to dryland salinity management

The evaluation framework provides guidelines for mapping, monitoring and modelling of key biophysical attributes

The evaluation framework provides guidelines for mapping, monitoring and modelling of key biophysical attributes that include groundwater levels and salinity, surface water salinity concentrations and salt loads, the extent of land salinisation, land cover and land use, contextual data and alternative attributes. The guidelines are designed to give direction on how to:

- define the extent, severity and impacts of dryland salinity;
- predict likely future extent, severity and impact;
- refine understanding of the processes causing dryland salinity;
The groundwater flow system classification is used as the technical framework to help identify appropriate evaluation activities. This hydrogeological framework groups catchments of similar landscape and groundwater processes contributing to salinity and where similar management options apply. The evaluation systems should be designed to assess a range of physical processes, using the key biophysical attributes, according to an understanding of the scale of the groundwater flow system. The key attributes have been chosen for their ability to provide unambiguous information and because they are scientifically credible and cost effective.

For example, when monitoring the biophysical attribute of groundwater levels, the design for a monitoring system for a local scale groundwater flow system (for example, in deeply weathered granitic terrain in small catchments in southwestern Western Australia) will be very different from the design for a monitoring system for a large regional alluvial aquifer system (such as the riverine plains of the Murray-Darling Basin). Monitoring design differences are largely a function of the size of the catchment and response time to changes in the system. Monitoring design will vary in terms of placement, frequency and measurement method. It will also result in a difference in the type, coverage and accuracy of the resulting data that can be achieved – largely as a consequence of differences in catchment size and response times.

The report covers specifics for monitoring, mapping and modelling the biophysical attributes (with respect to the groundwater flow systems) in detail. It also provides a comprehensive summary of current arrangements and technologies for monitoring dryland salinity at a Federal and State/Territory level. It is anticipated that the dryland salinity evaluation framework outlined in this report will provide invaluable help to regional groups as they develop their salinity control strategies under the National Action Plan for Salinity and Water Quality, and the Murray Darling Basin Commission’s process of integrated catchment management and planning.
Acknowledgments

The recommendations in this report would not have been possible without the insights gained from several decades of work in the field of dryland salinity by many people in Commonwealth and State agencies, and community organisations.

PPK Environment and Infrastructure Pty Ltd collated information provided by State officials relating to our current capacity to evaluate dryland salinity (Appendix C). This was subsequently completed by Rob Braatten from BRS. David Dent, BRS and independent consultant Patty Please undertook final editing.

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- **Steve Tickell** - Northern Territory Department of Lands, Planning and Environment
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1. Introduction

1.1. The need for an evaluation framework

The National Land and Water Resources Audit (2001) estimates the spread of dryland salinity in Australia from the current 5.7 million hectares to as much as 17 million ha in the next 50 years. The Audit’s estimates also suggest that over this period 20,000 kilometres of streams may be affected by salinity; 52,000 kilometres of roads will be at risk of salinity damage; and more than 200 towns are expected to suffer infrastructure damage. The area of native vegetation at risk is likely to have expanded from the present 630,000 ha to around 2,000,000 ha by 2050.

It is clear that sustained investment in salinity management is called for at all levels including community, business and government. Despite the considerable resources directed to managing dryland salinity over the past decade, however, success is not measurable. Clear improvements have been evident in some cases, but generally we struggle to make interim assessments of whether the management approach is having any effect. This severely limits our ability to determine whether the approach was appropriate and whether there is value in applying it in other areas. To make the best use of limited resources we need a strategic approach to establishing clear targets, identifying salinity management options and reviewing their effectiveness and appropriateness.

1.2. Strategic context

1.2.1. National Action Plan

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

- Setting targets and standards for natural resource management based on good science and economics, particularly for water quality and salinity;
- Integrated catchment and regional management plans developed by communities, that are accredited for their strategic content, proposed targets and outcomes, accountability, performance monitoring and reporting;
- Capacity building for communities and landholders to help them develop and implement integrated catchment and regional plans, together with technical and scientific support, and engineering innovations;
- 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 framework to deliver and monitor implementation of the plan.

The plan recognises the importance of knowledge to underpin management change. Regional communities and landholders need to know about the current condition of the natural resources and be able to assess the effectiveness of their management.
1.2.2. Regional strategies

State and regional strategies for addressing dryland salinity management are being developed and revised across Australia.

- The New South Wales Government released its State Salinity Strategy in August 2000 (NSW Government, 2000). Key tools of the strategy include development of end-of-valley salinity targets that reflect the salinity levels the community is prepared to accept and can afford to live with; investment in upgrading data and analytical tools; and ensuring that information is accessible and understandable.

- 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 southwestern Victoria. 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 validity of the assumptions on which the plans were based;
  - new information that contributes to a better understanding of the dryland salinity problem.

It is expected the reviews will emphasise the achievement of targets for catchment health.

- In Queensland, 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 knowledge about salinity and provide the technical support to underpin government policy initiatives in land and water management and vegetation clearing. Implementation of the salinity work plan will be part of Queensland’s response to the National Action Plan for Salinity and Water Quality.

- In South Australia, a whole-of-government approach to managing salinity has been adopted with the formation of the State Salinity Committee. 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). A key recommendation of the State Dryland Salinity Strategy is to improve the knowledge base.

- The West 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 include providing communities with the capacity to address salinity issues and to manage the changes brought about by salinity.

One of the major investments in salinity management in Western Australia is the Land Monitor Project, a Natural Heritage Trust and West Australian State Government initiative to map and monitor the extent of salinity through satellite imagery at the farm and catchment scale for the whole of the southwestern agricultural region of Western Australia.

- In Tasmania, as a result of the Audit-funded initiative to assess the extent and impacts of dryland salinity the Environment/Resources Heads of Agencies Group endorsed the development of a state salinity management strategy.
1.3. A systematic approach to dryland salinity management decision making
The common threads through each of the State strategies and the Murray Darling Basin Commission salinity management strategy (MDBMC, 2000) are:

- The need for performance targets, particularly in relation to stream salinity concentrations and salt loads;
- The need to base dryland salinity management decisions on a sound knowledge base;
- Empowering communities to develop salinity management plans.

However, in some areas dryland salinity is only beginning to emerge as an issue and regional communities are at an early stage of recognising the symptoms. In other areas, serious salinity problems have been a part of the landscape for decades and regional communities are well advanced in developing and implementing salinity management plans. Despite the obvious differences in knowledge and capabilities to identify management responses to dryland salinity, each of these groups needs to adopt a systematic and iterative approach to dryland salinity decision-making.

- defining the scope of the problem and identifying feasible management options (*problem definition*);
- understanding the physical drivers of dryland salinity (*knowledge generation*);
- formulating policy responses to the problem (*policy formulation*);
- implementing activities to address the problem in accordance with policy responses (*implementation*);
- assessing the effectiveness of management activities (*evaluation*).

The questions that must be answered in each phase are very similar across the country.

The components of such an approach are represented diagrammatically in Figure 1.
This systematic approach to dryland salinity management does not begin at the same point in every case and will not be achieved in a single pass through the critical steps. It is an iterative process, working toward an increasingly sophisticated understanding of the feasible options for dryland salinity management as new knowledge becomes available. In many instances this new knowledge will come from experiences in implementing and evaluating planned activities. In other instances it will arise through increased understanding provided by research and development programs.
The critical phases of a systematic approach to catchment based salinity management are outlined below, together with the logical flow of questions that must be answered at each phase and the information needed to provide the answers.

1.3.1. Problem definition
Defining the scope of the problem involves identifying the current extent and impacts of dryland salinity, and predicting the likely future extent and impacts. Both have been undertaken at national and regional scales through recent Audit assessments (NLWRA, 2001).

(a) Defining baseline conditions
Mapping the extent of salinity and defining its impacts and costs is the essential first step of salinity management. To understand what is being achieved by the adoption of a particular strategy, we must first understand the behaviour of the system in the absence of intervention.

The objectives of this phase are:
- to establish the extent of salinity in the planning region;
- to understand why it occurs;
- to understand the costs (market and non-market) it imposes;
- to provide a benchmark of the current situation to monitor changes in the future with or without intervention.

The questions that should be asked are:
- what is the current status of the system?
- what is the current extent of soil salinity, and in which landscapes is it most prevalent?
- to what extent is stream salinity an issue, and in which landscapes is it most prevalent?
- what is the impact of dryland salinity on agricultural production, infrastructure, rural communities and biodiversity?
- how is dryland salinity affecting water quality?

Key information sets to answer these questions include:
- maps showing the current extent of soil salinity;
- aerial photos and satellite images in relation to different land types and land uses;
- maps showing affected streams and water resources
- water quality data from stream gauging stations;
- point measurements of stream salinity under various seasonal conditions;
- maps showing salt-affected wetlands and riparian zones;
- inventories of affected infrastructure, including roads, building foundations, pipes and cables; and
- inventories of the economic impact of salinity on agricultural production, water resources, biodiversity and infrastructure.
(b) Assessing future salinity risk

To prioritise intervention investments we need to understand the areas and assets likely to be at future risk of dryland salinity in and beyond planning timeframes.

Ideally, future salinity risk will be assessed from both no intervention and intervention perspectives. However, this requires a detailed understanding of biophysical processes, so risk assessment is fundamentally linked to the research phase and is often an iterative process that advances with the understanding of landscape/biophysical processes.

The objectives of this phase are:

- to establish the extent to which salinity will affect the planning region in the future;
- to identify the assets at risk;
- to estimate the timeframes in which salinity will have impacts on the region; and
- to prioritise planning and intervention in areas of high risk.

The questions that should be asked in this phase of the decision-making cycle include:

- what is the likely future status of the system?
- at what rate is groundwater rising (if at all) in each of the landscape/groundwater flow systems, and how do these rates correlate with land use and climate?
- under what conditions does groundwater rise occur?
- what will be the form of groundwater discharge when water tables begin to intersect the land surface?
- where is salinity likely to occur in the future compared with existing groundwater discharge areas?
- how will salinity impact on agricultural production, water resources, biodiversity and infrastructure in specified time periods?

There are many ways of assessing salinity risk. Long-term groundwater records can be examined to identify trends; regions with a particular geological or geomorphic base may indicate a propensity for salinity; the historical onset and development of salinity in particular regions may indicate salinity risk for similar regions elsewhere, and groundwater modelling may provide insight into areas of high risk.

The key information sets needed to assess future salinity risk will vary according to the assessment technique used, but should include:

- current extent of salinity impacts on agricultural production, water resources, biodiversity and infrastructure;
- time series information demonstrating groundwater trends for each groundwater flow system;
- digital elevation models that depict the elevation of the land surface in relation to the groundwater surface;
- attributes of aquifers that indicate relative importance of surface water and baseflow processes and their impact on stream salinity;
- climatic data correlated with long-term groundwater records; and
groundwater records that illustrate the impact of land use and land management on groundwater levels.

1.3.2. Knowledge generation

In most parts of Australia the controlling processes for dryland salinity are not understood well enough to know how they will respond to intervention. In some catchments our understanding is so limited that knowledge generation may be the primary focus of salinity management activities for some years to come, in combination with the adoption and evaluation of ‘‘best bet’’ management practices. In other catchments our understanding is better and knowledge generation will be a secondary component of the decision making process, while the main focus will be on implementing and assessing the efficacy of management options. In any case, a fundamental step in management planning for any catchment will be to review the existing level of information and understanding. At a minimum, there should be enough information to define the scale at which critical groundwater flow systems operate, where they discharge, where they are recharged, the nature of recharge, the nature of the aquifers, the physical drivers of dryland salinity and the responsiveness of the groundwater system to changes in land management and climatic fluctuations.

The objectives of this phase are:

- to define the nature of the groundwater systems and establish how they work in relation to the landscapes in which they occur;
- to determine the extent and nature of salinity benefits that might result as a consequence of intervention and the time required for these benefits to accrue;
- to understand the relative merits of different forms of salinity management options depending on the nature of component groundwater flow systems; and
- to provide the information necessary to perform economic analyses on the costs and benefits of salinity management.

The questions that should be asked in this phase of the decision making cycle are:

- how does the system work and what are the realistic options for dryland salinity management?
- what are the nature and hydraulic properties of the aquifer that is causing the salinity problem?
- what is the terrain?
- what is the geological and geomorphic nature of the terrain in which salinity occurs?
- where does groundwater recharge occur, and under what circumstances?
- in what climatic regime does the groundwater flow system occur, and how is this likely to influence groundwater recharge?
- how does the groundwater system interact with the land surface to cause soil and stream salinity?
- how much salt is stored in each groundwater flow system?
- what are the controlling processes for salt and water movement?
- what recharge reductions are necessary to slow/halt/reverse dryland salinity?
how quickly will the aquifer respond to changes in groundwater recharge?
what land management systems are available to reduce groundwater recharge?
how extensively do these land management systems need to be adopted across the catchment to achieve necessary recharge reductions?

The key information sets needed to answer these questions should include:

- spatial layers identifying geology, landform and slope characteristics;
- maps showing soil and regolith;
- rainfall and evaporation data;
- spatial layers indicating groundwater heads in each groundwater flow system;
- time series information showing changes in groundwater elevation over time in each groundwater flow system;
- data for the hydraulic properties of aquifers;
- digital elevation models; and
- regional data for the amount of salt stored in each groundwater flow system, from stream salinity transects, groundwater salinity concentrations and/or salt store mapping.

1.3.3. Policy formulation

This phase of decision-making assesses the most appropriate responses to the dryland salinity problem and designs management and evaluation systems to achieve the plan’s objectives and measure its performance. It involves comparing the relative feasibility and cost of achieving different management objectives and the assets likely to be affected by future dryland salinity. This will inevitably involve trade-offs between biophysical, social and economic values. Where there is not enough information on which to make these assessments, “best bet” options will need to be identified.

The objectives of this phase are:

- to define the objectives and desired outcomes of intervention;
- to identify a set of catchment priorities for immediate actions and short term benefits and longer term objectives to achieve these objectives and outcomes;
- to ensure adequate resources are allocated to the implementation, evaluation, review and further development of the plan;
- to identify where the information base is insufficient and to allocate resources to make good the inadequacies.

Questions that will need to be addressed in this phase of decision-making are:

- what are the feasible options for dryland salinity responses and their various advantages and disadvantages?
  - what interventions are feasible from a landscape/biophysical perspective, given the current extent of salinity, the likely future extent and the physical processes that operate to cause salinity in each of the groundwater flow systems in the catchment?
  - are these interventions likely to be socially acceptable?
  - what are the economic costs and benefits of each form of intervention?
where implementation is not likely to occur through market forces alone, what other incentives might be applied and what level of cost sharing will be appropriate?

- in what timeframe might salinity benefits accrue?
- will the benefits accrue to affected landholders, or are they more likely to occur offsite?
- will there be any adverse environmental impacts of implementing salinity management strategies?

- taking into account the considerations above, what management objectives and practical management responses should be adopted?
- what should be the management responses, and where should they be implemented?
- what performance standards will be used to evaluate the effectiveness of management?
- what are the evaluation requirements?
- what resources will be required to implement the plan?
- what resources will be required to monitor and review and further develop the plan?

**Key information sets for answering these questions include:**

- spatial information showing the extent of current salinity damage to agricultural production, water resources, biodiversity and infrastructure;
- spatial information showing the likely future extent of current salinity damage;
- groundwater flow system map showing the range of systems and salinity processes found in the catchment;
- databases of groundwater flow systems indicating the inherent properties, responsiveness to land management, and rankings of the efficiencies of the range of salinity management options;
- maps and databases indicating the key social and economic circumstances of catchment communities; and
- costs and benefits of each salinity management strategy.

### 1.3.4. Implementation

Once management responses to dryland salinity have been specified, their practical implementation and continuing monitoring form the major focus of activities.

### 1.3.5. Evaluation

Assessing the effectiveness of management in achieving specified objectives is a critical component of the decision-making cycle; only then can we judge if management is appropriate or refine the underpinning science. First, an assessment needs to be made of how adequately and comprehensively management strategies have been implemented and, where appropriate, a review of the reasons for incomplete implementation. Different approaches for assessing the effectiveness of management options will then be appropriate, depending on the objectives of a dryland salinity strategy, the options adopted and physical characteristics of individual groundwater flow systems.
In the past, evaluation has been overlooked or become a casualty of budget constraints and changes in agency policies and directions; however, unless management activities are routinely reviewed we have little capacity for improving performance. This step is no less critical to the development and improvement of dryland salinity management than reviewing the adoption of management options and evaluation their implementation. It will require comparison of the effectiveness of the management strategy against the stated management objective and against the refined understanding of the system being monitored; and subsequent refinement of the management approach.

**The objectives of this phase are:**

- to assess the implementation of planned management activities;
- to evaluate the effectiveness of management activities;
- to provide feedback to revising the knowledge base and policy response to dryland salinity; and
- to report on outcomes.

**The questions that should be asked to achieve these objectives include:**

- how comprehensively have dryland salinity management activities been implemented?
- what are the reasons for incomplete implementation of management and monitoring activities?
- how effective have dryland salinity management options been in meeting their objectives?
- how are key indicators such as groundwater levels, stream salt loads and salinity concentrations responding to management strategies?
- how are systems such as in-stream water quality, wetlands and soils responding to changes in groundwater levels?
- how well has the conceptual model and predicted future behaviour of the system compared with the actual behaviour under the chosen management approach?
- do we need to review the conceptual basis for management?
- how should we revise our management strategies to better manage dryland salinity?

**Data for assessing the implementation of management strategies will vary according to the activity undertaken, but may include:**

- land use change mapping;
- land cover change and vegetative health mapping;
- per cent retention of native deep-rooted vegetation in high risk areas;
- proportion of landscape where water-efficient land use is adopted;
- mass of salt intercepted and disposed of;
- volume of water and mass of salt diverted;
- proportion of potential discharge area treated;
- increase in productivity from salinised area;
increase in gross margin from salinised areas determined from farm financial information;
 proportion of potential discharge zone under salt-tolerant land uses;
 rate of adoption of new industries exploiting saline resources;
 increase in long term productivity from non-saline resources; and
 rate of adoption of new practices that optimise non-saline resources.

The key datasets for measuring management effectiveness will also vary according to the management objective and the particular groundwater flow system, but will include:

- maps of the extent of land salinised;
- long-term groundwater level trends; and
- long-term stream salinity and salt load trends.

1.4. An evaluation framework for dryland salinity management

The sheer number and variety of key questions to be asked in each phase of the systematic decision making process, and the many datasets needed to answer them, demand a comprehensive evaluation framework.

This involves the interrelated activities of mapping, modelling and monitoring:

- mapping to define baselines for the problem definition phase that informs policy formulation, and to serve as a standard against which to evaluate the effectiveness of management;
- modelling to define the future dryland salinity problem and to predict the outcomes of different management regimes;
- monitoring to assess the comprehensiveness of implementation and the effectiveness of management, and refine knowledge for future decision making.

Much information is needed to serve the development and implementation of informed salinity management plans. Attention must be given to how this information is stored and retrieved so it will be readily and freely available. A well structured, easily accessible, up-to-date database is vital for monitoring and modelling. The evaluation framework is presented in Chapter 3.
2. Context for dryland salinity evaluation

2.1. Basic biophysical elements of an evaluation framework

2.1.1. Spatial and temporal aspects of dryland salinity

Dryland salinity is a problem of increased water supply in salty landscapes. This additional water is associated with the change of land use from native vegetation to crops and pastures that use less water. Climate, land cover, soil characteristics, salt stores and the hydrogeology and geomorphology of the landscape determine whether this increase in water is enough to cause dryland salinity.

These factors vary enormously across the continent so there are considerable differences in the character of dryland salinity.

The differences include:

- *incidence of dryland salinity* - different timeframes between clearing and the manifestation of dryland salinity in different landscapes, from a few decades in highly responsive landscapes to hundreds of years in slow-response systems;
- *responsiveness of systems to management* - different timeframes for managing dryland salinity, from decades in highly responsive systems to hundreds of years in slow-response systems;
- *form of dryland salinity* - as soil or surface water salinisation and whether it occurs as localised, discrete outbreaks or across extensive regions; and
- *scale of required intervention* - differences in the spatial extent and nature of required management action.

These differences have significant implications for targeting scarce resources to the most effective management options and for the design of appropriate monitoring and evaluation procedures. To this end, the Audit has recently developed a national classification of groundwater flow systems as a framework for dryland salinity management in Australia ([www.nlwra.gov.au/atlas](http://www.nlwra.gov.au/atlas)). Groundwater flow systems characterise similar landscapes in which similar groundwater processes contribute to similar salinity issues, and where similar salinity management options apply. Twelve groundwater flow systems have been identified on the basis of nationally distinctive geological and geomorphological characteristics (Figure 2).
This framework allows knowledge of dryland salinity gleaned from well studied areas to be appropriately extended to other areas. The same is true for the design of salinity management and evaluation systems at a national scale. At regional scales, the same approach used to develop the national map can be applied using more detailed datasets to inform the design and implementation of regional salinity management and evaluation systems. This approach is already being applied in the Murray-Darling Basin in Queensland; the Macquarie, Bogan, Castlereagh, Lachlan and Murrumbidgee catchments in NSW; the North East, North Central, Wimmera regions, and Mallee regions in Victoria; and the Murray-Darling Basin in South Australia.

2.1.2. Broad planning units
Salinity strategies throughout Australia focus on the major river basins as fundamental management units in national, State and regional approaches to dryland salinity management. This makes good sense, since the water quality in the rivers usually reflects the salinity processes occurring in the catchments. Catchments are also a logical management unit in a social sense, since regional communities often have an affinity with the catchments in which they live. Catchments also reflect some sense of the economic and industrial base of regional Australia and, increasingly, catchment boards or authorities are assuming responsibility for managing issues environmental sustainability.
Since catchments usually encompass many landscapes and function differently according to discrete landscape and groundwater processes, catchment planning for salinity management will require the disaggregation of catchments into component groundwater flow systems. A powerful knowledge base can be established extending this qualitative groundwater classification to include more specific, quantitative characteristics such as the spatial and temporal nature of groundwater recharge, the hydraulic properties of the aquifers, the location and amount of salt stored in the landscape, and the amounts of salt being exported from each groundwater flow system. In some cases the groundwater flow systems extend beyond the jurisdiction of individual management authorities.

**In short, while catchments are practical planning and implementation units, the design of management and evaluation systems must be based on additional information relating to the groundwater flow systems in the catchment and their more detailed characteristics.** Where these groundwater flow systems extend beyond the catchment boundary, management and evaluation activities must also be co-ordinated with adjacent catchment management activities.

### 2.1.3. Focusing on representative areas for detailed studies

Cost is clearly a consideration for the implementation of evaluation systems. Comprehensive mapping, modelling and monitoring are not feasible for every part of every catchment; indeed, it may be more informative to focus on understanding the processes causing salinity in representative sub-catchments.

The selection of representative areas as benchmarks for improving our understanding of the processes causing dryland salinity or for reviewing the effectiveness of management will be an important component in the design of monitoring systems.

**Criteria for the selection of representative sites should include:**

- the sites are broadly representative of the landforms, geology, groundwater flow systems, climate and land uses in the region;
- the existing extent of land salinisation is or can be mapped accurately;
- there are comprehensive existing baseline datasets for groundwater levels and salinity and stream salinity and salt loads; and
- there is good information relating to land cover, hydrogeology and climate.

Extrapolations can then be made to other similar catchments by the use of an appropriately scaled groundwater flow systems framework in a climatic and land use context.

### 2.2. Existing evaluation context

Future evaluation activities should build on existing monitoring networks and complement existing activities. These activities have been reviewed in some detail and are discussed in Appendix C.

A number of recent studies (George *et al.*, 2000; Martin and Metcalfe, 1998; NLWRA, 2001; Webb and Price, 1994) have provided opportunities to test the usefulness of available data and tools for providing management advice. They have identified inadequacies in available data, and shortfalls in our abilities to ascertain the current extent and impacts of dryland salinity and to predict the future extent and impacts under current and alternative management options.
2.2.1. Mapping baseline conditions

Groundwater
While all States maintain groundwater databases, most bores in the State databases have been established for reasons other than salinity evaluation.

The results are:
- the construction and location of bores are often not ideal for salinity monitoring;
- where bores have been installed to monitor salinity they have been concentrated in discharge areas and are under-represented in the upper slopes;
- in most States there is insufficient information on the salinity risk outside those catchments already affected;
- many of the existing bores are poorly documented;
- many existing bores are not regularly monitored;
- in most States groundwater level data have been collected over too short a period to separate the effects of land use change from long-term climatic cycles;
- poor location data of many bores is common, preventing spatial modelling; and
- elevation of bore sites is often unknown, limiting the usefulness of trend data across the landscape.

Surface water
All States except Tasmania have collected flow and salinity data for most or all of their larger rivers, but data for minor, unregulated streams are either not available or have not been consistently used in salinity assessment. Data for most sites are irregular and sparsely sampled, and flow data are generally more extensive than salinity data. In most cases salinity data have been collected at monthly or greater intervals.

Usually, surface water data have been collected over too short a period and have not been focused toward salinity process knowledge to separate the effects of land use change from variations in surface water flows and salinity concentrations in response to long-term climatic cycles.

All States have recognised the importance of monitoring the current extent of dryland salinity. Most have mapped either the entire state or those areas at risk from salinity; the notable exception is New South Wales, where salinity mapping is lacking for parts of the Murray-Darling Basin and most coastal catchments. Mapping methods are highly variable, incorporating surveys of regional officers (Tasmania, Queensland), aerial photograph interpretation (South Australia, NSW), satellite image interpretation (Western Australia) and interpolation of groundwater levels from bore measurements (Victoria, NSW, WA). This inconsistency means meaningful comparisons between States are not possible. A priority for a national salinity evaluation plan should include a consistent method to map the extent of dryland salinity in all states.

The NLWRA Dryland Salinity Project achieved some success in harmonising mapping methods. For example, the method based on groundwater levels and hydrogeomorphic units was used for Victoria, WA and the Queensland portion of the Murray-Darling Basin. New South Wales also attempted this approach but it was deemed inappropriate because of data quality problems.
Future national salinity audits could incorporate re-assessment of salinity extent on a regular basis using similar methods.

**Mapping of land cover/land use**

State-led land use mapping in Western Australia and South Australia, combined with Commonwealth-funded mapping through the Bureau of Rural Sciences’ national land use mapping program, provides excellent coverage of most of the country. The map scales range from 1:25 000 for most intensively used areas to 1:250 000 for more remote areas. While a snapshot of current land use is valuable, regular monitoring of land use change, especially land clearing, is not undertaken except in Queensland and WA. Other states such as South Australia indirectly record some aspects of land use change through the legal system because of approval requirements for land clearing.

**Impacts**

There has been little work prior to the NLWRA Extent and Impacts of Dryland Salinity project to assess the economic, social and biodiversity impacts of salinity. Biodiversity impacts have been assessed directly or indirectly through other State agency programs in Victoria, SA and WA, and impacts on infrastructure have been assessed in WA.

2.2.2. Capability of techniques

**Mapping the current extent of dryland salinity**

This is not straightforward and several methods have been used for extrapolating the incidence and areas at risk of salinity from existing data. Each has advantages and limitations (summarised in Martin and Metcalfe, 1998). Some approaches map the actual extent of characteristics associated with land salinisation, such as salt scalds and salt-tolerant vegetation; others use surrogate attributes for predicting the likely extent of land salinisation. They include regional anecdotal surveys to identify known sites of soil salinity (Tasmania, Qld); aerial photograph interpretation of soil salinity and vegetation decline (SA, NSW); satellite image interpretation of soil and stream salinity and vegetation decline (WA); and interpolation of groundwater level surfaces from bore measurements (Victoria, NSW, WA). Because of approximations inherent in the surrogate techniques and the different types of survey, the current extent of salinity is not known accurately (even at a regional scale) in most areas.

The most recent assessment of the extent or areas at risk of dryland salinity nationally ([www.nlwra.gov.au/atlas](http://www.nlwra.gov.au/atlas)) has highlighted the inconsistencies in assessment methods resulting in a level of uncertainty when combining data from different sources.

**Modelling the future extent and impacts of dryland salinity**

A review of current approaches to risk assessment (Gilfedder and Walker, 2001) concludes “there is no readily accepted and adopted approach for the consistent prediction of dryland salinity at a regional scale”.

For an approach to be suitable it would need to incorporate:

- landscape disaggregation to provide consistency in application of suitable salinity risk prediction methods, linked to the driving processes;
salinity risk assessment with a range of approaches that target key processes and provide salinity risk assessment in each landscape element, followed by GIS-based methods to extrapolate the assessment to similar landscape elements;

- Temporal changes to allow predictions to incorporate lead-in times (in the order of 50 years) to implement strategic management interventions.

Techniques commonly used to predict the future extent and impacts of dryland salinity include analysis of observed groundwater level trends, the use of stream salinity trend analysis, and landscape-based spatial analysis tools. The limitations of these are discussed below.

**Groundwater trend analysis**

In the recent Audit project assessing the future extent of dryland salinity in Australia, several States based their estimated future areas at risk on an inferred relationship between groundwater level trends and groundwater surface elevation. The other States and the Northern Territory resorted to coarser methods because of a lack of suitable groundwater level data. Like the incidence and risk mapping, the groundwater trend risk assessments are not directly comparable between States due to the varying methodology. Their obvious shortfall is that they do not provide an indication of the likely severity of surface water salinisation; only the likely extent of land salinisation.

Other methodological constraints include:

- the assumption of a linear trend in groundwater level rise. In reality, as groundwater rises to close beneath the ground surface, the rate of rise is attenuated by evaporation, plant use and discharge at low points in the landscape. It is very difficult to quantify at a broad scale the effects these processes have on groundwater level trends, but the assumption of a linear trend will lead to an overestimate of the area subject to dryland salinity;

- the difficulty of separating the effects of land use change and climatic cycles, particularly with datasets of fewer than 10 years. This can lead to the dramatic over- or under-estimation of the future extent of dryland salinity, depending on how significantly the recent climatic characteristics have varied from average conditions; and

- reliance on defining the relationship between groundwater level trends and surface elevation. Currently, digital coverages of ground surface elevation are very coarse in scale, and modelling based on them is not sensitive enough to capture the significant influence relatively subtle changes in land surface can have on groundwater flow and discharge. For this reason some States use land systems as the basis for recognising where salinity will occur in the landscape in the future. If it is deduced that a particular land system is likely to become salinised from groundwater level rise in a particular area, and then it is assumed that the land system is prone to salinisation everywhere, this almost certainly results in the dramatic overestimation of the future extent of dryland salinity.

**In a key study in WA (Campbell et al., 2000), analysis of trends in bore hydrographs was undertaken by three methods:**

- least squares regression analysis;

- segmentation of the hydrograph into different periods of medium- to long-term linear trends and estimation of the periodic responses to seasonal variations; and
• hydrograph analysis of rainfall and time trends (HARTT), which separated the effect of atypical rainfall events from the underlying time trend and explicitly analysed the lag between rainfall and its impact on groundwater.

The project concluded that:

‘The ability to separate the linear and cyclic trends in hydrographs, and to separate segments during which both trends are constant, has the potential to permit a better understanding of landscape response to hydrological changes such as differences in rainfall pattern and land use. However, because this analysis is tied to the detail of the historic pattern of these hydrological changes, it is of less use to predict what the hydrograph trend will be in the future. If the thresholds are caused by changes in rainfall rather than land use, linear trends fitted by eye and experience may be more useful for prediction than the trend analysis if the hydrograph covers a long period, because of the likelihood (or possibility) that the pattern of rainfall changes will continue into the immediate future. The HARTT method of determining hydrograph trends and of separating the effect of treatments from rainfall is potentially useful since the rainfall record is much longer and complete than are bore records, though the impact of assigning rainfall to a bore by interpolating from the nearest stations needs to be assessed.’

In summary, while groundwater trend approaches are the best tools we have for predicting future dryland salinity extent, their predictions may over- or under-estimate the likely future extent of salinity in different areas. In addition to the constraints associated with the groundwater trend approaches to predicting future groundwater levels, there are many difficulties in predicting the movement of salt through landscapes and into rivers. These include inadequacies in our understanding of the processes involved, and in the data and analytical tools needed to model these processes. This does not diminish the value of existing predictions of future extent for current decision making, but it does mean there is a need for better techniques, understanding and data to refine these predictions.

Stream salinity trends analysis
The major difficulties in using stream salinity trends to predict future conditions lie in the relatively short length of data available; the difficulty in discerning trends in data that are highly influenced by climatic variability; and the fact that historical trends are not necessarily a guide to the future. These statistical approaches do not incorporate any process-based modelling, so their ability to predict future trends or eventual hydrologic equilibrium is limited.

For example, in studies of historical stream salinity trends in the Murray-Darling Basin very few locations were found with a long record, particularly in the dryland regions (Walker et al., 1998; Jolly et al., 2001). The work developed a new approach to defining the statistical analysis of the available data but, apart from identifying areas that were undergoing change in terms of their salt concentration, was unable to provide information about future trend.

The Murray-Darling Basin Salinity Audit produced values for future salt loads and concentrations for the major streams of the Basin, based on modelling of groundwater level trends and related salt discharge in hydrogeomorphic or geological units. Different modelling approaches were used in different States. The main limitations were spatial and temporal data availability; the lack of any mechanism to reach an eventual equilibrium, and in the lack of modelling of salt wash-off (Walker et al., 1999).

There is a clear need to develop a capability to predict future salt concentrations in streams. The scale at which this is undertaken will depend on whether predictions are required to generate knowledge (in which case more detailed, tributary-scale modelling will be appropriate) or to set
targets for evaluating management effectiveness (in which case broader, catchment-scale modelling is more likely to be appropriate).

**Landscape-based spatial analysis tools for predicting salinity risk**

Bradd (1997) developed salinity risk maps using the Weights of Evidence Method (a variation of a composite index approach to GIS analysis). An alternative analysis of landscape shape, FLAG (Roberts *et al.*, 1997) calculates a gridded landscape index that can then be trained by comparison with known outbreaks of land salinisation. This information can then be used to identify similar areas that might also be at risk from salinisation.

The major drawback to these approaches used to predicting the future extent of dryland salinity is that they are not based on any robust process model. Furthermore, these landscape-based approaches cannot be used to predict future stream salinity or the time frames of future land salinisation.

**2.2.3. Modelling outcomes of dryland salinity management options**

Case studies undertaken as the Audit’s Salinity Theme Project 3 modelled the likely effect of different management options on dryland salinity outcomes in four monitored catchments. They used a combination of broad, catchment-scale and detailed, point-scale modelling of water balances (Stauffacher *et al.*, 2000; Baker *et al.*, 2001; Hekmeijer *et al.*, 2001; Short *et al.*, 2000)

These studies indicated that broad, catchment-scale groundwater modelling can indicate the magnitude of recharge reduction and the relevant timeframes needed to achieve different recharge management objectives. The available data (bore hydrographs, borelogs, land use and topography) were adequate for building the model though they were generally inadequate for validating the models. However, the scale of available data limits the scale of modelling that can be undertaken and in most parts of Australia is unlikely to be suitable for any modelling more detailed than sub-catchment scale.

More detailed, point-scale modelling of the deep drainage beneath different farming systems demands far more data, and the applicability and reliability of the results are limited by the quality and quantity of available data. In the case of many catchments in Australia, the lack of data particularly for checking model output - will limit the usefulness of this approach.

The fundamental shortfall of the modelling approaches for water balances at both the catchment and point scale is that neither approach has integrated surface and shallow subsurface processes, and the deeper groundwater zone. This is clearly an area for further work as it is critical to predicting the farming systems that are likely to achieve management objectives.

**2.2.4. Capacity to manage and interpret data and report on implications**

A great deal of effort has been expended on collecting data, but considerably less effort has gone into managing and interpreting these data. Data management and interpretation have not been part of a holistic management strategy and have therefore been given low priority and have been easy targets for agency budget cuts. The availability of qualified personnel to undertake this work is an often overlooked but critical limitation in our capacity to underpin dryland salinity management decision-making with appropriate information.

The results of salinity evaluation need to be reported at national, State, regional and catchment levels and jurisdictions. While planning activities at these levels focus at different scales, the
data requirements needed to underpin decision making have considerable commonality, with the key attributes described above relevant to all levels.

To make the most effective use of evaluation data there is a need to ensure consistency

This can be achieved through:

- the adoption of common specifications for evaluation activities (as described in the following section); and
- the use of a groundwater flow systems approach at an appropriate scale to help appropriate aggregation of data and allow comparison of similar areas in different jurisdictions.

While State agencies are already undertaking this role, there is no national organisation with the role of managing monitoring data and periodically reporting on the status of salinity and salinity risk. These inadequacies should be corrected (Table 1).

Table 1 contrasts our current capabilities for assessment of dryland salinity with our needs. Several areas require more resources if we are to make investment decisions based on an understanding of the current and future likely extent of dryland salinity under different management regimes.
Table 1: State of dryland salinity assessment

<table>
<thead>
<tr>
<th>Information required</th>
<th>Current capabilities</th>
<th>Future needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mapping the current extent of land salinisation</td>
<td>Methods that map land salinisation at a variety of scales, from standard field based mapping approaches and air photo interpretation to airborne and satellite-sensed data analysis</td>
<td>Our current capability can be fine-tuned in some areas, but is adequate for the tasks. Future needs relate to access to relevant data, the ability to apply the correct analysis technique in the required situation, and resources to be able to undertake repeat surveys</td>
</tr>
<tr>
<td>Modelling of the future extent of land salinisation</td>
<td>Reliant on the assumption of linear infinite trend in groundwater response, where the future trend is the same as historical trends. Landscape index approaches trained on known salinisation are limited by their inability to predict the timeframe of salinity risk</td>
<td>Tools to produce definitive predictions of actual areas likely to be salinised Adequate data to parameterise and calibrate models Qualified personnel to undertake modelling</td>
</tr>
<tr>
<td>Modelling of the future severity of stream salinity</td>
<td>Limited to linking land salinisation to stream salinity by poorly developed process models Some stochastic/mechanistic modelling has been undertaken</td>
<td>Process-based tools that can account for equilibrium conditions and are based on knowledge of key groundwater/surface water interaction models calibrated for local conditions. These tools will also need to be able to differentiate between climatic factors and land use influences Adequate data to set parameters for and calibrate models Qualified personnel to undertake modelling</td>
</tr>
<tr>
<td>Modelling of the efficacy of different management options on dryland salinity</td>
<td>Current capabilities are extremely limited: most analysis relies on the detection of a reduction in groundwater levels adjacent to the treatment site</td>
<td>Tools that can describe the interactions between surface and groundwater processes, and the effect of climatic variation on groundwater response, and thereby describe any land use change influence Adequate data to set parameters for and calibrate models Qualified personnel to undertake modelling</td>
</tr>
</tbody>
</table>
3. An evaluation framework for dryland salinity

3.1. Design considerations

3.1.1. Management objectives and options

In the past, dryland salinity management has been applied with the implicit objective of ameliorating causes and symptoms through a range of approaches to reduce or manage discharge. We now know that salinity management objectives must be more explicit. To achieve this we must take into account the characteristics of the groundwater flow systems and their interaction with surface water hydrology. These objectives should reflect a realistic understanding of the feasibility of reversing, halting or slowing the manifestation of dryland salinity.

Dryland salinity management objectives and options broadly consist of:

- prevention and protection (for example, native vegetation retention);
- treatment of cause (for example, recharge management or interception of groundwater);
- amelioration of symptoms (for example, interception and storage of salt, managing saline discharge or developing alternative production systems); and
- living with salt (for example, alternative use of saline land and water resources, optimisation of the use of non-saline resources).

The mix of management options appropriate to achieving these objectives in any particular region is further discussed in *Australian Dryland Salinity Assessment 2000* (NLWRA, 2001). The evaluation approaches taken to achieve the management objectives must vary according to the management activities and performance targets specified in plans, and the scale at which these objectives are to be addressed.

3.1.2. Evaluation objectives and approaches

The evaluation approach should also be developed in a framework of explicit management objectives:

- to define baselines of the extent/severity/impacts of dryland salinity;
- to predict the likely future extent/severity/impact of dryland salinity;
- to refine understanding of the processes causing dryland salinity;
- to measure the effectiveness of previous management activities;
- to provide data to decide on the most appropriate management options for delivering the changes to catchment water balances, and the likely time frames over which these might be achieved;
- to measure how well proposed management activities been implemented; and
- to measure changes in extent/severity/impacts of dryland salinity.
The attributes chosen to map, model and monitor dryland salinity need to be:

- readily understood;
- able to be measured regularly and unambiguously;
- readily interpreted;
- informative and readily communicated;
- scientifically credible; and
- in accord with existing national standards, programs and policies.

Furthermore, the data being collected need to be relevant at a catchment scale and able to be aggregated for assessments at regional and national scales.

3.1.3. Recommended attributes for evaluating dryland salinity

Mapping, monitoring and modelling of the following attributes are necessary:

- as a baseline to define current rates of change, to inform conceptual models of dryland salinity processes and to underpin decisions about targets for evaluating dryland salinity management;
- to generate knowledge about processes controlling dryland salinity through the development of conceptual models or through investigations using numerical models;
- to assess the potential effectiveness of management activities using predictive scenario modelling; and
- to evaluate the effectiveness of dryland salinity management activities.

**Groundwater levels and groundwater salinity**

Monitoring of groundwater level trends provides information about change in groundwater pressures and likely discharge volumes in response to changes in recharge. Groundwater salinity concentrations may also provide a baseline against which changes can be detected. However, the practical complexities in measuring them and their usually limited value in indicating catchment salinity processes mean that they are not recommended as primary attributes for monitoring; nevertheless, occasional measurements can provide useful information to inform understanding of processes and to parameterise models.

**Surface water salinity concentrations and salt loads**

Monitoring of surface water salinity concentrations and salt loads provides a baseline against which changes can be detected. Trends in surface water salinity concentrations and salt loads provide information about changes in the volumes of discharging groundwater to surface water bodies and the amount of salt being exported from the catchment.

**Extent of land salinisation**

Mapping the extent of land salinisation provides information about the current extent and impacts of dryland salinity to define the problem and serve as a baseline against which changes can be measured.
**Land cover and land use**

Mapping of changes in land cover and land use provides a context for interpreting trends in groundwater, surface water and soil salinity data. Mapping can also be a direct measure of the implementation of some management activities.

**Contextual data**

Databases of the hydrogeological and soil characteristics of groundwater flow systems, climatic characteristics and digital elevation models provide a context for interpreting trends and assessing the effectiveness of management strategies. These data are also essential for setting parameters for predictive scenario modelling of dryland salinity processes.

**3.1.4. Alternative attributes for evaluating implementation**

Sometimes the recommended attributes will not be suitable for evaluating the implementation of management activities: for example, if the timeframes for assessment are too short to detect a direct landscape response to management, or data are not available. In these cases alternative attributes can be included in evaluation programs.

**Alternative monitoring attributes can include:**

- agricultural systems productivity;
- changes in land management practices;
- vegetation health;
- adoption of best-practice catchment planning approaches;
- socio-economic status of primary production;
- social viability of rural communities;
- degree of implementation of catchment strategic plans;
- volume of water and salt diverted from key assets;
- adoption of new saline industries; and
- level of funding applied to salinity management.

These data are ambiguous because they reflect a number of influences that may or may not affect dryland salinity. These attributes should only be used for evaluating implementation of management options, or where the recommended attributes are not available for a sufficient period or are not sufficiently comprehensive or representative. Table 2 shows the relationship between the range of management objectives and the desired outcomes, and the mix of recommended and alternative attributes to each case. Note that the list of alternative attributes is not exhaustive.
Table 2. Evaluation attributes for different dryland salinity management options

<table>
<thead>
<tr>
<th>Management objective</th>
<th>Strategy</th>
<th>Outcome sought</th>
<th>Recommended evaluation attributes</th>
<th>Alternative attributes</th>
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<tbody>
<tr>
<td><strong>Prevention</strong></td>
<td>Manage vegetation so deep drainage does not increase in high risk areas</td>
<td>Land and surface waters will remain free from degradation from salinity</td>
<td>Per cent retention of native deep-rooted vegetation in high risk areas</td>
<td>Land use management practices, Vegetation condition, Catchment planning based on resource assessment and daily water balance modelling</td>
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<td>Long-term groundwater level trends</td>
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<td>Long-term stream salinity and salt load trends</td>
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<td>Extent of land salinised</td>
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<td>Land cover change</td>
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<td>Digital elevation models</td>
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<td>Digital elevation models</td>
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<td>Proportion of landscape where water-efficient land use is adopted</td>
<td>Land use management practices</td>
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<td>Land use management practices</td>
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<td><strong>Treatment of cause</strong></td>
<td>Reduce recharge to the groundwater system by increasing vegetation water use through land management practices</td>
<td>Land and surface water salinisation will diminish</td>
<td>Long-term groundwater level trends</td>
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<td>Volume of water and salt diverted or pumped from groundwater</td>
<td>Land use management practices</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Land use management practices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interception of water prior to infiltration or from groundwater upgradient of discharge zone</td>
<td>Land and surface water salinisation will diminish</td>
<td>Long-term groundwater level trends</td>
<td></td>
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<td></td>
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<td></td>
<td>Long-term stream salinity and salt load trends</td>
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<td></td>
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<td></td>
<td>Extent of land salinisation</td>
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<td>Land cover change</td>
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<td></td>
<td>Hydrogeological and soil characteristics</td>
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<td>Climatic characteristics</td>
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<td></td>
<td></td>
<td>Digital elevation models</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volume of water intercepted and disposed</td>
<td>Mass of salt intercepted and disposed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interception and disposal of salt, and reduction of groundwater levels in transmission zones</td>
<td>Land and surface water salinisation will diminish</td>
<td>Long-term stream salinity and salt load trends</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extent of land salinisation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hydrogeological and soil characteristics</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Climatic characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Digital elevation models</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Evaluation attributes for different dryland salinity management options (continued)

<table>
<thead>
<tr>
<th>Management objective</th>
<th>Strategy</th>
<th>Outcome sought</th>
<th>Recommended attributes</th>
<th>Alternative attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Managing saline discharge</strong></td>
<td>Managing saline discharge</td>
<td>Land and surface water salinisation will diminish</td>
<td>Long-term stream salinity and salt load trends Hydrogeological and soil characteristics Climatic characteristics Digital elevation models</td>
<td>Volume of water and salt diverted Land use management practices</td>
</tr>
<tr>
<td><strong>Amelioration of symptoms</strong></td>
<td>Application of soil treatments (ameliorants)</td>
<td>Agricultural production from saline land is increased</td>
<td>Extent of land salinisation Soil water characteristics Climatic characteristics Digital elevation models</td>
<td>Proportion of potential discharge area applying treatments Increase in gross margin ($/ha) from salinised areas determined from farm financial information Land use management practices</td>
</tr>
<tr>
<td><strong>Productive uses of saline resources</strong></td>
<td>Establishment of salt tolerant land cover</td>
<td>Productivity from salt affected land will increase</td>
<td>Extent of land salinisation Land cover change Increase in production of biomass</td>
<td>Increase in long-term productivity from saline resource Proportion of potential discharge zone applying alternative, salt-tolerant land uses</td>
</tr>
<tr>
<td></td>
<td>Alternative use of saline land and water resources</td>
<td>Productivity from salt affected land and water will increase</td>
<td>Extent of land salinisation Land cover change</td>
<td>Rate of adoption of new saline industries</td>
</tr>
<tr>
<td></td>
<td>Optimisation of the use of non-saline resources</td>
<td>Productivity from non-salt affected land will increase</td>
<td>Land cover change</td>
<td>Increase in long-term productivity from non-saline resource Rate of adoption of new practices that optimise non-saline resources</td>
</tr>
</tbody>
</table>
3.2. Specifications for recommended evaluation attributes

The following tables provide guidelines for the monitoring of each of the recommended attributes, and describe evaluation and reporting techniques for each of these attributes. They also provide guidelines for which techniques are suitable for each type of groundwater flow system.

More detailed discussion of the biophysical considerations in designing evaluation systems and interpreting monitored data is provided in Appendix A. Descriptions of the critical groundwater flow system characteristics influencing the design of evaluation systems are provided in Appendix B.
3.2.1. Groundwater evaluation specifications

<table>
<thead>
<tr>
<th>MONITORING OF GROUNDWATER LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td><strong>Methods</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
## Monitoring of Groundwater Levels (continued)

<table>
<thead>
<tr>
<th>Location</th>
<th>Groundwater bores are best located in accordance with monitoring objectives that range from recording the status of salinity in a catchment or sub-catchment to evaluating the merit of treatments at farm or paddock scale. The capacity of monitoring systems to accurately meet these requirements varies considerably with each groundwater flow system (GFS), as does the requirement for groundwater observation points in key landscape locations.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evaluation at catchment/sub-catchment scale</strong></td>
<td><strong>Groundwater recharge zones</strong>: piezometers/observation bores are should be located in areas of known groundwater recharge. These may be regions in which the aquifer outcrops at the land surface, or where overlying strata provide permit ready infiltration of surface water. Piezometers are located at depths coincident with key strata or at convenient depths consistent with measurement of the accession of surface water to groundwater.</td>
</tr>
<tr>
<td></td>
<td><strong>Active or potential groundwater discharge zones</strong>: piezometers/observation bores should be located in existing or potential groundwater discharge areas to assess the status of salinity with and without catchment treatment. Piezometers are located in regions that are usually somewhat unique to each groundwater flow system, but may include breaks of slope, valley floors and drainage depressions.</td>
</tr>
<tr>
<td></td>
<td><strong>Mid catchment regions</strong>: piezometers/observation bores should be located at key points along the flowpath of groundwater systems. They are required in concert with other groundwater monitoring activities, to assess the overall catchment response to seasonal climatic events and the implementation of salinity management strategies. They may be simply located in mid-catchment regions or, alternatively, be located to coincide with geological/geomorphic features that might affect groundwater flow.</td>
</tr>
<tr>
<td><strong>Evaluation at sub-catchment/farm/paddock scale</strong></td>
<td>Groundwater monitoring to assess the merit of individual farm/paddock scale treatments is not possible in all GFSs.</td>
</tr>
<tr>
<td></td>
<td>As a general rule, groundwater monitoring to establish the efficacy of salinity management strategies will only be possible in lower transmissivity, local flow systems, or in those intermediate systems where the scale of implementation is large in compared with the size of the catchment.</td>
</tr>
</tbody>
</table>
|  | In moderate to high permeability intermediate or regional systems, any minor depression in the groundwater surface resulting from a paddock-scale recharge reduction is quickly filled by inflow from adjacent groundwater.
**MONITORING OF GROUNDWATER LEVELS (continued)**

| Frequency          | Irregular intervals coincident with site visits or occasional readings by landholders/catchment groups  
|                   | Routine measurements at regular (minimum monthly) intervals  
|                   | Frequency can be set by software; however, since most groundwater flow systems will respond slowly to seasonal climatic variations there is seldom value in recording at intervals of less than one day  
| Duration | Groundwater monitoring to establish significant trends that can be usefully interpreted in the context of dryland salinity risk with and without intervention demands a commitment to long-term monitoring: in most instances 10 to 20 years of records will be required to critically evaluate the status of regional salinity  
|       | The requirement for long-term groundwater data in establishing groundwater trends extends across all national groundwater flow system types  
|       | Longer term records are particularly important where salinity processes are driven by episodic groundwater recharge caused by unusually high seasonal rainfall and flooding  
|       | While the need for long-term data remains, in suitable groundwater flow systems much shorter term information can be very useful in assessing the impact of treatments, particularly where short-term responses can be viewed against a background of longer term regional trends  


## REPORTING OF GROUNDWATER LEVEL MONITORING

<table>
<thead>
<tr>
<th>Units of measurement</th>
<th>Groundwater depths should be measured in metres and read to the nearest centimetre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Groundwater trends are best displayed as simple hydrographs indicating changes in elevation/pressure over time, ideally in conjunction with seasonal rainfall data for the same period. It is also often instructive to compare longer term trends with the cumulative residual mass curve illustrating trends in seasonal rainfall over the same period</td>
</tr>
<tr>
<td>Data sources</td>
<td>There is currently no national groundwater database dedicated to dryland salinity evaluation in Australia. Most State agencies maintain groundwater databases that include time series data relating to groundwater elevation. Some contract the collection management of the data to consulting companies or water authorities. In many instances data are collected at two levels: the official data collected by State agencies and processed in their corporate databases; and data collected by regionally based operators and landcare groups. The latter information is generally more applicable to regional trials and monitoring of catchment treatments. The available data vary considerably in both quality and quantity across regions and across State boundaries.</td>
</tr>
<tr>
<td>Related attributes</td>
<td>The main related attribute is rainfall. This should be available as daily rainfall but, in most instances, be interpreted on a monthly basis. Groundwater salinity is an attribute that may also be measured over time. Annual sampling (or less) is, however, is usually enough as salinity does not normally vary greatly over time, and trends in salinity over time provide little additional information when compared with the time and technical difficulty in acquiring quality data.</td>
</tr>
<tr>
<td>Interpretation</td>
<td>The interpretation of groundwater information requires an experienced hydrogeologist, as many factors can influence groundwater behaviour. In some GFSs it is possible to equate changes in seasonal groundwater elevation in the watertable aquifer with groundwater recharge. This can be useful in calibrating numerical models. Care should be taken not to confuse very short-term groundwater fluctuations caused by barometric pressure or tidal influences with groundwater recharge. In many GFSs groundwater recharge will produce a single seasonal groundwater response. Where short-term information is considered, it should be viewed in the context of longer term regional trends established from other groundwater monitoring sites. Care should be taken to separate short to medium term response in groundwater to intervention activities from short to medium term aberrations in climate. Groundwater responses should be reviewed in the context of the location of observation bores, both in terms of their position in the groundwater flow system, and the landscape/groundwater processes operating in that system. Do not assume that groundwater recharge is caused solely by leakage from saturated soils.</td>
</tr>
</tbody>
</table>
SUITABILITY OF GROUNDWATER LEVEL MONITORING FOR EVALUATING SALINITY WITH RESPECT TO DIFFERENT KINDS OF GROUNDWATER FLOW SYSTEMS

Local groundwater flow systems

<table>
<thead>
<tr>
<th>Deeply weathered rocks</th>
<th>Recommended method: nested piezometers are the recommended system of groundwater monitoring. Monthly monitoring by trained technicians remains the most reliable method of data acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deeply weathered fractured rocks</td>
<td>Problem definition: groundwater monitoring provides the most useful information about the ultimate likely extent of dryland salinity, in that it can describe regional trends and the movement of the groundwater surface toward or away from the land surface. It is very difficult to predict with any certainty the extent of salinisation. The way the groundwater surface cuts the land surface and the resulting outbreaks of groundwater discharge will vary considerably in accordance with the inherent biophysical characteristics of each GFS</td>
</tr>
<tr>
<td>Fractured rocks</td>
<td>Knowledge generation: knowledge of salinity and salinity management increases with increased understanding of the way groundwater systems respond to both climatic variation and the implementation of salinity management strategies. In each GFS system, knowledge generation requires the establishment of case study areas in which more intensive groundwater monitoring systems are established. These case studies can then provide models of groundwater behaviour that support conclusions in regions where lesser information is available</td>
</tr>
<tr>
<td>Colluvial fans</td>
<td>Evaluating effectiveness of land use change: groundwater monitoring is the most effective method of assessing the impact of changed land use on salinity in all local groundwater flow systems</td>
</tr>
<tr>
<td>Fine grained sediments</td>
<td>Evaluating effectiveness of land management change: groundwater monitoring is very effective as a means of evaluating the influence of land management practices on salinity in all local groundwater flow systems</td>
</tr>
<tr>
<td>Fractured basalts</td>
<td></td>
</tr>
</tbody>
</table>
## SUITABILITY OF GROUNDWATER LEVEL MONITORING FOR EVALUATING SALINITY WITH RESPECT TO DIFFERENT KINDS OF GROUNDWATER FLOW SYSTEMS

### Intermediate groundwater flow systems

<table>
<thead>
<tr>
<th>Sedimentary sequences infilling large valleys</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended method:</strong></td>
<td>where the aquifer is largely unconfined, regularly monitored bores or piezometers are recommended; if the aquifer is confined, nested piezometers are recommended. In these moderately permeable systems in flattish landscapes, the groundwater surface will generally display low relief and changes in elevation should be readily apparent from a relatively small number of bores. Ideally, monitoring should occur on a monthly basis but, as significant changes in groundwater elevation will largely be driven mainly by very infrequent episodic high rainfall events, measurements should be taken immediately after such events. Otherwise, measurements at three to six monthly intervals may suffice</td>
</tr>
<tr>
<td><strong>Problem definition:</strong></td>
<td>as the groundwater surface is generally planar in this GFS there is often a strong correlation between the elevation of the land surface and areas of land affected by salinity. Thus, changes in groundwater elevation can be readily used to predict areas of land that may become saline</td>
</tr>
<tr>
<td><strong>Evaluating effectiveness of land use change:</strong></td>
<td>changes in groundwater level indicate the impact of regional land use on salinity, particularly where monitoring records are available from the time that regional land use changes are/were first imposed</td>
</tr>
<tr>
<td><strong>Evaluating effectiveness of land management change:</strong></td>
<td>groundwater level monitoring will generally not provide strong evidence of the effectiveness of land management treatments in this GFS unless the area of land treated is very large in comparison to the size of the catchment. The relatively high transmissivity aquifers will compensate for any recharge reduction through inflow of groundwater from adjacent areas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fractured rocks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended method:</strong></td>
<td>regularly monitored bores are recommended for monitoring intermediate fractured rock aquifers. These groundwater systems are largely unconfined or semi-confined and fracture zones occur throughout the rock mass, generally to depths of 50 to 100 metres. In most instances they behave as a single unconfined aquifer</td>
</tr>
<tr>
<td><strong>Problem definition:</strong></td>
<td>groundwater monitoring can be very useful in understanding the regions in which salinity occurs so that surveys are informed and targeted. Groundwater monitoring by itself will provide little information on the extent of salt affected land or water resources</td>
</tr>
<tr>
<td><strong>Knowledge generation:</strong></td>
<td>knowledge generation remains important, and consideration should be given to the establishment of case study areas in each significant GFS either already affected by salinity or at risk of salinity. Intensive monitoring in these study areas can be extrapolated to regions comprised of the same GFS that have less information</td>
</tr>
<tr>
<td><strong>Evaluating effectiveness of land use change:</strong></td>
<td>groundwater monitoring is a valuable tool in evaluating the impact of regional land use on salinity</td>
</tr>
<tr>
<td><strong>Evaluating effectiveness of land management change:</strong></td>
<td>groundwater monitoring does not provide a useful tool in understanding the impact of treatments at the farm of paddock scale in intermediate fractured rock aquifer systems. The relatively high permeability of the landscape compensates for the impact of the treatment through groundwater inflows from adjacent areas. Groundwater monitoring is useful, however, where the area treated is very large compared with the area of the catchment/sub-catchment</td>
</tr>
</tbody>
</table>
SUITABILITY OF GROUNDWATER LEVEL MONITORING FOR EVALUATING SALINITY WITH RESPECT TO DIFFERENT KINDS OF GROUNDWATER FLOW SYSTEMS

Regional groundwater flow systems

<table>
<thead>
<tr>
<th>Groundwater Flow System</th>
<th>Recommended method for alluvial aquifers</th>
<th>Recommended method for unconfined sediments and fractured basalts</th>
<th>Problem definition</th>
<th>Knowledge generation</th>
<th>Evaluating effectiveness of land use change</th>
<th>Evaluating effectiveness of land management change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvial aquifers</td>
<td>Nested piezometers are recommended. Regional alluvial aquifers are most often confined or semi-confined by overlying sediments, and discharge of groundwater is commonly caused by high groundwater pressures down-basin producing artesian conditions. Piezometers allow for the measurement of groundwater pressures over time.</td>
<td>Monitored bores are recommended. Piezometers are not required because groundwater discharge is not caused by elevated groundwater pressures; it simply occurs where the regional water table rises and intersects the land surface.</td>
<td>Groundwater monitoring can be a very useful way of establishing the extent of salinity or potential salinity over time; it is particularly useful in systems that comprise large high permeability aquifers that display planar groundwater surfaces of known elevation. The area at risk of salinity or affected by salinity can be estimated by considering those regions in which the groundwater surface approaches or intersects the land surface.</td>
<td>Knowledge generation remains an important aspect of groundwater monitoring in this GFS. Most systems are driven by the infrequent years of exceptionally high rainfall, and groundwater often recharges through periods of sheet flooding. Even the systems with the longest records provide insight into only two or three episodes where there are substantial changes in groundwater elevation. In some systems, leakage from rivers and other surface water bodies appears to be important. Clearly there is a great deal more to be learned about large alluvial groundwater flow systems and the ultimate extent of salinity they will cause, and monitoring of groundwater over extended periods will be critical to this.</td>
<td>Groundwater monitoring is not a suitable means of monitoring the effectiveness of treatments in most regional GFSs. Most regional systems comprise highly permeable, large aquifers that allow rapid groundwater inflows from adjacent areas, negating any impacts that treatments might otherwise have in lowering water tables.</td>
<td></td>
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</tbody>
</table>
### 3.2.2. Stream monitoring specifications

<table>
<thead>
<tr>
<th>MONITORING OF STREAM SALINITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td>Stream habitat and resource quality: stream salinity measurements monitor water quality, and indicate the capacity to sustain ecological systems and to provide for domestic and industrial uses.</td>
</tr>
<tr>
<td>Salt movement and trends: when measured over time, stream salinity measurements in combination with surface water flows provide an estimate of the movement of salt throughout the surface water network of a catchment. Such estimates provide <em>prima facie</em> indications of the spatial and temporal distribution of salinity risk with and without intervention.</td>
</tr>
<tr>
<td>Salt export: stream salinity and surface water flows records are essential to assess trends in water quality and salt export in river basins over time.</td>
</tr>
<tr>
<td><strong>Methods</strong></td>
</tr>
<tr>
<td>Spot check: stream salinity is established by measuring the electrical conductivity of stream water at regular or irregular intervals over time, in the field using a calibrated meter or on water samples in a laboratory.</td>
</tr>
<tr>
<td>Status: stream electrical conductivity is measured routinely at regular intervals throughout the year, in combination with continuous surface water flow data acquired from gauging stations. Instantaneous flows are also usually measured at the time of sampling.</td>
</tr>
<tr>
<td>Trend: stream salinity and surface water flows are measured continuously over time by in-stream electrical conductivity sensors and data loggers.</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Groundwater discharge: measurements at points in the catchment immediately above and below obvious groundwater discharge.</td>
</tr>
<tr>
<td>Adjacent to key assets: measurement at points in the catchment where water quality is critical to the maintenance of biodiversity, or where water is diverted for domestic or industrial purposes.</td>
</tr>
<tr>
<td>Effectiveness of works: measurement at points in the catchment immediately above/below regions in which salt intervention strategies have been adopted.</td>
</tr>
<tr>
<td>Salt load: measurement at strategic points in the catchment where salt loads must be calculated, for example either immediately above or immediately below the confluence of second or third order streams.</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>At irregular intervals that coincide with periods of interest; for example, during periods of high or low flows, or consistent with Saltwatch/Waterwatch events.</td>
</tr>
<tr>
<td>At monthly intervals consistent with the servicing of surface water flow recorders/data loggers.</td>
</tr>
<tr>
<td>At hourly or daily intervals consistent with the required purposes and the technical capabilities of the recorder/data logger.</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
</tr>
<tr>
<td>Several years: enough to establish the relative general condition of water quality in the stream over a range of climatic conditions.</td>
</tr>
<tr>
<td>Generally 10 to 20 years of data are required before any meaningful analyses can be performed.</td>
</tr>
<tr>
<td>5 to 10 years of data provide valuable insight providing the record spans the range of climatic conditions common to the catchment, but a minimum of 10 to 20 years is required to establish real understanding.</td>
</tr>
<tr>
<td>REPORTING OF STREAM SALINITY MONITORING</td>
</tr>
<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td><strong>Units of measurement</strong></td>
</tr>
<tr>
<td>The international unit for electrical</td>
</tr>
<tr>
<td>conductivity measurement and reporting</td>
</tr>
<tr>
<td>is deci-Siemen per metre (dS/m)</td>
</tr>
<tr>
<td>Micro-Siemen per centimetre (uS/cm),</td>
</tr>
<tr>
<td>however, remains a popular unit throughout Australia and is often referred to as EC (units). 1000 uS/cm is equivalent to 1dS/m</td>
</tr>
<tr>
<td>Electrical conductance is normally quoted at 25 degrees Celsius</td>
</tr>
<tr>
<td><strong>Presentation</strong></td>
</tr>
<tr>
<td><strong>Salt events</strong>: tabulated electrical conductivity measurements (by date) indicating periods of high and low salinity coincident with seasonal flows</td>
</tr>
<tr>
<td><strong>Salt loads</strong>: estimates of salt-loads based on flow-weighted averages with assessments of stream salinity under high and low flow conditions</td>
</tr>
<tr>
<td><strong>Salt trends</strong>: actual salt loads computed from continuous flow and electrical conductivity records, analyses of conditions under which high salt loads and high stream salinity occur, and assessments of potential responsiveness to salinity interventions</td>
</tr>
<tr>
<td><strong>Data sources</strong></td>
</tr>
<tr>
<td><strong>Custodians</strong>: agencies (mostly State) responsible for the collection and collation of data, including companies with responsibilities where data collection/management is outsourced</td>
</tr>
<tr>
<td><strong>Access constraints</strong>: many agencies require data exchange agreements to be signed prior to data acquisition</td>
</tr>
<tr>
<td><strong>Data format</strong>: Stream water quality and flow records acquired over many years may result in very large files. The information may range from raw data to calibrated and smoothed stream flow records at hourly, daily or monthly intervals. Both the storage and retrieval of information require careful consideration</td>
</tr>
<tr>
<td><strong>Related attributes</strong></td>
</tr>
<tr>
<td><strong>Stream flow</strong>: Isolated stream salinity measurements provide little insight into the nature of salt movement in a catchment other than indicating regions in which there may be serious concern over water quality. Stream flow measurements enable the spatial and temporal distribution of salt movement in a river catchment and provides insight into the processes causing salinity, and responsiveness to intervention. The movement of salt in a catchment relates more to the discharge of saline groundwater in the catchment tributaries</td>
</tr>
<tr>
<td><strong>Interpretation</strong></td>
</tr>
<tr>
<td>The analysis of streamflow data is technically challenging. While it is not too difficult to broadly estimate salt loads from gauged catchments, it remains difficult to assess how these estimates are changing over time. First and second order streams generally display low salt concentrations because they carry large volumes of surface flow; however, they may transport enormous salt loads. Third and fourth order streams generally exhibit higher salt concentrations because they are less diluted by surface water flow; however, they react strongly to shorter term climatic influences and produce considerable ‘noise’ in the data. For these reasons stream-flow salinity monitoring, recording, and assessment is best undertaken by experienced hydrologists</td>
</tr>
<tr>
<td><strong>Technical references</strong></td>
</tr>
</tbody>
</table>
SUITABILITY OF STREAM MONITORING FOR EVALUATING SALINITY IN AUSTRALIAN GROUNDWATER FLOW SYSTEMS

Local groundwater flow systems

<table>
<thead>
<tr>
<th>Deeply weathered rocks</th>
<th>The trend method is recommended for monitoring stream salinity where the most precise information is required and the cost of the installation can be justified. Instrumentation can be technically difficult, especially in small third or fourth order stream catchments because of the ephemeral nature of surface water flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deeply weathered fractured rocks</td>
<td><strong>Problem definition:</strong> Effective in monitoring the impact of salinity on regional water resources and the aquatic environment <strong>Knowledge generation:</strong> Provides fundamental information on all aspects of the hydrologic balance as it impacts on regional salinity issues <strong>Evaluating effectiveness of land use change:</strong> Highly suited to measuring the salinity impact of land use, where monitoring is applied to second or third order streams comprising many local flow systems</td>
</tr>
<tr>
<td>Fractured rocks</td>
<td><strong>Evaluating effectiveness of land management change:</strong> Suited to measuring the impact of mitigation and management strategies where salt export is generated through washoff and the objective is to reduce runoff.</td>
</tr>
<tr>
<td>Colluvial fans</td>
<td></td>
</tr>
<tr>
<td>Fine-grained sediments</td>
<td></td>
</tr>
<tr>
<td>Fractured basalts</td>
<td></td>
</tr>
</tbody>
</table>

An Evaluation Framework for Dryland Salinity
SUITABILITY OF STREAM MONITORING FOR EVALUATING SALINITY IN AUSTRALIAN GROUNDWATER FLOW SYSTEMS

**Intermediate groundwater flow systems**

| Sedimentary sequences infilling large valleys | Trend measurements are the preferred method, but are applicable only where a calibrated gauging station is technically feasible. This is seldom the case in the broad floodplain depressions typical of this terrain |
| Fractured rocks | Trend measurements are recommended and appropriate where the landscape permits the establishment of calibrated stream gauging stations |
| Fractured basalts and layered sedimentary rocks | Problem definition: Very useful in assessing the extent of regional stream salinity and salt loads, and impacts on aquatic ecosystems and water resources |
| | Knowledge generation: Provides fundamental information on all aspects of the hydrological balance as it impacts on regional salinity issues |
| | Evaluating effectiveness of land use change: Technique is valuable in assessing the impact of regional land use on stream salinity and salt export from upland fractured rock terrain. Requires calibrated gauging stations at key locations in the catchment |
| | Evaluating effectiveness of land management change: Seldom useful in assessing the benefits of land management in intermediate fractured rock systems, except in circumstances where alternative land management systems are so widely adopted that they impose regional land use change; for example, through afforestation of catchment headwaters |
### SUITABILITY OF STREAM MONITORING FOR EVALUATING SALINITY IN AUSTRALIAN GROUNDWATER FLOW SYSTEMS

#### Regional groundwater flow systems

| Alluvial aquifers | Trend measurements are recommended because they provide the only means of collecting stream salinity data that can be interpreted in the context of salt export. Instrumentation may be difficult and the construction of gauging stations may only be possible on first or second order streams |
| Problem definition: Stream monitoring may provide insight into salt accessions to streams from alluvial floodplains |
| Evaluating effectiveness of land use change: Stream salinity monitoring provides some insight into the salinity impacts of regional land use; however, as these much larger systems usually occur in the lower river basin the technique is problematical because the salt load in the streams includes accessions from further up the catchment |
| Evaluating effectiveness of land management change: Stream monitoring is generally not suited to measuring the effectiveness of land management techniques practised for salinity control in regional systems. The scale of land use change required to affect stream-flow and salt loads is large, groundwater systems are strongly buffered against change, and the highly transmissive nature of the aquifers generally overrides treatments applied at a sub-regional scale |

| Unconfined sediments | Regional groundwater flow systems in this category occur mainly in the Mallee. This region lacks an integrated drainage network; consequently, stream monitoring is inappropriate |

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An Evaluation Framework for Dryland Salinity

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### 3.2.3. Specifications for mapping land salinisation

<table>
<thead>
<tr>
<th><strong>MAPPING LAND SALINISATION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td>Land salinisation occurs where soils and vegetation are degraded by the discharge of saline groundwater that begins to occur when groundwater reaches in 1 to 2 metres of the soil surface. At this point water is drawn up by capillary action and concentrated by evaporation so only the most salt-tolerant species survive. Ultimately, saline groundwater discharge kills most vegetation and salt tolerant volunteer species colonise the discharge site. Where high salinity groundwater discharges, soil structure is degraded and the surface soils are lost through erosion. Monitoring the expansion or contraction of salt affected land provides an effective tool for assessing changes in salinity status over time.</td>
</tr>
<tr>
<td><strong>Methods</strong></td>
</tr>
<tr>
<td><strong>Spot checks</strong>: Soil samples are collected from salt-affected and adjacent land at irregular intervals and analysed for their salt content</td>
</tr>
<tr>
<td><strong>Soil surveys</strong>: Soil samples are taken from at key locations along surveyed traverses across salt-affected land and analysed for their salt content</td>
</tr>
<tr>
<td><strong>EM surveys</strong>: Soil salinity is measured in the field with hand-held electromagnetic induction instruments. Surveys are conducted along surveyed traverses or a surveyed grid. Airborne electromagnetic survey offers rapid, accurate coverage of large areas with locations of salt stores and conduits to depths greater than 100m below ground surface</td>
</tr>
<tr>
<td><strong>Benchmarking</strong>: Soil sampling is conducted at grid intersections, electromagnetic readings are taken at the same sites, groundwater observation bores are established at key grid intersections</td>
</tr>
<tr>
<td><strong>Air photo interpretation</strong>: The expansion or contraction of salt affected over time is recorded by plotting visibly affected land on successive air photos</td>
</tr>
<tr>
<td><strong>Remote Sensing</strong>: Images are captured either from satellites or aircraft using several wavelengths and combined with other spatial information to map dryland salinity</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Most techniques are appropriate to most areas affected by salt affected lands</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>Generally repeated at five yearly intervals</td>
</tr>
</tbody>
</table>
## LAND SALINISATION - REPORTING

<table>
<thead>
<tr>
<th>Units of Measurement</th>
<th>Electrical conductivity of soils is usually measured on 1:5 soil water extracts or saturation extracts and the results reported in μS/cm or mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Tables, graphs and contoured plans</td>
</tr>
<tr>
<td>Data Sources</td>
<td>Custodians: most surveys are conducted by the State agencies that generally hold the data</td>
</tr>
<tr>
<td>Related Attributes</td>
<td>Elevation, groundwater levels, geomorphology</td>
</tr>
<tr>
<td>Interpretation</td>
<td>Interpretation of sophisticated imagery requires specialist skills. Soil salinity measurements are interpreted on the basis of electrical conductance measurements taken from soil-water extracts. The expansion or contraction of salt affected land is best viewed in conjunction with groundwater records from the same region, and with consideration of seasonal climatic variations.</td>
</tr>
</tbody>
</table>
## SUITABILITY OF LAND SALINISATION MAPPING FOR EVALUATING SALINITY IN AUSTRALIAN GROUNDWATER FLOW SYSTEMS

<table>
<thead>
<tr>
<th>All groundwater flow systems</th>
</tr>
</thead>
</table>
| **Recommended methods:** Applications will depend on the purpose of the survey and the resources available  
Soil surveys to monitor salt affected land can obviously be conducted throughout Australia irrespective of GFS  
As a general rule, remote sensing and satellite imagery will prove most useful in regional groundwater systems where soil salinity is extreme and in local, deeply weathered, high salt store landscapes where very saline groundwater produces similar extremes in land salinity. In contrast, direct measurements by airborne or ground EM can be applied everywhere  
Traditional techniques including field surveys and mapping may be a more efficient means of monitoring salinity in the local and intermediate fractured rock terrain of southeastern and eastern Australia  
**Problem definition:** soil surveys provide the best means of assessing soil salinity. Rapid surveys may be conducted by remote sensing, particularly through the use of satellite imagery and airphoto interpretation. Airborne electromagnetic surveys now offer very rapid, very precise assessment of salinity to depths of more than 100m below the surface  
**Evaluating effectiveness of land use change:** airphoto interpretation and other surface remote sensing methods will provide the best overview of the response of land salinisation to land use change. There are often difficulties with the technique, however, where a range of vegetation is found on salt-affected lands. The technique appears to be easier to apply in the southern and western parts of the continent where the expression of salinity is dramatic  
**Evaluating effectiveness of land management change:** soil surveys provide little information on the impact of land use practices on salinity. Most GFSs are strongly buffered against change because groundwaters are well elevated in the landscape above salt-affected lands. Long delays (in most instances) are expected between treatments and the amelioration of soil salinity
### 3.2.4. Specifications for mapping land cover and land cover change

#### MAPPING LAND COVER AND LAND COVER CHANGE

| Rationale | In southern Australia the area of land cleared of native vegetation is well correlated with the mass of salt exported in streams flowing from local and intermediate groundwater flow systems, so it can be assumed that revegetation of zones of groundwater recharge will ultimately lead to a reduction in stream salt loads. Equally, the introduction of crops that use more water — for example, perennial pastures — may lead to similar reductions in salt load. Estimates of changes in land cover are thus a useful indicator for forecasting salinity trends and setting parameters for models. They should, however, always be considered in the light of knowledge of the responsiveness of groundwater flow systems because there may be a long lag time between the change in land cover and salinity benefits. |
| Methods | **Satellite imagery:** satellite imagery provides the most efficient and effective method of assessing changes in land cover as they apply to re-vegetation of catchments with trees/native vegetation. It is also useful in assessing changes in land cover in terms of the introduction of perennial pastures, though experience in this area illustrate that timing of the analyses and ground truthing are critical in achieving useful outcomes.  

**Farm surveys:** farm surveys are variously conducted through techniques ranging from mail and phone surveys through to farm visits. Changes in vegetation are normally plotted on aerial photos or satellite images.  

**Australia census information:** acquisition of time series information relating to changes in land cover could be gathered through additional information collected under the Australian Population and Housing Census and the Australian Agricultural Census. The census information could be used to establish where change is taking place and the information could be subsequently documented using API or imagery. |
| Location | The location of mapping will depend on the objectives of management and evaluation activities. It will vary between whole catchment assessments (most suitably undertaken by remote sensing techniques) or more detailed benchmark studies (most suitably undertaken by more detailed farm studies).  

There currently exists a 25m resolution digital data set showing land cover for intensively used agricultural areas across Australia (1995). Detailed specifications for mapping land cover and land cover change (25m, 1:100 000) have been agreed with state agencies. Changes from 1990/91 to 1995 have been mapped for all States. Queensland and NSW subsequently mapped changes from 1995–97 and 1997–99. Victoria is currently implementing more detailed mapping (1:25 000) and the Northern Territory is to update the 1990-95 information. |
| Frequency | The frequency of analyses must depend on the extent of revegetation activities. Monitoring land cover in response to heightened investment in plantation forestry may call for repeat surveys at two-year intervals, while monitoring changes in land cover through changes in farm management might be more appropriately conducted at intervals of three to five years. |
| Duration | **Life of the salinity management plan:** changes in land cover are a direct indicator of effective implementation of land and water management plans and the potential for further action. From both perspectives, surveys should be continued throughout the life of the plan. |
## REPORTING OF LAND COVER MAPPING

<table>
<thead>
<tr>
<th>Units of Measurement</th>
<th>Hectares or percentage of land cover change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Maps and tables illustrating extent and location in relation to target areas</td>
</tr>
<tr>
<td>Data Sources</td>
<td>State and Federal agencies with responsibilities for agriculture, forestry and natural resources management; commercial suppliers of satellite imagery</td>
</tr>
</tbody>
</table>
| Related Attributes   | Changes in groundwater head under re-vegetated areas  
Groundwater flow systems in targeted areas  
Maps of high groundwater recharge areas in relation to targets |
| Interpretation       | Consideration of changes in land cover in the context of actual and potential salinity responses in the groundwater flow systems in the targeted areas |
**SUITABILITY OF LAND COVER MAPPING FOR EVALUATING SALINITY IN AUSTRALIAN GROUNDWATER FLOW SYSTEMS**

<table>
<thead>
<tr>
<th>All groundwater flow systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended methods:</strong> applications will depend on the purpose of the survey, the scale of the groundwater flow system and the resources available</td>
</tr>
<tr>
<td><strong>Problem definition:</strong> land cover mapping provides useful baseline information and contextual information for setting parameters for models of groundwater flow system responsiveness</td>
</tr>
<tr>
<td><strong>Evaluating implementation and evaluation of land use change:</strong> land cover mapping is an important measure of the implementation of land use change. It is ambiguous as an indicator of the effectiveness of land use change, particularly in the larger groundwater flow systems. Regional systems are too complex and poorly responsive for the technique to be appropriate as an alternative attribute for evaluating the effectiveness of salinity management</td>
</tr>
</tbody>
</table>
### 3.2.5. Specifications for characterising hydrogeology

#### ESSENTIAL HYDROGEOLOGICAL CHARACTERISTICS TO UNDERPIN EVALUATION ACTIVITIES

<table>
<thead>
<tr>
<th>Rationale</th>
<th>The hydrogeological characteristics of groundwater flow systems determine how the system will behave in response to climate and land use. Interpretation of groundwater trends and modelling groundwater behaviour calls for knowledge of the inherent properties of individual groundwater systems</th>
</tr>
</thead>
</table>
| Applications | (a) **Interpreting monitored data**: an understanding of the hydrogeological characteristics of the groundwater flow system is essential to making appropriate interpretations of monitored data  
(b) **Modelling**: hydrogeological characteristics are required to parameterise models of future catchment behaviour |
## ESSENTIAL HYDROGEOLOGICAL CHARACTERISTICS TO UNDERPIN EVALUATION ACTIVITIES (continued)

<table>
<thead>
<tr>
<th>Hydrogeological Characteristics</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aquifer hydraulic conductivity:</strong></td>
<td>a measure of the permeability for a unit of cross-sectional area of the material transmitting groundwater</td>
</tr>
<tr>
<td><strong>Units:</strong></td>
<td>metres/day</td>
</tr>
<tr>
<td><strong>Aquifer transmissivity:</strong></td>
<td>a measure of the potential for the aquifer to transmit groundwater. Calculated as the product of hydraulic conductivity and aquifer thickness</td>
</tr>
<tr>
<td><strong>Units:</strong></td>
<td>metres²/day</td>
</tr>
<tr>
<td><strong>Specific yield:</strong></td>
<td>specific yield is equivalent to the drainable porosity of the aquifer which has a direct influence on the extent to which water tables respond to climate and land use</td>
</tr>
<tr>
<td><strong>Units:</strong></td>
<td>Percentage</td>
</tr>
<tr>
<td><strong>Hydraulic gradient:</strong></td>
<td>the potential gradient driving groundwater flow through an aquifer from positions of high groundwater elevation to positions of lower groundwater elevation</td>
</tr>
<tr>
<td><strong>Units:</strong></td>
<td>dimensionless</td>
</tr>
<tr>
<td><strong>Confined/unconfined nature of the aquifer:</strong></td>
<td>the extent to which the aquifer and the groundwater it contains is confined/not by overlying materials of low permeability</td>
</tr>
<tr>
<td><strong>Spatial distribution of aquifers:</strong></td>
<td>the dimensions of the aquifer transmitting groundwater in relation to the catchment; for example, thickness, width, location</td>
</tr>
<tr>
<td><strong>Spatial distribution of recharge:</strong></td>
<td>the location of areas in the catchment where groundwater recharge occurs, extending to areas in which recharge is high and those areas where it is relatively low or moderate. Recharge distribution is usually assessed on the basis of soils and geomorphology</td>
</tr>
<tr>
<td><strong>Temporal distribution of recharge:</strong></td>
<td>the distribution of recharge through time. May include seasonal recharge, occurring in response to normal seasonal climatic conditions or episodic recharge occurring mainly in years of unusually high rainfall</td>
</tr>
<tr>
<td><strong>Form of groundwater discharge:</strong></td>
<td>the extent to which groundwater discharge into stream is derived from baseflow, where the aquifer discharges directly into the stream channel or wash-off where stream salinity is affected by salt derived from run-off from saline soils</td>
</tr>
<tr>
<td><strong>Salinity concentration:</strong></td>
<td>the typical salinity concentration of groundwaters in each aquifer of interest</td>
</tr>
<tr>
<td><strong>Units:</strong></td>
<td>commonly used international unit for electrical conductivity measurement and reporting is deci-Siemens per metre (dS/m). Micro-Siemens per centimetre (μS/cm), however, remains as a popular unit throughout Australia and this is often referred to as EC (units). One deci-Siemen per metre is equivalent to 1,000 micro-Siemens per centimetre</td>
</tr>
<tr>
<td><strong>Scale of groundwater flow:</strong></td>
<td>the extent of groundwater flow. <em>Local flow systems</em> occur over distances fewer than 5 kilometres. <em>Intermediate systems</em> occur over larger distances, up to 50 kilometres, and <em>regional systems</em> occur over distances in excess of 50 kilometres. Intermediate and regional systems may flow across surface catchment boundaries</td>
</tr>
</tbody>
</table>
3.2.6. Specifications for characterising soils

<table>
<thead>
<tr>
<th>ESSENTIAL HYDRAULIC PROPERTIES OF SOILS REQUIRED TO ASSESS THE PERFORMANCE OF GROUNDWATER RECHARGE IN RESPONSE TO CATCHMENT MANAGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td>The hydrological properties of soils and interactions involving climate and vegetation control the amount and timing of groundwater recharge. The interactions between soils, vegetation and climate can be numerically modelled to estimate the influence of biological management options on groundwater recharge and salinity mitigation. The process involves the application of models that simulate plant water use and estimate the hydrological balance in the soil zone. This requires an understanding of the properties of soils that influence their capacity to store rainfall, to interact with vegetation, and to allow percolation of water beyond the root zone. Usually there are several distinct, more or less horizontal layers (horizons) in the soil and the characteristics of each layer should be determined.</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
</tr>
<tr>
<td>Information about soil characteristics is required to develop conceptual models and parameterise numerical models of catchment behaviour</td>
</tr>
<tr>
<td><strong>Hydrological characteristics of soils</strong></td>
</tr>
<tr>
<td><strong>Soil thickness</strong>: the thickness of each soil layer, which determines the capacity of the soil to store and transmit water</td>
</tr>
<tr>
<td><strong>Soil texture</strong>: the particle size distribution of each soil layer, which determines the capacity of the soil to store and transmit water</td>
</tr>
<tr>
<td><strong>Bulk density</strong>: the bulk density of each soil layer, which relates to porosity and the capacity to store water in the soil</td>
</tr>
<tr>
<td><strong>Saturated water holding capacity</strong>: the volume of water at saturation</td>
</tr>
<tr>
<td><strong>Soil water holding capacity — drained upper limit</strong>: the volume of water retained immediately after drainage has ceased following saturation</td>
</tr>
<tr>
<td><strong>Soil water holding capacity — lower limit</strong>: the volume of water retained when the soil has been dried by evapo-transpiration</td>
</tr>
<tr>
<td><strong>Slope of the water retention curve</strong>: relationship that allows the estimation of soil permeability over the range of potential water content</td>
</tr>
<tr>
<td><strong>Saturated hydraulic conductivity</strong>: the rate at which water will percolate through each soil layer under saturated conditions</td>
</tr>
<tr>
<td><strong>Seasonal changes in soil water</strong>: Time series information identifying soil water content beneath different treatments, as measured by tensiometers, neutron probes, soil sampling etc. The primary use of this information is in calibrating soil-water vegetation models</td>
</tr>
<tr>
<td><strong>Time series groundwater heads</strong>: soil-water-vegetation models often overestimate groundwater recharge. They are also prone to compound errors because of the difficulties in estimating relatively small recharge values from a range of complex variables that comprise the water balance. Therefore, they should be calibrated against estimates of recharge from other sources. In most instances, estimates from groundwater fluctuations measured over time provide the most acceptable calibration</td>
</tr>
</tbody>
</table>
# 3.2.7. Specifications for characterising climate

<table>
<thead>
<tr>
<th>MONITORING CLIMATIC CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td>Climate interacts with soils and vegetation in determining whether rainfall will run off, recharge an aquifer, or return to the atmosphere through evaporation or transpiration. Climatic conditions govern the magnitude and the spatial and temporal distribution of groundwater recharge</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
</tr>
<tr>
<td>Climatic data are fundamental to interpretations of groundwater and surface water trends, and to setting parameters for numerical models of catchment processes</td>
</tr>
<tr>
<td><strong>Climatic characteristics</strong></td>
</tr>
<tr>
<td><strong>Precipitation</strong>: measurement of the rainfall equivalent at a given point in a given period, expressed in mm/year, mm/month and so on</td>
</tr>
<tr>
<td><strong>Evaporation</strong>: measurement of the depth of water evaporated from a point in a given period. Evaporation pan measurements should be adjusted using an appropriate coefficient to more closely approximate to water use by the vegetation/crop of interest. Usually expressed in mm/time period</td>
</tr>
<tr>
<td><strong>Uses</strong></td>
</tr>
<tr>
<td>(a) <strong>Interpreting monitored data</strong>: long-term climate climatic data (mainly rainfall and evaporation) are compared with long-term groundwater level and stream salinity fluctuations to ascertain the climatic conditions that cause groundwater recharge occur and rising groundwaters (seasonal, episodic, flood and so on). In turn this information focuses effort on understanding the conditions that must be managed to avoid or lessen groundwater recharge</td>
</tr>
<tr>
<td>(b) <strong>Modelling</strong>: a combined monitoring and modelling approach can be applied to inform assessments of the effectiveness of particular treatment. Under these circumstances, a range of climatic data including rainfall, evaporation and wind speed may be collected for use in numerical computer-based soil-water vegetation models that simulate the water balance</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Long term precipitation and evaporation records suitable for correlation with records of groundwater fluctuations are usually available for the region of concern from the Bureau of Meteorology. Instrumentation is established on-site to monitor detailed climatic conditions in a region where a salinity management option is being implemented and evaluated</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>Monthly rainfall and evaporation data usually suffice for correlation with long term groundwater trends, although daily data may be required for interpreting processes in systems driven by episodic rainfall events. Climatic data may be required at daily or hourly intervals to run some soil-water-vegetation models</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
</tr>
<tr>
<td>Ideally, 10 to 20 years of rainfall information and similar long-term groundwater records should be available to establish the climatic conditions under which groundwater rises in response to climatic conditions. The length of record is particularly important when recharge is suspected to occur through infrequent episodes of unusually high seasonal rainfall. On-site measurements of sufficient duration to adequately calibrate models of the performance of the salinity management option</td>
</tr>
</tbody>
</table>
## MONITORING OF CLIMATIC CHARACTERISTICS

<table>
<thead>
<tr>
<th>Units of measurement</th>
<th>Rainfall and evaporation (millimetres)</th>
</tr>
</thead>
</table>
| **Presentation**     | Graphs illustrating average monthly rainfall and evaporation  
                        Databases of climatic data recorded from site |
| **Data sources**     | Bureau of Meteorology  
                        State and Federal R&D agencies (land and water) |
| **Related attributes** | Long-term groundwater level fluctuations |
| **Interpretation**   | Simple comparative analyses relating rainfall trends to changes in groundwater elevation  
                        Incorporation of climatic data in complex numerical models describing interactions between climate-vegetation-soils and groundwater recharge |
| **Technical references** | Nothing specific for salinity, but information can be obtained on the Bureau of Meteorology’s web site at [www.bom.gov.au](http://www.bom.gov.au) |
### Digital Elevation Models (DEMs) for Planning Salinity Management in Catchments

#### Rationale

**Digital Elevation Models (DEMs):** DEMs are constructed from elevation data and used in Geographic Information Systems to describe the three-dimensional shape of the land surface. Their digital nature allows the incorporation of slope classes with other digitised spatial information such as soils, geology, landform and vegetation in the analyses of landscape/salinity process.

#### Applications

**Groundwater Flow Systems:** DEMs are used to spatially define groundwater flow regimes based on the intersection of slope classes with geological and geomorphic factors that influence groundwater behaviour. They are also fundamental datasets for setting parameters for numerical models of catchment processes.

- **Identifying recharge areas:** DEMs may be useful at sub-catchment scales in defining zones where groundwater recharge is high. This is generally most applicable in upland terrain where the steeper slopes define the outcrop of local or intermediate fractured rock aquifers.

- **Identifying actual/potential discharge areas:** where the shape of the groundwater surface can be defined relative to the elevation of the land surface, DEMs can be utilised to define areas of groundwater discharge or potential groundwater discharge. Attempts have been made to extend the DEM approach to estimating salinity risk by considering the conversion of groundwater surfaces and land surfaces over time, based on trends established from groundwater hydrographs.

- **Catchment/farm scale planning:** the spatial distribution of soils and landscapes across catchments and farms often varies according to the relief and slope of land surfaces. In turn, the intersection of these factors defines the hydrogeological conditions that drive salinity at regional and sub-regional scales. The DEM provides a means of rapid landscape analyses for catchment planning and priority setting at farm/paddock scales.

#### Scales

DEMs are constructed from latitude, longitude and elevation data derived from interpolation of points of known elevation. The resolution of a digital elevation model is a reflection of the extent and accuracy of the elevation data from which it is derived.

#### Sources

State and federal agencies with responsibilities for the management of natural resources remain the main custodians of regional DEMs.
### 3.3. Specifications for monitoring alternative attributes

#### Monitoring Alternative Attributes – Measurement

<table>
<thead>
<tr>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity management can never be effective unless it is practised on a scale that is significant in terms of the scale of the catchment in which it is applied, and the nature of the component groundwater flow systems. This will be the case irrespective of whether the priority actions relate to recharge reduction, engineering intervention or adapting to increasing levels of salinity. Significant public and private investment in catchment-based salinity management therefore calls for monitoring to account for the achievement of a meaningful scale of implementation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benchmarking:</strong> this is a matter of establishing current land use and management as the basis for comparing progress toward the land use required to achieve the desired salinity outcomes.</td>
</tr>
<tr>
<td><strong>Satellite imagery:</strong> where a catchment salinity strategy calls for significant vegetation change and there are targets to be achieved in a given timeframe, progress toward those targets may be measured through interpretation of satellite imagery.</td>
</tr>
<tr>
<td><strong>Farm surveys:</strong> where the activity to be monitored cannot be resolved through remote sensing, changes in land use may need to be monitored through farm/landholder surveys. These would usually be conducted by sampling landholders and properties either by mail-out, telephone or personal interview.</td>
</tr>
<tr>
<td><strong>Australia Census Information:</strong> acquisition of time series information on structural adjustment and regional land use through additional survey information collected under the Australian Population and Housing Census and the Australian Agricultural Census.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>In each groundwater flow system (GFS) National/catchment Census: Census information needs to be geo-coded in order to relate to catchments and GFS boundaries.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveys will normally be repeated at intervals of three to five years.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveys will normally be repeated for the duration of the land and water management plan. In most instances this will require a commitment that extends over at least 30 years.</td>
</tr>
</tbody>
</table>
## MONITORING ALTERNATIVE ATTRIBUTES - REPORTING

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Hectares of treatments adopted, number of engineering works completed, numbers of saline industries developed Changes in land use, property size, landholder age, agricultural production, forestry/farm forestry, industry base and so on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Rates of adoption of management practices should be expressed as a percentage of the area of the catchment to be treated, and comparisons with the desired progress as stipulated under a catchment salinity strategy Maps, graphics and so on should be used to display trends in social and economic circumstances that both reflect and influence rates of adoption of salinity management practices</td>
</tr>
<tr>
<td>Data sources</td>
<td>State agencies, Australian Bureau of Agriculture and Resource Economics</td>
</tr>
<tr>
<td>Related attributes</td>
<td>Biophysical data that allow the establishment of links or potential links between rates of adoption of implementation strategies with consequent salinity benefits.</td>
</tr>
<tr>
<td>Interpretation</td>
<td>Assessment of the rates of adoption of regional catchment salinity strategies interpreted in the context of the social and economic drivers that govern change, together with an analysis of the implications for salinity management in each GFS and the implication for achievement of salinity targets</td>
</tr>
<tr>
<td>Capacity and implementation</td>
<td>The national capacity to monitor the biophysical aspects of the implementation of salinity management strategies is adequate in that the technology is proven, the techniques are well established and skilled operators are available The same is generally true for assessment of the social and economic factors that relate to salinity management; however, monitoring could be radically improved through additional information being recorded in the Australian Agricultural Census and the Australian Population and Housing Census</td>
</tr>
</tbody>
</table>
4. Conclusions and recommendations

4.1. Conclusions

1. Knowledge generation and performance evaluation are essential activities in dryland salinity management strategies. Chapter 1 elaborates a framework for a systematic approach to decision making. Such an approach consists of a logical and iterative progression through problem definition, knowledge generation, policy formulation, implementation and evaluation.

2. The range of physical processes causing dryland salinity across the continent has led to significant variations in the manifestation of salinity, in the scale of effective management activities and in the timeframes for developing and remediating the problem. The particular characteristics of a given region should be fundamental considerations for the design of management activities and evaluation systems. Groundwater flow systems frameworks at an appropriate scale can help identify appropriate evaluation activities. They are also a good basis for extrapolations from benchmark sites to similar catchments.

3. The importance of evaluation activities in dryland salinity management is well recognised, but recent studies have identified:
   - inadequacies in the available data;
   - shortfalls in our abilities to accurately map the current extent and impacts of dryland salinity;
   - shortfalls in our ability to model future extent and impacts under current and alternative management options;
   - limited capacity to collect, manage and interpret data; and
   - a need for consistency of approaches between different regions so data can be aggregated from local scales to regional scales.

If management decisions are to be informed by appropriate knowledge, investment in the data, tools and qualified personnel are needed to address these shortfalls. This should be undertaken as part of a systematic evaluation program.

4. Evaluation programs should provide the information necessary to underpin systematic decision-making. The objectives should be:
   - to define baselines of the extent/severity/impacts of dryland salinity;
   - to measure changes in extent/severity/impacts;
   - to predict the likely future extent/severity/impact;
   - to refine understanding of the processes causing dryland salinity;
   - to judge the most appropriate management options for delivering changes to catchment water balances and the likely time frames over which these might be achieved;
   - to measure how well the proposed management activities have been implemented; and
   - to measure the effectiveness of previous management activities.
5. The approaches and attributes used for evaluation will vary according to the objectives of management, and according to the physical characteristics of the region and the scale at which the objectives need to be achieved. The attributes being monitored should be clearly identified in a framework of explicit management objectives:

- monitoring of groundwater level trends can be used to define current rates of change, to generate knowledge about processes controlling dryland salinity and to assess the effectiveness of management activities;
- monitoring of surface water salinity concentrations and salt loads can be used to define current rates of change, to generate knowledge about processes controlling dryland salinity and to assess the effectiveness of management activities;
- mapping of the extent of land salinisation provides information to define the problem and serves as a baseline against which changes can be measured;
- mapping of changes in land use or land cover provides a context for defining the problem and can also be a direct measure (depending on the management option) of the implementation of management activities; and
- hydrogeological and soil characteristics of groundwater flow systems, climatic characteristics, and digital elevation models provide a context for interpreting trends, assessing the effectiveness of management strategies, and setting parameters for scenario modelling.

Alternative attributes may also be necessary for assessing the implementation of management activities and where the recommended attributes are not available in management timeframes.

4.2. Recommendations

Decision-making under the National Action Plan for Salinity and Water Quality and the MDBC catchment planning process should:

1. Include evaluation activities as a fundamental and properly resourced component of any dryland salinity management plan. This will ensure that:
   - management change is underpinned by knowledge;
   - targets and standards for dryland salinity management are based on good science; and
   - the performance of management activities is evaluated against these targets and standards.

2. Design systems for evaluating dryland salinity to accommodate the range of physical processes causing dryland salinity, according to the understanding of the groundwater flow systems identified at an appropriate scale.
   - Include detailed studies of representative areas as benchmarks for improving understanding of the processes causing dryland salinity, and for reviewing the effectiveness of management.
   - Extrapolate the implications of evaluation of benchmark catchments to similar catchments using an appropriately scaled groundwater flow systems framework in a climatic and land use context. The Framework developed in Chapter 3 provides a basis for this evaluation. It may be adapted to the circumstances of different regions and groundwater flow systems.

3. Invest in upgrading our mapping, monitoring and modelling capacity. Specifically this should include:
- data for a number of regions to make repeatable assessments of the current extent and areas at risk of land salinisation at catchment scales;
- data to parameterise and calibrate models of areas currently at risk of salinisation and areas likely to be at risk in the future;
- data to parameterise and calibrate models of the effectiveness and timeframes of management options;
- tools to make definitive assessments of areas at risk;
- tools to predict the magnitude of rises in salinity concentrations and/or salt loads;
- tools to assess the likely timeframes and effectiveness of different management options at a catchment scale; and
- qualified personnel to undertake modelling.

Ensure consistency of approaches in different regions so data can be aggregated from local scales to regional, State and national scales through:
- adopting common specifications for monitoring activities; and
- the use of a groundwater flow systems approach at an appropriate scale to allow comparison of similar areas.

Assign the role of managing monitoring data and periodically reporting on the status of salinity and salinity risk throughout Australia to a national organisation. This organisation will require appropriate resources to support the States in sustaining a national approach to dryland salinity monitoring.

4. Make explicit the objectives of dryland salinity evaluation programs:
- to define baselines of the extent/severity/impacts of dryland salinity;
- to measure changes in extent/severity/impacts of dryland salinity;
- to enable predictions of the likely future extent/severity/impact of dryland salinity;
- to refine understanding of the processes causing dryland salinity;
- to provide data for predictions of the most appropriate management options for delivering changes to catchment water balances and the likely time frames over which these might be achieved;
- to measure how well proposed management activities been implemented; and
- to measure the effectiveness of previous management activities.

5. Use the following attributes to inform evaluation of dryland salinity wherever possible:
- groundwater levels;
- surface water salinity concentrations and salt loads;
- mapped extent of soil salinity; and
- mapped land cover/land use.

Ensure that data interpretation and modelling of systems responses are undertaken in the context of other core datasets such as hydrogeological, soil and climate characteristics, and good digital elevation models.

Augment the set of recommended attributes with alternative attributes only when the recommended attributes are not available in planning timeframes.
Appendix A: Biophysical considerations for designing monitoring systems and interpreting monitoring data

Conceptual model of biophysical processes causing dryland salinity

Groundwater recharge
Recharge is the amount of water that reaches the groundwater system. In the context of dryland salinity it is usually the amount of leakage that passes below the root zone of vegetation. The amount of water that recharges groundwater systems depends on a variety of factors including climate, soil and subsoil, and vegetation characteristics.

There are two main types of recharge. ‘Seasonal’ recharge is where rainfall exceeds potential evaporation for a period of the year (usually in wetter areas) and ‘episodic’ recharge is where exceptional circumstances result in large amounts of rainfall over shorter periods but only very infrequently — once every three to 20 years (usually in dry environments). Understanding which process is primarily responsible for recharging the groundwater systems is critical to designing evaluation systems for dryland salinity.

Recharge is generally potentially possible over the full surface extent of an aquifer (except where the hydraulic gradients are upward towards the surface), though it will be greatest in areas where the sub-subsurface material has high permeability and/or the effective rainfall is greatest. In some cases recharge can also occur directly from surface water bodies such as lakes and rivers.

Monitoring systems should aim to characterise the response of the groundwater system to recharge events. The design of monitoring programs must therefore take into consideration the climatic characteristics of the region influencing recharge events; in particular, the distribution of rainfall with respect to evaporation as well as the total volume of rainfall. The location of monitoring sites should include those that will best enable characterisation of the groundwater system's response to recharge events: immediately down-gradient of known high recharge zones, and of average recharge zones if these are more characteristic of the groundwater flow system.

Groundwater discharge
Groundwater discharge is the water that leaves the groundwater system to the soil or surface water systems. This occurs where groundwater flow is reduced by changes in the types or dimensions of aquifer material. Where saline groundwater reaches the surface it results in land salinisation and/or increased salinity of surface waters.

Land salinisation
Soil salinity generally occurs through the direct discharge of saline groundwater to the soil surface, or where groundwater reaches in 1-2 meters of the land surface and is drawn up by capillary action. The severity of degradation is strongly governed by the relationship between the salinity of the discharging groundwater, and the climate in which it occurs. The physical relief of the discharge zone and the volume of discharging groundwater govern the size and dimensions of degradation.
**Surface water salinisation**

Surface water salinisation can occur through two processes:

- ‘baseflow’, or direct groundwater discharge can occur as the result of seepage through the streambed. This is most common where the stream has incised into an underlying aquifer; and
- ‘washoff’ salt can also accumulate on the land surface in areas of high water tables as soil salinity and be washed off into adjacent streams via overland flow.

At the catchment or groundwater flow system scale both processes will contribute salt to a stream in varying proportions: one may dominate at the individual tributary scale. The time scales of both processes will be related to the size of the stream. In a smaller stream it is more likely they will occur over shorter time frames; at the smallest level they may only be observable at hourly intervals. The frequency of data collection is thus very important if a monitoring system is to be designed to identify the mode of origin of salt in a stream.

Monitoring systems should aim to detect changes in the volumes and salinity concentrations of discharging groundwater to land or surface waters, as well as the effects of groundwater discharge. This will mean their design should take into consideration the likely time scales of changes, the likely magnitude of these changes and whether soil salinisation and/or stream salinisation resulting from baseflow and/or wash-off are likely to result from the changes.

The locations of monitoring sites should reflect the locations at which groundwater discharge is likely to occur now or in the future: at points in the groundwater flow system where there are changes in the structural characteristics of the aquifer material or in the topography of the catchment.

**Hydrological equilibrium**

Hydrological equilibrium refers to the balance between the amount of water flowing into and out of the groundwater system. Under constant recharge conditions a balance is maintained between the inflow and outflow volumes; however, if these conditions change (for example, from land use change or climatic variability) the balance is perturbed, resulting in changing groundwater pressures and discharge rates. Once the system has equilibrated to the new recharge regime the groundwater pressures and discharge volumes will stabilise in balance with the inflow volumes. The period for this new state to be attained is termed the equilibrium response time, and varies with the characteristics of the groundwater flow systems. In local, transmissive groundwater flow systems it may be in the order of decades, but up to hundreds of years for less responsive, regional flow systems.

The concept of hydrological equilibrium is important for designing management and monitoring systems because we ideally need to know how close the system is to reaching a new equilibrium before setting management objectives and monitoring attributes. If the system is close to equilibrating, management objectives and monitoring attributes can be identified on the basis of a more or less stable salinity situation with a given level of degradation; however, if the system is tens or hundreds of years away from equilibrating, the extent and impacts of dryland salinity are likely to worsen considerably over that period, with major implications for feasible management objectives and appropriate monitoring approaches.

In larger, slower groundwater flow systems (regional and less responsive intermediate systems), monitoring should aim to discern changes in groundwater pressures and salinity levels along the groundwater flow line, since it may be some decades before these become evident at discharge zones. Monitoring systems design must therefore take into account the scale and responsiveness of the groundwater flow systems contributing to dryland salinity...
and the likely time scales of change. The locations of monitoring sites should be regularly spaced along the groundwater flow system but ideally include points where these changes are likely to be most evident in the timeframes of a management planning cycle. This will require an understanding of the likely future behaviour of the system to probable land uses, based on predictive modelling.

**Interpreting groundwater level trends**

Simply establishing rising, falling, or stable groundwater trends from observation bores in a particular region only provides the very broadest indication of the status of salinity. Groundwater observations need to be recorded at critical points in the landscape before judgments can be made with any real sense of confidence. These critical positions vary according to the nature of groundwater flow, as defined by the regional geological and geomorphic character. The design of a monitoring system for a large regional alluvial aquifer system in the Riverine Plains of the Murray-Darling Basin in eastern Australia will be quite different from that required for monitoring local groundwater flow systems in deeply weathered granitic terrain in the small catchments in the southwest of Western Australia. The scale at which groundwater operates in these systems is very different, as are the individual groundwater flow processes. To effectively monitor salinity status with and without intervention we must first understand the groundwater processes operating in the landscape at local and regional scales.

The simple conceptual model of groundwater behaviour discussed in Chapter 2 provides the basis for designing the elements of a groundwater monitoring program that is capable of accurately reporting the status of salinity in the catchment over time. Groundwater observation bores should commonly be established in obvious or suspected recharge areas, mid catchment break of slope regions and in or adjacent to groundwater discharge zones. Additional monitoring bores should also be included upgradient of sites where groundwater flow is interrupted as a consequence of geological structures or changes in catchment morphology.

Sets of screened bores (nested piezometers) should be installed at a range of depths rather than installing open groundwater observation bores, to establish pressures at a range of depths in different aquifers along the flow paths. It is also important to ensure that the major aquifer(s) contributing to dryland salinity are monitored where there is more than one aquifer.

At a broad level, this conceptual model is common to all groundwater flow systems, so there are similar monitoring requirements of groundwater flow systems of a similar scale and undergoing similar management strategies.

**Local groundwater flow systems**

Groundwater observation bores should be established in each of the main points described above, along a major groundwater flow line. The scale of the groundwater flow system will mean the observation bores are likely to be spaced no more than a kilometre apart.

**Intermediate groundwater flow systems**

The same general conceptual model applies to intermediate groundwater flow systems, particularly in larger catchments comprising little more than very large local flow systems, where groundwater flows occur over larger distances but recharge still occurs on the slopes and crests of the catchment and groundwater discharge still occurs in the adjacent valley floor.

However, some intermediate flow systems are more complex than just large local groundwater flow catchments; for example, the landscape, may be moderately permeable to depths of 50 metres or more, allowing considerable opportunity for groundwater flow to
occur across catchment boundaries, particularly where the terrain is of lower relief. This is particularly apparent in the fractured rock systems common in the uplands of eastern Australia, especially where faulting and shear zones provide enhanced capacity for inter-catchment groundwater transfers.

In intermediate groundwater flow systems, observation bores should be established in the same points of the landscape as in the local groundwater flow systems, but are likely to need to be up to tens of kilometres apart. In the more complex intermediate systems where intercatchment flow occurs, groundwater monitoring should also include additional observation bores in locations where inter-catchment groundwater flows are expected.

**Regional groundwater flow systems**
Regional groundwater flow systems function over very large distances, generally on the scale of hundreds of kilometres. Groundwater flow usually occurs through highly permeable regional aquifers operating at the scale of large river basins. The principles of monitoring regional flow systems remain somewhat the same as in intermediate and local systems, except that the scales are very different and there are likely to be complexities caused by interactions between different aquifers. In regional groundwater flow systems, observation bores should be established in the same points of the landscape as in the intermediate groundwater flow systems but are likely to need to be more than 10 to 20 kilometres apart.

**Factors influencing the elevation of groundwater over time**
Before considering the design characteristics for monitoring salinity with Australian groundwater flow systems there is a need for a broader view of the range of conditions that generally cause groundwaters to rise or fall, or perhaps remain at the same level in landscapes.

**Rising groundwater trends**

**In response to seasonal groundwater recharge**
A rising trend in groundwater elevation over several years may occur as a consequence of many hydrological circumstances. Perhaps the most common of these is the rise that occurs in response to an increase in seasonal groundwater recharge following changes in land use. This most common land use change leading to salinity occurs where native vegetation is removed and land is developed for agriculture. Lower water use by introduced vegetation causes a higher incidence of groundwater recharge in response to seasonal rainfall. Changes in land use therefore cause filling of aquifers and groundwater rises in the landscape, albeit modulated by seasonal climatic fluctuations.

**In response to episodic events**
Groundwaters often rise in response to years of above average annual rainfall. This ‘episodic’ rise is most significant where seasonal rainfall is low and in regions where annual rainfall is summer dominant or occurs uniformly throughout the year. Under these circumstances the normal seasonal water budget may not allow for significant groundwater recharge.

In regions where the rising groundwaters are caused by episodic recharge groundwater trends are often not evident in the intervening years. Distinct rises in groundwater elevation leading to salinity may only occur once in every 10 years or more, in a ‘step-like’ fashion in response to particularly high rainfall events.
Event based recharge may also in occur response to severe flooding, where the landscape is inundated for extended periods.

Event based recharge leading to considerable filling of the aquifer over a short time is not exclusive to lower rainfall or summer dominant rainfall regimes. It may also occur in regions experiencing seasonal recharge in areas of moderate to high seasonal rainfall, overprinting a dramatic rises in otherwise seasonally rising trends.

**In response to several years of higher annual rainfall**
Groundwaters often rise quite rapidly in response to a succession of high rainfall years. Under these circumstances groundwater levels have little opportunity to recede to the level prior to the rise caused by the current and subsequent seasonal rainfall. It is therefore wise to look at data from bores that have the longest records, to establish background trends before attempting to attribute groundwater behaviour to some form of intervention. As a general rule a minimum of five or preferably 10 years’ information is needed for reasonable assessments.

**In response to leakage from rivers and other water bodies**
Rising groundwaters are not driven exclusively by seasonal or event based recharge caused by reduced evapo-transpiration following clearing. Changes in the water budget of rivers, reservoirs and wetlands also cause greater leakage and commonly rising groundwater.
Close proximity to major irrigation areas may also cause rising groundwater trends as the groundwater mound that most commonly develops beneath irrigated lands expands laterally into adjacent dryland terrain.

**Falling trends**
Falling groundwater trends may indicate a lessening of salinity risk, but just as there are a number of factors that can cause groundwater to rise, there are several factors that can cause groundwater heads to decline.

**In response to changed land management**
Just as increased groundwater recharge caused by a decrease in biological water use in response to land management change may lead to rising groundwater, increased biological water caused by high water using vegetation may reduce groundwater recharge and falling groundwater.
Typically these trends have been measured where land is re-forested, or where higher water using perennial vegetation such as lucerne pastures are deployed in favourable hydrogeological circumstances.

**In response to several years of lower annual rainfall**
Declining groundwater trends may also occur where successive years of lower than average seasonal rainfall effect low recharge. The rate of decline and its significance again depend on the hydrogeological character of the landscape.
In response to groundwater pumping
Under some circumstances prolonged groundwater pumping may bring about a decline in groundwater heads over time. We must therefore be cautious in interpreting falling trends in the vicinity of pumped groundwater bores, particularly where production bores draw large volumes of groundwater from regional aquifers, as the draw-down from the pumping operation may extend for considerable distances.

Post episodic recharge events
Falling groundwater trends in more arid regions or perhaps more summer dominant rainfall climates should also be viewed with a level of caution. A falling groundwater trend may in fact represent the recession of groundwater in the years following a particularly high rainfall/recharge year, or several years of high rainfall/recharge. Care should always be taken to establish regional trends before attributing changes in groundwater elevation to some form of treatment or intervention.

Groundwater heads remain constant over time
Where the elevation of groundwater in the landscape appears not to change over time other than in response to seasonal conditions, an equilibrium between groundwater recharge and groundwater discharge may be indicated; that is, a new balance has been established where the volume of groundwater discharge is now equal to the volume of groundwater recharge, and the average hydrological condition is one in which groundwaters neither rise nor fall in the medium to long term.

Equilibrium between groundwater recharge and discharge is a common phenomenon in salt affected catchments, particularly smaller catchments with less storage capacity. It is important to acknowledge this when planning monitoring bores. The results from two adjacent catchments may vary considerably according to the presence or absence of groundwater discharge consistent with attainment of or progress toward hydrological equilibrium.

Ideally, the status of regional salinity should be assessed by monitoring a mix of salt affected catchments and catchments that are not yet seriously affected by salinity.

Where groundwater heads appear not to be changing over time we must also take care in interpreting a general condition of hydrological equilibriums. Again, upward trends may only occur in response to episodic events involving seasons of unusually high rainfall and the dynamics of the groundwater flow regime may be heavily buffered against change in the intervening years, even where these extend over a decade or more.

Interpreting stream salinity trends
Surface water salinity concentrations and salt loads provide information about the impacts of dryland salinity, changes in the volumes of discharging groundwater to surface water bodies and the amount of salt being exported from the catchment.

Local groundwater flow systems
In most instances, monitoring of surface water flows and salt loads in local groundwater flow systems is only appropriate at the outlet of the catchment.

In these small systems surface water flows and salinity concentrations are governed almost entirely by short-term runoff events in response to daily, and in many instances hourly rainfall events. Where salt loads are caused by wash-off, measuring the mass of salt exported
from the catchment requires technology capable of continuous measurements of salinity and surface water flow over very short periods. The same technology must equally be capable of withstanding long periods in which there is little or no flow. Where salt loads are sustained by ‘baseflow’ processes, additional challenges occur as a result of needing to accurately measure higher salinity concentrations at low flows, yet equally to account for high volume, low salinity responses to rapid runoff.

**Intermediate groundwater flow systems**

The choice of sites should include sites near the outlet of the catchment to characterise the total salt load for the stream. They should also include sites above and below obvious groundwater discharge zones to establish their relative contributions to total salt flow and to determine the significance of those parts of the catchments they represent. Where surface water salinity concentrations and salt loads are influenced by inter-catchment groundwater flows, the location of monitoring sites also needs to aim to characterise the relative contribution of groundwater from intra- and inter-catchment flow.

Monitoring the effect of individual treatments using salt loads is usually not a viable option because of the background noise coming from third- or fourth-order tributary streams and because of the length of record required to ascertain the effect of the treatment. This is particularly the case where the treatment has an impact on surface water yield as well as groundwater recharge.

**Regional groundwater flow systems**

The usefulness of stream monitoring in regional systems is more questionable in comparison to local or intermediate flow systems. This is because the impacts of salinity usually occur in the down-basin regions of the catchment, but rivers in the lower basin reflect the integration of all of the salinity generating mechanisms throughout the river basin. They are also very strongly buffered by the integrated effects of contributing surface water flows. Monitoring rivers in the lower river basin is of limited value in assessing the impact of salinity management strategies on regional groundwater flow systems in the short to medium term, though it remains a very worthwhile activity in terms of knowing the relative contributions of rivers to regional salt loads. Any monitoring of processes in the regional groundwater flow systems should therefore focus on case studies of processes in individual sub-catchments.

**Flow and salinity variability**

Generally, both flow and salt concentration in streams and rivers is highly variable – more so in unregulated streams. The range of variation of flow may be several orders of magnitude between low flow and peak flow conditions (for example, from less than 1 ML/day to more than 10 000 ML/day). Salt concentration may vary by one order of magnitude (for instance, from around less than 200 mg/L to over 2000 mg/L).

It is now generally accepted that the changes in land use that have brought about the increases in recharge have also been responsible for an increase in run-off. Much evidence exists to show that smaller tributaries have changed from ephemeral to perennial streams.

The magnitude of the change in both stream salt concentration and flow, however, is very small compared with the natural variation due to changing climatic conditions, between seasons and over decadal Southern Oscillation Index-type timeframes.

Our ability to be able to discern trends due to land use changes as opposed to climatic changes using short periods of data is very limited. Usual practice suggests that land use change trends may only be discernible with about 20 to 25 years of data. For instance, the Murray-Darling Basin Salinity Management Strategy is likely to adopt a 25-year benchmark period for stream flow and salinity records as the length of record that is likely to capture the natural variability of the system.
Some studies have shown non-linear trends in salt load or salinity over short periods. In some instances these trends have been averaged as a linear trend and used in prediction models for future conditions. When longer data sets are used for the same streams, the non-linear trends originally observed have invariably changed. In some cases the trend has completely reversed.

**Correlation between flows and salt load**

Salt load (the mass of salt moving in the stream) is calculated by multiplying the volume of water flowing in the stream by the concentration of the salt. There is usually a high correlation between flow and salt load in most surface water systems in Australia (see Figure A.1). The relationship between salinity and flow is much less precise: usually the highest salinities are recorded during the lowest flows, and the lowest salinities during the highest flows. Most rivers/streams will converge towards a lower limit for salinity at the very highest flows, and this limit will be different for different systems. For instance, the Macquarie River has a lower salinity limit of around 100 mg/L even at peak flood flows of 80 000 ML/d (Figure A.2). This limit reflects the background salt contribution from a variety of sources in the catchment, over and above that derived from the salinisation process. Even in their undisturbed state, surface water systems carry measurable salt concentrations.
Figure A.1: Time series plots of flow, salt load and salinity for Macquarie River downstream of Burrendong Dam, Central NSW for 1998–2000. Note the high correlation between flow and salt load (data courtesy DLWC, NSW)
Figure A.2: Flow and salinity (upper) and flow and salt load (lower) relationship for the Macquarie River downstream of Burrendong Dam, Central NSW for 1998-2000. Note the large variation in flow compared with the variation in salinity. Salinity is generally highest at low flows and lowest at high flows, but this is not always the case. A range of salinity values has been recorded for any given flow rate. Note the high correlation between salt load and flow (data courtesy DLWC, NSW)
One measure of salt flux that has been used in a range of studies of salinity in Australia has been the concept of salt export rate (salt load per unit area of catchment). This flux rate is usually measured in either kg of salt/ha/year or tonnes of salt/km²/year. The export flux rate can also be compared with the influx rate of salt from rainfall. A useful measure that has also been reported is the ratio of export flux rate to rainfall influx – the salt output to input ratio for a catchment.

By its nature, the salt export flux rate is highly correlated with stream flow, as the flux rate is salt load divided by a constant.

Flux rates vary widely depending on the catchment, with values in the order of thousands of kg/ha/yr possible as instantaneous rates. Annual flux rates tend to be significantly lower, with rates between 100 and 600 kg/ha/yr common. Rainfall input is also highly variable, depending on the amount of rainfall and distance from the oceanic source of salt.

**Interpreting land salinisation/soil salinity mapping**

Mapping of the extent of soil salinity provides information about the impacts of dryland salinity as well as changes in the volumes of discharging groundwater to surface water bodies. The scope and techniques used to monitor land salinisation must take into account variations in the size, dimensions and severity of salinised land.

**Local groundwater flow systems**

In local groundwater flow systems salinity is most common in drainage depressions and at breaks of slope and accordingly it often appears as narrow elongate zones that are variously affected, ranging from barren exposed saline soil seeps to areas supporting a vast range of salt tolerant volunteer vegetation.

**Intermediate groundwater flow systems**

As in local groundwater flow systems the manifestation of soil salinity in intermediate groundwater flow systems varies considerably from system to system, largely in accordance with terrain and groundwater salinity. Soil salinity in the larger palaeo-channel systems in the Wheatbelt of Western Australia is extensive and extreme because of the emergence of very saline groundwater in otherwise low relief landscape. Soil salinity associated with intermediate fractured rock groundwater systems in the uplands of eastern Australia, however, takes a different form. There salinity tends to occur as large, elongate groundwater discharge zones associated with dissected valleys and drainage depressions; rather than the bare, salt encrusted land surfaces common to intermediate systems in Western Australia, saline discharge zones caused by the emergence of lower salinity groundwater are typically recognised by the presence of salt-tolerant volunteer species such as spiny rush (*Juncus acutis*) and sea barley grass (*Hordium marinum*).

**Regional groundwater flow systems**

Most regional groundwater systems experiencing dryland salinity occur over expansive regions in relatively low relief terrain, and the salinity concentrations of discharging groundwater is normally quite high. Dryland salinity under these circumstances is readily identifiable by the presence of salinas, degraded wetlands or large areas of barren saline soils, often with exposed saline subsoils.

**Designing mapping systems for land salinisation**

The techniques used for mapping land salinisation depend more on the physical characteristics of soil salinisation than on the scale of the flow system.
Soil salinity has several forms depending on how much salt accumulates in the soil. This in turn depends on the salinity of discharging groundwater, the climate and the texture of the affected soils. In some arid regions where very saline groundwater discharges, soil salinity is stark and extreme. In contrast, less saline groundwater discharge in more humid regions may cause dryland salinity that is much less obvious to the untrained eye.

Extreme dryland salinity leaves soils barren, supporting only isolated patches of the most salt tolerant plants including sea barley grass and samphire. Exposed saline subsoils dominate because vegetation that binds the soil together dies, salt depletes the soil structure and the topsoil is stripped from the land by wind erosion. In some places salt efflorescence may occur as white films on the soil surface, a sign that is usually from incidental sulfate salts rather than the main chloride salts that cause most of the damage.

Only the most salt-tolerant plants grow near very saline soils. Conventional agriculture usually will not survive unless water tables are deeper than about 1.8 to 2 metres. High salinity soils are the hardest to manage and contribute vast amounts of salts to rivers and streams in the catchments where they occur. Sites can export thousands of tonnes of salt annually to streams during seasonal runoff.

Not all salt-affected lands are easily recognised through barren and degraded soils. Many regions have low to moderate salinity discharges and moderate to high seasonal rainfall, so salt accumulation does not occur to the same extent as in more arid regions. The land is still affected by salinity, however; salt-tolerant volunteer plants prevail in the affected areas. Spiny rush and sea barley grass are found in the salt-affected hilly uplands of SA, Vic and NSW, and colonies of these and other tolerant plants identify saltlands.

In some soils only mildly affected by salinity there are few outward signs of plant stress. Closer inspection may reveal decline in pasture or crop productivity, stunted growth or lower than usual yields. More sensitive species such as white clover may be absent, while more tolerant strawberry and balansa clovers remain.

Soil salinity ranges between these extremes and varies with salt accumulation in the root zone of vegetation. Three classes of land are commonly recognised:

**Class 1** soil is only mildly affected
**Class 2** soil is affected by salinity, but supports salt tolerant volunteer plants
**Class 3** soil is badly affected and barren saltlands are clearly evident

Simple observations of plant species and soil productivity help rapid recognition and assessment of soil salinity, but sometimes the symptoms of soil salinity can be due to other factors. Dying trees may be suffering insect infestation, freshwater springs may be infested with spiny rush, pasture species’ productivity may fall because of poor soil nutrition, increasing soil acidity or other soil fertility issues.
Table A-1: Indicators for dryland salinity

<table>
<thead>
<tr>
<th>Soil salinity class</th>
<th>MDBC classification</th>
<th>Criteria</th>
<th>Common salt tolerant grass species for each class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not affected</td>
<td>Non-saline. Salt sensitive species present. No reduction in yield on pasture or crops</td>
<td>subterranean clover and other clover species present</td>
</tr>
<tr>
<td>1</td>
<td>Slightly affected</td>
<td>Incipient salinity. Productivity of pastures and crops noticeably affected. Crop species stunted. No bare patches or salt fluorescence. Approximate soil salinity EC 1-5 range is between 300 and 600 mS/cm</td>
<td>wallaby grass; wimmera rye-grass; sea barley grass; couch; Australian saltmarsh grass</td>
</tr>
<tr>
<td>2</td>
<td>Moderately affected</td>
<td>Salt tolerant species dominate the plant community. Some plant species show signs of stress. Salt stains are visible, and small areas (less than 1m²) are present. Soil salinity EC 1-5 range is between 600 and 1400 mS/cm</td>
<td>sea barley grass; Australian salt grass; tall wheat grass; slender barb grass; annual beard grass; windmill grass</td>
</tr>
<tr>
<td>3</td>
<td>Severely affected</td>
<td>Only highly salt tolerant species are left or ground is bare. Extensive areas of bare ground are present with fluorescence present. Trees are dying or dead. Approximate soil salinity EC 1-5 range is greater than 1400 mS/cm</td>
<td>club rush; bucks horn plantain; beaded glasswort; samphire; sea blite</td>
</tr>
</tbody>
</table>

Adapted from Allan (1996) Table 1 and the MDBC information sheet on Dryland Salinity.

1 Indicative list only

Soil salinity assessments need to consider:

**Location in the landscape:** for example, bare soils on or near a hill top or beside a tree may indicate sheep camps; spiny rush in a depression may be due to constant wet conditions.

**Sampling for salinity:** where there are reasonable doubts over the presence of salinity.

**Location in catchment terrain:** Salinity often occurs in common geomorphic locations in the same terrain type. Break-of-slope salinity is common in some landscapes, valley floor issues may be more common in others and some regions may have problems in broad depressions.

Other landscape information also needs to be taken into account as well as observing soils to assess the extent of soil salinity in a region.
The best assessments will consider:

- **the hydrogeological/biophysical setting** in which salinity occurs. Look for signs at the break of slope, valley floors, depressions, wetlands or other low points in the landscape;
- **periods of assessment and monitoring** when signs of soil salinity will be at their most evident, such as spring to early summer when changes in pasture vigour/stress are most evident;
- **soil sampling** to assess salinity in areas where incipient salinity is suspected; and
- **mapping** the signs of soil salinity

By collecting information on the location and changes in soil salinity over time we can understand the development of soil salinity, which will help us establish and adjust soil salinity management strategies.
Appendix B: Flow system characteristics for consideration in monitoring design

The following discussion describes the important characteristics of each groundwater flow system type from an evaluation perspective, although these are intended to be indicative only. The design of evaluation systems for catchments will require more detailed information about the physical characteristics of their groundwater flow systems than is provided here.

Local flow systems in fractured rocks
These groundwater flow systems are characterised by a large number of small, local flow systems correlating very closely with topographical catchments. Groundwater recharge occurs in all parts of the landscape and causes saline groundwater discharge to land and to streams, mainly where the hydraulic gradient reduces with slope and bedrock variation. Recharge occurs in phase with seasonal rainfall patterns and produces a distinctive filling and draining response in high areas; this response pattern is more attenuated lower in the landscape. The rocks are usually only superficially weathered, with groundwater flow generally converging on the down-slope regions. Ephemeral and perennial stream networks receive groundwater discharge as baseflow. Salt storage in the catchments is usually low, but the volumes of saline stream water exported from the system cause off-site impacts. Response times to changed groundwater conditions can be rapid (one or two decades), with equilibrium conditions taking significantly longer to establish.

The main issue for management and evaluation activities is the need to consider offsite impacts, whether these relate to the impact of increased vegetation on reducing runoff and thus increasing stream salinity concentrations or the impacts of extracted/drained groundwater on stream salinity concentrations.

Land extent
Land affected by salinisation is widespread, but individual occurrences are small. In some landscapes outbreaks appear random and, coupled with low salt stores, are closely linked with waterlogging. Outbreaks occur at break of slope, in drainage lines and on valley floors. Overall, only a minor part of the total landscape is likely to be salinised.

Stream salinity
Stream salinity is likely to be controlled by both washoff and baseflow processes. At issue in some of these landscapes is the large increase in salt flux rather than the absolute magnitude of the salt flux. All streams in the network will be affected, but more particularly second- and third-order streams.

Change in groundwater elevation
Groundwater elevation change due to increased recharge from land use change in these local flow systems is likely to be masked by climatic variation in the short term. Large amplitude hydrographs are likely in the recharge zones, with variation between seasons dominating. Long hydrographic records are required to observe trends that can be confidently correlated to increased recharge.

Climate
These landscapes can be found across a range of climatic zones, so care must be exercised in attributing the correct climatic model to the GFS and making any extrapolation of trends.
Local flow systems in deeply weathered rocks
These groundwater systems typically occur in ancient landscapes 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 evapo-transpiration. In these simple systems, groundwater recharge generally occurs on the slopes of catchments. Groundwater flow converges on the lower landscape, causing rising water tables 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, of the order of 20 years. Once full, however, 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 and monitoring are low permeability of the aquifers and relatively high groundwater salinity concentrations.

Land extent
Land salinisation occurs as individual break of slope seeps and valley floor discharge. High soil salinities in discharge sites can result from the high salt stores of these groundwater flow systems. Discharge is likely to be widespread but each seepage is small in extent.

Stream salinity
Groundwater discharge to streams is likely to be dominated by washoff processes. High salinities may result in some rivers; smaller second- and third-order streams may be the most affected.

Change in groundwater elevation
Groundwater elevation change will be controlled primarily by climatic inputs. Fluctuations in recharge areas are likely to be great and long records may be needed to demonstrate any trends due to increased recharge.

Climate
These landscapes tend to be in winter-dominated areas. Some regions may experience episodic recharge.
Local flow systems in deeply weathered fractured rocks

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 comprise the remnants of early Tertiary land surfaces that have been extensively and variably dissected and eroded. They typically comprise fractured rock aquifers exposed in the upper slopes and crests of the catchments, 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 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, and saline groundwater discharge typically causes extensive severe salinity.

The issues for managing and monitoring salinity in these systems are the low permeability of aquifers in the lower parts of catchments and 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 concentrations.

Land extent

Groundwater discharge is most likely to be visible at break of slope positions. In flatter terrains larger areas may be affected. Higher salt stores may cause more severe salinisation; it may be rare to see waterlogging alone.

Stream salinity

Washoff processes, except in regions where the stream network is more deeply incised, may affect stream salinity. All streams in the network will be affected.

Change in groundwater elevation

Groundwater elevation changes due to increased recharge may be hard to see in the short term. Observable trends may only be apparent when key sites (such as break of slope areas) in the flow system are monitored. Bore hydrographs will respond more closely with climatic fluctuations between seasons and across inter-decadal variations.

Climate

These flow systems can be found in a variety of climatic settings. In the more reliable rainfall regions, recharge will coincide with the main rainfall season. In more arid regions, rainfall and hence recharge will be more episodic.
Local flow systems in fine grained unconsolidated sediments

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 comprised of marine clay deposits in the Heytsbury/Barwon Downs region of southwestern Victoria. Local flow systems develop in the low permeability clays as a consequence of recharge on the slopes and crests of a catchment.

The main issue for managing and monitoring dryland salinity in these systems relates to the low permeability of the aquifers and thus their limited ability to drain enough to lower groundwater levels.

Land extent
Groundwater discharge occurs at breaks of slope or on adjacent valley floors.

Stream salinity
Washoff processes are most likely to affect stream salinity. The smaller streams in the drainage network will be most affected.

Change in groundwater elevation
Groundwater elevation change may be hard to see in these systems due to the low permeability of the aquifers and the variable nature of rainfall.

Climate
The main occurrence of these flow systems is in regions with winter dominant rainfall and hot, dry summers.
Local flow systems associated with sand dunes

This groundwater flow system type is developed in highly permeable sand dunes and is characterised by ephemeral perched groundwater flow in response to seasonal ‘filling up’, which discontinues once the system has drained of the seasonal pulse. This means the management timeframes for the system are relatively brief and that positive benefits from recharge control can be expected in years of their application. However, the highly permeable nature of the surface material and the episodic nature of recharge means salinity management and monitoring activities must be designed to accommodate considerable and highly variable volumes of water, and at other times through long periods with little moisture.

Land extent
Groundwater discharge occurs around the base of the sand dunes, with individual seepages small in area.

Stream salinity
Stream salinity is usually not compromised in these systems, as the landscape has little integrated surface water drainage.

Change in groundwater elevation
The recharge pulse may dominate groundwater elevation change in these landscapes during the rainfall season with associated drainage during the dry season. Observable trends of increasing groundwater level may not be visible, owing to the system’s significant drainage capacity.

Climate
Most sand dune flow systems are likely to be located in arid to semi-arid regions, with recharge mechanisms likely to be highly episodic in nature.
Local flow systems associated with colluvial fans

These groundwater systems typically occur where coarse colluvial slope wash material overlies massive, unjointed bedrock. This leads to a contrast in hydraulic conductivity between the permeable slopewash and the relatively impermeable underlying rock. Thus most groundwater flows downslope via the colluvial material, which is usually 1 to 2 metres thick on the highest slopes and up to 20 metres 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 use upgradient of discharge zones and means the timeframes for management of salinity are relatively brief, with positive benefits from effective recharge control possible in a decade or so of their application.

Land extent

Groundwater discharge will occur primarily at the break of slope associated with hydraulic gradient changes due to sediment variation or to changes in the slope of the land surface. These discharge sites are likely to be small but widespread.

Stream salinity

Washoff processes associated with overland flow in the discharge areas will affect stream salinity. The minor streams in the drainage network are the most likely parts to be involved.

Change in groundwater elevation

Groundwater elevation change in the colluvial fan will be highly variable.

Climate

This groundwater flow system will be found across a broad range of climatic zones.
Intermediate flow systems in sedimentary sequences infilling large valleys
This groundwater flow system comprises ancient valleys that once formed an integrated river basin draining the southwest of Western Australia. The old valleys, however, were extensively disrupted by tectonic activity during Tertiary times and have been infilled with 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 10-20 kilometres 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 in these linear plains.

Land extent
Dryland salinity is extensive and very severe in these systems. High salinity groundwaters outcrop extensively in the alluvium that infill broad valleys, and extreme soil salinity is commonplace.

Stream salinity
Many of the regions that experience this form of salinity lack integrated drainage, but saltloads are most often extreme where they are drained by stream networks salinity. Both base-flow and washoff processes are common.

Change in groundwater elevation
Groundwater recharge tends to be highly episodic, reflecting the low rainfall environments in which the groundwater flow systems are usually located. Seasonal fluctuations of one to two metres a year are common, but overprinted by recharge in years of extreme annual rainfall. Groundwater recharge occurs on the slopes of the broad valleys as well as in the alluvium.

Climate
Most of these groundwater systems and their associated salinity problems occur in semi-arid regions, in particular in the Wheatbelt of eastern Western Australia.
Intermediate and local flow systems in fractured basaltic rocks and layered sedimentary rocks

This flow system can be found in 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 — that is, flow passing across catchment boundaries — while in other regions flow is more constrained in 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 tens of kilometres and across sub-catchment boundaries. Groundwater discharge and salinisation typically occur 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 these 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 improve conceptual models of the dominant processes controlling dryland salinity and appropriate management monitoring options.

Land extent

Land salinisation is usually associated with discharge where groundwater flow has been obstructed by more resistant rock layers. This can be at the local or intermediate scale, depending on the nature of the less permeable impediments to flow. Saline outbreaks usually correlate with areas where the resistive layers outcrop with salinity sites arranged around the contour. The excess discharge can also lead to waterlogging in the drainage lines. Salt storage in these systems is highly variable. Where salt storage is high, significant salinisation may occur.

Stream salinity

Stream salinity is probably most affected by washoff from the salinised parts of the catchment. Where streams have incised and intercept major resistant layers, baseflow contributions of salt may be significant. Second- and third-order streams may be the most affected.

Change in groundwater elevation

Groundwater elevation change in this system at the local scale may be difficult to monitor. In some cases flow may be virtually perched, and careful siting of observation points will be required.

Climate

These groundwater flow systems can be found in a variety of climatic settings and hence, they experience a wide range of conditions.
Intermediate flow systems in fractured rock aquifers
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 moderate and where local relief is generally less than 20-30 metres. Under these circumstances groundwaters may flow across catchment boundaries.

Groundwater recharge typically occurs in regions where fractured rock outcrops, as is common in catchment headwaters. Groundwater flows down basin over distances of 20-30 kilometres 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, so salinity frequently occurs in mid- to upper catchment regions. Groundwater discharge is most common through baseflow to streams, often contributing to downstream rivers as much as 600 kilograms of salt per ha of catchment.

The issues for managing and monitoring these systems relate to the scale at which options must be applied; the moderate groundwater salinity concentrations (2000 to 6000 mg/L); and the timeframes required for aquifers to drain sufficiently to lower groundwater levels.

Land extent
Dryland salinity associated with intermediate fractured rock aquifers normally affects streams through base-flow, though washoff processes may be locally significant.

Stream salinity
Stream salinity and high saltloads are significant in these systems. Salinity is most notable in areas where there is significant change in the hydraulic gradient of groundwater systems in combination with a reduction in the regional slope of the landscape. Saltloads typically exceed 400 kg/ha/year and even small ephemeral streams may export more than 10 000 tonnes of salt a year.

Change in groundwater elevation
Groundwater fluctuation is greatest in recharge areas, usually where fractured rock aquifers outcrop, typically in catchment headwaters. In these regions annual groundwater fluctuations may exceed 4-6 metres a year, particularly in the more southerly landscapes experiencing cold wet winters and hot dry summers.

Climate
Those regions most impacted by dryland salinity in terrain in this groundwater flow system are found in the cooler temperate climates of SA, Vic and NSW.
Regional flow systems in alluvial aquifers

This groundwater flow system typically occurs in many inland alluvial sedimentary sequences such as 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 WA.

Groundwater in the MDB Riverine Plains is transmitted from upland valleys to the lower plains via very large regional gravel aquifers buried in ancient valleys beneath the Plains’ sand and clay sediments. The regional aquifers are recharged during episodes of sheet flooding and though leakage from regional river systems. Recharge is highest in alluvial fans formed near the upland front, and increased recharge post agricultural development in the down-basin sectors of the plain, ultimately resulting in regional groundwater discharge in the more down-basin plains. 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, though 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 groundwater has already been extensively developed, rising groundwater level trends are beginning to slow.

The pertinent management and monitoring issues for these groundwater flow systems include the existing volume of groundwater due to increased recharge already moving through them, the extent across which options must be applied to produce change, the significant contribution episodic events make to recharge volumes, the transmissive nature of the aquifers and the moderate salinity concentrations of groundwaters.

Land extent
Dryland salinity in this terrain develops where water tables associated with elevated groundwater pressures in shallow and deeper regional aquifers intersect the land surface. In the plains this usually occurs in shallow drainage depressions and wetlands; indeed, the onset of salinity is most commonly marked by the appearance of large strings of dead or dying trees associated with meandering stream traces on the plains.

Stream salinity
Stream salinity occurs through base-flow where incised streams intersect sand layers and prior streams in the shallow aquifers of the plains. Washoff may also occur and be locally significant where runoff occurs from saline soils.

Change in groundwater elevation
Groundwater recharge in these systems is strongly episodic, largely in response to occasional sheet flooding. In some regions there is also strong evidence of recharge occurring as a consequence of considerable leakage from regional rivers and streams. Seasonal responses are usually less significant.

Groundwater responses in these systems need to be measured over many years to account for the processes that effect salinity. Changes in head pressures tend to occur in a step-like fashion in response to periods of high surface water budgets.

Climate
Salinity risk in these systems is greatest in the southern Riverine Plains, which experience cool, wet winters and hot, dry summers.
Regional flow systems in unconfined sediments
This groundwater system typically occurs in 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 salinas were characteristic components of the landscape prior to widespread land use change, though this has increased since European settlement. The groundwater system is characterised by high salinity, a relatively permeable and extensive aquifer, very low hydraulic gradients and diffuse episodic recharge across the plains. Groundwater salinity is controlled by evaporative concentration in the sub-surface and discharge of water from hyper-saline 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, though 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 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; it must deal with already increased groundwater volumes moving through the system; and salinity is always likely to be a component of the landscape. Viable options for dealing with dryland salinity must therefore focus on using the saline water as a resource or managing saline land for its conservation and recreational values.

Land extent
Dryland salinity associated with regional, unconfined, moderate permeability aquifers is usually manifest where the flat lying water table lies at or above the land surface. The areas most commonly affected are shallow depressions and wetlands. Where these are invaded by high salinity groundwater, salinas commonly develop as large circular groundwater discharge zones. These are normally hyper-saline as a consequence of evaporation from discharging groundwaters.

Stream salinity
Though most of the regions experiencing salinity in these landscapes have little in the way of an integrated drainage network, they are often in part traversed by rivers that feed terminal lakes. Base-flow is a very strong contributor to river salinity under these circumstances, though washoff can also be a large problem. However, saline base-flows contribute to particular damage to regional rivers and frequently result in the deeper pools important to aquatic life becoming stratified and very saline.

Change in groundwater elevation
As these groundwater systems are found in the semi-arid lands, groundwater recharge in normal seasons is low and seldom important. Groundwater fluctuations in these years are normally low and are somewhat dampened by moderate to high aquifer storage characteristics of the aquifers.

Significant groundwater recharge only occurs in those occasional years (perhaps as little as one in 10 years) when seasonal rainfall is unusually high.

Climate
Dryland salinity in these systems is strongly controlled by episodic recharge in otherwise semi-arid conditions.
Regional and intermediate flow systems in fractured basaltic rocks

Typically this groundwater flow system occurs in extensive basalt landscapes that are relatively flat. The low relief means that 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, though 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, 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 reducing recharge through land use alternatives such as plantations or re-establishment of native vegetation, or pumping of less saline groundwater for horticulture or other purposes. Surface drainage is also an option, though as the region drains internally the issue of disposal of saline water is substantial. Historically, drains have fed existing lakes in surface depressions. However, the timeframes involved in reducing existing salinity using many of these options are considerable given the already elevated groundwater levels.

Land extent
Salinity typically occurs as seepages in valley floors and is marked by the presence of saline indicator species including sea barley grass and spiny rush. Groundwater salinity in the basalt rocks is not high, but considerable salt is stored in the underlying weathered rocks. Interactions involving mixing of the groundwaters in the fractured basaltic rocks and deeper, more saline waters along flow paths are largely responsible for moderate soil salinity in zones of groundwater discharge.

Stream salinity
Saline groundwater discharge to streams occurs through both base-flow where streams are incised into the fractured basalts, and through washoff processes where salts accumulate in the surface soils of groundwater discharge zones over the more arid months.

Change in groundwater elevation
Groundwater recharge occurs most readily in those regions where the fractured basaltic rock aquifers are exposed at the land surface, and may also occur locally through scoria cones and the like. In these regions groundwater fluctuations in response to recharge and discharge will be significant, with seasonal variations in groundwater heads amounting to 2-3 metres or more.

Climate
In southern Australia salinity in the basalt plains is driven by excessive groundwater recharge amplified by limited soil water storage, and low evaporative demand in the cool winter months.
Appendix C: Review of past and current monitoring activities

This review assesses the adequacy of current arrangements for monitoring the severity, impacts and likely future costs of dryland salinity. The assessment identifies the aspects of monitoring undertaken in each State and Territory that could be incorporated into a national framework.

The review is based primarily on a questionnaire sent to key State and Territory contacts. Additional information was provided by an examination of major Murray-Darling Basin Commission (MDBC) and National Land and Water Resources Audit (NLWRA) documents, review of significant publications on dryland salinity and a search of Federal and State agency websites.

Federal Government
While no Federal agency has specific responsibility for salinity management, several agencies are involved in research and the collection of data relevant to dryland salinity.

Agriculture Fisheries and Forestry – Australia (AFFA)
In November 2000 the Federal Government announced its $1.4 billion Salinity and Water Quality Action Plan (SWQAP), with funding to be split between the Commonwealth and the States. An important component of the plan was a commitment to fund mapping of salinity using airborne geophysics in 20 priority catchments across the country. AFFA has also committed about $1 million to a national land use mapping program.

Bureau of Rural Sciences (BRS)
BRS is taking a major role in the national salinity mapping program. Airborne electromagnetic, gamma radiometric and high resolution magnetic surveys will be flown in 20 catchments that have been identified as priorities for salinity management in the SWQAP. Based on the geophysical data and field survey, BRS will also produce models of the hydrogeological processes controlling dryland salinity in each catchment.

As part of a NLWRA project, BRS produced a national land use map at 1:1 000 000 scale based on Landsat and Agricultural Census data. BRS is also leading a national land use mapping program that aims to map most of the country by 2003 at scales from 1:25 000 to 1:250 000. The BRS Australian Land Cover Change (ALCC) project quantified land cover change from 1990 to 1995 for the entire intensive land use zone based on Landsat data.

Along with CSIRO Land and Water, BRS is also developing the Australian Soil Resources Information System (ASRIS), a nationwide database of soil attributes funded by the NLWRA.

Australian Geological Survey Organisation (AGSO)
AGSO is a partner in the airborne salinity survey described above. AGSO has also produced extensive geology and hydrogeology maps for the country at a range of scales; for example, mapping of the Murray Basin is available at 1:250 000 and mapping of the Darling Basin is available at 1:1 000 000.
Environment Australia (EA)
EA maintains several databases relating to aspects of biodiversity that could be at risk from salinity. This includes threatened species, internationally significant wetlands and World Heritage Sites.

Commonwealth Scientific and Industrial Research Organisation (CSIRO)
CSIRO, especially its Land and Water Division, conducts the most extensive research on salinity of any federally funded organisation. The Sustainable Agriculture and Sustainable Catchment and Groundwater Management programs of CSIRO Land and Water are two particularly important programs for salinity research.

National Land and Water Resources Audit (NLWRA)
The $29.4 million National Land and Water Resources Audit began in 1997 with a four-year mission to provide a comprehensive national appraisal of Australia’s natural resource base. The NLWRA consists of seven themes, of which Theme 2 is Dryland Salinity. Projects under Theme 2 include an assessment of the current extent and future risk of salinity in all States and Territories, a catchment classification framework for salinity management, several case studies on catchment management and salinity impacts, and recommendations on a national program for salinity monitoring.

Products from other themes of the NLWRA are also relevant to salinity. These include the National Vegetation Information System (NVIS), the Australian Soil Resources Information System (ASRIS) and the National Land Use Map produced by BRS.

Murray-Darling Basin Commission (MDBC)
The Murray-Darling Basin Commission is a partnership between the Federal Government and all of the States represented in the Murray-Darling Basin. MDBC commissions a wide range of research on salinity in the Murray-Darling Basin. Examples of current projects relevant to salinity include ‘Salinity control with sustainable farm salt balance through integrated management’ and ‘Catchment characterisation and hydrogeological modelling to assess salinisation risk and effectiveness of management options’.

Research and Development Corporations
Land and Water Australia (formerly the Land and Water Research and Development Corporation) commissions a range of research on salinity across the country. Land and Water Australia also leads the National Dryland Salinity Program (NDSP). The Rural Industries Research and Development Corporation (RIRDC) and the Grains Research and Development Corporation (GRDC) also commission research relevant to salinity.

Bureau of Meteorology (BOM)
BOM collects, archives and provides access to climate data such as rainfall and temperature from its network of climate stations across the country. BOM also maintains the SILO system (developed by Queensland Department of Natural Resources), which provides interpolated climate data for any point across the country.
Australian Bureau of Statistics (ABS)
Through the Agricultural Census and the Agricultural Commodity Survey, ABS collects yearly data by census area on crop production, livestock numbers, land use practices and the financial performance of agricultural industries.

Australian and New Zealand Environment and Conservation Council (ANZECC)
Core attributes have been developed by the State of Environment Reporting Task Force of ANZECC through extensive consultations involving government agencies and the general public (ANZECC, 2000). Examples of attributes important to dryland salinity assessment, risk or impacts include:

- L4 — area of rising water tables
- L5 — area affected by salinity
- BD9 — populations of selected species
- BD11 — marine and estuarine protected areas
- IW7 — surface water salinity
- IW13 — river health

ANZECC’s role does not include collecting any data for these attributes.

State Governments
Information on state salinity monitoring activities is presented under the following headings:

- responsibility for salinity monitoring;
- current extent of dryland salinity;
- ground water levels and trends;
- surface water flow and salinity;
- land use/cover;
- salinity impacts (social, economic, biological); and
- predictions of future extent of dryland salinity

The adequacy of the activities for monitoring both current and future extent and impacts of dryland salinity is then assessed.
Queensland

Responsibility
The Department of Natural Resources (DNR) has primary responsibility for the assessment, monitoring and management of dryland salinity in Queensland. In DNR the Salinity and Catchment Hydrology Group (SalCon) is responsible for research into dryland and irrigation salinity.

Mapping of land salinisation
Statewide estimates of the extent of dryland salinity in Queensland are based on a questionnaire sent to regional extension officers from DNR (then the Department of Primary Industries) (Gordon, 1990). Current extent estimates were based on areas nominated as severely affected by dryland salinity, displaying features such as scalds or prominent yield decline. The report includes information at district and regional scale (1:250 000). Some estimates in the report were updated to 1994.

More recent assessment of salinity extent has been conducted for the Murray-Darling Basin catchments of Queensland in the Murray Darling Basin Salinity Audit. The Salinity Audit estimated potentially waterlogged land by superimposing groundwater levels on hydrogeomorphic units. However, reliability is constrained by limited groundwater data for shallow aquifers, poor quality of groundwater data, and the lack of a high resolution digital elevation model. Similar problems were encountered in attempts to map current salinity extent for the Dryland Salinity theme of the National Land and Water Resources Audit, so salinity hazard rather than current extent was mapped for most of the State (Gordon, 2000).

Several small-scale studies have mapped salinity extent using airborne electromagnetics, interpretation of satellite imagery and ground-based electromagnetics. These studies have generally been funded from federal sources such as the Natural Heritage Trust.

Groundwater monitoring
The main source of groundwater level data in Queensland is DNR’s Groundwater Database, which contains records for all licensed and many unlicensed bores across the State. It also contains data from monitoring bores in irrigation areas and other key groundwater resource areas.

This database was established to manage groundwater extraction and it is often inappropriate for monitoring shallow water tables and hence dryland salinity. Problems with using the DNR’s Groundwater Database for dryland salinity assessment include:

- a lack of accurate bore location data;
- inadequate bore logs, particularly in the upper 50 metres;
- bores not maintained;
- bore casing not open in the top 50 metres;
- limited water level data, with most bores having only one or two water level records;
- limited water quality data.

The only area of the state where there are enough data to map groundwater levels on a catchment-wide basis is the Condamine-Balonne and Border Rivers catchments.

The spatial distribution of the bores in the Groundwater Database with respect to Australian Water Resources Council basins is summarised in Table C.1. Figure C.1 shows the distribution of bores in relation to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.
In addition to Queensland’s Groundwater Database, there are several hundred bores targeted specifically at monitoring shallow groundwater systems for waterlogging and salinity. These are located in specific problem areas or to monitor the impacts of revegetation or tree management strategies. With some exceptions, data have been collected on an *ad hoc* or project basis with little continuing data collection or central data storage beyond immediate project needs. These additional data could be tapped in a future salinity monitoring program.

**Table C–1**: Distribution of groundwater monitoring bores in groundwater flow systems in Queensland

<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
<th>km² per monitoring bore – regional GFS</th>
<th>km² per monitoring bore – entire basin</th>
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<tr>
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<td>BURNETT</td>
<td>14</td>
<td>9</td>
<td>143</td>
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<td>138</td>
<td>MARY RIVER (QLD)</td>
<td>MARY</td>
<td>—</td>
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<td>821</td>
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<tr>
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<td>—</td>
<td>—</td>
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<tr>
<td>143</td>
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<td>BRISBANE</td>
<td>—</td>
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<td>49</td>
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<td>145</td>
<td>LOGAN-ALBERT RIVERS</td>
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<td>3</td>
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<tr>
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<td>BORDER RIVERS</td>
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<td>343</td>
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<tr>
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<td>—</td>
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<td>132</td>
<td>CALLIOPE RIVER</td>
<td>CURTIS</td>
<td>—</td>
<td>0</td>
<td>—</td>
<td>28</td>
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</table>
Surface water monitoring
The Department of Natural Resources and Mines records stream levels, measures flow and collects water samples for laboratory analysis. All data are stored on its HYDSYS database. The stream height and stream flow records cover 1145 and 1055 sites respectively and the earliest data date from 1909. At present, 434 sites are monitored.

Water samples have been collected for analysis since 1960. The analyses include major ions and nutrients (filtered and unfiltered). 1726 sites have samples collected for analysis including EC. About 162 sites are in the water quality monitoring program and 167 sites are currently collecting continuous EC data. Continuous EC monitoring began in 1992.

Data summaries are available for all sites on the WaterShed website.

Mapping of land cover/land use
Queensland’s Statewide Landcover and Trees Study (SLATS) monitors Statewide changes in land cover based on satellite imagery (DNR, 2000). The purpose is to improve the greenhouse gas inventory for the land use and forestry sector in Queensland and to provide
information for review of vegetation management policies. Key components of the SLATS project are:

- the development of a satellite based monitoring system using Landsat Thematic Mapper (TM) satellite imagery for 1988, 1991, 1995, 1997 and 1999 to detect change in woody vegetation cover across the entire State;
- an analysis of clearing in Queensland based on Landsat Multi Spectral Scanner (MSS) satellite imagery for 1972, 1980 and 1984 to provide improved estimates of regrowth area cleared and historical clearing rates;
- mapping the extent of woodlands in Queensland by a detailed baseline land cover survey using 1991 TM satellite imagery.

DNR has mapped land use at 1:25 000 for the Fitzroy Basin for the Fitzroy Implementation Project of the NLWRA. The Bureau of Rural Sciences has contracted DNR to map a large proportion of the State as part of a national land use mapping program.

Salinity impacts
The NLWRA salinity report for Queensland summarised key assets at risk from salinity by intersecting the salinity current extent and future predictions maps with land use (Gordon, 2000).

Future extent
Salinity hazard was assessed for the NLWRA Dryland Salinity theme based on available datasets for geology, soils, elevation, land use change and potential excess rainfall (Gordon, 2000).
New South Wales

Responsibility
The Department of Land and Water Conservation (DLWC) has primary responsibility for dryland salinity management and research in NSW. The Department of Agriculture and the Environment Protection Agency are also prominent in salinity management.

Mapping of land salinisation
Mapping of dryland salinity in NSW is based on a system developed in 1981-1983, with some modifications where unique patterns were encountered. Scald areas, salt-tolerant species and surface soil salinity in gullies were mapped based on aerial photography and field checking, landholder surveys, satellite imagery and the knowledge of departmental officers. Not all of NSW is covered by this mapping system. While information is good for much of the Murray Darling Basin and for a number of coastal catchments including parts of Shoalhaven, Wollondilly, Hunter, Richmond Tweed and Sydney Western region, very little information is available for western NSW.

For the NLWRA Dryland Salinity Theme, DLWC combined salinity mapping according to the above method with areas where groundwater tables less than 2 metres below surface had been measured. This substantially underestimates salinity in the State as it has been mapped only where there is either airphoto interpretation or bore data (Littleboy et al., 2001).

Groundwater monitoring
DLWC maintains a groundwater database of two types of bores. The first, production bores, consist of only one measurement of groundwater level taken at the time of drilling. Production bore data contain many errors, especially in determining the depth of the water table. These data are collected by the driller and forwarded to DLWC. Often drillers neglect to complete the required data collection in enough detail and the reported water levels in bores may also not reflect equilibrium conditions after drilling. There are 7036 production bores with data from the period between 1980 and 2000. Littleboy et al. (2001) applied quality control procedures to reduce this number to 5943 suitable bores for salinity evaluation purposes.

The second type of bores in the database is monitored bores — bores that have time series data. While information for many monitoring bores is stored in the central database, an substantial amount of additional information is also maintained in regional datasets. A series of reconnaissance surveys was undertaken in the early 1990s to measure water level and salinity in these bores. In many cases there are only two measurements per bore, one from the time of drilling and another from the reconnaissance survey. Bores with more than two measurements are limited mainly to the Central West Region (Macquarie and Lachlan). In their NLWRA report, Littleboy et al. (2001) used 986 suitable two-point bores and 287 three-point bores.

The spatial distribution of monitoring bores only (not production bores) in NSW is summarised in Table C.2. Figure C.2 shows the spread of bores with respect to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.
Table C–2: Distribution of groundwater monitoring bores in groundwater flow systems in NSW

<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
<th>km² per monitoring bore – regional GFS</th>
<th>km² per monitoring bore – entire basin</th>
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<td>31</td>
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<td>COFFS HARBOUR</td>
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<td>28</td>
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<td>153</td>
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<td>411</td>
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<tr>
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<td>COFFS HARBOUR</td>
<td>74</td>
<td>93</td>
<td>543</td>
<td>259</td>
</tr>
</tbody>
</table>

Figure C–2: NSW monitoring bore network
Surface water monitoring
Most of the NSW historical stream data are held in the DLWC HYDSYS database and the DLWC TRITON water quality database. Further records are available at regional DLWC offices. While time series data for streamflow are quite extensive, stream salinity data are patchy; for example, for the outflows of major catchments across the State there are on average 20.5 years of continuous observed flow data and only 152 corresponding discrete EC measurements (Beale et al., 2000).

For current and recent stream information the Provisional River Data System provides information on water level, water temperature and water salinity from 350 locations using data gathered from monitoring sites by radio and telephone systems. These data are retained on DLWC’s website for three months before being archived.

Mapping of land cover/land use
DLWC has mapped land use at a scale of 1:25 000 in some small areas such as Young as part of the Murray-Darling Basin Commission Landmark study. The Bureau of Rural Sciences has contracted DLWC to map a large proportion of the State as part of a national land use mapping program.

Modelling of current impacts
The NLWRA salinity report for NSW summarised key assets at risk from salinity by intersecting the salinity current extent and future predictions maps with land use (Littleboy et al., 2001).

Future extent
Assessments of the likely trend in dryland salinity occurrence have been undertaken by DLWC for two catchment plans:

- Kyeamba Valley Study (1991–1992): information from four bores was used to predict the areas likely to be affected by future outbreaks of dryland salinity. The bore data were matched against slope/terrain mapping. All areas of colluvial soils (footslopes, drainage depressions) where the groundwater pressure was positive were deemed to be at risk. Alluvial areas were considered not at risk because the aquifer systems were still draining.
- Wantiool Catchment Plan (1993): the Wantiool Study adopted the same approach but without the benefit of bore data.

For the Dryland Salinity theme of the NLWRA, NSW produced maps of predicted 2020 and 2050 salinity based on a synthesis of current groundwater depth, measured rates of groundwater rise and identification of salt outbreaks from airphoto interpretation.

Work with the terrain analysis model FLAG, Fuzzy Landscape Analysis GIS, (Roberts et al., 1997) is currently being undertaken. FLAG provides several indices of landscape position based on a high resolution digital elevation model. These indices can be used to predict likely areas for surface expression of salinity and waterlogging. FLAG is also being combined with hydrogeological information to identify areas of accumulation and divergence and predict the subsurface flow of saline water.
Victoria

Responsibility
The Department of Natural Resources and Environment (DNRE) has primary responsibility for salinity management in Victoria. In DNRE, the Centre for Land Protection and Research contains salinity expertise. Some monitoring activities have been contracted out to the consulting firm Sinclair Knight Merz.

Mapping of land salinisation
DNRE undertook a 10-year assessment of dryland salinity at 1:25 000 scale that was completed in 1994. The assessment covered most of the State with the exception of the Mallee region, areas of West Gippsland east of the Gippsland Lakes and some areas of the Port Phillip region. The study was based on visual symptoms such as reduced groundcover and changes in botanical composition of pastures (Allan, 1994 and 1996).

Since this study, 46 monitoring stations have been established. These are not systematically co-ordinated by the State government, but are supported by community groups. The sites are generally visited once every four years. On each visit salinity is mapped using ground based electromagnetics and field observation of indicator plant species, impact on agricultural plants, observation of scalding or other surface indicators, and soil salinity measurements.

For the NLWRA Dryland Salinity theme, Sinclair Knight Merz estimated the extent of shallow water tables for hydrogeomorphic units based on water level data from groundwater monitoring sites. They derived relationships between ground surface elevation and water table elevation, existing salinity mapping and GIS layers showing location of streams, lakes and wetlands, urban areas, irrigation districts and forests and woodlands (Clifton, 2000).

Groundwater monitoring
Victoria has a substantial network of groundwater observation bores. These bores were constructed for water resource investigations and dryland salinity investigation and monitoring. Most salinity monitoring bores were constructed after the launch of the Victorian Salinity Program in the late 1980s. There are two main observation bore networks:

- State Groundwater Observation Bore (SGOB) network; and
- Victorian salinity monitoring network — a less formal network of observation bores established for community education, groundwater process investigation and salinity monitoring

Shortcomings in the groundwater monitoring network and databases that detract from their value in analysis of dryland salinity include (Clifton, 2000):

- concentration of bores in areas of shallow water tables;
- under-representation of ridge and upper slope areas;
- lack of accurate elevation information for many bores;
- errors in water level records; and
- poor representation of parts of the State outside those traditionally considered to be at risk of salinity.

The spatial distribution of monitoring bores in Victoria is summarised in Table C.3 and shown in Figure C.3 below. The figure shows the spread of bores with respect to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.
Table C–3: Distribution of groundwater monitoring bores in groundwater flow systems in Victoria

<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
<th>km² per monitoring bore – regional GFS</th>
<th>km² per monitoring bore – entire basin</th>
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<tbody>
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<tr>
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<td>—</td>
<td>4</td>
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<tr>
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<td>WIMMERA-MALLEE</td>
<td>—</td>
<td>—</td>
<td>33</td>
<td>47</td>
</tr>
</tbody>
</table>
Surface water monitoring
A single surface water quality monitoring network operates across Victoria. The Water Quality Monitoring Network (WQMN) consists of 280 stream gauging stations that have operated for up to 25 years, with water quality measurements taken at least monthly. Long-term continuous flow and salinity measurements are available for many stations.

Mapping of land cover/land use
DNRE’s Catchment Health Indicator Program aims to provide an indicator-based assessment of ‘health’ for Victorian Catchment Management Authorities. Several proposed indicators are related to land use/cover including remnant vegetation condition and land use and management compared spatially to land capability. The project is based on a combination of existing data and data collected specifically for the catchment health assessment. While the project is funded for four years, the project aims to set up an assessment framework that could provide continuing monitoring of catchment attributes.

DNRE has also mapped land use in the Gippsland region as part of a NLWRA implementation project. Land use mapping is under way in 2001 in the Goulburn-Broken catchment as part of the MDBC Landmark project. It is anticipated that MDBC will fund mapping of the remainder of the Murray-Darling Basin component of Victoria and that the rest of the State will be mapped as part of the Bureau of Rural Sciences’ national land use mapping program. Mapping scales range from 1:25 000 for intensive land use areas to 1:100 000 in more remote regions.
Modelling of current impacts
The Catchment Health Program incorporates several indicators relevant to salinity impacts including biodiversity, index of stream condition, and gross value of production.

The NLWRA salinity report for Victoria summarised key assets at risk from salinity by intersecting the salinity current extent and future predictions maps with land use (Clifton, 2000).

Future extent
Little modelling of future salinity extent was undertaken in Victoria prior to the NLWRA Extent and Impacts of Dryland Salinity project. For the NLWRA project, Sinclair Knight Merz superimposed observed groundwater trends on hydrogeomorphic units to estimate areas affected by waterlogging and salinity in 2020 and 2050 (Clifton, 2000).
Tasmania

Responsibility
The Department of Primary Industry, Water and Environment (DPIWE) has primary responsibility for management and monitoring of dryland salinity. Mineral Resources Tasmania (MRT) is the custodian for the State’s groundwater database.

Mapping of land salinisation
Mapping of dryland salinity has been undertaken on a 1:250 000 scale for land systems (areas with consistent patterns of annual rainfall, geology and topography). The first survey, completed in 1992, involved 20 Department of Primary Industry officers who were issued with 1:100 000 land systems maps of private and freehold land depicted on a topographic base and asked to delineate those areas in which they had seen visual symptoms of salinity. As part of the NLWRA Dryland Salinity theme, this assessment was updated based on field work by DPIWE’s Salinity Officer (Bastick and Walker, 2000).

Groundwater monitoring
MRT is the custodian for Tasmania’s groundwater database. About 4340 bores in the database have location coordinates; of these, 2930 contain records for ‘depth to water struck’. Most of these bores were drilled for mineral exploration and do not represent a structured sampling of the hydrogeology of Tasmania. Consequently, some areas known to contain salinity are under-represented, such as the Central Highlands LGA. Salinity measurements are available for only 444 of the 4340 MRT bores, including 70 drilled in 1999 to estimate the potential of groundwater for irrigation in five districts known to contain salinity. The only trend data are from a series of about 50 bores monitored by DPIWE mainly in the Cressy Longford area and the Coal River Valley irrigation schemes (Bastick and Walker, 2000).

The spatial distribution of these DPIWE bores is summarised in Table C.4. Figure C.4 shows the spread of bores with respect to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.
Table C–4: Distribution of groundwater monitoring bores in groundwater flow systems in Tasmania

<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
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<th>km² per monitoring bore – entire basin</th>
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<tr>
<td>319</td>
<td>PIPER-RINGAROOMA RIVERS</td>
<td>BASS STRAIT</td>
<td>49</td>
<td>44</td>
<td>—</td>
<td>95</td>
</tr>
<tr>
<td>302</td>
<td>EAST COAST</td>
<td>TASMAN</td>
<td>80</td>
<td>9</td>
<td>—</td>
<td>82</td>
</tr>
<tr>
<td>318</td>
<td>TAMAR RIVER</td>
<td>BASS STRAIT</td>
<td>10</td>
<td>2</td>
<td>46</td>
<td>35</td>
</tr>
<tr>
<td>317</td>
<td>RUBICON RIVER</td>
<td>BASS STRAIT</td>
<td>—</td>
<td>21</td>
<td>—</td>
<td>72</td>
</tr>
<tr>
<td>316</td>
<td>MERSEY RIVER</td>
<td>BASS STRAIT</td>
<td>88</td>
<td>36</td>
<td>88</td>
<td>71</td>
</tr>
<tr>
<td>304</td>
<td>DERWENT RIVER</td>
<td>TASMAN</td>
<td>159</td>
<td>146</td>
<td>—</td>
<td>154</td>
</tr>
<tr>
<td>303</td>
<td>COAL RIVER</td>
<td>TASMAN</td>
<td>7</td>
<td>4</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>306</td>
<td>HUON RIVER</td>
<td>GORDON</td>
<td>—</td>
<td>31</td>
<td>—</td>
<td>333</td>
</tr>
<tr>
<td>314</td>
<td>SMITHTON-BURNIE COAST</td>
<td>BASS STRAIT</td>
<td>20</td>
<td>6</td>
<td>439</td>
<td>118</td>
</tr>
</tbody>
</table>

Figure C–4: Tasmanian monitoring bore network
Surface water monitoring
Tasmania’s stream monitoring network is sparse. Twenty five of the 48 catchment areas in the State have had some surface water salinity testing which, in some cases, consists of just one sample. In 1994, 12 permanent record sites were installed by DPIWE to monitor flow and salinity.

Mapping of land cover/land use
Tree clearing/re-afforestation is assessed on a five-yearly basis by DPIWE. Land use mapping for the entire State will be undertaken at scales from 1:25 000 to 1:100 000 as part of the Bureau of Rural Sciences’ land use mapping program.

Modelling of current impacts
No assessment of the economic, social and biodiversity impacts of salinity was made prior to the NLWRA Extent and Impacts of Dryland Salinity project in which mapped salinity was intersected with infrastructure, endangered species and agriculture to estimate impacts (Bastick and Walker, 2000).

Future extent
Similarly, no modelling of future salinity extent was undertaken before the NLWRA Extent and Impacts of Dryland Salinity project in which the trends observed between the 1992 and 2000 salinity surveys were extrapolated to estimate future extent (Bastick and Walker, 2000).
South Australia

**Responsibility**
Primary Industries and Resources South Australia (PIRSA) and the Department of Water Resources (DWR) share responsibility for salinity monitoring and management in SA.

**Mapping of land salinisation**
Mapping of dryland salinity in SA has been completed using 1:40 000 aerial photographs. This involved mapping of individual seeps, scalds and other indicators of salt-affected land. Data have been compiled on 1:50 000 topographic maps. Data reliability is limited by lack of ground truthing. The airphoto analysis was used for South Australia’s report for the NLWRA Salinity Extent and Impacts project (Barnett, 2000).

**Groundwater monitoring**
SA maintains a groundwater database, OBSWELL, administered by DWR. The system has been integrated with the corporate drillhole database SA_GEODATA. Most bores were drilled for purposes other than salinity monitoring.

A five-year project called 'Dryland Salinity Catchment Investigation' began in 1989 to establish demonstration catchments in areas of the State affected by dryland salinity. This project implemented a groundwater monitoring network in each of five key catchments / sub-catchments:

- Naroonda, Kangaroo Island (16 piezometers)
- Wanilla, Lower Eyre Peninsula (30 piezometers)
- Jamestown, Mid North (17 piezometers)
- Darke Peak, Upper Eyre Peninsula (13 piezometers)
- Miniaton, York Peninsula (15 piezometers).

Barnett (2000) summarised the distribution of bores suitable for salinity monitoring in SA, as reproduced in Table C-5.
The regional groundwater systems of the Murray Basin are generally well monitored, with the only improvements required being in the western area between Morgan and Karoonda where a more comprehensive network is necessary to monitor the watertable rise that will increase saline groundwater inflows to the Murray. In other regions where local or intermediate flow systems predominate, the demonstration catchment observation bores are the only monitoring sites. Though restricted in areal extent, it is thought that these networks are sufficiently indicative of regional trends that extra monitoring is not necessary (Barnett, 2000).

The spatial distribution of monitoring bores in SA is summarised in Table C.6. Figure C.5 shows the spread of bores with respect to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.

<table>
<thead>
<tr>
<th>Region / catchment</th>
<th>Number of bores</th>
<th>Monitored by</th>
</tr>
</thead>
<tbody>
<tr>
<td>MURRAY BASIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal Plain</td>
<td>38</td>
<td>DWR (Contractor) 6 mthly (Mar Sep)</td>
</tr>
<tr>
<td>Upper South East</td>
<td>300</td>
<td>DWR (Naracoorte) 6 mthly (Mar,Sep)</td>
</tr>
<tr>
<td>Mallee</td>
<td>30</td>
<td>DWR (Naracoorte) 6 mthly (Mar,Sep)</td>
</tr>
<tr>
<td>EYRE PENINSULA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wanilla</td>
<td>30</td>
<td>DWR (Crystal Brook) 6 mthly (Apr,Oct)</td>
</tr>
<tr>
<td>Cummins Basin</td>
<td>17</td>
<td>DWR (Crystal Brook) 6 mthly (Apr,Oct)</td>
</tr>
<tr>
<td>Darke Peak</td>
<td>13</td>
<td>DWR (Crystal Brook) 6 mthly (Apr,Oct)</td>
</tr>
<tr>
<td>YORKE PENINSULA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minlaton</td>
<td>15</td>
<td>DWR (Crystal Brook) 6 mthly (Apr,Oct)</td>
</tr>
<tr>
<td>KANGAROO ISLAND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narroonda</td>
<td>16</td>
<td>Discontinued</td>
</tr>
<tr>
<td>MID NORTH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jamestown</td>
<td>17</td>
<td>DWR (Crystal Brook) 6 mthly (May,Nov)</td>
</tr>
<tr>
<td>MT LOFTY RANGES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrogate</td>
<td></td>
<td>CSIRO</td>
</tr>
<tr>
<td>Keyneton</td>
<td>21</td>
<td>PIRSA 2 mthly</td>
</tr>
</tbody>
</table>

Table C–5: Distribution of bores suitable for salinity monitoring in SA
Table C–6: Distribution of groundwater monitoring bores in groundwater flow systems in SA

<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
<th>km² per monitoring bore – regional GFS</th>
<th>km² per monitoring bore – entire basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>426</td>
<td>LOWER MURRAY RIVER</td>
<td>LOWER MURRAY</td>
<td>15</td>
<td>6</td>
<td>223</td>
<td>106</td>
</tr>
<tr>
<td>507</td>
<td>BROUGHTON RIVER</td>
<td>NORTH ST VINCENT-SPENCER GULF</td>
<td>3</td>
<td>3</td>
<td>—</td>
<td>31</td>
</tr>
<tr>
<td>505</td>
<td>GAWLER RIVER</td>
<td>ADELAIDE HILLS</td>
<td>0</td>
<td>150</td>
<td>—</td>
<td>50</td>
</tr>
<tr>
<td>414</td>
<td>MALLEE</td>
<td>WIMMERA-MALLEE</td>
<td>146</td>
<td>152</td>
<td>43</td>
<td>55</td>
</tr>
<tr>
<td>512</td>
<td>EYRE PENINSULA</td>
<td>NORTH ST VINCENT-SPENCER GULF</td>
<td>4</td>
<td>41</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>504</td>
<td>TORRENS RIVER</td>
<td>ADELAIDE HILLS</td>
<td>—</td>
<td>—</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>239</td>
<td>MILLICENT COAST</td>
<td>MILLICENT COAST</td>
<td>—</td>
<td>—</td>
<td>3</td>
<td>49</td>
</tr>
<tr>
<td>513</td>
<td>KANGAROO ISLAND</td>
<td>NORTH ST VINCENT-SPENCER GULF</td>
<td>—</td>
<td>6</td>
<td>—</td>
<td>13</td>
</tr>
<tr>
<td>1201</td>
<td>GAIRDNER</td>
<td>GAIRDNER</td>
<td>10</td>
<td>262</td>
<td>—</td>
<td>852</td>
</tr>
</tbody>
</table>

Figure C–5: South Australian monitoring bore network
**Surface water monitoring**

In the early 1970s, a network of surface water monitoring was established by DWR to meet the needs of water users. Surface water monitoring involves both water quality and flow monitoring. Barnett’s (2000) summary of stream data available in the State is reproduced in Table C-7.

Jolly *et al.* (2000) found that statistical analysis of SA stream data was constrained by short-term, irregular or sparsely sampled records in some areas.

**Table C–7: Summary of stream data available in SA**

<table>
<thead>
<tr>
<th>Region / catchment</th>
<th>Monitoring data available</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KANGAROO ISLAND</strong></td>
<td></td>
</tr>
<tr>
<td>Middle River</td>
<td>No data</td>
</tr>
<tr>
<td><strong>MID NORTH</strong></td>
<td></td>
</tr>
<tr>
<td>Baroota, Bundaleer, Beetaloo</td>
<td>No data</td>
</tr>
<tr>
<td>Wakefield</td>
<td>1 grab sample station</td>
</tr>
<tr>
<td>Broughton</td>
<td>3 grab sample stations</td>
</tr>
<tr>
<td><strong>EYRE PENINSULA</strong></td>
<td></td>
</tr>
<tr>
<td>Tod River</td>
<td>&lt;6 years of continuously monitored data, 2 gauging stations only</td>
</tr>
<tr>
<td><strong>MT LOFTY RANGES</strong></td>
<td></td>
</tr>
<tr>
<td>Angas Bremer</td>
<td>4 grab sample stations, 2 continuously monitored stations</td>
</tr>
<tr>
<td>Finniss</td>
<td>1 grab sample station</td>
</tr>
<tr>
<td>Marne</td>
<td>1 grab sample station</td>
</tr>
<tr>
<td>Myponga</td>
<td>1 grab sample station</td>
</tr>
<tr>
<td>Onkaparinga</td>
<td>5 grab sample stations, 3 continuously monitored stations</td>
</tr>
<tr>
<td>Torrens</td>
<td>4 grab sample stations, 1 continuously monitored station</td>
</tr>
<tr>
<td>North Para</td>
<td>5 grab sample stations, 6 continuously monitored stations</td>
</tr>
<tr>
<td>Wakefield</td>
<td>1 grab sample station</td>
</tr>
<tr>
<td>Broughton</td>
<td>3 grab sample stations</td>
</tr>
</tbody>
</table>

**Mapping of land cover/land use**

Throughout most of the State vegetation change and clearing are not monitored routinely. The exception is the Upper South East region, where approval is required for vegetation clearance.
Land use was mapped by PIRSA in the Mount Lofty Ranges in the early 1990s. Since then, portions of the Murray-Darling Basin in SA have been mapped at 1:25 000 – 1:100 000 scale as part of the MDBC Landmark project. South Australia plans to map the rest of the Murray-Darling Basin component of the state using MDBC funding, and the remaining part of the State in the intensive land use zone using funding from the Bureau of Rural Sciences’ land use mapping program.

**Modelling of current impacts**

A NLWRA study by Grear and Moyle (*in prep*) examined the threats to biodiversity in the agricultural regions of SA by intersecting biological data (vegetation associations, land cover type, threatened species, conservation tenures and wetlands) with information on depth to watertable and shallow aquifer salinity.

As part of South Australia’s NLWRA report on salinity extent and impacts, Barnett (2000) intersected salinity extent and projections with agriculture and infrastructure. This information was used with economic analysis to assess the potential costs of salinity impacts on agriculture, roads and building maintenance.

**Future extent**

The future extent of salinity in the Upper South East Region has been modelled using a digital elevation model in conjunction with groundwater trends. A 1993 Dryland Salinity Project estimated extent of dryland salinity for 2010 based on ‘guesstimates’ of the percentage increase in salinity in each region. Anecdotal information from individual landholders has also been used for local indications of increases in dryland salinity, but this information has not been used on a regional scale.

Barnett (2000) extended observed groundwater trends in regional flow systems such as the Murray Basin, to estimate salinity extent in 2020 and 2050. For most other areas of SA that do not have sufficiently accurate bore and topographic information for this approach, a combination of anecdotal evidence and professional judgment was used to determine percentage increase in salt affected land for 2020 and 2050.
Western Australia

Responsibility
A state salinity council has been established in Western Australia to monitor implementation of the state’s Salinity Action Plan. Responsibility for salinity in WA lies primarily with Agriculture Western Australia (Ag WA) and the Water and Rivers Commission (WRC). Conservation and Land Management (CALM) also plays an important role.

Mapping of land salinisation
The Land Monitor Project is producing maps of the extent and recent (~10 year) change in areas of salt-affected/persistent low productivity land based on Landsat satellite data. Spatial resolution is 25 m by 25 m. The project covers the entire southwestern agricultural area (24 million ha). Accuracy assessments of salinity mapping are carried out and published for sample areas in each region. Final products for one third of the region are complete, with the balance due by March 2001.

For the NLWRA Salinity Theme, Short and McConnell (2000) mapped the current extent of shallow groundwater for the entire State at scales of 1:50 000 and greater by attributing observed groundwater levels to landscape units. They also provided maps produced by the Ag WA Natural Resource Assessment Group (NRAG) of the proportion of wet and waterlogged soils by soil landscape. It was assumed that waterlogged soils or shallow groundwater tables corresponded to areas of current salinity extent or risk.

Groundwater monitoring
Both the WRC and Ag WA carry out groundwater monitoring programs. WRC is primarily concerned with monitoring potable/industrial groundwater resources (Short and McConnell, 2000). WRC’s State Water Resources Information System (SWRIS) database contains periodic groundwater level and quality data for 3200 state bores, and periodic groundwater level data for 13 000 private bores.

Ag WA maintains groundwater datasets in agricultural areas that are used primarily for salinity research. Ag WA has more than 5000 monitoring and research bores in its records. The Ag WA Catchment Hydrology Group has been progressively entering these to its database ‘AgBores’.

The NLWRA salinity project identified 4780 bores in AgBores that were suitable for future salinity monitoring. Ag WA has begun a census of bores currently monitored to determine those that should remain as priorities for long-term monitoring. An initial analysis has identified more than 1400 bores that should receive priority to provide long-term groundwater trend data (Short and McConnell, 2000).

The spatial distribution of monitoring bores in the AgBores database in WA is summarised in Table C.8. Figure C.6 shows the spread of bores with respect to local (light grey), intermediate (mid grey) and regional (dark grey) groundwater flow systems.
<table>
<thead>
<tr>
<th>Basin number</th>
<th>Basin name</th>
<th>Region name</th>
<th>km² per monitoring bore – local GFS</th>
<th>km² per monitoring bore – intermediate GFS</th>
<th>km² per monitoring bore – regional GFS</th>
<th>km² per monitoring bore – entire basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>618</td>
<td>YARRA YARRA LAKES</td>
<td>AVON</td>
<td>2</td>
<td>364</td>
<td>—</td>
<td>47</td>
</tr>
<tr>
<td>701</td>
<td>GREENOUGH RIVER</td>
<td>GERALDTON</td>
<td>1</td>
<td>5</td>
<td>40</td>
<td>21</td>
</tr>
<tr>
<td>617</td>
<td>MOORE-HILL RIVERS</td>
<td>MOORE</td>
<td>7</td>
<td>66</td>
<td>104</td>
<td>79</td>
</tr>
<tr>
<td>615</td>
<td>AVON RIVER</td>
<td>AVON</td>
<td>68</td>
<td>23</td>
<td>—</td>
<td>61</td>
</tr>
<tr>
<td>614</td>
<td>MURRAY RIVER (WA)</td>
<td>PERTH-MANDURAH</td>
<td>—</td>
<td>—</td>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>609</td>
<td>BLACKWOOD RIVER</td>
<td>WARREN-BLACKWOOD</td>
<td>0</td>
<td>8</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>601</td>
<td>ESPERANCE COAST</td>
<td>ESPERANCE</td>
<td>0</td>
<td>—</td>
<td>47</td>
<td>17</td>
</tr>
<tr>
<td>612</td>
<td>COLLIE RIVER</td>
<td>BUSSELTON-HARVEY</td>
<td>4</td>
<td>—</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>611</td>
<td>PRESTON RIVER</td>
<td>BUSSELTON-HARVEY</td>
<td>—</td>
<td>—</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>610</td>
<td>BUSSELTON COAST</td>
<td>BUSSELTON-HARVEY</td>
<td>10</td>
<td>—</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>602</td>
<td>ALBANY COAST</td>
<td>ALBANY</td>
<td>12</td>
<td>91</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>605</td>
<td>FRANKLAND RIVER</td>
<td>ALBANY</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>17</td>
</tr>
<tr>
<td>607</td>
<td>WARREN RIVER</td>
<td>WARREN-BLACKWOOD</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>43</td>
</tr>
<tr>
<td>604</td>
<td>KENT RIVER</td>
<td>ALBANY</td>
<td>0</td>
<td>14</td>
<td>—</td>
<td>3</td>
</tr>
<tr>
<td>603</td>
<td>DENMARK RIVER</td>
<td>ALBANY</td>
<td>1</td>
<td>—</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1204</td>
<td>SALT LAKE</td>
<td>SALT LAKE</td>
<td>51</td>
<td>386</td>
<td>1575</td>
<td>1143</td>
</tr>
</tbody>
</table>
Surface water monitoring
Surface water data are collected by WRC and stored in the SWRIS database. The database contains continuous water level data for 360 stream and lake sites and continuous stream salinity data for 65 sites. Periodic water quality samples are available for 500 sites.

Mapping of land cover/land use
The Land Monitor Project is monitoring changes in extent and condition of perennial vegetation across the region. All clearing of native remnant vegetation must be subject to a formal environmental review. Ag WA has mapped land use for the State at scales ranging from 1:25 000 to 1:250 000. This mapping was funded partially by NLWRA.
Modelling of current impacts

Damage to infrastructure is being monitored via the Rural Towns Program. Six towns have been selected for detailed analysis of hydrogeological characteristics, modelling of groundwater pumping strategies and development of an economic analysis model to quantify the infrastructure costs associated with the predicted rises in groundwater levels.

As part of the National Land and Water Audit, costs of salinity have been estimated for parts of the Great Southern and South Coast Regions (SS2020; NLRWA Implementation project). These will be linked to costs and benefits of available management options to provide better basis for policy decisions. Also as part of the Audit, a broad economic analysis was carried out after intersecting areas of shallow groundwater and salinity risk with infrastructure, water resources, agriculture and key areas for biodiversity conservation (Short and McConnell, 2000).

CALM has also been undertaking a biological survey of agricultural areas as part of the State Salinity Strategy. The agricultural zones cover all or significant parts of six of the eight biogeographical zones recognised in temperate southwestern Australia (CALM, 1999).

Future extent

Ag WA has predicted the change in dryland salinity extent based on scenario analysis using the MODFLOW and FLOWTUBE models in specific cases and MAGIC in the Water Resources Recovery Catchments. Currently the focus is on determining the endpoint rather than short-term trends. The groundwater database has been used as the main source of temporal data (hydrographs), with various levels of confidence.

Ag WA and CSIRO have developed hydrograph analysis systems as a part of the NLWRA Implementation Project to determine the impact of rainfall and related factors (Shao et al., 2000; Ferdowsian et al., 2000). This trend analysis model HARTT (Ferdowsian et al., 2000) is a major advancement in the analysis of hydrographs for salinity impact assessment and analysis.

The Land Monitor project is also developing methodologies to estimate salinity risk, defined as areas where there is a high probability of a shallow watertable developing at equilibrium. One model applies a water accumulation model derived from a high resolution digital elevation model \((z < 2m \times x, y, = 10m)\) to a catchment. An attempt is then made to identify areas that may become saline because of their position in the landscape and proximity to salt-affected areas. The parallel method uses a decision tree (expert driven), digital elevation model and related variables.

For the NLWRA Salinity Impacts and Extents project, Short and McConnell (2000) produced maps of salinity risk for 2020 and 2050 by attributing observed groundwater trends to landscape units.
Northern Territory

Responsibility
The Department of Lands, Planning and Environment has primary responsibility for salinity in NT. Salinity hazard mapping was undertaken by the Power and Water Authority in 1994.

Mapping of land salinisation
No systematic mapping of the current extent of dryland salinity has been undertaken and no monitoring systems have been implemented specifically to monitor salinity because it is not considered a serious problem in NT.

Groundwater monitoring
There are about 22,000 registered water bores in NT, many of which have one or more measurement of groundwater salinity. Groundwater monitoring of about 50 sites has shown no overall rising trends (NLWRA, 2001).

Surface water monitoring
Surface water monitoring data is held at the Department of Lands Planning and Environment in a HYDYSYS database as dbase files. Data exist from as far back as the late 1950s and early 1960s.

The data collected are primarily stream heights and rainfall. Only a small amount of routine water quality data exists and it tends to be temporally and spatially sporadic. There are currently about 130 gauging stations and 50 rainfall sites measured by the Department of Lands Planning and Environment.

Modelling of current impacts
Not applicable

Future extent
Salinity hazard has been assessed by combining information on various physical parameters that contribute toward the likelihood of dryland salinity (Tickell, 1997). No areas were classified as high hazard.
References

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.

Audit reports


### Key supporting references


\section*{State strategies}

Government of South Australia, 2000a, \textit{Directions for Managing Salinity in South Australia}, Primary Industries and Resources SA.


Government of South Australia, 2000c, \textit{State Dryland Salinity Strategy}, Primary Industries and Resources SA.

Government of Victoria, 2000, \textit{Restoring our Catchments}. Victoria’s Salinity Management Framework, Department of Natural Resources and Environment.
