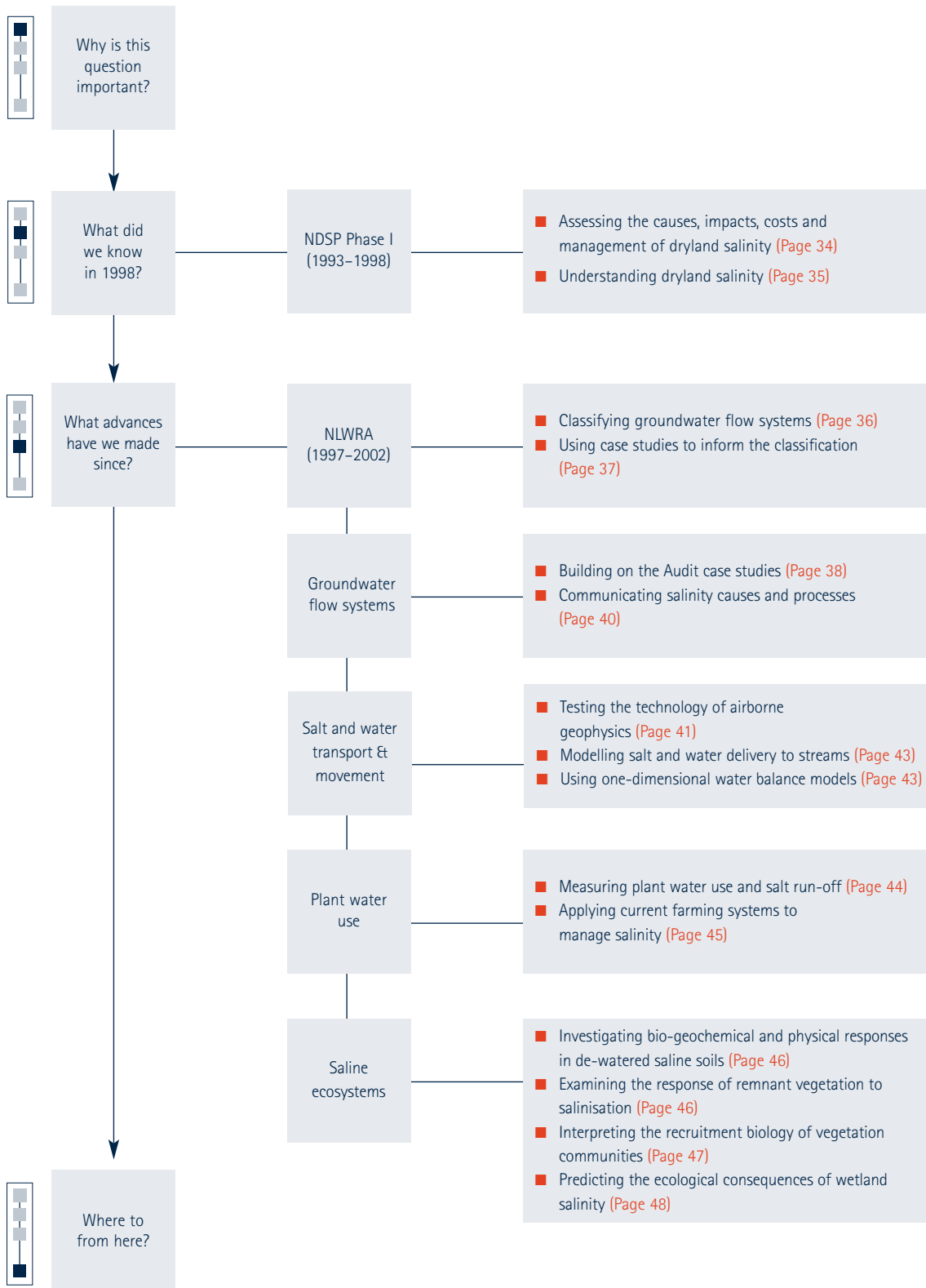


QUESTION 2

Roadmap

What are the causes and processes of dryland salinity?



What are the causes and processes of dryland salinity?



WHY IS THIS QUESTION IMPORTANT?

Understanding the causes and processes of dryland salinity will improve our ability to assess the likelihood of its expression in the landscape and its rate of spread, and to better manage the problem. This knowledge can be used to underpin basic or complex approaches to predicting the risk of salinity emergence or its spread. The more confident we are in understanding these factors, the more confident we can be in predictions and ability to take effective action.

Groundwater flow systems are at the core of this understanding as they vary from catchment to catchment and within catchments according to geology and geomorphology. Each system has key features that we must consider when assessing how that system operates and will respond to actions. This in turn helps regional and catchment planners address some of the questions that underpin their investment decisions.



WHAT DID WE KNOW IN 1998?

Our understanding of the causes and processes of dryland salinity in 1998 provided many of the foundations of today's advances. Chapter 1 in *Assessing the causes, impacts, costs and management of dryland salinity*¹ titled 'Where is the groundwater and salt in my catchment coming from?' looked at:

- Processes of salinisation
- Characterising a catchment
- Estimating recharge in a catchment
- Using recharge information for management of salinity problems
- A case study of the Liverpool Plains in NSW.

The section on 'processes of salinisation' acknowledged the importance of salt stored in the landscape. At the time, the importance of understanding the interaction between salt stores and groundwater movement was only just beginning to be more widely appreciated. In 1998, all leakage to groundwater exceeding natural rates was generally considered to be a problem, and appreciation of the need to maintain water yield and fresh water resources was limited.

The notion of 'characterising a catchment' was a new and promising concept in 1998, and a description of 15 conceptual models of groundwater related salinisation processes had just been published – known as the *National Classification of Catchments*.² This work provided the foundation for classifying groundwater systems under the Audit³, and the subsequent *Groundwater Flow Systems Framework*⁴ (discussed in Question 1, Section 1.2.1). Chapter 3 of *Understanding dryland salinity*⁵ on 'understanding salinity processes' looked at regional groundwater modelling, river catchment modelling (including the *National Classification of Catchments*) and farm scale modelling.

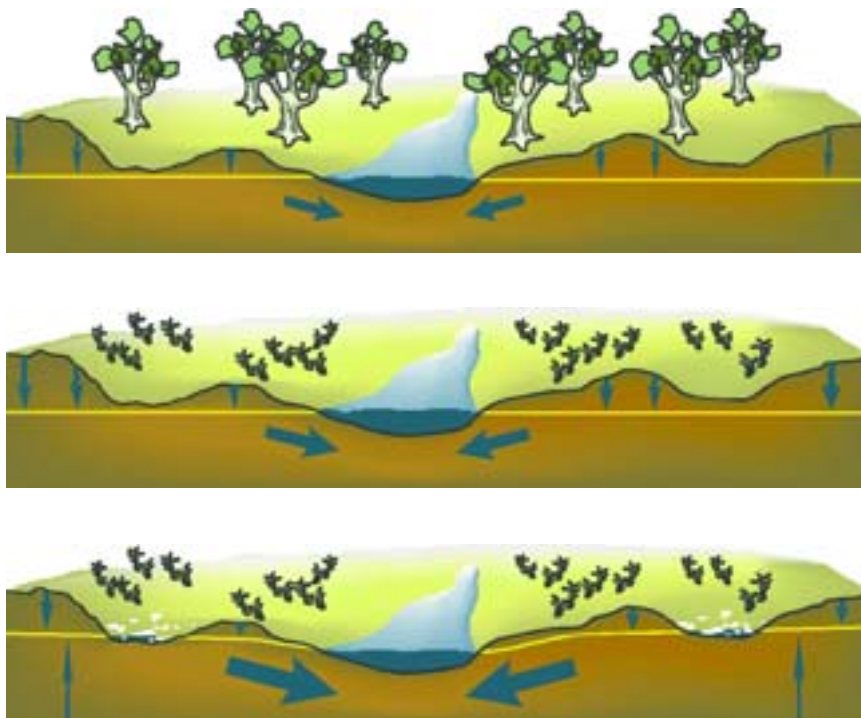
'Estimating recharge in a catchment' focused on the concept of groundwater balance. This is a simple concept where the inputs to the system need to match the outputs (i.e. the water that goes in must, eventually, come out). This approach still underpins modelling, except that our ability to measure the various inputs and outputs of water and salt is more accurate. Our understanding of these processes drives the groundwater models used to predict salinity risks. Many of the models used in 1998 have been further refined and are important tools for salinity managers today – FLOWTUBE, PERFECT, APSIM and WAVES. Water balance models are discussed in Question 4 under Section 4.3.1 'Selecting the right tool for the job'.

The Liverpool Plains case study was a seminal catchment-scale investigation, which informed later dryland salinity studies. The key findings are described in *Assessing the causes, impacts, costs and management of dryland salinity* and *Understanding dryland salinity*. Simple 'top down' catchment scale water balance modelling tools were developed and used for the first time (the FLOWTUBE groundwater model and Zhang curves – see Figure 2.3 – for catchment water yield under changed tree cover). These modelling techniques are less data intensive than the complex process-based models traditionally used in studies of large catchments and can therefore be applied more widely across Australia. In the Liverpool Plains, these new tools enabled an assessment of the relative contribution of different components of the catchment water balance to salinisation (run-off, sub-surface flow and groundwater) and highlighted the importance of whole catchment hydrology understanding for salinity management.

Figure 2.1

What causes dryland salinity? – A simplified dryland salinity scenario.

(Source: Commonwealth of Australia, 2001, *Dryland salinity in Australia: A summary of the National Land & Water Resources Audit's Australian dryland salinity assessment 2000 – Extent, impacts, processes and management options*, National Land & Water Resources Audit, Canberra ACT.)



QUESTION 2



WHAT ADVANCES HAVE WE MADE SINCE?

2.1 National Land & Water Resources Audit (1997–2002)

2.1.1 Classifying groundwater flow systems

The Audit added significantly to the understanding of dryland salinity by developing the *National Classification of Catchments* further by mapping the distribution of groundwater flow systems across Australia and providing detailed catchment case studies.

Measured data and expert knowledge were used to develop an understanding of the way a particular catchment will behave. These data include structural geology, geomorphology, aquifer properties and landscape topography, but the complexity of this task should not be underestimated given the spatial and temporal variability of catchments.

Groundwater systems are not the same across Australia and their contribution to dryland salinity also differs. The system of classification is based on recharge and flow behaviour. It uses measures such as length of flow paths through aquifers, aquifer permeability and driving pressure gradients to predict groundwater flow. Better understanding of how groundwater systems will respond to changing recharge under different land use scenarios, and what happens to the excess water is pivotal to managing dryland salinity effectively.

The Audit mapped and assessed 12 groundwater flow sub-systems. Three minor sub-systems of the 15 conceptual sub-systems defined in the *National Classification of Catchments* could not be mapped at continental scale. The assessment showed that:

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

The Audit produced continental and basin scale groundwater flow system maps and a series of fact sheets for each of the 12 groundwater flow sub-systems (see Table 2.1). Each fact sheet outlines the biophysical and landscape context in which salinity occurs, the attributes that determine groundwater responsiveness, and the processes that operate in the landscape to affect salinity. It is anticipated that the material will be updated as new information becomes available.

ACTION #2.1

Recognise that there is no one single approach to dryland salinity management, and start to understand the differences and similarities between each groundwater flow system in your region by reviewing the relevant fact sheets produced by the National Land & Water Resources Audit (www.nlwra.gov.au).



Table 2.1

Fact sheets describing major groundwater flow sub-system types

(Source: www.nlwra.gov.au)

Fact Sheet Name	
Fact sheet 1	Local flow systems in deeply weathered rocks
Fact sheet 2	Intermediate flow systems within sedimentary sequences infilling large valleys
Fact sheet 3	Local flow systems in fractured rocks
Fact sheet 4	Local flow systems in deeply weathered fractured rocks
Fact sheet 5	Local flow systems associated with colluvial fans
Fact sheet 6	Intermediate flow systems in fractured rock aquifers
Fact sheet 7	Local flow systems in fine grained unconsolidated sediments
Fact sheet 8	Regional flow systems in alluvial aquifers
Fact sheet 9	Regional flow systems within unconfined sediments
Fact sheet 10	Local flow systems associated with sand dunes
Fact sheet 11	Regional and intermediate flow systems within fractured basaltic rocks
Fact sheet 12	Intermediate and local flow systems in fractured basaltic rocks and layered sedimentary rocks

2.1.2 Using case studies to inform the classification

The Audit used intensive investigations of groundwater flow systems in five case study catchments in southern Australia to further understand the causes and processes of dryland salinity. The specific purpose of the case studies was to identify:

- Catchment areas where recharge changes significantly affects groundwater discharge and salinity
- How much recharge reduction is needed to reduce salinity
- Land use and farming system options for salinity management
- Information for a cost-benefit analysis, and the feasibility of options
- Constraints to achieving the change needed.

The catchments were selected on the basis of their salinity status and information availability, and because they were representative of the most salt-affected land types in Australia. The case studies built on the conceptual development and systems understanding gained through the NDSP Phase I focus catchments – in particular the Liverpool Plains (NSW)⁶, Upper South East (SA)⁷ and Loddon-Campaspe catchments (Victoria)⁸. The case study catchments were:

Kamarooka, Victoria⁹ – a local flow system in variably weathered fractured rock (groundwater discharge at break-of-slope)

Lake Warden, Western Australia¹⁰ – a local and regional groundwater flow system in alluvial sediments and deeply weathered rocks

Upper Billabong, New South Wales¹¹ – local and intermediate groundwater flow systems in variably weathered fractured rocks in connection to regional flow system in alluvial aquifers

Wanilla, South Australia¹² – a local to intermediate flow system in deeply weathered rock (groundwater discharge at break-of-slope and valley floors)

QUESTION 2

Great Southern, Western Australia¹³ – local and intermediate flow systems in deeply weathered rocks (this case study was not included in the *Groundwater Flow Systems Framework* publication).

The Audit studied data-rich catchments with well-documented information on many of the factors that affect groundwater recharge and discharge:

- Land clearing (when and where)
- Farming practices (what has been grown where)
- Deep drainage (leakage under various land uses)
- Seasonal rainfall, run-off and evaporation
- Piezometer and borehole data
- Landscape elevation
- Soil properties
- Regional geology.

Groundwater modelling using FLOWTUBE¹⁴ was undertaken to simulate the major processes driving the recharge and discharge of water in each of the groundwater flow systems studied. Data availability enabled researchers to simulate the groundwater behaviour exhibited by the catchment under the current salinity conditions using FLOWTUBE. The model was then used to predict likely behaviour under different land use and land management scenarios. These case studies gave confidence in the conceptual models, which may then be used to help prioritise actions in other similar catchments.

In keeping with earlier findings from the Liverpool Plains case study reported in *Assessing the causes, impacts, costs and management of dryland salinity*, the case studies highlighted the difficulties in reconciling outputs from the crop and pasture models with those from the groundwater models. While some further advances are described in this chapter under section 2.3.3 'Using one-dimensional water balance models', this remains a key gap in understanding and integrated modelling capabilities.

ACTION #2.2

Evaluate the availability of local data for each groundwater flow system in your catchment, and assess the likelihood of gathering additional data and the extent to which you will need to draw on understanding of like systems elsewhere to inform management decisions.



ACTION #2.3

Identify whether any of the groundwater flow systems in your catchment are of the same type as the 10 case study catchments investigated by the Audit and the Catchment Classification project. If so, review the relevant technical reports for more detailed information.



2.2 Groundwater flow systems

2.2.1 Building on the Audit case studies

Since the Audit report on salinity, the 'Catchment Classification'¹⁵ project has investigated a further five case studies:

- **Liverpool Plains, New South Wales**¹⁶ – a regional flow system in alluvial aquifers
- **Southern Loddon Plains, Victoria**¹⁷ – a regional flow system in alluvial aquifers
- **Kyeamba Creek catchment, New South Wales**¹⁸ – intermediate and local flow systems in fractured rock
- **Axe Creek catchment, Victoria**¹⁹ – intermediate and local flow systems in fractured rock
- **Brymaroo catchment, Queensland**²⁰ – a local flow system in fractured basalts.

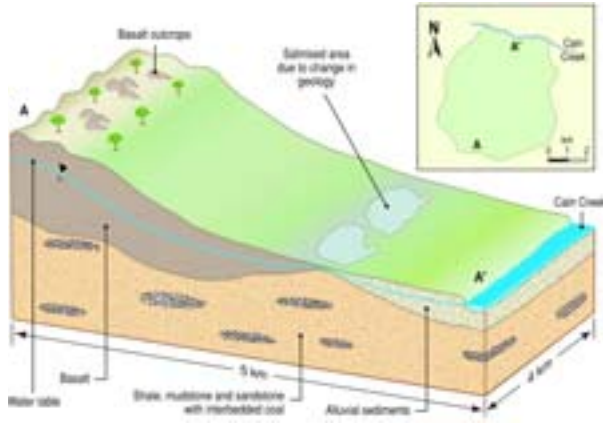
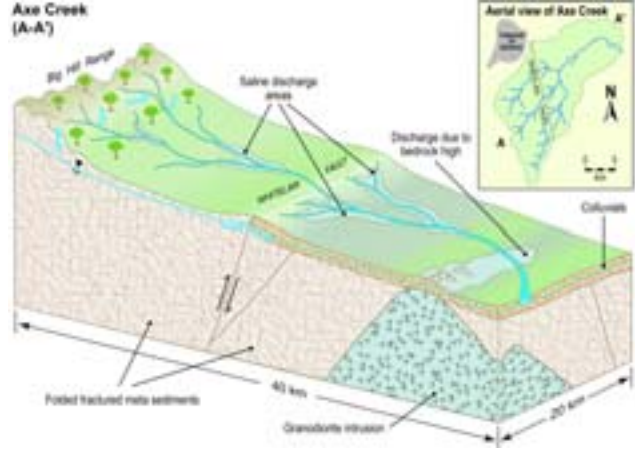
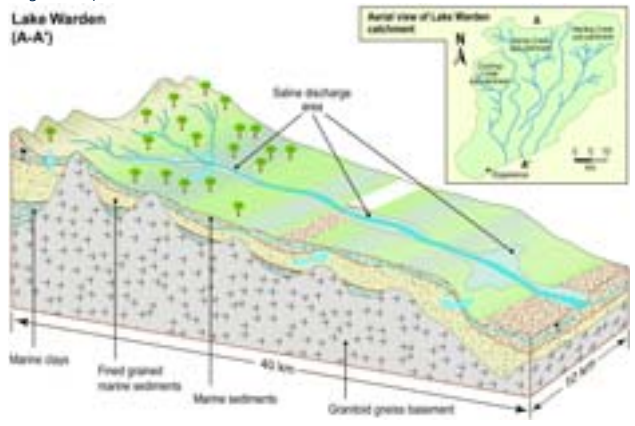
The value of the 10 case studies is much greater than just the light they shed on particular catchments if the lessons can then be extended to other catchments. The first and most important test made by the 'Catchment Classification' project was to check that the case studies represented the conceptual models developed by the *National Classification of Catchments* (NCC) (see Table 2.2).

At the broadest level of the *National Classification of Catchments*, our detailed understanding of the case study catchments matched the range of different groundwater flow systems types. This agreement gives confidence in the system, and in our ability to map groundwater flow systems.

Table 2.2

Comparison of generic predictions with modelled case studies

(Source: modified from Walker G., Gilfedder M., Evans R., Dyson P., and Stauffacher M., 2003, *Groundwater flow systems framework: Essential tools for planning salinity management*, MDBC Publication 14/03, Murray–Darling Basin Commission, Canberra ACT)

GFS	Predictions of NCC conceptual model	Case study modelling
<p>Local systems</p> 	<ul style="list-style-type: none"> ■ Farm-based solutions involving revegetation and perennial cropping in recharge areas and limited use of engineering treatments such as surface drains 	<ul style="list-style-type: none"> ■ 50% recharge reduction should reduce salinity by 30% in 20 years (Brymaroo catchment) ■ 50% recharge reduction should reduce salinity export by 50% (Kyeamba catchment)
<p>Intermediate systems</p> <p>Axe Creek (A-A')</p> 	<ul style="list-style-type: none"> ■ Surface appearance of salinity may be very limited, but there may be extensive salt export to local streams ■ Longer time lag between recharge reduction and impact on discharge ■ Groundwater pumping from fractured rock systems can be difficult to establish 	<ul style="list-style-type: none"> ■ Discharge predominantly into local streams ■ Discharge commenced 50–100 years after clearing; 90% recharge reduction over 500 years to stop discharge (Axe Creek catchment) ■ Groundwater pumping was not considered
<p>Regional systems</p> <p>Lake Warden (A-A')</p> 	<ul style="list-style-type: none"> ■ Amenable to groundwater pumping ■ Farm-based and vegetation strategies precluded by magnitude of system (long response times) ■ Productive use of salt is an option 	<ul style="list-style-type: none"> ■ Respond positively to pumping ■ 50% recharge reduction requires 75% of area revegetated with perennials, resulting in a reduced rate of groundwater rise by 2100 (Lake Warden catchment) ■ Productive use of salt is successful where discharge is not highly saline

QUESTION 2

ACTION #2.4

Refer to the Tools Information Packages, Healthy catchment guide, Salinity management handbook and Rapid Catchment Appraisal program to better understand the causes and processes of dryland salinity (or use them as a model), and consider developing conceptual diagrams for each major groundwater flow system using the Wimmera Regional Information Package as a guide.



2.2.2 Communicating salinity causes and processes

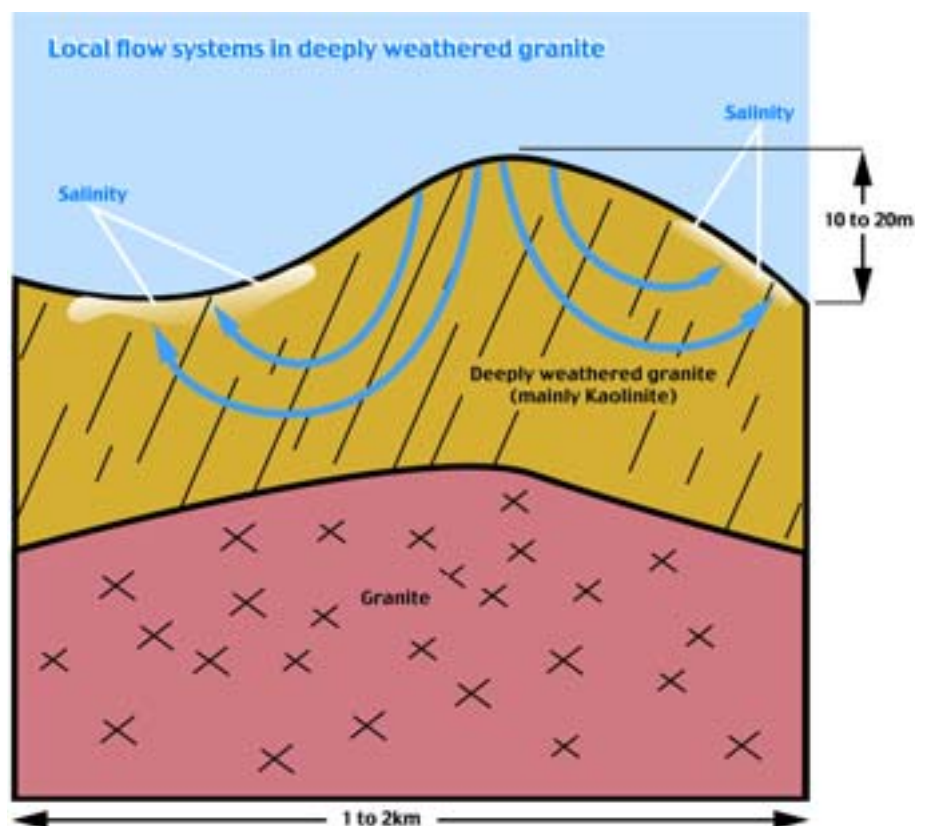
The Tools²¹ project developed an overarching *Salinity Information Package*,²² which was described in the Introduction. The 40 information sheets in this package include descriptions of the causes and processes of dryland salinity. Likewise, the 10 *Regional Information Packages*²³ for major catchments of the Murray–Darling Basin describe the causes and processes of salinity for each groundwater flow system type, and what this means for the management options. The packages were developed in consultation with regional stakeholders and technical experts, and incorporate local knowledge of groundwater processes and behaviour.

The Wimmera region in Victoria has progressed to developing a 'second generation' information package, building on the framework of the first version. The region has revised its salinity plan and investment strategy, and the outcomes of this process have been embodied in the new *Wimmera Regional Information Package*²⁴. The package is supported by diagrams of the conceptual models that inform each of the groundwater flow system types (see Figure 2.2). A list of *Regional Information Packages* for catchments of the Murray–Darling Basin is provided in Question 1 (page 17).

Figure 2.2

The Wimmera Regional Information Package provides an example of a conceptual diagram of groundwater flow systems

(Source: Murray–Darling Basin Commission, 2004, *Tools for improved management of dryland salinity in the Murray–Darling Basin – Wimmera regional information package* (Version 2), Murray–Darling Basin Commission, Canberra, ACT.)



A practical handbook entitled *Healthy catchment guide*²⁵ has also been published for the South West Slopes of the Murray Catchment (NSW). It looks at salinity processes relevant to the South West Slopes and discusses why this area is a 'salinity priority' in greater Murray River Catchment (NSW) context. It draws on the *Groundwater Flow Systems Framework*, the 'Tools' information packages and *Land Capability Classification* to provide a practical guide to priorities for vegetation placement for salinity, which can be applied at a property level.

For north-eastern Australia and as a model more broadly, the *Salinity management handbook*²⁶ has been developed that provides a comprehensive and practical introduction to salinity. It comprises three parts – understanding salinity, investigating salinity and managing salinity. 'Understanding salinity' describes the three major types of salinity and looks at salinity and hydrology management. 'Investigating salinity' provides practical information for planning and carrying out salinity investigations, considering geomorphic features, climate and land use. Indicator plant species and soil and water data are used to determine the extent of salting and the processes contributing to the problem. 'Managing salinity' considers vegetation, irrigation and engineering applications, and the process of developing an integrated plan of management.

In Western Australia, the *Rapid Catchment Appraisal* (RCA) program (<http://agspsrv34.agric.wa.gov.au/environment>) under the Western Australian Salinity Strategy²⁷ uses satellite-based salinity mapping to estimate current extent and risk, analyse the impact of management options, and direct salinity management at the regional level.

2.3 Salt and water transport & movement

2.3.1 Testing the technology of airborne geophysics

Airborne geophysics has been used to improve our understanding of the process by which salts move through the landscape from where they are stored to their discharge to land or water. Understanding these processes enables better prediction of risks and effective options for management.

The *National Airborne Geophysics Project*²⁸ (NAGP) comprised five pilot studies in four States included extensive field surveys to test several geophysical systems in airborne electromagnetics (salt), magnetics (geology) and radiometrics (soils). It analysed these systems and their ability to map salt, geology and soils. The work emphasised the value of airborne geophysics datasets in improving understanding of the landscape, sub-surface structure and hydrological process at catchment scale. It has provided a list of 12 core datasets required for salinity-related catchment planning (see Table 2.3), concluding that airborne geophysics is most beneficial when used in conjunction with other datasets when preparing detailed management plans at the catchment and paddock level.

The project concluded that airborne geophysical systems were accurate and that they provided an effective means of improving our understanding of the landscape, sub-surface structure and the hydrological process at catchment scale. However, airborne geophysical data are analytically complex, consume time, funds and test the capacity of researchers and providers alike. The future application of these systems depends on there being a clear cost and benefit statement and that the best systems are chosen to answer the specific question being posed. Regionally-based and generic tests of revised airborne electromagnetic systems are no longer required; emphasis on applications and delivering benefits to investors should be the major focus.

Table 2.3

Twelve key biophysical datasets required for salinity-related catchment planning

(Source: George R., Beasley R., Gordon I., Heislors D., Speed R., Brodie R., McConnell C., and Woodgate P., 1998, *Evaluation of airborne geophysics for catchment management*, The National Airborne Geophysics Project, Department of Agriculture, Fisheries and Forestry – Australia and National Dryland Salinity Program, Canberra ACT.)

1.	Topography and drainage derived from a hydrologically sound Digital Elevation Model (DEM ± 1 m accuracy)
2.	Orthophotos
3.	Hydrological data (water table depth, salinity, hydraulic properties and trends)
4.	Multi-spectral data (satellite: Landsat TM) and classifications (e.g. salinity, chemistry, vegetation)
5.	Magnetics (to improve geology)
6.	Radiometrics (to improve geology and soils/landscapes)
7.	Field geology and related interpretations
8.	Electromagnetics (ground and airborne; targeted application)
9.	Meteorological data (rainfall, evapotranspiration, etc.)
10.	Soils – Land Management Units (LMUs and other classifications)
11.	Land use (spatial and temporal)
12.	Cadastral and GIS data on related infrastructure

Analysis of the benefits and costs of airborne geophysics²⁶ suggest that it is more likely to be effective and economic where:

- There is relatively poor existing natural resource data available to assess the risks and options for management, and the relative importance of this knowledge in management is high
- The options for salinity management are understood (both impacts and costs) and cost-effective
- Specific management actions can be derived from the geophysics
- Off-site and on-site benefits are high (for example, protecting major public assets), and can be quantified.

These findings were supported by the *NSW Western Slopes cropping*²⁹ project, which concluded that:

- Salt mass-balance is hard to evaluate both within and between catchments due to the uneven distribution of salt stores and mobility. Recent improved modelling of airborne electromagnetic (AEM) data enables us to determine salt stores in landscapes. Subsequent understanding of groundwater movements will assist to provide quantitative estimates of salt fluxes through the landscape.
- The commonly used salt input/output ratio does not consider the dynamics of salt mobility. Accession of salt to the landscape is mostly via precipitation (cyclic salt) and dry deposition of wind-blown salts from inland lakes. Some weathered and re-mobilised salt will also leave, but most salt is relatively young in origin.
- Use of the *Groundwater Flow Systems Framework* approach to understanding dryland salinity should be developed to account for the interactions between stacked or overlain systems.

A number of airborne geophysical studies across the country have shown the applicability of the technologies to salinity such as in Honeysuckle Creek (Goulburn–Broken catchment, Victoria) and Upper Billabong Creek (Murrumbidgee catchment, NSW). The *South Australia Salinity Mapping and Management Support*³⁰ project was the first to target specific questions related to salinity, rather than purely mapping the distribution of salt, soils and sub-surface features. This covered the Riverland and Tintinara (investigating a clay-rich layer that reduces recharge rates to the underlying aquifer and the subsequent rates of discharge of salt to the Murray); around Jamestown (the underground network of palaeo-channels defined the causes for salinity without directly mapping salt); and beneath the Angas–Bremer Plains (the extents of the lower salinity aquifer were defined with improved accuracy and storage estimates made from the airborne electromagnetics).

2.3.2 Modelling salt and water delivery to streams

The paper *Mobilisation of Salts in Australian Landscapes*³¹ considers an integrated understanding of catchment surface water flows, groundwater dynamics, salt distribution and salt transport processes within different parts of the landscape. It summarises contemporary techniques used to describe and predict catchment water balances and salt mobilisation, including the *Groundwater Flow Systems Framework*. It concludes that we generally lack the critical biophysical data and integrated modelling approaches needed to define the timeframes and specific management requirements of individual catchments.

The *Salt Delivery*³² project sought to develop an understanding of landscape processes in areas at high risk of waterlogging and salinity using an integrated approach to interpreting landscape function, including airborne geophysics. The study focused on the Simmons Creek sub-catchment (177 km²), located in the Billabong Creek catchment near Walbundrie in southern New South Wales and was aligned with the *Heartlands*³³ initiative.

It incorporated the disciplines of pedology, hydrology, hydrogeology, terrain analysis and modelling. Data collection, monitoring and modelling activities included:

- A soil and regolith survey, with spatial modelling of soil properties
- Groundwater monitoring
- Stream gauging (water quantity and quality)
- Weather observation
- Conceptual modelling of hydrology and salt movement
- High resolution terrain analysis
- Hydrological modelling of water and salt movement.

The project has developed an understanding of the hydrological function of the Simmons Creek catchment, determined the salinisation processes and suggested management options.

2.3.3 Using one-dimensional water balance models

One dimensional water balance models are widely applied in crop production simulations. These models do not, however, predict lateral sub-surface flow of water. Any water draining below the root zone is assumed to move vertically and recharge the groundwater system. This limits their relevance in a salinity context which requires a more robust conceptualisation of excess water partitioning (2–3 dimensions). Water balance models and the methods used to improve the prediction of recharge are described in more detail in Question 4 (section 4.3.1 – Selecting the right tool for the job).

ACTION #2.5

Use airborne geophysics in a strategic way to help understand the process by which salts move through the landscape where available information supports its application.



ACTION #2.6

Consider the relevance of the sub-catchment scale approach used in the Salt Delivery project and the Heartlands initiative to understanding hydrological function and the mechanisms of salt transport within parts of your region.



ACTION #2.7

Be aware that using the outputs of one-dimensional models for dryland salinity planning and management and water allocation in hilly terrain has limitations and that decision-making processes should take reasonable account of sub-surface lateral flow and vertical drainage.



QUESTION 2

2.4 Plant water use

2.4.1 Measuring plant water use and salt run-off

Woody vegetation retention and increasing the perennials in a landscape through planting trees or perennial pastures are key strategies of many salinity management plans. Advances have been made in plant water use processes and their implications for catchment water yield and salinity.

The publication *Plantations, farm forestry and water: A discussion paper*³⁴ considers water balance in the landscape, planted forests and water issues, and the effects of afforestation on water and on salt mobilisation. Case studies for the Murray–Darling Basin southern high-rainfall region, the Green Triangle, Macquarie Valley and south-west of Western Australia are provided.

The following four review papers are presented in the report 'The ways trees use water'³⁵:

- Tree water use and its implications in relation to agroforestry
- Does leaf water efficiency vary among eucalypts in water-limited environments?
- Relationships between water use efficiency and tree production
- Root distributions and water uptake patterns in eucalypts and other species

A recent publication called *Planning for Change – Understanding the impacts of afforestation on catchment runoff and river salinity*³⁶ considers the amount of water used by plants and the effects of afforestation on the catchment water balance, with particular reference to effects on seasonal flows and changes in low flows and the implications for in-stream salt concentrations. It demonstrates that reforestation targeted at medium rainfall zones (500–800 mm/yr) is more beneficial for dryland salinity management than in the higher rainfall zone, as it has less impact on runoff quantity (dilution flows) but similar benefits in recharge reduction.

It builds on the report *Predicting the effect of vegetation changes on catchment average water balance*,³⁷ documenting the so-called 'Zhang curves' (see Figure 2.3), and particularly draws on the work of the 'Environmental impacts'³⁸ project and its related 'Impacts and land use change'³⁹ project. The report summarises the current state of knowledge as:

- Mean annual run-off from catchments will decrease following land use change from grass to trees; the reduction can be estimated using a simple water balance model.
- Reduction in mean annual run-off is dependent on the kind of revegetation carried out. In south-eastern Australia, pine plantations yield less run-off than native eucalypt plantations, primarily due to the greater interception of rainfall by pines. Productive hardwood plantations probably yield as much water as pine plantations, though little data is available to support this assertion.
- Run-off reduction following afforestation is generally proportional to the percentage of tree cover. In small catchments, it is difficult to detect a yield change if less than 20 per cent of the catchment has experienced a change in land cover.
- Groundwater recharge under forest is lower than under pasture and crops and is often close to zero. Hence plantations can lower groundwater levels. This may or may not be a good outcome, depending on the utility and salinity of the groundwater system underlying the plantation.
- While afforestation has the greatest impact on absolute flow in high rainfall areas, the greatest *proportional* reduction is in the low rainfall areas or at times of low flow.

- The number of low or zero flow days is likely to increase following afforestation. Complete afforestation of small headwater catchments with mean annual rainfall of c. 900 mm can reduce the number of zero-flow days from 0–50 to 175–225 days per year.
- Run-off reductions are minor for the first five years after afforestation and are greatest 10–20 years after planting.
- Water yields from forests slowly increase after 30 years of age as water use starts to decline in association with reduced growth rate.
- Thinning forest and forest clearing can also lead to increased water run-off. The magnitude of the run-off increase depends on the proportion of the forest cleared and the age of the trees.

ACTION #2.8

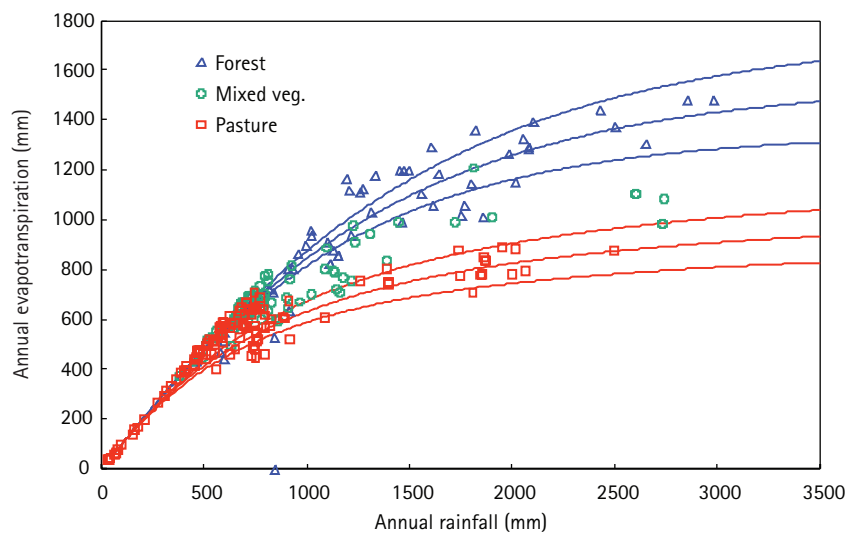
Inform yourself about the trade-offs between managing the movement of salt versus the movement of water in the landscape before considering large-scale afforestation in any part of your region, and refer to Australian case studies where large-scale afforestation has taken place.



Figure 2.3

The Zhang curves show the relationship between annual evapotranspiration and rainfall for different broad vegetation types. The middle blue curve indicates the relationship for *forested* catchments, and the middle red curve for *pasture* catchments, with *mixed vegetation* catchments somewhere between the two. The lines either side indicate 95% confidence intervals.

(Source: Zhang L., Vertessy R., Walker G., Gilfedder M., and Hairsine P., (in press), *Planning for change – Understanding the impacts of afforestation on catchment runoff and river salinity*, CRC for Catchment Hydrology Industry Report, CRC for Catchment Hydrology, Clayton VIC.)



2.4.2 Applying current farming systems to manage salinity

The report *Effectiveness of current farming systems in the control of dryland salinity*⁴⁰ and its companion document *A revolution in land use: Emerging land use systems for managing salinity*⁴¹ show that farming systems based largely on shallow-rooted annual crops and pastures simply cannot control leakage to groundwater where rainfall exceeds 600 mm – even when adopting current recommended practices (the 'Landmark'⁴² project has produced a directory⁴³ of industry current recommended practices for traditional dryland broadacre agriculture).

QUESTION 2

ACTION #2.9

Identify where woody perennial vegetation will be of greatest benefit in your catchment with due consideration to the location of salt stores.



ACTION #2.10

Establish the extent to which dryland salinity management is reliant on the development of alternative farming systems in your catchment.



ACTION #2.11

Use the classification system developed by the Saline Soils project to identify the types of saline soils amenable to de-watering in your catchment.



There is very sound evidence that lucerne⁴⁴ has potential to provide significant soil water deficits and contribute to reduction of recharge, although establishment and persistence are limited by soil constraints, particularly acidity and aluminium toxicity. Alley farming and phase farming systems may be effective in reducing groundwater levels but variable profitability limit their application at this stage.

Widespread leakage below traditional farming systems which mobilises salt stores through increased hydraulic pressure is the fundamental cause of our expanding dryland salinity problem. While groundwater recharge contributes flows to rivers and downstream water users, we need profitable solutions for turning off the unwanted groundwater recharge driving dryland salinity. At present, alternative farming systems are largely confined to lucerne, forestry and farm forestry options.

2.5 Saline ecosystems

2.5.1 Investigating bio-geochemical and physical responses in de-watered saline soils

The *Saline Soils*⁴⁵ project aimed to improve understanding of the chemical, physical and biological changes in soil after salinisation. Prior to this project, uncertainties existed on the bio-geochemical processes involved in saline soils and being able to predict the physico-chemical changes that occur when they are drained or disturbed, partly because saline soils have been considered to have little agricultural value.

A classification system was developed identifying 22 types of dryland saline soils in farming regions of southern Australia with differing properties.

Seventeen paired sites were studied in eight different groundwater flow systems. The researchers found that progressive development of saline environments is caused by different physico-chemical processes when land is drained or disturbed.

Three generic conceptual models have been developed to summarise the processes involved in the changes leading to different soils or poor water quality when a saline landscape is drained or disturbed. The three models include saline soils progressively affected by:

- sodium and chloride from groundwaters (halite-dominant)
- sulphur, sodium and chloride from groundwaters (sulphidic-, gypsic-dominant)
- transient salinity in the root zone (dry saline land), restricted permeability within sodic subsoil layers.

It was found that saline soils do not always return to their former state after being drained or disturbed, and that tailored management is needed.

2.5.2 Examining the response of remnant vegetation to salinisation

While the physiological processes of salinity and/or waterlogging tolerance on native species are well understood, few studies in Australia have focused on how native plant communities respond to the development of secondary salinity. Given that remnant vegetation on Australian agricultural land is often small in extent, highly fragmented and likely to be degraded by grazing, weeds and other factors, rising water tables may deliver the final blow to maintaining their ecological integrity.

Because of the availability of pre-existing data, the *Restoring Native Vegetation*⁴⁶ project was conducted in the upper and middle Blackwood Basin in Western Australia. One reason for choosing this location was that the south-west of Western Australia has been designated one of 25 world 'hot spots' for biodiversity and the only one in Australia.

The investigations concluded that all remaining native vegetation is valuable in terms of conserving diversity and providing ecosystem services to surrounding farmland. It is difficult, if not impossible, to determine clear eco-hydrological tolerances for plant communities due to the temporal and spatial variability of water levels and flows and the variability in species compositions across small distances (at least in south-west Western Australia).

The project findings also question the relevance of determining such tolerances. Plant communities seem to collapse, often due to unusual or infrequent events and, within this context, tolerance of 'average' conditions may not be relevant.

Investigation of the interactions between groundwater characteristics and dynamics, soil characteristics, micro-topography and vegetation responses elucidated opportunities for managing vegetation at the micro-scale. For example, where micro-topographic differences influence vegetation health, then opportunity exists to maintain some elements of the current vegetation in areas of higher micro-topography, with the rest planted with salt-tolerant species, thus creating a new ecosystem mosaic.

Two papers presented at the 9th Murray–Darling Basin Groundwater Conference on *Groundwater lowering and environmental flow options for Chowilla*⁴⁷ and *The floodplain impacts model: A tool for assisting the assessment of groundwater inflows to the floodplains of the lower River Murray*⁴⁸ provide detailed background and references on the extensive research effort on floodplain salinisation and the health of River red gums. A simple, one-dimensional analytical model⁴⁹ has been developed that distributes floodplain groundwater discharge as seepage at the break-of-slope, evapotranspiration across the floodplain and as groundwater flow into and out of the river. The model has been applied using regional scale GIS data to the lower River Murray in south-eastern Australia. It can be used as a planning tool to assess potential impacts to floodplain and wetland vegetation and the river from irrigation developments and river management. The report *Spatial modelling of groundwater discharge patterns to predict floodplain salinisation and impacts on vegetation health*⁵⁰ looks at using the quasi-three dimensional groundwater model MODFLOW 96 to simulate regional groundwater flow through a floodplain on the lower River Murray, achieving good accuracy for total volumes of evapotranspiration and seepage on a floodplain scale.

2.5.3 Interpreting the recruitment biology of vegetation communities

The *Recruitment Biology*⁵¹ project aimed to develop a greater ecological understanding of vegetation affected by dryland salinity and waterlogging at plant community scale. Salinity levels in riparian wetlands and the groundwater under adjacent plant communities are rising and destroying large areas of remnant vegetation. Remnants along drainage lines are particularly vulnerable to hydrological change. Many of south-western Australia's rivers are associated with low gradients and deeply weathered landscapes in which salt has accumulated over tens of thousands of years. Plant communities, such as those associated with yate (*Eucalyptus occidentalis*) woodland, persist along these naturally saline rivers in the upper tributaries of the Gairdner River in Western Australia, where this project was based.

ACTION #2.12

Apply a precautionary principle in the management of remnant vegetation affected by, or at risk of, dryland salinity, recognising that plant communities can collapse due to unusual or infrequent events, and consider opportunities for managing vegetation at a micro-scale.



ACTION #2.13

Identify remnant vegetation on riparian land, along drainage lines and in wetlands vulnerable to hydrological change or in need of restoration, and use the findings of the 'Recruitment Biology' project to support your management decisions.



QUESTION 2

ACTION #2.14

Study the relationship between increasing salinity and the health of wetland ecosystems in your region, using results of the Wetland salinity project as a guide.



R&D TIP #2.1

Review the strategic plan for the National Land & Water Resources Audit Phase II (www.nlwra.gov.au), the Catchment Modelling Toolkit (www.catchment.crc.org.au) and the 'National Evaluation Framework' project for information on proposed data and model development.

R & D TIP #2.2

Further development of the Groundwater Flow Systems Framework will take place at several levels – nationally through the NLWRA and the National Evaluation Framework project (www.brs.gov.au); for the Murray–Darling Basin through the MDBC (www.mdbc.gov.au); as well as at State and regional levels.

Interim results confirm that a greater understanding of vegetation response to changes in soil/water regimes is necessary to identify the key processes driving changes to plant community health, structure and diversity in saline lower landscapes. Soil and water regime thresholds need to be identified to maintain biodiversity in remnant riparian systems and restore sites affected by hydrological change. Even plant communities adapted to naturally saline conditions are not immune to change when critical thresholds are exceeded.

2.5.4 Predicting the ecological consequences of wetland salinity

The *Wetland salinity*^{52,53} project is investigating the relationship between increasing salinity and the structure of biological communities that develop from aquatic plant seeds and zooplankton eggs stored in the sediments of wetlands and rivers. The first stage of this project has been completed. Preliminary results indicate that salinity above 1500 EC units reduces the diversity and abundance of aquatic plant and invertebrate communities. However, plant and animal communities from different wetlands responded to different salinity levels in different ways. The effects of increasing salinity were more obvious in edge plant communities than those more frequently flooded.

WHERE TO FROM HERE?

National Land & Water Resources Audit

The Audit concluded that further integration of groundwater models with farming systems models is needed to more accurately predict the effectiveness of individual farming systems on managing salinity. To do this, the processes that underpin the models need to be better understood. This will require more detailed data about the land systems characteristics of those groundwater flow systems, which is not yet available in most catchments at risk of dryland salinity.

Groundwater flow systems

We can claim to broadly understand the causes and processes of dryland salinity, and have developed the *Groundwater Flow Systems Framework* to extend what we know about one part of the landscape to other parts in some instances. The level of detail we need about dryland salinity processes will depend upon the management and investment decisions in question. For most parts of Australia, what we know about dryland salinity processes, particularly guided by the type of groundwater flow system (local, intermediate, regional), is adequate for some broad-scale prioritisation decisions. Getting down to the design phase will require more specific investigations about processes.

We need to continue to refine the *Groundwater Flow Systems Framework* and its associated groundwater dynamics by better understanding how individual systems function – their hydraulic gradients, specific yields, etc. – and the linkages between stacked or layered groundwater flow systems. Further case study investigations are needed to unravel the complexities of these systems and understand their similarities and differences. There are no case studies for some sub-system types.

The 1:250,000 resolution regional groundwater flow systems maps and supporting 'Tools' information packages developed for the Murray–Darling Basin are more detailed than for most other parts of Australia; however 1:100,000 resolution maps will be needed to design activities

in priority areas. The development of regional information packages could be extended outside of the Murray–Darling Basin, especially to high priority areas for dryland salinity management. Within the Murray–Darling Basin, catchments could progress to developing second generation packages similar to that developed in the Wimmera Region (Victoria).

Salt transport & movement

The application of airborne geophysics technology should be closely aligned with the *Groundwater Flow Systems Framework*. Airborne geophysics can deliver three of the 12 critical data sets for salinity planning identified in Table 2.3. It should both be guided by and inform the refinement of the *Groundwater Flow Systems Framework*, ensuring that mechanisms are in place to transfer relevant information between regions. As an expensive technology that generally requires interpretation in the light of other biophysical data, it should be strategically targeted within priority areas.

Further understanding of processes governing the delivery of salt and water to streams requires good quality, strategic monitoring of stream flows, groundwater levels and salt concentrations. These are essential for developing a sound conceptual model and subsequent quantitative model of catchment function. Investment in a program of field investigation should be followed up with critical monitoring as the most cost-effective means of resolving remaining uncertainty.

The knowledge that potential water yield and stream flow could be adversely affected under certain treatments (e.g. tree planting) suggests that catchment managers need to proceed with caution when implementing certain treatments that, in the past, have been considered as best-bets.

Plant water use

Understanding plant water use and the movement of water and salt in the landscape remains a hurdle in understanding dryland salinity processes, and consequent ability to model water balances accurately. The coupling of groundwater and farming systems models to adequately account for the lateral movement of water in the landscape both across and beneath the surface is an important area for further investigation.

Improved understanding of the movement of water and salt in the landscape will assist in refining estimates of seasonal flow (and zero flow) and the associated salt loads and concentrations. More refined estimates are necessary for ensuring water security in terms of both quality and quantity of supply, and in setting and meeting end-of-valley salinity targets.

The potential for lucerne and other perennials to manage groundwater recharge requires further evaluation for various groundwater flow systems and climatic regions. In addition, management constraints due to soil characteristics need to be addressed.

Native grasslands occupy a significant part of the landscape, supplying substantial fresh water to aquatic ecosystems and downstream users, and representing important ecosystems in their own right. More detailed understanding about the role native grasslands play in water delivery processes and as part of our terrestrial biodiversity estate is needed, and their protection from large-scale conversion to sown pastures or woody perennials.

R & D TIP #2.3

Keep abreast of activities and advances in airborne geophysics mapping and research findings (www.affa.gov.au).

R & D TIP #2.4

Follow up on the progress of the Heartlands initiative (www.clw.csiro.au/heartlands)

R & D TIP #2.5

Consider the on-going development and measures in place to implement and monitor the agreed end-of-valley targets under the Basin Salinity Management Strategy (www.mdbc.gov.au).

R & D TIP #2.6

Review the CRC for Catchment Hydrology web-site (www.catchment.crc.org.au) to keep abreast of improvements in modelling to account for plant water use and lateral movement of water in the landscape.

R & D TIP #2.7

Consider the CRC for Plant-based Management of Dryland Salinity (www.crcsalinity.com) Program 3, Subprogram 5, which includes research on native grasses and lucerne.

QUESTION 2

R & D TIP #2.8

Consider the CRC for Plant-based Management of Dryland Salinity (www.crcsalinity.com) Program 2 on 'Function of natural ecosystems', which includes research on how ecosystems function in recharge zones, and how ecosystems function in soil affected by salinity and waterlogging, and Program 7 on opportunities for enhancing biodiversity in salinising landscapes.

Saline ecosystems

There is a need for a coordinated national framework of dryland saline soils sites to provide long-term data on changes in saline soils. Datasets are scarce or non-existent in groundwater flow systems outside southern Australia and there is little monitoring of long-term changes in saline soils anywhere. In particular, datasets are scarce for Western Australia and New South Wales, and no data exist for Tasmania, Queensland and Northern Territory.

We need much better information on the responses of remnant native vegetation communities at risk from salinisation to extreme events that cause their collapse. Remnant vegetation needs to be managed so that the natural system is well within its buffering capacity for extreme events, and this may not be achieved if we aim to manage vegetation at the upper end of its tolerance limits.

Information on plant communities existing on naturally occurring saline soil, and their regeneration and restoration potential is limited. Vegetation response to salinity along saline drainage lines has also received little attention. An understanding of recruitment strategies and vegetation health, structure and diversity of plant communities in saline soils will help improve restoration plans for land affected by secondary salinity and waterlogging.