Dryland Salinity: On-Farm Decisions and Catchment Outcomes

A Guide for Leading Producers and Advisors

National Dryland Salinity Program

Know-how to tackle salinity

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Australia's National Dryland Salinity Program is a collaborative research and development effort that is investigating the causes of, and solutions to, the national problem of dryland salinity. It was initiated by Land & Water Australia (formerly LWRRDC) in 1993 and has involved a wide range of funding partners and research organisations. It has been managed by Land & Water Australia since its inception.

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Finally, Dr Richard Price managed the National Dryland Salinity Program for 11 years from its inception to the production of these synthesis reports. For the first 10 years Richard worked as a program manager within Land & Water Australia and in this final year as a consultant to Land & Water Australia. Throughout this period, Richard's enthusiasm, drive, keen insights, extensive network and excellent program management skills have been fundamental to the success and impact of the NDSP. This has been an important contribution to salinity research in Australia, and to the wider understanding within the Australian community of the salinity challenge we face and how to manage it.

The National Dryland Salinity Program is jointly supported by the following organisations

State Governments of South Australia, New South Wales, Queensland, Western Australia, Victoria and Tasmania.

FOREWORD

This report represents in part the culmination of an extraordinary adventure.

The National Dryland Salinity Program (NDSP) was established in 1993 by Land & Water Australia, the National Landcare Program, the Murray Darling Basin Commission and the State governments of New South Wales, Queensland, Victoria, South Australia and Western Australia, in recognition of the need for a coordinated approach to dryland salinity research in Australia. The NDSP has invested over $40 million into new knowledge and understanding, technologies, decision-support systems and information products that are helping people across Australia to manage dryland salinity.

This investment has led a national shift in salinity research and policy, responding flexibly to the changing political environment and on-ground demands over this time. It played a major role in the report to the Prime Minister's Science, Engineering and Innovation Council, that provided a compelling case for establishment of the National Action Plan for Salinity and Water Quality (NAP). The NDSP had already brought the States and industry together under a national approach to salinity research and management. An independent review of the NDSP in 2003 confirmed the pre-eminent contribution it has made to developing solutions applicable at catchment and farm scales.

Over this past year, the 11th year of the program, the NDSP has invested a full year in harvesting and synthesising the efforts of over 300 researchers who investigated the causes, costs, consequences, solutions and management of dryland salinity in Australia over the past 10 years of the program.

This great portfolio of scientific and practical knowledge has been synthesised into three landmark reports, of which this is one. The three synthesis reports are designed to help people to make better decisions at farm scale, at catchment scale, and in developing policy respectively, based on the best available knowledge in Australia about salinity.

The foundation for these reports, and their companion resources, is solid science. This ground breaking research has brought together the contributions of hydrologists, economists, soil and plant specialists, ecologists, sociologists, biologists, agronomists, geologists, mathematicians, engineers, professional communicators and many others.

The synthesis process has been based on collaborative learning and analysis, spiced with vigorous discussion, debate and argument in public meetings and among partners. Drafts of the reports were road-tested in workshops in every State, involving catchment managers, farmers and their advisors.

The NDSP has been about more than just science. Indeed, it has been about professional communication developing solutions for farmers, catchment managers and others, backed by good science. This ambitious attempt to pull together a vast amount of scientific knowledge, and to package it to make it more useful for its end users, was made possible through funding from Land & Water Australia, the Department of Agriculture, Fisheries and Forestry (under the NAP), the Murray-Darling Basin Commission, Meat & Livestock Australia, the Rural Industries R&D Corporation, the Grains R&D Corporation, the Department of Natural Resources & Mines (Qld), the Department of Agriculture (WA) and the Department of Water, Land and Biodiversity Conservation (SA).

On behalf of the Governing Board and the NDSP partners that invested so much in this program, I commend these reports to you.

Kevin Goss, Chairman
National Dryland Salinity Program

HOW WAS THIS DOCUMENT PRODUCED?

This report was researched and written by John Powell (Optimal ICM) as Leader of the Production Team for the NDSP Enhanced Communication Year.

The report was comprehensively reviewed by Focus groups convened in Queensland, New South Wales, South Australia, Tasmania, Victoria and Western Australia in February and March 2004.

Report preparation and production was overseen by the NDSP Production Team, comprising:

- Professor Mike Ewing (CRC for Plant-Based Management of Dryland Salinity, Western Australia).
- Trevor Dooley (Primary Industries and Resources, South Australia).
- Colin Bastick (Department of Primary Industries, Water and Environment, Tasmania).
- Elizabeth Madden (NSW Agriculture).
- Mark Warnick (NDSP Communication Coordinator, Queensland).
- Bruce Munday (Clear Connections, Adelaide).
- Cameron Allan (Meat and Livestock Australia, New South Wales).
- Stuart Kearns (Grains Research and Development Corporation, Canberra).

Input was also provided by Dr Richard George (Department of Agriculture, Western Australia), Dr Richard Price (Kiri-ganai Research/NDSP National Manager), Lisa Robins (Robins Environmental Consulting), and Melanie King (Land & Water Australia).

The final draft of the report was reviewed by the NDSP Operations Committee.

Contents

EXECUTIVE SUMMARY

INTENDED READERSHIP

This report is national in scope and technically quite complex.

It is intended as a reference document for **proactive producers** who lead (for example) regional Landcare networks and large-scale (possibly State-wide) conservation farming and grazing groups. These producers influence development of salinity management options, industry research and development programs, and community/government salinity management initiatives.

It will also be useful to **experienced extension advisors** who facilitate liaison between the above groups and between the groups and State agencies and regional catchment management organisations. These advisors influence agricultural extension and natural resource management programs and community/government salinity management initiatives.

This report adds significant value to other salinity management guides by reviewing actual case studies that indicate the **amount or level of farm to catchment-scale outcomes that can be expected from applying different combinations of options in different situations**.

PURPOSE OF THIS REPORT

Within the limitations of regional to national scale studies undertaken by NDSP and associated research, this report makes as much progress as possible in providing answers to key farm-scale questions:

- Is salinity likely to be severe enough to justify action?
- If action is justified, is there sufficient knowledge about salinity processes, impacts, and management options to decide on the best approach and preferred management options?

In assisting producers and advisors to obtain answers to these questions, this report guides them through the following decision-making sequence:

- **Assessing salinity risk** (and the nature of the salinity problem).
- **Short-listing possible approaches** to managing it.
- **Reviewing tactics and management options.**
- **Considering possible farm to catchment-scale outcomes** from implementing the options.
- **Deciding on the best approach** or approaches.
- **Confirming preferred tactics and options.**

ASSESSING RISK

Many sources of information can assist producers and advisors in assessing salinity risk and the nature of the salinity problem in their area (i.e. whether it is a land salinisation problem, a river salinisation problem, or both).

In addition to the hundreds of extension brochures and publications produced by State agriculture and catchment management organisations, most mainland States have developed regional catchment strategies and local action plans. These planning processes have assessed salinity risk at the regional to sub-regional scale, and the nature of that risk.

The **Groundwater Flow Systems (GFS) framework** is a valuable tool for assessing risk and for contributing to analyses of possible outcomes of management options at the regional scale. A GFS is a model that describes and explains the behaviour of groundwater in response to recharge.

SHORT-LISTING APPROACHES

After assessing the extent and nature of the salinity risk in their area, and its implications at the farm scale, the next step for producers and advisors is to shortlist possible approaches that may suit their situation. Five common approaches that can apply from farm to catchment-scales are:

- **Prevention** (retaining native vegetation to prevent salinity occurring).
- **Recovery** (bringing saline land back into full production).
- **Containment** (preventing the maximum extent being reached, or 'buying time').
- **Adaptation** (using saline resources for production and profit).
- **Do nothing** (implementing 'best practices', but not expecting measurable salinity outcomes).

The **FLOWTUBE water balance model** is a valuable tool that can assist catchment managers in shortlisting approaches. It has been developed to use GFS information in answering questions such as: What are the likely future salinity impacts under different management scenarios, including doing nothing? Can we justify the costs of management options? Can regional salinity targets be met?

In short-listing approaches, producers and advisors need to find out whether their catchment managers have decided on approaches for their local area, and if so, which one(s). They also need to consider how to balance on-farm objectives against catchment objectives and weigh-up potential trade-offs, for example the effect of leakage reduction on reducing run-off into dams and streams.

Deciding on the right approach for a particular property cannot be completed until producers and advisors have reviewed the merits of various tactics and management options, and the possible outcomes of implementing the options.

REVIEWING TACTICS AND MANAGEMENT OPTIONS

After producers and advisors have short-listed approaches, the next step is to consider what tactics to employ. The main tactics available to producers and advisors include: **reducing leakage**; **controlling surface flows**, **sub-surface flows and groundwater**; and **managing saltland**. All three tactics can often be used together on one property. For each of these tactics, there are management options to explore in more detail.

Options that can be used to reduce leakage are: retaining and re-invigorating remnant vegetation; establishing and enhancing perennial pastures; phase-farming and inter-cropping with lucerne; opportunity cropping; and farm forestry.

Options that assist in controlling surface flows, sub-surface flows and groundwater levels are: shallow drains and banks; contour drains and diversion banks; deep drains; well points, multiple independent wells and single wells, and tile and mole drains.

Options that assist in managing saltland for production and profit include salt-tolerant shrubs, grasses and legumes in saltland grazing systems.

Each of the above options, with some quantification of what they can achieve individually (e.g. the level of leakage reduction that can be expected with vegetation management options) is described in detail in *Chapter 4*. The merits of combinations of options for addressing salinity in different GFS situations are discussed in *Chapter 5*.

Key messages arising from this report's review of leakage reduction options are:

- **Managing water on farming and grazing properties is a balancing act between farm and catchment needs.**
- **Producers need to maximise the use and value they get from rain that falls on their property, while taking into account the need to allow some good quality run-off to provide adequate streamflows.**
- **Designing a revegetation strategy should start by focusing on those sub-catchments with the greatest potential for benefits and the areas at greatest risk — it is important that the GFS are understood so that expectations are appropriate.**

CONSIDERING POSSIBLE FARM TO CATCHMENT-SCALE OUTCOMES

Chapter 5 describes a **salinity management matrix, based on information from actual case studies, that shows how the various factors in decision-making can fit together and possible outcomes of those decisions.** The matrix summarises, for different GFS in different catchments and regions:

- The nature of the salinity problem being addressed (i.e. land or stream salinisation).
- Approaches to salinity management being adopted or considered.
- Tactics being employed or researched.
- Management options being implemented or researched.
- Level or amount of change expected from implementing the options.

Key messages arising from case studies reviewed for this report that have implications for producers and advisors over wide areas are:

- **Many local GFS in mainland south-eastern Australia appear to be at or close to hydrologic equilibrium, but reducing leakage may still be worthwhile to reduce waterlogging.**
- **Groundwater pumping may assist in stabilising water tables in regional-scale alluvial GFS along the south-western margin of the Great Dividing Range.**
- **Local GFS in WA can be managed, but leakage reduction has to exceed 50 per cent.**

Appendix 1 provides additional information about impacts, priority areas for action, and recommended management options for producers and advisors who may not be covered by the case studies. *Appendix 2* contains a brief summary of the findings of recent reviews of the effectiveness and possible outcomes of engineering options.

FUTURE RESEARCH AND INVESTIGATIONS

In concluding, the report identifies future national research priorities to further develop salinity management options. It also identifies future local to regional scale investigations to assist producers and advisors (and catchment managers) to decide on *why* they should apply the options, *where* they should be applied, and the *scale* (or level of intervention) at which they should be applied.

1. INTRODUCTION

1.1 WHO IS THIS REPORT FOR?

This report is national in scope and technically quite complex.

It is intended as a reference for **proactive producers** who lead (for example) regional Landcare networks and large-scale (possibly State-wide) conservation grazing or farming groups. These producers influence: producer-driven development of salinity management options; industry research and development programs involving salinity management as part of improved production systems; and community/government salinity management strategies and plans;

The report will also be useful to **experienced extension advisors** who facilitate liaison between the above producer groups, and liaison between the groups and State agriculture and natural resource management agencies and regional catchment management organisations. These advisors influence: design and delivery of agricultural extension and natural resource management programs; and community/government salinity management strategies and plans.

These producers and advisors already have considerable knowledge about the causes, costs and consequences of salinity, and an appreciation of how more sustainable farming and grazing systems can contribute to salinity management.

They want to enhance their existing knowledge by accessing, in synthesised form, key findings from 10 years of national salinity research that may be relevant to them.

1.2 WHAT IS THE NDSP?

The National Dryland Salinity Program (NDSP) was established in 1993 and its first five-year phase focused on understanding causes of dryland salinity and establishing a national collaborative research and development effort. A larger second phase, completed in June 2003, involved new funding partners. Research projects were grouped into seven themes that aimed to address remaining gaps in understanding salinity and develop practical, profitable and sustainable solutions.

The seven themes related to understanding and managing salinity were:

- Audit and Monitoring
- Policy and Operating Environment
- Industry Solutions
- Productive Use of Saline Resources
- Environmental Protection and Rehabilitation
- Infrastructure Management
- Regional and Community Initiatives.

Ten years of research through the NDSP tells us:

- There is still much to be done
- The focus has shifted to include impacts on infrastructure – roads, bridges, buildings and other engineered structures
- Practical and economic solutions are not easy to find and their impact may not be felt for decades
- Salinity management should be integrated with other natural resource management strategies
- In some cases we will have to live with salinity and must find the institutional and practical means to make that possible.

Important points

1. This report is not intended for the broad producer community. Most NDSP and associated research from 1993 to 2003 has been regional to national in scale, and was aimed primarily at providing the science to underpin government and industry-wide responses to salinity.

2. State agencies and catchment management organisations are collating results of on-farm demonstrations and field experiments addressing salinity in their local area, interpreting them in the light of regional to national scale research, and developing salinity management information for the broad producer community.

3. Producers requiring basic information about salinity should:

- Talk with their local advisors, including extension staff in State agencies, catchment management organisations, agribusiness companies, non-government organisations, and private consulting firms.
- Read some of the comprehensive publications concerning salinity including, for example the *TOOLS Salinity Information Package*[1], the book *Assessing the causes, impacts, costs and management of salinity*[2], and the *Salinity Management Handbook*.[3]

1. INTRODUCTION

In summary, the key messages described in the companion report *Breaking Ground – Key findings from 10 years of Australia's National Dryland Salinity Program (NDSP)* are:

1. Salinity costs are significant and rising: Protection must be strategic.
2. Profitable options for reversing the trend are lacking (but under development).
3. There is no one salinity problem: It challenges us to look beyond traditional policy instruments.
4. Integrated catchment management must be seen as only one approach to deal with dryland salinity.
5. Vegetation management remains the key to managing water resources, although the benefit-cost of revegetating catchments requires careful analysis.
6. Lack of capacity is an important, but secondary constraint, to managing salinity.

1.3 WHY WAS THIS REPORT PREPARED?

Leading producers and advisors need definitive answers to the following questions to make strategic and informed decisions about addressing salinity:

- What is the nature and extent of current and possible future salinity impacts, and are they severe enough to justify action?
- If the impacts justify action, can catchment or regional managers explain the processes causing salinity on the property (e.g. what is/are the prevailing GFS? Where are the salt stores? Where are the high recharge areas? How are these linked to discharge areas? How is salt mobilised to streams and the land surface? Where are the high salt export reaches of streams running through the property? Is the GFS system on the property in hydrologic and/or salt equilibrium?)
- Have catchment and regional managers identified the best approach to managing salinity at catchment and property scales (e.g. prevention, recovery, containment, adaptation, do nothing), and for that approach, the full range of leakage reduction, surface and groundwater control, and saltland management options, their costs and benefits, and any trade-offs between the options?
- Are there any financial and other assistance measures available to assist producers in implementing the options and for involving them in monitoring the effectiveness of the options?

The last question is beyond the scope of this report. However, catchment managers have the capacity to answer it, taking into account their involvement in natural resource management funding programs.

This report was prepared to guide producers and advisors through a decision-making process designed to make as much progress as it can in helping them answer the first three questions, within the limitations of the latest regional to national scale research findings.

1.4 WHAT DOES THIS REPORT DO?

This report guides producers and advisors through the following decision-making sequence:

- Assessing salinity risk (and the nature of the risk, i.e. land or stream salinisation).
- Short-listing possible approaches to managing it.
- Reviewing tactics and management options.
- Considering possible farm to catchment-scale outcomes from implementing the options.
- Deciding on the best approach or approaches.
- Confirming preferred tactics and options.

This report adds significant value to other guides on salinity management by providing an indication of the **level or amount of change to land or stream salinisation that can be expected from applying different combinations of options in different situations**.

In concluding, the report identifies future national research priorities to further develop individual salinity management options and enhance our understanding of how they might work more effectively in combination with each other.

It also identifies future local to regional scale investigations to assist producers and advisors (and catchment managers) to decide on *why* they should apply the options, *where* they should be applied, and the *scale* (or level of intervention) at which they should be applied.

Important point

The sequential decision-making steps described in this report should be undertaken in consultation with the best professional advice available from catchment managers, researchers and other advisors.

1.5 WHAT INFORMATION IS THIS REPORT BASED ON?

1.5.1 Inclusions

The report is based on project reports and papers from NDSP and 'associated' research and development (R&D) from 1993 to 2003. Chapter 5, which discusses possible farm to catchment-scale outcomes, is based largely on regional case studies conducted under national R&D programs.

'Associated' R&D refers to R&D by Basin to national-scale organisations including the Murray-Darling Basin Commission, CSIRO Land and Water, and the Cooperative Research Centre for Catchment Hydrology. Major rural industry R&D programs are also included, for example Sustainable Grazing Systems and Joint Venture Agroforestry. The grains industry, through the Grains Research and Development Corporation (GRDC), was a partner in NDSP itself from 1998 onward.

This report also incorporates feedback received on an earlier draft discussed at workshops by samples of potential end users.

1.5.2 Exclusions

It was beyond the scope of this report to synthesise the many hundreds of local to State-scale salinity research projects that have been conducted in recent decades. Nevertheless, many of the projects reviewed take into account the knowledge and experience that has been building up in local, regional and State organisations. State organisations either led projects or made a major contribution to projects reviewed for this report.

The report does not attempt to comment on the merits of salinity management options recommended in regional catchment plans and strategies (for example those prepared under State strategies and/or funding programs such as the National Action Plan for Salinity and Water Quality) or local action plans.

A comprehensive research directory and action manual[4], which is a companion document to this report, has been developed to facilitate improved salinity planning by catchment managers.

1.6 WHAT ARE THIS REPORT'S LIMITATIONS?

Notwithstanding the relationships that exist between dryland and irrigation salinity in some regions, the NDSP and associated research have focused on dryland salinity. Hence this report excludes irrigation salinity R&D.

This report synthesises national salinity research findings, many of which are based on *modelled predictions* of salinity processes. There is a strong emphasis on Groundwater Flow Systems (defined in Chapter 2) and on FLOWTUBE (described in Chapter 3) and other catchment-scale models.

Many of the models' predictions are most relevant at regional (whole of catchment) to sub-regional (multiple farms) scales.

1.7 TERMS USED IN THIS REPORT

Some salinity management terms have different meanings in different States. For example 'deep drainage' in Western Australia refers to the construction of deep drains to manage groundwater. In the eastern States, the term 'deep drainage' commonly refers to water that leaks past the root zone of plants.

To avoid confusion, this report uses the terms as defined below, *except where a direct quote from a research report or paper appears*, in which case the actual words used in the report or paper are retained:

Leakage* = the process whereby water leaks past the root zone of plants.

Recharge* = leakage that actually reaches the water table or an aquifer.

Discharge = the process whereby groundwater intercepts the land surface.

Lateral flow, **throughflow** = leakage that moves laterally above the main aquifer.

Baseflow = groundwater that discharges directly to streams or other water bodies.

Deep drainage = the process of constructing drains to intercept lateral flow, throughflow or baseflow.

* In the absence of a detailed local-scale understanding of how a particular GFS functions, there can be some uncertainty between the definitions of 'leakage' areas and 'recharge' areas. The critical difference is that not all leakage reaches groundwater – it may be lost via lateral flow to deep-rooted trees and shrubs in alley farming systems, or may discharge to the land surface from perched aquifers some distance away from where the leakage occurred.

2. ASSESSING RISK

2.1 ACCESSING INFORMATION AND ADVICE

Assessing salinity risk is the first step in strategic decision-making by producers and advisors. It also helps to clarify the nature of the salinity problem in their area (i.e. whether it is land salinisation or stream salinisation).

Land salinisation is the major salinity problem in the Western Australian wheatbelt, whereas both land and stream salinisation are major problems at catchment scale in the Murray-Darling Basin (MDB). At sub-catchment scale in the MDB, salinity can be primarily a land salinisation problem or a stream salinisation problem, or both.

There are many sources of information to help producers and advisors in assessing salinity risk and the nature of the salinity problem in their area. For example:

- In all States where salinity has been a long-standing priority issue, natural resource management planning processes have assessed its risks. These risks are described in coarse State-scale maps and in more detail in regional catchment strategies and local action plans. The terminology for strategies and plans can differ between States and regions.
- Western Australia has the *Land Monitor* survey that determined the extent of salinity at farm-scale and valley hazard at catchment-scale over 18 million hectares of farmland. WA is currently completing regional-scale assessments of salinity impacts, costs and consequences through the Rapid Catchment Appraisal process.
- South Australia has developed a salinity risk model based on the State's soil and land information database. The resulting salinity risk maps are in wide use, and feature a series of detailed catchment salinity management plans.
- The Murray-Darling Basin Commission and NDSP have developed Regional Information Packages for 10 priority regions. The Packages include a salinity impact statement, future risk, and priority GFS for action. Extracts from the Packages that cover these issues are incorporated in Appendix 1.

Notwithstanding the above initiatives, adapting the GFS concept to function reliably from regional scale down to farm-scale to improve risk assessment remains a challenge. Progress is being made on this issue through integration of catchment modelling with farm-scale modelling, informed by airborne geophysics and other data collection programs. However, in many areas of the eastern States in particular, it may still not be possible to quantify salinity risk in detail at the farm-scale.

In Queensland and Tasmania where salinity is largely an emerging problem, risk assessments are relatively undeveloped as key data is unavailable. However, the *Salinity Management Handbook*[1] contains information about investigations required to assess salinity risk.

Groundwater Flow Systems (GFS): the foundation for assessing risk and making good salinity management decisions

A GFS is a model developed by hydrogeologists to describe and explain the behaviour of groundwater in response to recharge. It is a conceptual model, similar to an architect's model of a building. It takes into account the geology and geomorphology of the catchment, and the hydraulic properties of the landscape and the aquifer.

That part of the landscape in which a particular GFS (or several systems of the same type) operates is referred to as a *salinity province*. Whilst the GFS is clearly influenced by catchment characteristics, the salinity province does not necessarily share a common boundary with the catchment. Surface flow systems do not necessarily match underground flow pathways.

A comprehensive explanation of GFS and how they influence salinity and its management is provided by the document *Groundwater Flow Systems Framework: Essential Tools for Planning Salinity Management*[2]. Much of the discussion of GFS that follows has been drawn from that document. See also NDSP *TechNotes*[3], and the *Groundwater Models booklet*[4] produced by the Murray-Darling Basin Commission.

Local groundwater flow systems

Local GFS are relatively small (< 5 km) flow systems that respond rapidly to increased groundwater recharge. Water tables rise rapidly and saline discharge typically occurs within 30 to 50 years of clearing of native vegetation for agricultural development. These systems can respond relatively quickly to salinity management options.

Intermediate groundwater flow systems

Intermediate GFS have a greater extent (5–50 km) and storage capacity and generally higher permeability than local systems. They take longer to 'fill' following increased recharge. Increased discharge typically occurs within 50 to 100 years of clearing of native vegetation. The extent and responsiveness of these groundwater systems presents much greater challenges for dryland salinity management than local GFS.

Regional groundwater flow systems

Regional systems are extensive (> 50 km) and have a high storage capacity and permeability. They take much longer to develop increased groundwater discharge than local or intermediate GFS, probably more than 100 years after clearing of native vegetation. The full extent of change may take thousands of years.

Multiple flow systems

GFS are usually nested. That is, landscapes often contain more than one aquifer in the same area. For example, regional GFS may be overlain by intermediate GFS, which can in turn be overlain by local GFS. In a nested system, determining which GFS affect salinity and how they interact is an important step in decision-making for salinity management.

Sub-types

Within each of the three broad categories, there are several sub-types. For example, a GFS map of the Murray-Darling Basin shows six local systems, one intermediate, and three regional.

Getting down to finer scale at the regional level, a map of the Goulburn-Broken catchment in Victoria shows 11 'sub-types' of local GFS, one intermediate GFS and one regional GFS. A total of 17 GFS have been developed for the Mid-Macquarie region of New South Wales.

3. SHORTLISTING APPROACHES

3.1 INTRODUCTION

After assessing salinity risk and the nature of the salinity problem, producers and advisors should 'short-list' one or more approaches to salinity management to guide consideration of tactics and options.

Five common approaches employed in catchment and farm-scale salinity management plans and strategies are described in this chapter — **Prevention**, **Recovery**, **Containment**, **Adaptation** and **Do nothing**.

A mix of these approaches could be used, for example containment to protect high-value land, and adaptation on land that has already become salinised.

Preferred approaches can vary over time as more information about salinity processes and the effectiveness of management options becomes available.

Deciding on the right approach cannot be completed until the full range of salinity management options described in Chapter 4 and the possible outcomes of those options described in Chapter 5 have been considered. They also need to take account of approaches being taken in regional and State salinity strategies and plans.

Deciding on the right approach is the most strategic part of decision-making to address salinity, as it affects all remaining decisions.

Tools developed under NDSP such as FLOWTUBE modelling have dramatically improved catchment managers' and producers' capacity to make better decisions concerning approaches (and subsequent decisions about tactics and management options).

Questions for producers and advisors to consider in short-listing approaches include:

- Are we at risk of salinity?
- How severe is the salinity problem likely to get?
- Does it appear technically feasible and cost-effective to reclaim salinised land or improve water quality?
- Does it appear technically feasible and cost-effective to prevent salinity from reaching its predicted extent?
- Will we have to 'live with it' and if so, are there opportunities to use saline land or water as productive and profitable resources?
- Do we have the capacity to answer these questions, or should we wait until more information or improved technologies become available?

FLOWTUBE modelling: examining the effects of recharge and discharge management on catchment groundwater

The Groundwater Flow Systems Framework provides an understanding of groundwater processes and helps us with a qualitative assessment of management options.

However there are major questions that require quantitative answers to assist catchment managers (and producers and advisors) to decide on the most appropriate approach. These include, for example: What are the likely future impacts under different management scenarios, including doing nothing? Can we justify the costs of management options? Can regional salinity targets be met?

Researchers have developed the FLOWTUBE model to assist in answering these questions. Briefly summarised, FLOWTUBE is a mathematical model that can predict the position of a shallow water table and the amount of discharge that will result from a particular rate of recharge, for most types of GFS, particularly local systems. It therefore provides the capacity to estimate the likely effects of recharge control options such as perennial pastures and afforestation.

Confidence in FLOWTUBE as a tool for predicting salinity management is high, as it was validated in nine case study catchments across Australia during the National Land & Water Resources Audit that represented a diverse range of GFS and where there was already a high level of existing data and knowledge about salinity processes and outcomes of management options.

FLOWTUBE requires a minimum quality dataset including groundwater parameters such as water table elevation, aquifer thickness, hydraulic conductivity, rate of rise and some knowledge of the areal extent of the groundwater systems.

A user-friendly version of the FLOWTUBE model can be downloaded from **www.agric.wa.gov.au**

3.2 PREVENTION

This approach involves **retaining native vegetation to prevent future salinity**. It is mostly applicable in uncleared landscapes, but may also be relevant to native grasslands that have the potential to be developed or cropping.

A key assumption underlying prevention is that avoiding salinity is more cost-effective than developing alternative land use systems that will prove sustainable in the long-term.

3.3 RECOVERY

This approach involves **bringing saline land back into full production under its former land use**, for example salt-sensitive cropping or grazing systems.

It could also involve bringing stream water quality back from saline to fresh levels, but this does not appear feasible in most situations. Desalination appears to be emerging as a favoured option for reducing water salinity, but is not always cost-effective with current technology.

It does not appear feasible with current salinity management options to achieve recovery of all saline land. However, where issues associated with disposal of saline drainage water can be resolved, drainage systems (for example in the Upper South East of South Australia) appear to have the potential to recover significant areas of land.

Across Australia, there appear to be numerous specific local examples where recovery was achieved at the paddock scale, although lower than average rainfall over long periods may have been a factor.

3.4 CONTAINMENT

This involves **some expansion in the salinised area, but preventing the maximum predicted extent from being reached**. Typically, containment strategies result in slower rates of water table rise and can 'buy time'.

Containment has been the focus of most activities to date concerned with investigating, planning and managing salinity. Most effort has been put into vegetation management options for recharge control, although engineering options such as drains and pumping are becoming more popular because of their more immediate effect and potential to assist recovery.

3.5 ADAPTATION

Under the adaptation approach, **the extent of land and stream salinisation reaches its ultimate extent within the predicted timeframe, but salinised resources are used for production and profit**. This approach has received the least attention to date, but is also becoming more popular where salinity:

- Provides livestock production systems with additional feed or out-of-season feed.
- Appears to be a particularly intractable problem, and there are no other cost-effective options.

3.6 DO NOTHING

In practice, this approach encourages producers and advisors to pursue **'best practice' farming and grazing systems for the range of production and conservation benefits** that they can generate.

However, the 'do nothing' approach acknowledges that the 'best practice' systems are not being implemented to achieve the specific and measurable salinity outcomes that would be sought under Recovery, Containment and Adaptation approaches.

'Do nothing' is mostly applicable in areas where salinity may not be severe enough to warrant action, or where impediments prevent producers and advisors from taking a more active approach.

3.7 ISSUES

Producers and advisors should consider some issues before they assess the potential merits of management options. These include:

- **Balancing on-farm salinity management objectives with other on-farm objectives.** For example, *containment* to reduce the area of land salinised, by significantly expanding the area under perennial vegetation, may be inconsistent with producers' objectives to shift from grazing to cereal cropping.
- **Balancing on-farm objectives with off-farm catchment objectives.** For example, *adaptation* may be the most cost-effective approach at farm-scale, but it may be inconsistent with a catchment *containment* approach to reduce the predicted increase in salt loads and concentrations in streams.
- **Considering trade-offs that affect both on-farm and off-farm outcomes.** For example, maximum leakage control to achieve a *containment* outcome both on and off-farm may reduce run-off into farm dams and adversely affect streamflow for downstream users and riparian environments.

How can we quantify the trade-offs associated with on-farm change to achieve a catchment outcome?

Salt load targets have been proposed for the major tributaries in the Murray-Darling Basin. These are *containment* targets, as they seek to prevent the ultimate predicted extent of river salinisation from being reached.

If salt concentrations in streams are stable or increasing, the simplest way to achieve a salt load containment target is to reduce streamflow volume by reducing run-off and baseflow. However, in many areas this is not an option because run-off and baseflow, even if slightly saline, are highly-valued by producers and downstream communities, especially in dry periods.

Key research questions to inform consideration of the trade-offs between using rain where it falls or delivering it to streams are:

- What is the level of leakage reduction that achieves the targeted reduction in salt load with minimum reduction (or an increase if possible) in run-off and baseflow?
- What is the effect of the preferred level of leakage reduction on farm finances and local economies?

A research team within NSW Agriculture is investigating these questions. Its latest report[1] shows that their analysis and methods:

- Provide a way of examining the 'big' picture of the economic, social and environmental factors associated with salt load targets and streamflow.
- Enable an understanding of the scale of changes in vegetation needed to deliver more water and less salt (or any other combinations of water and salt) to downstream uses.
- Allow the integration of the key bio-physical parameters which form the basis for a more comprehensive economic analysis at appropriate scales.
- Permit straight-forward aggregations of the water and salt yield of sub-catchments to catchment scales.

However, the report notes that 'the present paper deals only with the biophysical factors as a step before the economic analysis'. It 'draws attention to the need for defining the biophysical model more adequately'. The research team is close to reconciling predicted 'end of valley' streamflows and salt loads with actual measurements.

4.4 Managing saltland

4. REVIEWING TACTICS AND MANAGEMENT OPTIONS

4.1 INTRODUCTION

This chapter provides producers and advisors with a comprehensive description of existing salinity management options, and provides some quantification of what the options can achieve individually (e.g. the level of leakage reduction that can be expected with vegetation management options).

It does not provide an assessment of the merits of the options for particular situations. These assessments are contained in Chapter 5, based on the case studies reviewed for this report.

The headings under which the options are described (i.e. reducing leakage, controlling surface flows, sub-surface flows and groundwater, and managing saltland) can be called *Tactics*. Some of the more common approaches to salinity management, for example containment and adaptation, may require all three tactics used together.

In this report, reviewing *tactics* comes after approaches have been short-listed, but before options are fully explored. A matrix that explains how these decision-making steps fit together appears in Chapter 5.

Important point

Salinity is usually only one of several natural resource management issues being addressed through on-farm changes. The tactics and options described in this report should be evaluated not only for their contribution to salinity management, but also for their contribution to other farm management objectives.

4.2 REDUCING LEAKAGE

4.2.1 Introduction

In considering leakage reduction options, the following factors should be considered:

- In uncleared areas, what is the volume of leakage (if any), and how does water move within the GFS? If the area is to be cleared and/or developed, will the new leakage exceed the aquifer discharge capacity and if so, by how much and what would be the likely impacts?
- In cleared and developed areas, what is the volume of current leakage and how does water move within the GFS? Does current leakage exceed aquifer discharge capacity and if so, by how much and what are the impacts?
- Can leakage reduction options match aquifer discharge capacity, and if they cannot, what can they achieve in terms of impact minimisation?

Most National Land & Water Resources Audit case studies show that the major limitation to salinity management is low aquifer discharge capacity. In systems that are not yet in hydrologic equilibrium, very high leakage reduction rates are required to contain salinity.

4.2.2 Remnant vegetation

Remnant vegetation retention may be an option under several approaches, particularly prevention and containment.

Guidelines for retaining remnant vegetation to prevent salinity occurring appear in the *Salinity Management Handbook*[1]. Decisions to retain or clear vegetation based on these guidelines need to be made in conjunction with all other tree retention/clearing guidelines, legislation and limitations. In addition to preventing salinity, there are many other reasons for retaining remnant vegetation, including conserving biodiversity, ensuring good quality water run-off, preventing soil erosion, and retaining the aesthetics of the landscape.

The first step in preventing salinity through remnant vegetation retention is to investigate salinity risk and/or any existing expressions of salinity. If there is existing salinity or the potential salinity for salinity to develop, investigations should be expanded to include other areas in the catchment with similar characteristics to the sites already investigated, as well as the following areas: potential discharge areas of local landform types at risk of salinity; low-lying or break of slope areas; and other suspect areas based on unusual soil or vegetation conditions.

Containing the spread of salinity in areas already affected can also be assisted by remnant vegetation retention, and *re-invigoration* or *rehabilitation*. Many of the benefits of native vegetation relate to larger remnants, although all remnants play some role in the landscape, including leakage reduction.

Research suggests young mixed species eucalypt forests use more water than mature stands[2]. Hence re-invigoration or rehabilitation of degraded remnants through inter-planting or regeneration with understorey species may assist in reducing leakage, providing there is a net increase in water use.

Fencing off remnant vegetation allows understorey rehabilitation, reducing leakage and enhancing biodiversity'

Source: John Powell

4.2.3 Perennial pastures

A large body of research has concluded that leakage under annual pastures is significantly higher than under perennial pastures. This has led to the almost universal call for more widespread use of perennial pastures to minimise leakage.

Reducing leakage using perennial pastures

A CSIRO report[3] in the late 1990s summarised the potential of perennial pastures to reduce leakage.

In the high rainfall zone (**more than 600 mm/year**) near Rutherglen in Victoria, leakage under perennial grasses was estimated to range from 50–120 mm/year depending on grazing management and [plant] nutrition. Researchers concluded a high proportion of trees would need to be incorporated into the landscape to achieve a significant reduction in leakage, should salinity be a problem.

In the medium rainfall zone (**400–600 mm/year**), studies have shown that perennial systems reduce leakage by 20–50 per cent when compared with annuals, but leakage remains two to three times greater than that occurring under the original woodland. However, lucerne grown continuously can reduce leakage by up to 90 per cent.

In some areas of the low rainfall zone (less than 400 mm/year) in the Upper South East of SA, lucerne has been shown to reduce leakage to the level of natural mallee vegetation (< 1 mm/year). In western NSW, there appeared to be no increase in leakage on heavier soils when trees were replaced by well-managed grazing systems.

4. REVIEWING TACTICS AND MANAGEMENT OPTIONS

Whilst we have a good knowledge of leakage rates under perennial versus annual pastures, there has been little research into how leakage and run-off are partitioned under different types of perennial pastures, for example native compared with introduced pastures. Maintaining run-off from pastures for on-farm and downstream becomes a particularly important consideration for producers and water users in regional towns during dry periods.

Sustainable Grazing Systems (SGS) Program

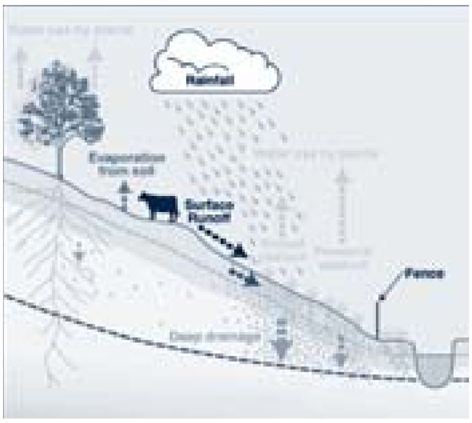
The best available knowledge about how leakage and run-off are partitioned under native and introduced perennial pastures was generated by the SGS Program[4]. SGS assessed over six years the water-related effects of a range of different pasture/tree systems on different soil types in different rainfall zones in four States.

The following text is based on information in *Towards Sustainable Grazing: the professional producer's guide*[5], a book that incorporates the key findings of SGS. It also draws on findings from research into catchment hydrology.

The basics of the water cycle and water balance

The three main components of the water cycle are evapo-transpiration (ET), leakage (water that leaks past the plant root zone) and run-off (surface run-off to dams and streams). These are also components of catchment water *balance*, which refers to the amount of water coming into the catchment from rainfall, compared with the amount of water leaving the catchment through ET, leakage, and run-off.

The water cycle



Note: Throughout this report, the 'deep drainage' shown by the large blue arrow in the above diagram is called leakage as it passes below the plant root zone, and recharge as it enters the water table. The authors have used these terms to avoid confusion, as 'deep drainage' in WA refers to the construction of deep drains to intercept and remove groundwater. The sub-surface 'run-off' as shown by the brown arrow in the above figure, is called lateral throughflow or baseflow. These are synonymous terms.

Source: *Towards Sustainable Grazing: The Professional Producer's Guide*, Meat and Livestock Australia

Leakage can leave a farm or catchment in three ways, as *direct recharge* to underground aquifers, as *lateral throughflow* on top of an aquitard or impermeable 'C' horizon, or directly as *baseflow* which intersects the banks or beds of streams.

Rising water tables occur when an aquifer beneath a farm or catchment cannot discharge all of the incoming recharge from leakage.

It was not possible within SGS to study the fate of leakage. **Leakage can be both negative and positive: it can cause waterlogging and salinity in wet years, but can provide valuable additional water supplies to producers and downstream users in droughts.** Throughflow is often seen as springs, and baseflow is often seen as permanent creeks. Depending upon the location of salt stores and other factors, the springs and creeks may or may not be saline.

When rainfall exceeds evapo-transpiration (ET), the excess moves as surface run-off or leakage, with the size of the excess being influenced by the amount of rainfall. Rainfall distribution also has a major effect on the fate of the excess rainfall. Figures 2a and 2b compare ET, leakage and run-off at two centres with very similar annual rainfall but different distributions. Vasey in western Victoria has winter-dominant rainfall, while Barraba on the north-west slopes of New South Wales has summer-dominant rainfall.

Figure 2a

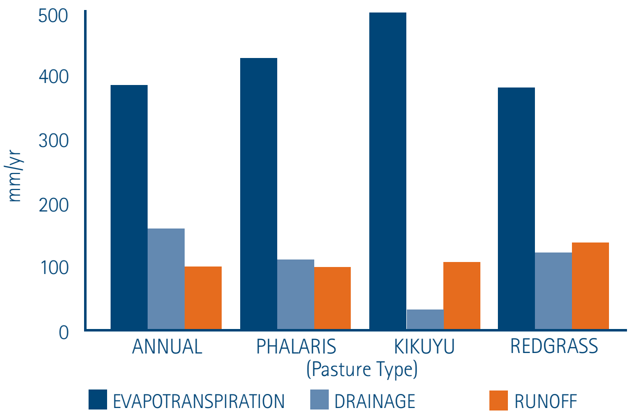
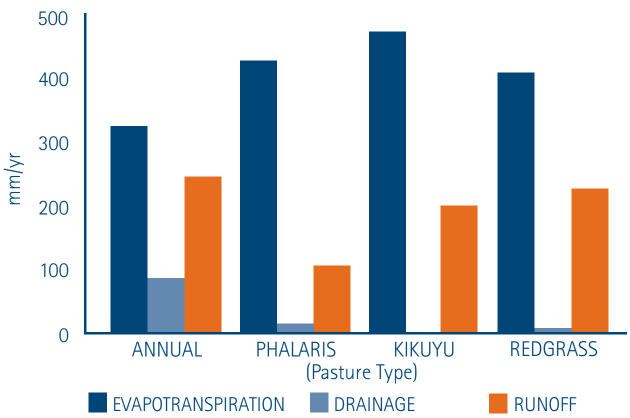


Figure 2b



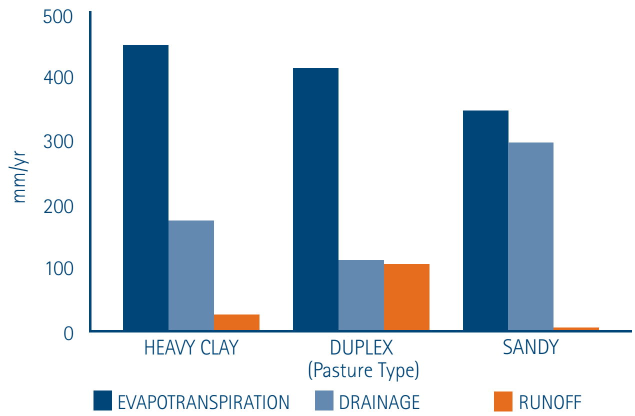
Source: *Towards Sustainable Grazing: The Professional Producer's Guide*, Meat and Livestock Australia

The figures show that whilst ET is the major component of the water balance in both areas, leakage can also be a significant component, irrespective of pasture type. Long, wet winters make it difficult to prevent leakage, while summer rainfall is more likely to result in run-off.

In order to reduce leakage dramatically in winter rainfall areas, it is important to dry the soil profile in summer and autumn (i.e. create a large soil water deficit) to maximise its capacity to store excess water in the following winter.

Figure 3 shows that soil type also plays a part in determining what happens to rainwater that falls on a property or catchment. There is little that producers can do to influence the effect of soil type on water balance, except to match their production system to the characteristics of the prevailing soil type.

Figure 3



Source: *Towards Sustainable Grazing: The Professional Producer's Guide*, Meat and Livestock Australia

Deep, heavy clays can absorb and hold a lot of water, allowing a perennial pasture to use up to 100 mm/year more than a sandy soil. Lighter sandy soils not only have less capacity to store water, but also tend to have high infiltration rates. The result on sandy soils is little or no run-off, greater leakage, and pasture plants wilting more quickly during dry periods.

In southern Australia, the more common duplex soils tend to generate about equal amounts of leakage and run-off, whereas in the northern summer rainfall zone, similar soils produce a lot of run-off and very little leakage.

Critical management factors

Rooting depth, pasture type and to a lesser extent pasture and grazing management, can also have major effects on water balance.

Plant rooting depth and soil moisture storage capacity have a major bearing on how much water is transpired by plants. Perennial pasture grasses commonly have a rooting depth from 1.5 to 1.8 metres, while annual grasses and legumes usually root to less than 1.0 metre and commonly to only 0.6 metres. Factors such as soil depth, compaction, sodicity, acidity and salinity can restrict rooting depth and hence restrict transpiration rates.

In summer rainfall zones where high evapo-transpiration rates coincide with periods of highest rainfall and increased run-off occurs due to the intensity of summer storms, perennial pastures can reduce leakage to low levels, possibly to the point where it has no negative impacts.

In southern winter rainfall zones receiving more than about 600 mm average annual rainfall, perennial pastures cannot create a sufficiently large soil water deficit in summer and autumn to store the following winter/spring excess of rainfall over evapo-transpiration. Leakage beyond the plant root zone occurs, although less than that which would occur with annual pastures. Much of the beneficial effect of perennial pastures in reducing leakage is due to the combination of their deeper root systems and their longer growing season.

Compared with differences between pasture types, pasture and grazing management has only a minor — but positive — effect on water balance. Rotational grazing increases water use and reduces leakage slightly (perhaps by 10–20 mm/year) by allowing plants to grow actively between grazings. Increasing pasture production with fertiliser can also result in positive or negative effects on plant water use — positive if perennials respond and dominate the pasture sward, and negative if annuals dominate.

4.2.4 'Low-recharge' cropping

An 'Industry' theme was introduced in the NDSP in 1998, with funding support from the Grains Research and Development Corporation (GRDC). It focused on developing less leaky cropping systems for major grain-growing areas. Key findings of major projects and activities are reported below.

Phase farming with lucerne

The folder *Success with lucerne*[6] is a comprehensive guide to using lucerne as a major component of low-recharge cropping systems. Paraphrased extracts from the sections of the folder dealing with water use are presented below.

Lucerne's deep root system and high water use reduces the risk of leakage, rising water tables and dryland salinity. It also provides a range of other benefits by improving soil structure, enhancing nutrient cycling, assisting with weed management and reducing soil acidification. Phase farming with lucerne can dry out the soil profile and hence delay the onset of waterlogging in difficult soils when returning to the cropping phase.

Key message

Managing water on farming and grazing properties is a balancing act between farm and catchment needs. Producers need to maximise the use and value they get from rain that falls on their properties, while taking into account the need to allow some good quality run-off to provide streamflows for downstream consumption and to maintain healthy rivers and aquatic ecosystems.

Carefully managed grazing of perennial pastures reduces leakage while ensuring fresh run-off for downstream use

Source: John Powell

Reducing leakage using lucerne in phase farming

A key challenge in designing farming systems that minimise leakage is ensuring that the systems can cope with rainfall variability.

Long-term simulation of continuous [cereal] cropping in a 614 mm/year rainfall area of central New South Wales produced an average leakage of 107 mm/year. In this environment, three years of lucerne rooting to 3 m can create a dry soil buffer of 200 mm.

The modelling suggested that leakage of > 200 mm (hence overtopping the buffer) would occur in 17 per cent of crop years due to higher than average rainfall. If such an event occurred in a year after several years of cropping when the dry buffer is depleted and the sub-soil is already saturated, significant leakage would occur.

Conversely, a series of dry years would allow the length of the cropping phase to be extended without leakage. (Paraphrased version of phase farming in a CSIRO publication on land use change[7]).

Length of phases

The lucerne phase needs to be long enough to dry out the subsoil to the extent that a dry subsoil buffer will allow a number of annual crops to follow before recharge to groundwater recommences. Most de-watering of the soil profile by lucerne occurs within the first 18 months establishment.

The ability of lucerne to dry out the profile and the number of crops that can be grown before recharge recommences depend on many factors. Soil type (e.g. sand versus clay), soil barriers, rainfall and specific rainfall events are key factors in deciding how long a particular phase should be, at least from a water balance and recharge perspective.

In medium to high rainfall districts (450 to 600 mm annual rainfall) research has shown that three to four years of lucerne can dry up the excess water generated by a three to five year cropping phase. In low-rainfall environments where lucerne grows well, the dry soil buffer may allow a cropping phase longer than three to five years.

The lucerne phase is rarely shorter than three years. This allows the pasture to establish adequately in the first year, with maximum production gained in subsequent years. Once lucerne reaches its maximum rooting depth, then growth will be limited by annual rainfall unless the plants have access to stored soil water. In low-rainfall areas, stand densities may decline in later years if rainfall is lower than average.

A short-term lucerne phase of only one or two years may be an option in low-rainfall areas. In addition, a younger stand should be easier and less costly to remove than older stands. The younger plants would also decompose faster than older plants after killing, leading to a faster release of mineral nitrogen.

Producer experience with lucerne in Western Australia

Throughout Western Australian cropping areas, the area under lucerne has grown from 5000 hectares in 1995 to 150,000 ha in 2001[8]. Benefits include:

- Increased use of rainfall and stored water.
- Reduction in leakage and reduced risk of salinity in lower parts of the landscape.
- Use of excess water allowing phase cropping in areas prone to transient waterlogging.
- High quality sheep and cattle feed available over a longer period than with annual pastures and responsive to summer rains.

Investigations indicate that lucerne can assist with water table drawdown in local GFS with moderate slopes and relatively low salinity [for Western Australia] groundwater (< 15,000 EC). In these local systems, continuous water table drawdown of up to 3 m was observed during long lucerne phases. In addition, salinised areas reduced in size.

In contrast, limited water table drawdown occurred in intermediate systems where slopes are flatter and groundwater salinities are higher[9].

Economics of phase farming with lucerne

A comprehensive report on the economics of salinity management options for cropping regions in Australia has been edited by Kingwell[10]. The report includes a case study involving the introduction of lucerne into a lupin:wheat rotation on 200 hectares of a mixed livestock/cropping farm in the GRDC Northern Zone. Average growing season rainfall is 270 mm. Full details of the case study appear in pages 52–60 of Kingwell's report.

The case study took account of the potential of lucerne water use to either positively or negatively affect crop yields. In dry years following lucerne, crop yields would be reduced due to a lack of subsoil moisture. In wet years following lucerne, waterlogging would be delayed or avoided, thus increasing crop yields. The study assumed that these effects would compensate each other and that water use by lucerne would have no net effect on crop yields.

In analysing the financial outcomes of the case study, Kingwell concluded;

- Introduction of a lucerne-based rotation could be either profitable or unprofitable, depending upon price and yield relativities, paddock management, and the lucerne system transition.
- The major sources of profit gain were the reduced frequency of the relatively less profitable lupin phase and extra revenue from production of the lucerne/cereal stubble hay.
- The increase in profits did not include any reduced rate of rise in the water table that would delay the onset of salinisation.

Producer experience with lucerne in South Australia

In the Bundaleer Valley in SA where average annual rainfall is 475 mm, producers report the following successes with lucerne:

- 'In 1974 we had an exceptionally wet year, raising the water table significantly. Then in 1979 along came the blue-green and spotted aphids to decimate most of the Hunter River stands. On top of this, we had another very wet year in 1981, which brought with it the first signs of salinity. All up, about 1500 hectares of prime land in this and the next valley were affected by these events.
- Together with other farmers we began successfully establishing aphid-resistant lucerne on some of the elevated land in the mid-1980s, and as the water table retreated and salt was flushed laterally into the drainage lines, other areas became possible for further lucerne
- We now have about 130 hectares of lucerne grown primarily for seed, some of it thriving on land that had been absolutely useless in the 1980s. In total, on all farms in the valley, there would be in excess of 1000 ha of lucerne for seed production, whereas 20 years ago there might have only been 100 ha.
- The beauty of the system we are using now is that most components are profitable in their own right. Throughout the whole of the Bundaleer Valley the flats are now supporting lucerne again on land that could not find a buyer a few years ago. This has improved the profitability for all farmers in the valley through the production of lucerne seed, hay and enhanced sheep and prime lamb production and by keeping the groundwater and salt down we are reducing the salt load downstream into the Broughton River.'

Phase farming with lucerne reduces leakage and adds nitrogen

Source: John Powell

Similar positive experiences with lucerne have been reported from in other areas of SA, for example at Meningie and Keith in the Upper South East.

Economics of phase farming with lucerne in Victoria

In a recent study[11], 14 producers in Victoria's Wimmera/Mallee, North Central and North East regions volunteered their farms to assess the impact of replacing annual pastures with lucerne in cropping rotations. Among other things, reasons given by participating producers for establishing lucerne included waterlogging control.

Average annual rainfall ranged from 324–583 mm, with growing season rainfall ranging from 212–383 mm. Soils included red and white sands, heavy grey clays, red/grey and black alluvial soils, sandy loams and box/buloke flats.

Financial analyses indicated that incorporating lucerne increased cropping and livestock gross margins by an average of 20–30 per cent. The effect on the cropping enterprise gross margin for any one farm ranged from –29 to +263 per cent. The effect on livestock enterprise gross margin ranged from –5 to +282 per cent.

On average, producers increased livestock carrying capacity by 75 per cent. Lucerne had the greatest effect on profitability in enterprises that produced lambs for the meat trade.

Economics of phase farming with lucerne in southern NSW

At the farm-scale, the Landmark project[12] in the Upper Billabong has examined the effects on leakage and farm finances of current recommended practices, e.g. including canola and lucerne in cropping-grazing rotations. The study found that:

- Compared with continuous wheat, including canola in the rotation in the Western Cropping Zone would increase leakage by 17 millimetres per year.
- Compared with continuous wheat/canola, three years of wheat/canola followed by three years of lucerne would reduce leakage by 50 per cent from 167 to 83 mm/year, but would reduce farm income by 12 per cent from $491 to $430 /ha (equivalent to a cost of $0.72 /mm of reduction in leakage).

Inter-cropping with lucerne

Inter-cropping involves sowing an annual crop (usually a cereal) into a perennial pasture such as lucerne, allowing the annual crop to be grown and harvested without killing the pasture. The practice is also known as 'over-cropping' or 'companion cropping'.

Inter-cropping maintains the de-watering benefits of lucerne whilst taking economic advantage of the returns from the cereal crop. There is also the advantage of being able to graze the lucerne almost up to the point of sowing, and again immediately after harvesting the cereal crop.

The disadvantage is that there is competition between the cereal and the lucerne to the extent that the yields of both are reduced compared with a situation where they are each sown alone. Hence, inter-cropping is better suited to the higher rainfall grain-growing areas (> 450mm average annual rainfall), where the risk of competition for moisture is less[13].

A series of interviews with producers undertaking lucerne inter-cropping in Central Victoria found that:

- Decreased inter-cropping grain yields/ranged from 10–40 per cent compared with sole crops. The magnitude of the decrease appeared to be influenced by seasonal conditions, with dry conditions around crop grain-filling tending to compromise grain yield.
- The potential yield penalties associated with inter-cropping are likely to deter mainstream producers from adopting the practice.
- Producers who did not perform in-crop lucerne suppression experienced grain contamination problems at harvest and their produce was restricted to feed markets.
- There was concern that in-crop lucerne suppression might kill plants and that alternative chemicals for inhibiting growth should be developed to avoid this threat.
- The gap in production between sole cropping and inter-cropping needs to be reduced if lucerne inter-cropping is to become a viable option in the high rainfall cropping zone.

Important point

The Liverpool Plains research reported in this section sought to:

- develop a modelling technique for estimating [farm-scale] water balance and predicting the production and profitability of alternative farming systems.
- Use the validated model with soil hydraulic characteristics and weather records to predict leakage, productivity and economic returns.

The research provides a detailed understanding of the effects of opportunity cropping on production, profit and leakage at farm-scale.

Future investigations could consider the expected effects of opportunity cropping on land or stream salinisation, and the timeframe for those effects to be expressed at farm and catchment scales. This step requires the capacity to link farm-scale models with catchment-scale models. The NSW Government is making progress on this issue — see Appendix 1.

These concerns are being addressed through further research by the CRC for Plant-based Management of Dryland Salinity (see www.crcsalinity.com.au) which is developing guidelines for successful inter-cropping.

Early results show that the hydrological effect of lucerne in an inter-cropping situation is as good as lucerne by itself, and that the yield penalty can be reduced through careful management. Researchers are also examining economic factors to assess to what extent the benefits outweigh costs.

Opportunity cropping

The Liverpool Plains in northern New South Wales was a focus catchment under NDSP Phase 1. During that period and since then there has been substantial research into opportunity cropping as a salinity management option. Much of the following text is based on a research report that brings together that knowledge[14].

Soils and land use

'More than 80 per cent of dryland cropping is based on Vertosols (cracking clay soils) of basaltic origin which generally have very high plant available water holding capacities of around 150–300 mm for annual crops'[14].

The predominant cropping system is 'one wheat and one sorghum crop grown in three years with an intervening 10–14 month fallow period. Although [this is] a low risk system with potentially high crop yields, the low cropping intensity suggests that it is leaky.' 'The area of salt-affected land with > 80 per cent reduction in yields is around 500–1000 hectares.'

Cropping systems investigated

Opportunity cropping is based on sowing on stored soil water. When a predetermined sowing rule based on depth of moist soil, usually measured using a push probe is satisfied within the sowing window for an appropriate crop, that crop is sown. If the depth of moist soil is less than the rule, the paddock remains fallow until the next sowing window.

The cropping systems investigated by the Liverpool Plains research involved only wheat and sorghum 'to avoid disease issues when verifying the model against winter pulses (chickpea, field pea) in the opportunity cropping treatments at the [field] experimental site.'

The APSIM (Agricultural Production Systems Simulator) model was used to predict the potential for modifying farming systems to lessen leakage. APSIM is a one-dimensional model that operates at a point scale or that of a homogeneous paddock. A more detailed description of APSIM appears in pages 17 and 18 of the Ringrose-Voase *et al.* report.

Results

- 'On Vertosols (cracking clay soils) in areas with less than 700 mm/year rainfall, opportunity cropping (OP) is predicted to reduce the drainage from about 50 mm/year under LF [long fallow] or continuous wheat (W) to about 15 mm/year which is near that under perennial vegetation (< 10 mm/year).'
- 'The major benefits of opportunity cropping compared to LF [long fallow] are a reduction in mean annual deep drainage [leakage] and an increase in average gross margin. These benefits come at the expense of increased annual variable costs and hence increased risk of a negative gross margin in any one season. The year to year variability of gross margin is greatest for OP [opportunity cropping] and least for LF [long fallow].'

Among other things, the Ringrose-Voase *et al.* report concludes that:

- It is possible to have productive agronomic systems without large amounts of leakage in the [Liverpool Plains] environment and similar ones in northern New South Wales with summer-dominant rainfall and soils with large water-holding capacity, unlike many agricultural areas of Australia.
- The analysis has quantified water balance and production. Hence it enables more than just qualitative evaluation of alternative cropping systems. It enables the assessment of the impacts of land use change on a complex range of soils and climates [in the Liverpool Plains region], together with quantitative economic assessment.
- Results show that appropriate cropping systems can reduce leakage to small values on some soil types in the Liverpool Plains — values very close to those expected from native vegetation.

Other research into low-recharge cropping systems

Million hectares for the future

This project commenced in 1999 and is due for completion in June 2004. It operates throughout major grain-growing regions in South Australia and Western Australia. The project supported development of the *Success with lucerne* folder.

The key aim of the *Million Hectares for the Future* project is to develop Environmental Improvement Systems (EIS) in partnership with grower groups and have the EIS adopted by growers who manage one million hectares in SA and WA. It is expected that the EIS will have the following components:

- Practical indicators for growers to evaluate the environmental performance of their business (particularly the impact on salinity).
- Benchmarks for each indicator, to allow growers to understand the performance of their business against weak, average or strong performances.
- Tools to allow growers to identify potential management changes for their business, the likely environmental impact of those changes (particularly with respect to salinity), and the ease of implementing those changes (including impact on finances, skills required, and timing of farm operations).
- Tools to allow growers to test the changes — in particular documented protocols and analysis tools for on-farm R&D.
- Tools to allow grower groups to continuously improve their EIS — in particular, comprehensive, documented methodologies for group facilitators[15].

Important point

The current inability to reliably link farm-scale water balance models (e.g. APSIM) with catchment-scale water balance models (e.g. FLOWTUBE) to provide an improved understanding of the large-scale hydrological effects of on-farm change is a recurring theme in this report. An integrated modelling capacity is needed to:

- Give individual producers the ability to consider how changes in their management practices on-farm can contribute to catchment-scale water quantity and quality targets.
- Give catchment managers the ability to more precisely identify the localities within a catchment where on-farm change may be desirable to achieve catchment water quantity and quality targets, and the level of change required.

Progress is being made in developing this capacity in New South Wales with the FLUSH (Framework for Land Use and Spatial Hydrology) model and CATSALT. CATSALT simulates water flow and stream salinities for medium-sized catchments from 500 to 2000 km^2. The Boorowa River and Mandagery Creek studies highlighted in Chapter 5 were based on CATSALT modelling. See also work by CSIRO for Simmons Creek in Chapter 5.

Farming systems with lower recharge for Western Australia

This project operated from 1999 to 2003[16]. The project report records that the project:

- Planned and executed an effective participatory research approach for the development of highly innovative farming systems.
- Identified and investigated innovative approaches to including perennials into cropping systems in low rainfall areas of the wheatbelt.
- Generated new information in regard to a number of key issues that could make-or-break the introduction of perennials into cropping systems in low rainfall areas.
- Assessed performance and improved the lucerne module in APSIM (a computer model that can predict the amount of leakage past the root zone).

The report also noted that the project, through its participatory approach linked to rigorous research in areas and systems that were not being addressed at the time, has improved the appreciation of lucerne as a potentially viable component of broadacre cropping systems for the lower rainfall areas of the wheatbelt of Western Australia.

National workshop on managing water to improve productivity and control dryland salinity

In February 2003, Grains Research and Development Corporation (GRDC) convened a national workshop to 'consolidate existing knowledge and to define areas of deficiency in our understanding of soil and water management in agricultural environments.' The workshop reviewed the findings of GRDC and other research projects in the context of sustainable water balance.

Key findings of the workshop included:

- 'Evidence suggests that significant increases in water use can be achieved through improved agronomy, but that even with this the long-term water use by cropping systems remains significantly less than that of native plant communities.
- The four main factors affecting water use by crops are soil type (and its water availability and retention characteristics), crop or pasture type, weather/climate influences (particularly the amount and distribution of growing season rainfall), and agronomic management (especially as it affects leaf area and duration of active water use).
- Partitioning of excess water (into run-off, lateral flow and deep drainage) will vary from location to location. In the sub-tropical northern wheatbelt, which is subject to intense rainfall, run-off can be greater than deep drainage. In duplex soils subject to a range of subsoil constraints (both chemical and physical), excess water will be partitioned between run-off, sub-surface lateral flows and deep drainage, and the relative distribution between these flows is likely to vary widely. For sodic soils, diminished soil hydraulic conductivity due to dispersion can be refected in waterlogging and a relatively high proportion of excess water being removed as run-off and/or evaporation.

- The ability to characterise catchments in terms of scale, responsiveness [to change], and discharge capacity of Groundwater Flow Systems is a significant step forward, but more detailed information is required about recharge sites and rates, where recharge is a problem in mobilising salt and other contaminants (as against its beneficial contribution to streamflow for water users lower in the catchment), and where and what type of interventions are required. The latter is essential before individual landholders can make appropriate decisions'[17].

The workshop identified the following key knowledge/capacity gaps:

- The ability to accurately partition excess water into its different flow pathways.
- The need to develop effective linkages between farm-scale (one-dimensional) and catchment-scale (three-dimensional) models, enabling land use and agronomic data to be linked to catchment-wide effects.

4.2.5 Farm forestry

A comprehensive account of how trees may be used to 'slow down the advance of salinity' (the containment approach) appears in the book *Trees, water and salt: an Australian guide to using trees for healthy catchments and productive farms*[18].

The book reflects the thinking among leading scientists, policy makers and catchment managers in the mid to late 1990s that a key objective of salinity research should be to develop new land use systems that 'mimic' the water balance of natural systems and use almost all of the rain that falls.

Hence while the book acknowledges that maintaining run-off is a factor to consider in designing farm forestry systems to manage salinity, much of its content appears to be based on the view that the preferred outcome is the *least possible* leakage.

Whilst this view remains relevant in low to medium rainfall areas, a more contemporary view for medium to high rainfall areas is that minimising leakage should be balanced with the need to maintain run-off, especially in 'fresh' catchments.

The book includes chapters on:

- The basics of catchment hydrology.
- The role of trees in the water and salt balances of catchments.
- Woodlots in rotation with agriculture.
- Tree belts on hillslopes.
- Mixing tree belts with agriculture.
- Planting trees over shallow, saline water tables.
- Species selection and the management of farm forestry plantings.
- Balancing productivity and catchment health.

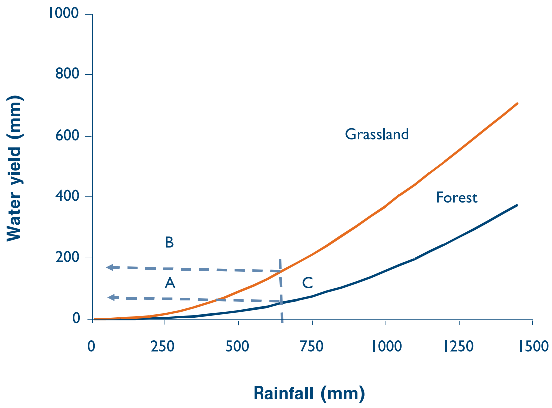
It is beyond the capacity of this report to provide a full summary. However, the chapter on *The role of trees in the water and salt balances of catchments* describes general relationships between tree cover and catchment hydrology, and the last chapter brings together much of the information presented throughout the book. Paraphrased extracts from these two chapters are presented below.

Water use by trees compared with grassland

Dense stands of trees (natural or planted) will use more water than any other kind of vegetation, and afforestation of cleared catchments can reduce catchment water yield.

Figure 4 below shows the relationship between rainfall and water yield that can be used to estimate the likely reduction in stream flow following afforestation. These curves are known as the Zhang (1999) curves. They are based on data from hundreds of cleared and forested catchments from around the world.

Figure 4



Source: *Trees, water and salt. An Australian guide to using trees for healthy catchments and productive farms.* Joint Venture Agroforestry Program

The curves in Figure 4 show that a grassland or cleared site receiving annual rainfall of 650 mm yields about 190 mm (1.9 megalitres per hectare) of run-off per year, while a fully forested catchment yields only 60 mm (0.6 ML/ha). Intermediate levels of afforestation would result in a proportional decrease between these two yield values.

In uncleared landscapes, the leaf area index (LAI) of the natural vegetation reaches a predictable, dynamic equilibrium with the amount of water available. [That is, the type, density and extent of grasses, shrubs and trees are determined by rainfall, soil type etc.] Where rainfall is below 900 mm and LAI of the vegetation is in equilibrium with the amount of water available, there will be little or no leakage and hence recharge to groundwater.

Farm forestry design for salinity management

Farm forestry design for salinity management has twin goals: to achieve the best hydrological control [water management] with the least displacement of agricultural land; and to maximise profitability of the tree products.

There are five ways to achieve the first goal. Leakage per unit area planted to trees is minimised when:

- Trees are located on areas with preferential leakage.
- Woodlots are moved around the landscape to create a buffer that reduces leakage from subsequent crops.
- Tree belts on sloping land use water moving laterally.
- Tree belts in alley designs access soil water from land occupied by crops or pastures.
- Trees use water from the water table.

Maximising profitability of the tree-growing enterprise can complement the first goal. Areas of preferential leakage are often characterised by thin, sandy or stony soils where annual crops and pastures perform poorly, and it is possible to site trees where they can grow faster than they would using rainfall alone.

Catchment hydrology and salinity management objectives

Trees, water and salt has a strong emphasis on catchment hydrology, and in common with the case studies and reports reviewed for this report, develops preferred options for different Groundwater Flow Systems (GFS). The type of GFS is important because it provides understanding of catchment discharge capacity, and its response time to change.

The book notes that in addition to gaining an understanding of the prevailing GFS, it is important to be specific about the aims of revegetation for salinity management, for example:

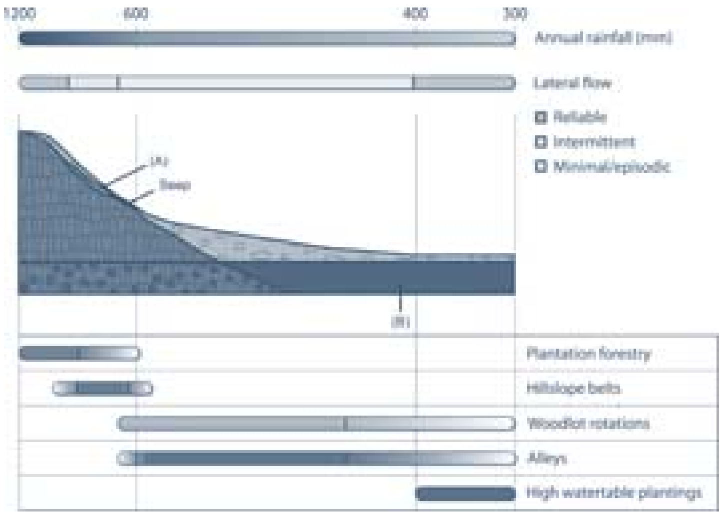
- Are we trying to dry up transient, localised patches of waterlogging?
- Do we want to reclaim saline areas to stop them from spreading?
- Are we trying to reduce the amount of salt entering rivers?

These questions are aimed at identifying appropriate approaches, tactics and options.

Catchment-scale revegetation options

Figure 5 shows where different farm forestry designs may be appropriate in a hypothetical catchment. The depicted catchment is large, with an average annual rainfall of 1200 mm in the upland country, falling to 300 mm on the flat riverine plain. There are two separate GFS, a fresh local system at A and a regional saline system at B.

Figure 5



Source: *Trees, water and salt. An Australian guide to using trees for healthy catchments and productive farms.* Joint Venture Agroforestry Program

In the Figure 5, the local GFS sits above a fractured rock basement. The fractured rock itself is an aquifer, and the soil layer immediately above the bedrock is finely weathered with very low hydraulic conductivity. Water moving through the fractured rock and the soils on the slopes and plains contributes to the adjacent regional saline GFS. The discharge capacity of the regional GFS is less than the amount of leakage occurring throughout the entire catchment, so the regional water table is rising.

Key message

Designing a revegetation strategy should start by focusing on those sub-catchments with the greatest potential for benefits and the areas at greatest risk. It is important that the Groundwater Flow Systems are understood so that expectations are appropriate.

Farm forestry needs to be targeted to specific positions in the landscape

Source: John Powell

Commercial timber plantations are a clear option in wetter, steeper areas as conventional tree cover uses more water than any other vegetation. An exception to the plantation option would be when a cleared sub-catchment is producing fresh water and thereby diluting downstream salinity. Large-scale revegetation would reduce this beneficial effect.

As annual rainfall declines towards 600 mm, conventional woodlots become more susceptible to drought death. **Hillslope belts**, which can intercept water moving laterally as run-off on the surface or as throughflow above the basement rock, will be more productive than woodlots per unit area planted, as long as there is a reliable lateral flow within reach of the tree roots.

As the land becomes flatter, there is less lateral flow. Since water will not move to the trees, trees need to be moved to the water. This can be achieved by **rotating woodlots** with crops and pastures to dry up water that has accumulated in the subsoil. When the trees are harvested, they leave behind an empty buffer of subsoil that can accommodate leakage from the agricultural phase before recharge to groundwater recommences.

Another way of moving trees to the water is to grow belts of trees in cropping or pasture lands. This is known as **alley farming**. The trees have access to rainfall in the area occupied by their canopies, but their roots can also explore the soil occupied by the crops and pastures.

The objective of alley farming is to design the number and width of belts and alleys to ensure that there is sufficient perennial leaf area to use all the excess water. However, the chief drawback with alley farming is that we cannot control the extent to which the trees rob the crops of water. Hence if the system is designed to use all of the rainfall in an average year, some production losses will occur during dry times within seasons or in drier-than-average years.

Caveats concerning farm forestry

Zhang *et al.*[19] modelled the effects of afforestation on moderate-sized catchments (1000–10,000 ha) with local GFS where salt in streams comes mainly from groundwater discharge. The results predicted that:

- Tree planting will not necessarily lead to immediate decreases in river salinity, but in some cases might initially worsen it.
- Eight years after afforestation, run-off [and hence dilution flow] reduces by half, but the volume of [saline] groundwater discharged to the stream takes about 35 years to halve.
- As a consequence, river salinity deteriorates markedly in the first 10 years after afforestation, then gradually returns to pre-afforestation levels after 35 years [there is no net improvement in river salinity because of the halving of dilution flow].

The effect of afforestation on streamflow magnitude is also an important consideration, because water security becomes particularly critical during dry times. Zhang's modelling predicted that flows of all magnitudes are reduced by afforestation. The number of zero-flow days per year can increase significantly, especially in small catchments (180–320 ha).

More detailed and quantified case study examples of farm forestry designs for salinity management, that take into account specific features of some local and intermediate GFS, appear in pages 34–41 of *Trees, water and salt.*

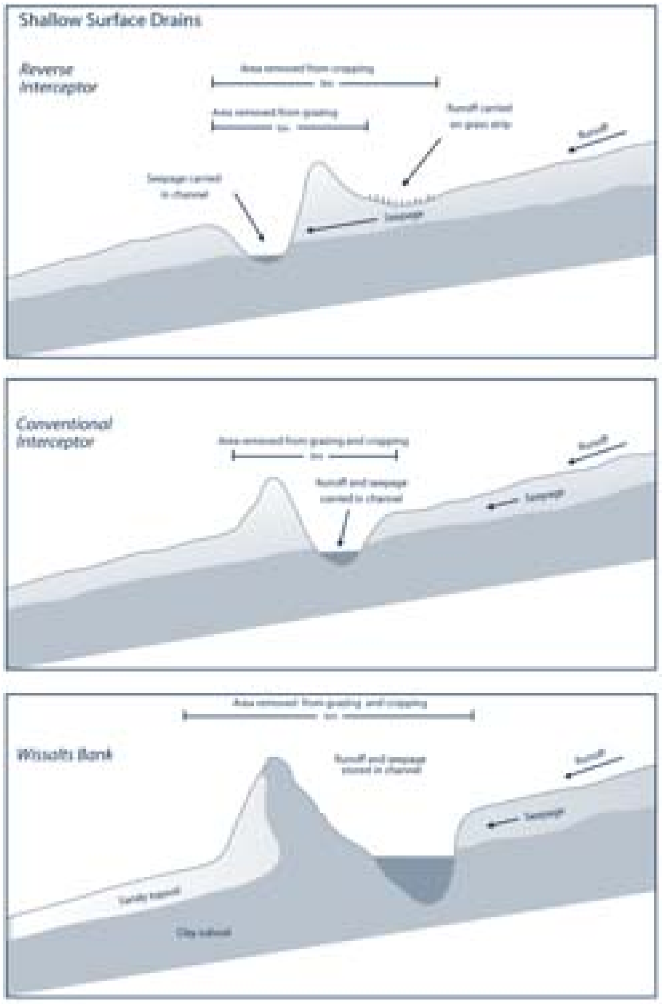
4.3 CONTROLLING SURFACE FLOWS, SUB-SURFACE FLOWS, AND GROUNDWATER

The following text is based on NDSP Fact Sheets on the *To drain or not to drain* CD[20]. Recent reviews of the effectiveness of engineering options are summarised at Appendix 2.

4.3.1 Surface drainage: shallow drains and banks

Shallow drains can intercept lateral groundwater flows along the top of the clay B-horizon in duplex soils to reduce waterlogging and in some cases, recharge to groundwater. They are usually constructed in conjunction with grade banks that divert surface run-off.

Figure 6



Source: NDSP and DESIGN SCENE, Norwood, SA

When shallow seepage interceptor drains and banks are properly constructed and maintained, they are effective in:

- Reducing the impact of winter waterlogging on crop yields.
- Protecting land down slope of hillside seepage areas from shallow-moving saline water.
- Intercepting and removing salts to a degree from the landscape to the main drainage system.
- Helping prevent soil erosion.

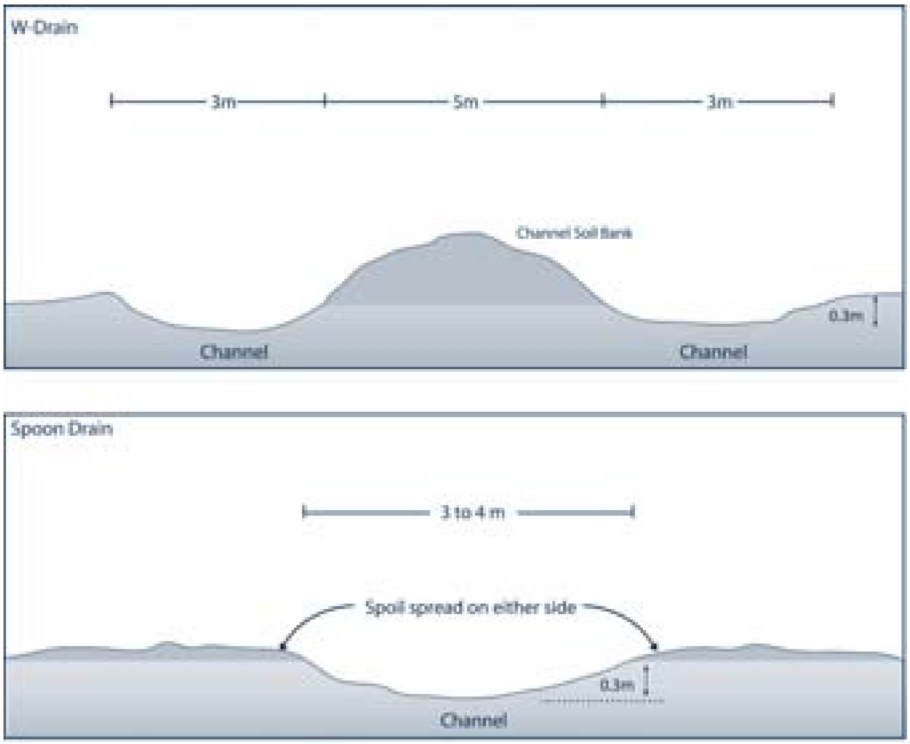
Important point

Water collected or intercepted by engineering options may be of poor quality, and it may be inappropriate or illegal to dispose of this water in some areas. Professional technical and legal advice should be sought before implementing these options.

4.3.2 Surface drainage: contour drains

Contour drains may reduce leakage by collecting and diverting surface run-off away from areas where water may pond and infiltrate, resulting in leakage. Diversion banks, which are similar in construction to some contour drains, can divert surface flow away from discharge sites, thus assisting rehabilitation of the sites. Three common methods are used to manage surface run-off: spoon (U-drains) and W-drains; bedding and parallel banks/ditches; and landforming.

Figure 7



Source: NDSP and DESIGN SCENE, Norwood, SA

Contour drains are effective where:

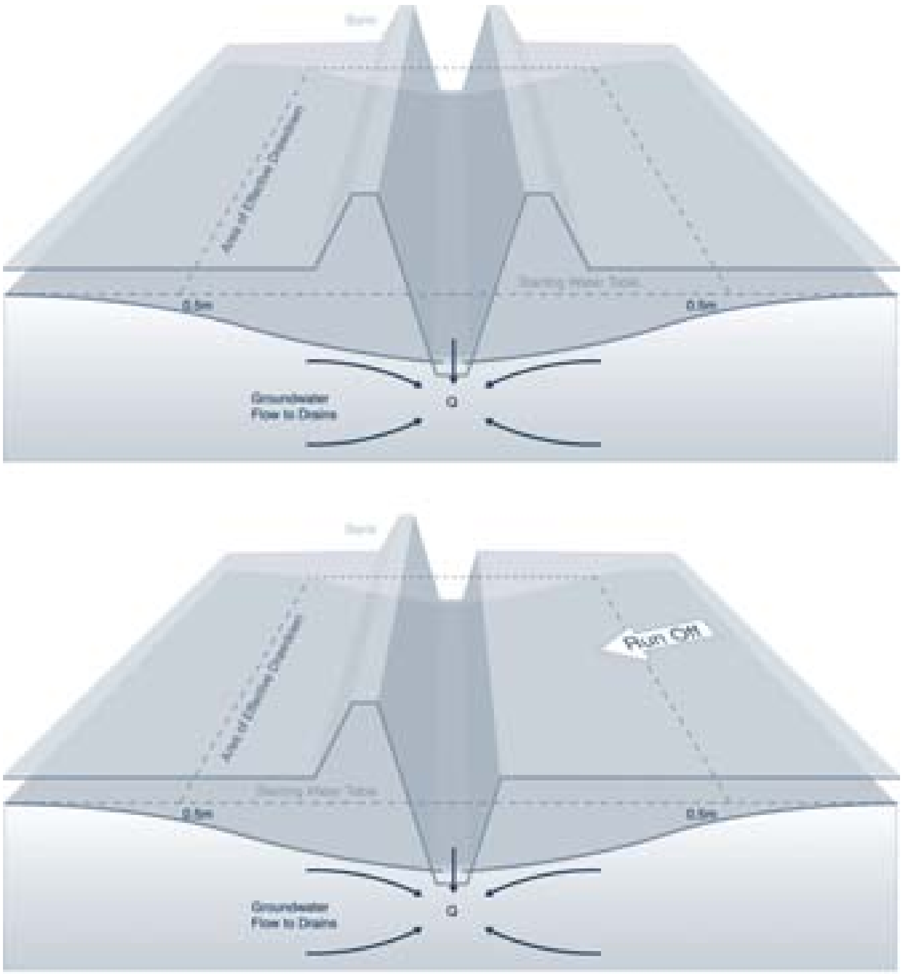
- Topography is relatively flat and soils are impermeable to highly variable (e.g. clays).
- Surface water can be diverted from depressions that hold water.
- Natural drainage lines are ill-defined or discontinuous.

4.3.3 Surface drainage: deep drains

The aim of deep drains is to intercept the water table and control groundwater levels to contain salinity or bring salinised land back into production. The potential to bring salinised land back into production depends on what happens to soil chemical and structural characteristics during and after water tables have fallen (see the study by Fitzpatrick *et al.* on page 34).

Deep drains also remove excess run-off and thus reduce waterlogging and groundwater accession. They are usually constructed to a depth of 1.5 to 3 m.

Figure 8



Source: NDSP and DESIGN SCENE, Norwood, SA

For local and sub-catchment scale projects, the effectiveness of multiple or single deep open drains appears to depend on:

- Constructing them in high permeability soils; or
- Locating the drain on the break of slope where the maximum lateral inflow or groundwater upflow occurs.

Deep drains have been used extensively in WA (11,000 km) and the Upper South East (USE) of SA. The zone in which they have an effect is highly variable, ranging from 10–300 m maximum radial impact in valley sediments in WA to as much as 2 km in the limestone of the USE. Careful site selection and cost:benefit analysis is required[21].

Drainage water may be highly saline and/or acidic. The impact of deep drains on receiving water bodies needs to be established. Alternatives to deep drainage may include pumps, siphons, shallow drains and raised beds.

4.3.4 Groundwater pumping: Well points, multiple independent wells, siphons and single wells

Well point systems are closely-spaced wells, connected to a header pipe and usually pumped by a collective suction lift pump. Their aim is to lower water tables. Multiple independent wells or a single well can also be used for this purpose. Siphons can be used in areas with local Groundwater Flow Systems and slopes that exceed three per cent.

The effectiveness of groundwater pumping from well point systems, multiple independent wells, or single wells is determined by:

- The physical properties of the material (e.g. soils) the groundwater is being pumped from.
- The local aquifer and landform.
- The volume extracted.
- Availability and cost of energy (except siphons).
- Options for disposal of the water.

4.3.5 Sub-surface drainage: tile drains and mole drains

Sub-surface tile or tube drains can be used to control rising water tables. Tile drains comprise buried pipes (open slotted, perforated or open-ended) that intercept and remove excess water from waterlogged areas or where groundwater levels are high. Drainage water collected by the tile drains is usually disposed to land, waterways or evaporation basins.

Mole drains are also used to control rising water tables and waterlogging, especially in low transmissivity heavy clay soils. They are constructed by a mole drain plough and unlike tile drains are not piped except to a collector pipe system. They are usually constructed at a closer spacing than tile drains, typically 1–2 m but up to 5 m apart.

The effectiveness of tile and mole drainage is determined by:

- Soil hydraulic conductivity [and transmissivity]
- The extent and type of soil layers – the presence of multiple aquitards or impervious layers can restrict water movement
- Soil stability – sodic and other weakly-structured soils will not hod mole drains and may silt up.

What happens to the soil when water tables are lowered?

Fitzpatrick *et al*[22] investigated the physical and chemical changes that operate when dryland saline soils are drained or otherwise disturbed (eg when annual crops and pastures on saline sites are replaced by perennial pastures that dry the soil profile, when engineering works are installed, or when pugging occurs due to animals grazing waterlogged soil). See also NDSP *TechNotes*[23]. The project:

- Published a literature review.
- Selected 17 representative case study sites across southern Australia and agreed on the experimental approach.
- Developed a user-friendly classification system for categorising inland saline soils.
- Developed generic conceptual models that encapsulate the various processes observed at the case study sites.
- Recommended generalised principles that lead to the implementation of best management practices for ameliorating identified categories of inland saline soils.
- Identified knowledge gaps and the scope for future research and development.

4.4 MANAGING SALTLAND

4.4.1 Introduction

A new book *Saltland pastures in Australia: a practical guide*[24] brings together years of producer experience and scientific research with saltland grazing systems. It is based mainly on findings from Western Australia, but also incorporates material from other States.

The book opens by summarising 10 case studies[25] from across Australia where producers have invested much time and effort (often over decades) in developing saltland grazing systems. The producers needed to know:

- What is the most cost-effective way to fence saltland?
- What pastures perform best in various salinity and waterlogging situations?
- What is the most cost-effective way to establish these pastures and what fertiliser applications or other soil ameliorants are necessary?
- How can stock water be provided and what is too salty for some stock?
- After initial establishment, what is the best grazing regime?
- How do animals perform on the pastures, especially young sheep?
- What is the best way to run sheep and cattle on saltland?
- What is it likely to cost and how much will it return?
- What annual maintenance will it need and will it need resowing?

Answers to these questions were generally not available when these producers were getting started in saltland management in the 1980s. They learned mainly through trial and error.

The producers who were interviewed for the case studies were aware that new saltland management systems would be more complex than existing systems. However, they accepted this complexity in return for a potential turnaround in the productivity and sustainability of their whole farm system, and in some cases to regain their pride in the appearance of their farm.

Volunteer saltland pastures can provide a palatable source of additional protein for Merino sheep in summer

Source: John Powell

4.4.2 Benefits of saltland grazing systems

The case studies show that saltland pastures are diverse and applicable to a range of farming situations throughout southern Australia. In general, producers sought to improve whole farm profitability, and hence saltland pastures were often one of a number of changes to the farming system.

Common features of the systems are:

- Systems based on tall wheat grass, puccinellia and clovers prevailed in the less saline, higher rainfall areas in both the east and the west. South Australian saltland systems are dominated by puccinellia, and saltbush formed the basis of saltland systems in the WA wheatbelt and the northern riverine plains of Victoria.
- Surface water flows that could cause waterlogging and inundation were controlled using a variety of structures.
- Feed production in late summer/autumn was explicitly named as the key benefit in many cases.
- Pasture growth on saltland decreased salinity at the soil surface and achieved water table drawdown.
- Fertiliser use clearly contributed to the success of puccinellia.
- Four of the case studies used rotational grazing to improve the productivity and diversity of saltland pastures.

The main principle behind these systems is that they have a productive plant tolerant of saline conditions. Productivity can be enhanced with fertiliser, soil ameliorants and grazing management.

Generic benefits from the saltland grazing systems described in the case studies included: deferred grazing/paddock spelling; greater surety of feed availability, with seasonal certainty; enterprise diversification; changes to flock structure; improved aesthetic value of the land; and pride in what they have done and are doing.

The *Saltland Pastures* book incorporates a wealth of knowledge and understanding about:

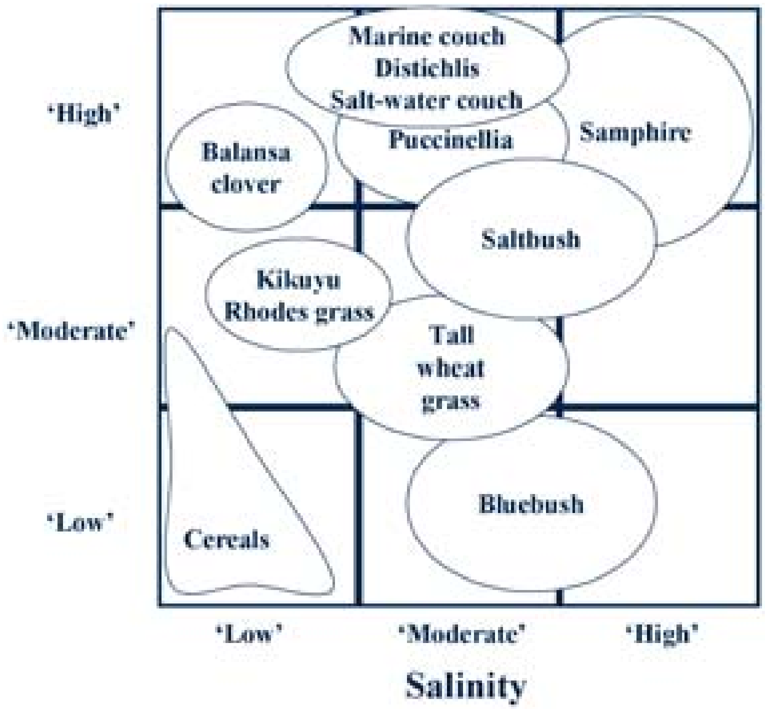
- Salinity and options for saltland in Australia (discussed further below under the OPUS project).
- Factors affecting plant growth on saltland.
- Pasture plants for saltland.
- Establishing saltland pastures.
- Grazing value of saltland pastures.
- Productivity of saltland pastures.
- Assessing the economic value of saltland pastures.

It beyond the capacity of this report to summarise every chapter of the book, however, extracts concerning saltland pasture plants and their grazing value are presented below.

4.4.3 Salinity/waterlogging tolerance of pasture plants

Pasture plants have different tolerances to salinity and waterlogging that can be seen in how they perform near banks, drains and roads. A two-dimensional salinity/waterlogging matrix showing the relative rankings of different saltland pasture species is shown in Figure 9.

Figure 9



Source: Saltland Pastures in Australia. A Practical Guide. Second Edition. EG Barrett-Lennard

4.4.4 Grazing value of saltland pasture plants

Salt-tolerant shrubs

Samphire survives moderate grazing, but its use for this purpose is not recommended. The plants adapt to salinity by storing salt in their fleshy stems and can have salt concentrations of 30–45 per cent. They must be grazed in conjunction with other feed such as crop stubble or dry annual plants, and sheep must have access to fresh water.

Trials suggest that **saltbush** (which contains high salt concentrations) should be fed to stock with low-salt hay, stubble or understorey plants. On its own, saltbush leaf is a maintenance forage for sheep. It has relatively low digestibility (46–62 per cent) and high ash concentrations (17–33 per cent), which reduce its value as a source of energy. However, saltbush leaves also contain high concentrations of nitrogen and average crude protein levels of 15 per cent have been found.

Saltbush does not tolerate long-term continuous grazing and plants should be allowed to recover after grazing.

Saltbushes also use groundwater, which can assist the growth of higher-value understorey plants such as clovers. It seems likely that at least some of the grazing benefits achieved on saltbush-based pastures have been due to improvements in understorey.

Bluebush provides good grazing and recovers well. Fodder from plants grown in the field has average crude protein levels of about 18 per cent and ash concentrations of 22–30 per cent. Producers in many districts of WA regularly graze sheep on bluebush in summer to late autumn, with pasture or stubble. This strategy is necessary to avoid poisoning by the oxalate in the leaves. Hungry sheep should not be introduced to bluebush unless adequate other feed is available.

Sown salt-tolerant pastures can produce high quality beef

Source: John Powell

Salt-tolerant grasses

The grazing value of **puccinellia** depends on the growth stage. It should not be grazed in the first year [after sowing], although stands can be lightly grazed in the second year. During winter and early spring, when the leaves are green, the plant contains high protein (10–18 per cent) and digestibility (60–78 per cent).

Nutritive value of puccinellia declines as the plant flowers and matures. Salt concentrations of about 10 per cent have been reported. Although the grass is palatable in late summer and early autumn (possibly due to the retention of some sappy green stems), its nutritive value appears to be reasonably low at this time (crude protein less than five per cent, and digestibility less than 50 per cent).

Puccinellia growth is highly responsive to nitrogen applications in late winter. In one trial in SA, a split application of 65 kg/ha (about 25 per cent in June and 75 per cent in August) increased dry matter production from 2.2–7.8 tonnes per hectare.

The quality of **tall wheat grass** stems declines rapidly in late summer, so it is important to graze the pasture before the stems are fully mature. Heavy crash grazing encourages leafiness and helps maintain feed quality.

If tall wheat grass is planted as a companion species with Balansa clover, then grazing should be regulated to allow the Balansa to complete its growth cycle. Grazing needs to stop when the Balansa is flowering (usually in September) and can recommence when the Balansa seed has set (usually in December). Mixed stands of tall wheat grass and Balansa clover may be managed for silage production.

Both sheep and cattle have been observed grazing **distichlis** (being marketed as NyPa Forage™), but there is little documented information on its value for animal production. Crude protein concentrations of 10 per cent have been reported in young leaves. As the leaves have highly efficient salt glands, salt concentrations in the leaves are likely to be lower than for other plants grown under comparable conditions of salinity and waterlogging.

No information is available on the grazing value of **saltwater couch** *(Paspalum)*. As the plants grow on very waterlogged sites, care needs to be taken with grazing to avoid pugging. Dry matter production can range from 1–7 tonnes per hectare on saline land. Yields will be affected by site fertility.

Despite its lack of bulk, **marine couch** *(Sporobolus)* can provide useful grazing. The fine-leafed forms have provided valuable grazing during droughts on coastal beef properties [in Western Australia], but the more fibrous coarse-textured types have little forage value.

Grazing of **Rhodes grass** should be managed in summer and autumn so that annual species (especially legumes) establish in the stand following winter rains. Avoid heavy grazing during the first two seasons' growth to allow the stand to thicken through stolon development.

Salt-tolerant legumes

Balansa clover leaves contain 15–18 per cent protein. In the establishment year, lightly graze to ensure that grasses and broad leaved weeds do not flourish. Stands should not be grazed during the spring flush and flowering.

Balansa clover is highly nutritious. In one experiment, young sheep grazing a mixture of Balansa clover and Concord ryegrass gained weight at a rate of 60 grams per head per day over two months in summer. In contrast, [similar] animals grazing the natural pasture, tall wheat grass or puccinellia lost weight.

Melilotus contains the secondary metabolite coumarin. In mouldy hay, this breaks down to form dicoumarol, which is toxic and can cause blood loss and death. Varieties with low coumarin levels are being selected. In its early growth stages, melilotus is of similar nutritive value to lucerne. It is highly palatable to animals in spring, but it becomes less palatable as they become woody and the concentrations of the bitter-tasting coumarin increase.

At Glenthompson in southern Victoria, stocking rates over summer for melilotus-based and control pastures (tall wheat grass and barley grass) were 2480 and 520 sheep grazing days per hectare respectively. During grazing, the sheep on melilotus had a liveweight gain of 6.5 kg, while there was no gain for animals on control pastures.

Additional technical information on the nutritive value of saltland pasture plants appears in the chapter titled *Grazing value of saltland pastures* at page 94.

4.4.5 Future research into saltland pasture plants

In its discussion on pasture plants for saltland, the *Saltland Pastures* book notes that it is highly likely that future saltland pastures will be based around a broader range of plant species than at present. An unpublished database lists more than 100 plants with potential for saltland forages in Australia. However, while trials are continuing, adaptation studies in the field have been conducted for only a small proportion of potential species.

Saltland Pastures also notes that [preferably] saltland pastures should comprise diverse and interacting species. In winter rainfall areas, salt-tolerant shrubs and puccinellia are likely to be key groundwater-using elements of the system. However, in summer rainfall areas, salt-tolerant grasses are likely to be more important groundwater users. Virtually no adaptation testing to date has focused on the value of saltland plants in mixtures.

4.4.6 Other options for productive use of saline resources

The Options for Productive Use of Salinity (OPUS) project[26] examined a wide range of potential opportunities for more innovative and productive uses of saline land and water resources.

Some of the more novel approaches to more productive use of saline resources included:

- Using distichlis as a new crop/pasture for saline land.
- Raising trout in saline dams in Western Australia.
- Harvesting of salt products from Pyramid Hill in northern Victoria.
- Harvesting of magnesium in northern Victoria and New South Wales.
- Growing and harvesting alginate products from seaweed in northern Victoria.
- Producing heat energy from saline ponds.

4.4.7 Communication networks for saltland managers

Producer groups

State producer groups include *Saltland Solutions* in South Australia and the *Saltland Pastures Association* in Western Australia. At the national level, the *Productive Use and Rehabilitation of Saline Land* (PUR$L) group promotes the development of saltland pastures. It operates under a national committee of State agency and producer representatives, and conducts national workshops every 1–2 years at various locations around Australia.

Sustainable Grazing on Saline Lands

Sustainable Grazing on Saline Lands (SGSL), is a sub-program of the national *Land, Water & Wool* initiative stimulating further producer interest in developing improved saltland grazing systems. It is supporting a national producer network that aims to:

- Facilitate and support a network of producers with salinised land.
- Share and build on local knowledge and experience.
- Set local priorities for action.
- Develop and test practical solutions.
- Support farm practice change.
- Provide linkages with and direction to relevant research projects.

Contact details for the PUR$L and SGSL groups are available from State agriculture agencies (see *Where to get help*, at the end of this report).

5. CONSIDERING POSSIBLE FARM TO CATCHMENT-SCALE OUTCOMES

5.1 INTRODUCTION

This chapter incorporates a matrix that shows producers and advisors (and catchment managers) how the various factors involved in salinity decision-making can fit together. The matrix is based on NDSP and associated case studies described in more detail in Section 5.3 and that have wider relevance beyond the case study area.

Similar matrices (without outcomes) are contained in the *Tools* Regional Information Packages developed for 10 regions in the Murray-Darling Basin.

Appendix 1 summarises the selected sections of the Regional Information Packages covering salinity impacts, priority Groundwater Flow Systems (GFS) for action, and management options. It also includes similar information for Western Australia. Appendix 1 may be useful for producers and advisors whose situation is not covered by the case studies in Section 5.3.

The matrix presented below builds on information in the *Tools* Regional Information Package packages by using the latest research findings and by including a Possible Outcomes column that indicates **the actual amount or level of change expected from implementing various combinations of options** for different salinity problems (eg land or stream salinisation) in different GFS.

The Possible Outcomes column refers to the case studies on which they are based.

Important points

1. In Queensland, there is limited research concerning possible outcomes of remnant vegetation retention as a salinity prevention option. However, the Brymaroo case study described in this chapter indicated 50–80 per cent revegetation is required to reduce salt expressions, which would suggest that 50–80 per cent remnant vegetation retention is warranted in similar Groundwater Flow Systems in Queensland[1].

2. Notwithstanding the potential for some saltland management options to lower water tables and hence assist in reducing land salinisation, none of the case studies considered the land or water salinisation outcomes of combining saltland management options with other salinity management options. This remains a priority for future research.

5.2 SALINITY MANAGEMENT MATRIX, BASED ON MAJOR CASE STUDIES

GROUNDWATER FLOW SYSTEM	GFS DESCRIPTION	REGION OR CATCHMENT	NATURE OF THE SALINITY PROBLEM
Local	A local flow system in variably weathered rock. Groundwater discharge occurs at break of slope	Kamarooka, North Central, Vic	Land salinisation
Local	Local GFS in fractured volcanic rocks. A self-contained groundwater catchment independent from a Regional GFS to the south	Brymaroo, Darling Downs, Qld	Land salinisation
Local and Intermediate	Local and Intermediate-regional system in alluvial sediments and deeply weathered rocks	Lake Warden, Esperance, WA	Land salinisation
Local and Intermediate	Local and Intermediate GFS that typically have low permeability and low gradients	Eastern and central wheatbelt, WA	Land salinisation
Local and Intermediate	As above	Western wheatbelt, WA	Land salinisation, and stream salinisation in >600mm rainfall zones
Local and Intermediate	Local to Intermediate flow system in deeply weathered rock	Wanilla, Lower Eyre Peninsula, SA	Land salinisation
Local and Intermediate	Intermediate fractured rock aquifer overlain by a shallow secondary local aquifer	Kyeamba Creek, southern NSW	Stream salinisation
Local and Intermediate	Intermediate flow systems in the Macquarie Alluvium overlain by local GFS	Mid-Macquarie, central NSW	Land and stream salinisation
Intermediate	Intermediate GFS where discharge occurs in low-lying areas	Upper South East, SA	Land salinisation
Intermediate and Regional	Intermediate to Regional GFS in alluvial deposits	Liverpool Plains, northern NSW	Stream salinisation
Regional	Highly permeable regional alluvial plains aquifer with additional shoe-string sand lenses and spill-over sands	South Loddon Plains, North Central Vic	Land salinisation

APPROACHES	TACTICS	OPTIONS	POSSIBLE FARM TO CATCHMENT-SCALE OUTCOMES
Probably **containment**, but dependent upon case study results	50 per cent leakage reduction 90 per cent leakage reduction	Conversion of annual pastures to lucerne Introduction of 80 per cent tree cover uphill from break of slope	Salinity situation is already at equilibrium. There will be little growth in salinised land with no intervention. 50 per cent leakage reduction would lead to a 50 per cent reduction in area at risk within 20 years and could increase farm gross margins by 40 per cent. 90 per cent leakage reduction reduces the area of high water tables more quickly, but would reduce net farm incomes by 40 per cent. **See case study #1**
Containment and **adaptation**	Leakage reduction, groundwater management	50 per cent leakage reduction by placing the upper part of the catchment under perennial pastures, and a 90 per cent recharge reduction by revegetating the catchment with native trees	The groundwater system is [already] full. The expansion of salinity has largely culminated and further salinisation is expected to be minimal if current land use is maintained. A 50 per cent leakage reduction would see groundwater levels in the upper catchment falling by up to 5 m after 20 years. **See case study #3**
Containment and **adaptation**, recovery dependent upon asset value and risk	Leakage reduction, saltland management groundwater management	Lucerne, farm forestry, low-recharge farming, saltland pastures, drainage and groundwater pumping for public assets	Relatively poor response to < 50 per cent leakage reduction. At higher levels of intervention (90 per cent leakage reduction) the system would stabilise by 2020 and reverse by 2050. **See case study #4**
Containment and **adaptation, recovery** dependent upon asset value and risk	Leakage reduction, saltland management groundwater management	Some lucerne, oil mallees, low-recharge farming, saltland pastures, drainage and groundwater pumping for public assets	Leakage reduction options result in almost as much salinised land as current practice, but buy 20–60 years of time. Pumping and deep drains may significantly alter this outcome. Leakage reduction on hillslopes expected to have limited impact. Priority landscapes are valleys with deep water tables at high risk. **See case study #5**
Containment and **adaptation, recovery** dependent upon asset value and risk	Leakage reduction, saltland management groundwater management	Lucerne, farm forestry, low-recharge farming, saltland pastures, drainage and groundwater pumping for public assets	Relatively quick response to leakage reduction options (< 10 yrs). At higher levels of intervention some land would be prevented from becoming saline. Stream salinity unaltered. Targeted leakage reduction throughout landscape. **See case study #5**
Probably **containment**, but dependent upon case study results	50 per cent leakage reduction	All pastures in lower catchment replaced with lucerne; all upper catchment planted to trees	Hydrologic equilibrium almost reached already. The area affected by high water tables would increase from 8 per cent to 12 per cent over the next 20 years, and to 13 per cent over the next 50 years. **See case study #6**
Containment and **adaptation**	Leakage reduction, groundwater management	Revegetation/reforestation of upper catchments using perennial pastures, native pasture, and native trees, possibly with some groundwater pumping	High groundwater levels are in dynamic equilibrium, but are well connected to the alluvium and highly responsive to rainfall events. Saline outbreaks could be expected to expand and contract according to rainfall. Large-scale reforestation in 800 mm areas would have only local effects on groundwater pressure heads. **See case study #7**
Containment and **adaptation**, but influenced by case study results	Leakage reduction, saltland management	Farm forestry, saline agroforestry, remnant vegetation conservation, riparian zone conservation, perennial pastures, saline pastures	GFS methodology proved a mixed success. Indications are that local systems that dominate the region have reached equilibrium. Lack of data prevents estimates of current and future salinity distributions. Proper prioritisation of sub-catchments for salinity management action is [still] not possible. One catchment previously targeted for recharge reduction is providing fresh flows. **See case study #8**
Containment, and **recovery** of salinised land where possible	Leakage reduction, groundwater management	Regional drains controlling surface and groundwater, revegetation, perennial and salt-tolerant pastures, wetland management	Lowered groundwater levels up to 2.5 km from the drains. Control of surface flows from 27,500 ha. Localised recovery of discharge areas. Productive and profitable salt-tolerant pastures. **See case study #9**
Containment of salt exports	Leakage reduction	Engineered structures to control flooding, opportunity cropping, perennial pastures and tree planting	Leakage reduction options were not modelled, but a 'no change' scenario results in only small increases in groundwater heads mainly in the upper parts of the catchments, and only minor rises near the [catchment] outlet. **See case study #11**
Probably **containment**, but dependent upon case study results	Groundwater management	Pumping from the deep lead aquifer	While groundwater heads would not be reduced below ground everywhere, up to 10 m of drawdown can be established over up to 300 km^2. **See case study #12**

5.3 WHAT FARM TO CATCHMENT-SCALE OUTCOMES CAN BE EXPECTED IN DIFFERENT GROUNDWATER FLOW SYSTEMS?

This section describes major case studies conducted under NDSP and associated research. They were undertaken to clarify salinity risk in particular catchments and to predict what may actually be achieved with different salinity management options. Most of them are referred to in the matrix above.

The studies cover a range of salinity problems being addressed in different catchments. Possible outcomes in some catchments may be relevant to other catchments that share similar biophysical characteristics (e.g. climate, land use and groundwater flow systems).

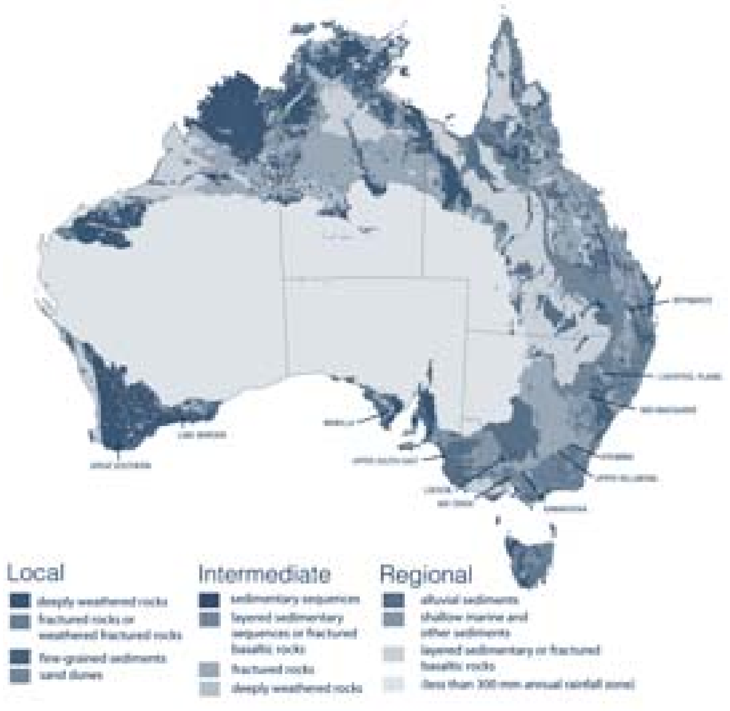
Hence the case studies have been grouped under GFS type to encourage readers to review case studies in areas that may be biophysically similar to their own. Some of the GFS types comprise more than one GFS. This is consistent with the explanation in Chapter 2 that several systems can occur in one catchment or region.

Map 1 shows the three main types and sub-types across Australia, and the **approximate** location of the case study catchments. Due to the coarse scale of the map, it does not precisely locate the case study sites according to their exact GFS.

To assist producers and advisors in considering the detail of the case studies and interpreting their implications, the description of each case study is structured according to headings in the matrix.

Where appropriate, 'Important Points' commenting on particular case study findings are provided. In some cases they refer to feedback received on a draft of this report.

The key messages are based on an overall assessment of the findings and other research.



Source: National Land & Water Resources Audit and DESIGN SCENE, Norwood, SA

Caveat concerning the FLOWTUBE model

The NLWRA case studies summarised in this section (Lake Warden, Great Southern Region, Wanilla, Kamarooka and Upper Billabong) used two hydrological modelling approaches developed by CSIRO and other partners: farm-scale modelling to assess the relative effectiveness of different farming systems to manage recharge and water use; and catchment-scale groundwater modelling (using FLOWTUBE) to simulate the major processes driving recharge and discharge.

The following caveat concerning the modelling appears at **www.nlwra.gov.au**. 'The case studies indicate that FLOWTUBE can broadly predict the impact of land use change on dryland salinity. However, they also identified that we lack data for making the best use of the predictive powers of FLOWTUBE. Its widespread use will require considerable effort to establish databases of aquifer characteristics and groundwater level trends across all major flow systems, particularly in those known to be at risk of dryland salinity.'

5.3.1 Local Groundwater Flow Systems

Case study #1 Kamarooka, Central Victoria

Kamarooka is one of the salinity case studies undertaken under the National Land & Water Resources Audit. The following text is based on information on Kamarooka at www.nlwra.gov.au and a technical report by Barr[2]. Text in quotation marks comprises direct quotes from the Barr report.

Catchment description

'The Kamarooka case study is a small area located half an hour's drive north of Bendigo on the northern edge of the Whipstick forest. Kamarooka is on the boundary between the northern slopes of the Great Dividing Range and the riverine plains of the Murray-Darling Basin.'

Groundwater Flow Systems

'A local flow system in variably weathered fractured rock. Groundwater discharge [occurs] at break of slope.'

Nature of the salinity problem and risk

'The salinity in this small area is typical of that [which] occurs along the inland slopes of the Great Dividing Range of south-east Australia. Recharge occurs on the hills and slopes. Discharge occurs along the break of slope. The case study area has 400 hectares of salinised land and [salinity] affects 10 per cent of the study area.'

Approach

Rather than starting with a preferred approach, the National Land & Water Resources Audit case studies examined the possible outcomes of options to assist stakeholders in choosing approaches.

Tactics

Leakage reduction.

Important point

Feedback on a draft of this report noted that Kamarooka is close to the major provincial city of Bendigo, and hence a large proportion of the area is managed as 'lifestyle blocks'. Kamarooka landholders' views about lucerne may differ from broadacre producers, many of whom are finding lucerne to be a useful and profitable option for salinity management (see Producer experiences with lucerne in Section 4.2.4.

Options

Two options were examined:

- 50 per cent leakage reduction through conversion of annual pastures to lucerne; and
- 90 per cent leakage reduction by the introduction of 80 per cent tree cover on those parts of the study area uphill from the break of slope.

Possible outcomes

Barr's report made the following points:

- [FLOWTUBE] modelling of the groundwater systems suggests that the salinity situation is at equilibrium and there will be little growth in the current extent of salinity with 'no intervention'.
- A 50 per cent reduction in leakage would lead to a 50 per cent reduction in the area *at risk of salinity* within 20 years and an eventual elimination of salinity in 100 years. Economic analysis suggests this conversion is profitable for landholders, offering the potential to increase gross margins by 40 per cent.
- A 90 per cent reduction in leakage reduces the area of high water tables much more quickly. There would be a 50 per cent reduction in the area of *saline land* within 20 years and a complete reduction within 100 years. However, the 90 per cent reduction would lead to a 40 per cent reduction in net farm incomes over a 50-year period.

Barr also noted that notwithstanding the predicted increase in profitability from converting annual pastures to lucerne, there are constraints to this occurring, including:

- The majority of farm family income is earned off-farm.
- Lucerne is relatively complex to introduce into a pastoral management system.
- Cropping has been a more profitable enterprise [than grazing lucerne] for the past decade.
- Drying out the soil profile [with lucerne] may increase crop production risk if the following season's rainfall is below average.
- A core 30 per cent of landholders are disinterested in lucerne [for various reasons, including that set stocking of annual pastures is a better lifestyle fit with their off-farm work].

Case study #2 Upper Billabong (Simmons Creek), southern NSW

Cresswell *et al*[3] reported on generation and delivery of salt to the Upper Billabong (referred to in their conclusions below as the Billabong Creek) from the 16,900 ha Simmons Creek catchment (see also NDSP *TechNotes*[4]). Their study is one of the most detailed salinity case studies conducted to date by CSIRO in NSW. Text in quotation marks comprises direct quotes from their report.

Catchment description

'Simmons Creek catchment is located at the eastern edge of the Riverine Plain, immediately east of Walbundrie township in southern NSW. The mean annual rainfall is approximately 570 mm, with most precipitation falling in the winter months.'

Groundwater Flow Systems

Simmons Creek catchment is a local GFS. Water tables rise rapidly and saline discharge typically occurs within 20–30 years of agricultural development. There is a deeper regional GFS below Billabong Creek, in which groundwater tends to be fresh and is not a concern.

Some groundwater/salt mobilisation processes are unique to Simmons Creek, e.g. a mid-catchment basement barrier effectively plugs the whole system and may have predisposed this catchment in particular to concentrated accumulation of solutes.

Highly saline groundwater and major salt stores are largely confined to the uppermost 15 m [of regolith], whilst deeper aquifers typically contain fresh groundwaters. Stored salt is being mobilised through elevated water tables contributing to increased stream salt loads. Highly saline groundwater at 14,000–32,000 EC underlies a very large proportion of the lowland area of the southern half of the catchment. Water tables associated with these saline aquifers are at 4–6 m below the ground surface in the lowlands (Billabong Creek plain).

Nature of the salinity problem and risk

'Stored salt is being mobilised through elevated water tables contributing to increasing saltloads [in Billabong Creek]. Highly saline groundwater, 14,000–32,000 [EC units], underlies a very large proportion of the lowland area of the southern half of the catchment.'

'Salinity processes in the catchment are groundwater-driven. The lower reach of Simmons Creek intersects the saline water table whereupon the creek channel functions as a groundwater drain that exports saline groundwater (half the salinity of seawater) directly to Billabong Creek.'

Approach

Rather than starting with a preferred approach, the study focused on improving stakeholders' understanding of how their landscape functioned so that they would have a more informed basis for choosing approaches.

Specific objectives of the study were to:

- 'Provide a conceptual understanding of groundwater systems in the catchment.
- Define the patterns and processes of recharge, pathways of salt transport, and groundwater discharge.
- Contribute to an understanding of landscape processes in areas affected by, or at risk from high water tables and salinity, including an understanding of the relative importance of salt transport via surface and near-surface wash-off processes versus baseflow.
- Contribute to an understanding of the mechanisms controlling the generation and delivery of salt to streams in riverine landscapes generally.'

Tactics

Leakage reduction as a preferred tactic.

5. CONSIDERING POSSIBLE FARM TO CATCHMENT-SCALE OUTCOMES

Important point

The Simmons Creek study indicates the detailed nature of investigations that may be required to determine the exact nature of the salinity problem and to identify appropriate management approaches.

The study has pioneered development of a hydrological modelling framework that links farm scale water balance modelling with catchment or GFS-scale water balance modelling. This provides a *local scale* understanding of where to locate recharge reduction options, and a local scale appreciation of the positive and negative effects of those options on salinity and streamflow.

The modelling framework appears to have wide relevance to other landscapes fringing riverine plains in south-east Australia with 500–800 mm annual rainfall.

Options

Leakage reduction options such as 10 per cent tree cover, 20 per cent perennial pasture [cover], and tree planting were under consideration by catchment stakeholders at the time of the study.

Possible outcomes

With regard to patterns and processes of recharge, pathways of salt transport, and groundwater discharge, the study concluded that:

- 'Surface wash off processes are not important in terms of salt acquisition [to Billabong Creek]. Catchment-wide run-off waters are fresh … most salt mobilisation occurs via baseflow or interflow. [However] the lower Simmons Creek channel intersects highly saline groundwater and functions as a groundwater drain most of the time, rather than as a surface drainage line for fresh run-off water. About 164 tonnes of salt per year enters Billabong Creek directly from the 'groundwater drain'.
- No major salt contributions to the Billabong Creek are derived from this [south eastern] part of Simmons Creek catchment. Elevated salinities for this stretch of Billabong Creek near Morgan's lookout must accordingly be sourced from either the southern side of Billabong Creek or from Kangaroo Creek sub-catchment to the east of Morgan's Lookout.
- Relatively fresh groundwaters are no doubt seeping into the (Billabong) creek, at least along the reach from Morgans Lookout to around Brittas Reserve. This inferred fresh groundwater flow is no doubt important towards dilution of salt loads.
- Whilst a new dynamic hydrologic equilibrium has apparently been attained in Simmons Creek catchment sometime since clearing, a new salt equilibrium (salt output:input ratio of 1) will take much longer to be established. Under the present hydrologic regime, … it may take well over a hundred years for existing salt stores to be flushed from the catchment.'

Taking the above hydrological and salt mobilisation processes into account, the study made the following point about management recommendations:

- 'Mitigation measures need to be directed towards the catchment groundwater system with the aim of: (a) lowering the water tables in the southern part of the catchment in the local areas where there are high salt concentrations [in groundwater]; (b) reducing recharge in the northern part of the catchment to prevent water table rise and salt mobilisation.'

Cresswell *et al.*'s report incorporates specific recommendations addressing points (a) and (b) above. These recommendations involve precise targeting of revegetation (trees and perennial pastures) to particular localities in the catchment to achieve specific outcomes for land salinisation, salt accession to Billabong Creek, and conservation of biodiversity.

Case study #3 Brymaroo, Eastern Darling Downs, Queensland

Salinity management in the Brymaroo catchment was studied in 1992 by Doherty and Stallman[5]. It was also investigated by Smitt *et al.*[6] as one of the case studies under the Murray-Darling Basin Commission's *Catchment Characterisation* project. The following text is based on reports of these studies.

Catchment description

The 1400-hectare Brymaroo catchment is on the eastern Darling Downs, north-west of Oakey. The northern boundary is formed by Cain Creek, while all the other boundaries lie at catchment divides. Average annual rainfall at Oakey is 670 mm/year. Of this, more than half falls between November and March. The dominant land use is grain cropping. However, much of the catchment is under perennial pasture, including the alluvial flats bordering Cain Creek, as well as much of the catchment uplands.

Groundwater Flow Systems

The Smitt *et al.* report[6] notes that the Brymaroo catchment is a local GFS in fractured volcanic rocks and is relatively responsive to changes in water balance. It is a self-contained groundwater catchment independent from regional systems to the south.

Nature of the salinity problem and risk

Approximately four per cent of the catchment is salinised. This has been inferred from aerial photos, whilst minor groundtruthing was undertaken in early 2001. The main area where saline discharge occurs lies in the northern half of the catchment surrounded by several smaller outbreaks.

Approach

Whilst the reports do not specifically define approaches, the options examined indicate that containment and adaptation are the preferred approaches.

Tactics

Leakage reduction and groundwater management.

Options

The options modelled by Smitt *et al.* included a 50 per cent leakage reduction by placing the upper part of the catchment under perennial pastures, and a 90 per cent leakage reduction by revegetating the catchment with native trees.

The earlier Doherty and Stallman report recommended groundwater pumping to reclaim waterlogged and salt-affected areas. The Smitt *et al.* report of 2003 noted that 'In Brymaroo catchment, groundwater is currently pumped from two bores, one located in the upland basalts, and the second located closer to Cain Creek, in the alluvial sediments.'

Possible outcomes

The Smitt *et al.* report noted that:

- 'The catchment's groundwater system is full.
- The expansion of salinity has largely culminated [reached its largest extent]; further salinisation is expected to be minimal if current land use is maintained.
- A 50 per cent reduction in recharge (achieved by replacing annual crops and pastures with perennial pastures) would see groundwater levels in the upper catchment falling by up to 5 m after 20 years, slightly reducing the amount of salinised land within the discharge zone.'

Key message

Many local groundwater flow systems in mainland south-eastern Australia appear to be at or close to hydrologic equilibrium, but reducing leakage may still be worthwhile to reduce waterlogging.

Petheram *et al.*[7] examined five local 'Type III' GFS in three different States to assess the extent to which salinity management information can be transferred between hydrogeologically similar catchments.

Local Type III GFS are characterised by discharge from weathered, fractured rock aquifers at break of slope, and are prominent in salinised regions in south-eastern Australia. The five catchments studied were all either approaching or had attained hydrological equilibrium (i.e. discharge to the land surface is equalling recharge).

In summary, Petheram *et al.* concluded that '[all of] the catchments' responses to incremental reductions in recharge were reasonably similar. Furthermore, due to the wide variety of sizes, shapes, gradients, climates and geographic locations of the catchments tested, they expected that poorly documented catchments of the same type would respond in a similar manner.'

More specifically, the authors considered that the following 'generic inferences' could be made:

- 'Waterlogging would still occur 50 years after recharge reduction, irrespective of how extreme the land use change. Even small catchments that initially responded very quickly to vegetation clearing [in terms of groundwater rise], would take many decades to return to their pre-clearing state after revegetation.
- Reducing recharge by 30 per cent will produce a reduction in the area of waterlogged land of about 10–25 per cent after 20 years, with little improvement thereafter.
- Reducing recharge by 50 per cent will produce a reduction in the area of waterlogged land of about 25–50 per cent after 50 years, with only a small improvement thereafter.
- Reducing recharge by 90 per cent will produce a reduction in the area of about 70–90 per cent after 50 years and 85–100 per cent (removal of waterlogging) at a new hydrologic equilibrium.'

5.3.2 Local and Intermediate Groundwater Flow Systems

Case study #4 Lake Warden, Esperance, Western Australia

Lake Warden is one of the salinity case studies undertaken under the National Land & Water Resources Audit. The following text is based on information on Lake Warden at www.nlwra.gov.au and a technical report by Barr[2].

> **Important point**
>
> Systems at Lake Warden are now considered to be local and intermediate.

Catchment description

Lake Warden is near Esperance on the south-east coast of Western Australia. Salinity impacts appear mainly on farmland and around important internationally acclaimed RAMSAR wetlands, as well as other low-lying waterbodies.

Groundwater Flow Systems

The GFS is described at www.nlwra.gov.au as 'a local and regional groundwater flow system in alluvial sediments and deeply weathered rocks.' The case study noted that in this system 'with its low to medium permeabilities and low to moderate groundwater gradients, the catchment has a low to moderate ability to move groundwater.'

Nature of the salinity problem and risk

At present eight per cent of the catchment is salinised by shallow water tables but this area is expanding rapidly. Without management, the extent is predicted to increase to 45 per cent of the catchment over the next 50 years.

Approach

Rather than starting with a preferred approach, the National Land & Water Resources Audit examined possible outcomes of options to assist stakeholders in choosing approaches.

Tactic

Leakage reduction.

Options

Leakage reduction of 50, 75 and 90 per cent from current levels. The 50 per cent option included replacing all annual pastures with kikuyu and replacing 50 per cent of the cropped land with kikuyu. The 75 per cent option included replacing all annual pastures with kikuyu, replacing 67 per cent of cropped land with trees, and replacing the remaining cropped land with a rotation based on phase farming with lucerne. The 90 per cent option included replacing all annual pastures with trees and replacing 90 per cent of cropped land with trees.

Possible outcomes

The modelling predicted that:

- If current land use is maintained, shallow water tables will develop in most of the lower parts of the landscape within 40 years.
- A 50 per cent reduction in leakage would not decrease the ultimate expanse of the area at risk of shallow water tables when compared to the *status quo* scenario.
- A 90 per cent reduction in leakage would stabilise rising groundwater level trends by 2020 and would reverse the trends by 2050[8].

> **Important point**
>
> Feedback on a draft of this report suggested that there were some concerns about the relevance of some of the management options (particularly kikuyu) modelled. Notwithstanding these comments, the principle of using perennial vegetation to reduce leakage is important.

Case study #5 Great Southern Region, Western Australia

The following text is based on a comprehensive salinity risk assessment for the Great Southern Region[9]. The Salt Scenarios 2020 (SS2020) case studies were undertaken to develop the modelling methods used in the other National Land & Water Resources Audit case studies. Except where otherwise indicated, the text in quotation marks comprises direct quotes from the report of the assessment.

Region description

The Great Southern Region is located in south-west Western Australia. Land use is dominated by mixed cropping and grazing. As part of SS2020, three catchments on which FLOWTUBE modelling was conducted were chosen from representative areas of the 'wheatbelt' of Western Australia (~18 million hectares).

'North Baandee [330 mm rainfall] is considered to be similar to much of the approximately 8 million hectares of the low rainfall wheatbelt, while Toolibin [400 mm rainfall] is believed to be similar to the central wheatbelt (~4 million hectares), and Date Creek [600 mm rainfall] the western wheatbelt or woolbelt (~2 million hectares).'

Groundwater Flow Systems

The GFS in the Great Southern are described as 'local and intermediate groundwater flow systems [that] typically have low permeabilities and gradients and therefore a low ability to move groundwater. Similar local and intermediate systems are widespread in the agricultural regions of Western Australia and Eyre Peninsula of South Australia.'

Nature of the salinity problem and risk

'Producers have already lost 5–10 per cent of their productive land to salinity. The rate of increase has accelerated recently, as aquifers have filled since clearing took place in the past 30–100 years. There is the potential to lose up to 30 per cent of the most productive land in the State [due to shallow water tables].'[8]

Approach

Rather than starting with a preferred approach, the SS2020 case studies examined the possible outcomes of salinity management options, to assist stakeholders in choosing approaches. The studies sought to answer four key questions:

- 'How large will the problem eventually be under current land practices? How large might it be in 2020?
- What is the risk if the area under threat grows that large?
- To what degree can we change the eventual extent of salinity with land use alternatives that are both feasible and available?
- What are the costs and benefits of intervening with these alternative land uses?'

Tactic

Leakage reduction and groundwater management.

Options

Salinity management options assessed were 'based on currently available systems already being established by farmers in the regions. The options were chosen to be both optimistic and realistic' and included agroforestry and lucerne as part of phase farming.'

Low and medium levels of intervention included 'low recharge' farming systems (e.g. lucerne in cropping rotations) and revegetation (e.g. with oil mallees, tagasaste, pines and eucalypts). High levels of intervention included the medium revegetation interventions, plus groundwater pumping. Drains were not considered.

Possible outcomes

Overall implications include:

- 'For all but the steepest landscapes, intervention in the form of land use change would need to be substantial and widespread [to meet a recovery goal].
- When alternative enterprises (e.g. trees for pulp and timber production) are limited to only the most appropriate soils, the ultimate extent of salinity does not radically change, although the impact is delayed [for 20+ years[10]].
- Since salinity risk abatement associated with low-recharge land use systems largely benefits the land they are planted on and nearby [less than 100 metres[10]], these alternative farming systems must be profitable in their own right.
- The non-farm assets at risk require large-scale, local, mainly non-economically-driven intervention.
- Given the scale of revegetation required to substantially change the ultimate extent of salinity, it does not appear feasible with the available low-recharge farming systems and tools which are at our disposal to make up the gap in farm profitability associated with alternative, low-recharge farming systems.
- While 'low-recharge high water use' farming will ultimately leave almost as much land at risk to salinity as current practice, the possibility that decades might elapse before the full impact of salinity is realised has considerable social and economic value. If nothing else, it gives families and governments more time to adapt to a salinised landscape and possibly for some innovative solutions to be developed.
- With no external subsidies for farm costs, treatments should be commercially profitable in their own right if they are to be attractive to farmers and the wider community.'

More specifically, for the eastern and central wheatbelt:

- 'Modelling suggests that catchments in the eastern and central region, similar to North Baandee and Toolibin, do not significantly respond in the very long-term (330 years) to recharge reductions modelled in this project.
- In any event, modelling suggests that medium levels of intervention buy a significant amount of time [20–60 years[10]] in catchments with deep water tables. Episodic recharge will reduce the amount of time 'bought' by new farming systems;
- Only engineering systems (e.g. pumping) significantly alter this outcome;
- Preliminary economic analysis suggests that none of the interventions are currently close to 'break even' for farmers.'

Important point

Analysis suggests that areas at risk that still have deep water tables are priority locations for leakage reduction in the eastern and central wheatbelt, not hillsides. Reducing water table rise will buy time and preserve cropping systems[10].

Key message

Local Groundwater Flow Systems in WA can be managed, but leakage reduction has to exceed 50 per cent

Local GFS in sloping areas of South Western Australia can be managed by perennial pastures, trees or engineering options, but impacts are minimal until leakage reduction exceeds 50 per cent at the catchment scale. In flatter, eastern areas, rates of leakage reduction being proposed will not alter the rate of water table rise. However, leakage reduction buys time and has economic merit. Saltland management and groundwater management are appropriate tactics for salinised areas.

For the western regions:

- 'Modelling suggests that catchments in the western region, similar to Date Creek, respond to recharge reductions modelled in this project relatively quickly [less than 10 years[10]]. At higher levels of intervention, some land may be prevented from becoming saline, [and some could be reclaimed[10]].
- Engineering systems (e.g. pumping and siphons) decrease the extent of land with a shallow water table.
- Economic analysis suggests that the low levels of intervention are most economic; however, none allows a 'break even' level to be achieved by farmers.
- Groundwater pumping in this area will be more expensive, as the pumping has a smaller impact' [siphons and deep drains are likely to be better options[10]].

'For all but the steepest of sections simulated in other western catchments modelled (e.g. Nunijup, Boscabel), the planned interventions buy only a marginal decrease in the eventual extent of salinity as represented by shallow water tables but up to several decades of time before full salinisation.'

Case study #6 Wanilla, Eyre Peninsula, South Australia

Wanilla is salinity case study undertaken under the National Land & Water Resources Audit. The following text is based on information at **www.nlwra.gov.au** and a technical report by Barr[2].

Catchment description

Wanilla is a small basin of about 17,000 hectares, about 40 km north west of Port Lincoln on the Lower Eyre Peninsula. It is one of the National Land & Water Resources Audit case study catchments for which Barr examined salinity processes, the cost and effectiveness of management options, and the capacity of producers to implement the options.

Groundwater Flow Systems

'A local to intermediate flow system in deeply weathered rock. Groundwater discharge [occurs] at break of slope and valley floors.'

Nature of the salinity problem and risk

Water balance modelling predicted that 'there will be an expansion in the areas of high water table from the current 8 to 15 per cent of the catchment over the next 20 years with a continuation of current land use and agricultural practice. Within 50 years the extent of the catchment with high water tables was predicted to grow to 16.8 per cent.'

Approach

Rather than starting with a preferred approach, the National Land & Water Resources Audit case studies examined the possible outcomes of options to assist stakeholders in choosing approaches.

Tactics

Leakage reduction.

Important point

Feedback on a draft of this report noted that as the Wanilla catchment drains to the sea, leakage reduction is a more appropriate tactic than groundwater management using deep drains. Poor quality drainage water from Wanilla's acid-sulphate soils could affect oyster farming in bays at the Wanilla outlet.

Options

A 50 per cent reduction in leakage, involving replacement of all upper catchment farmland with trees and replacing all pastures in the lower catchment with lucerne.

Possible outcomes

Under the 50 per cent leakage reduction scenario, 'the area affected by high water tables would increase from 8.1 per cent to 11.7 per cent over the next 20 years, and to 12.9 per cent over the next 50 years.' Furthermore, economic analysis indicated that 'optimistic assumptions [about the net financial effects of leakage reduction] produced a reduction in net farm incomes of 35 per cent. Pessimistic assumptions saw the total elimination of net farm income.'

Important point

Feedback on a draft of this report suggested that there needs to be 'a careful analysis of the assumptions underlying the hydrological and economic modelling. Small changes in assumptions could give very different outcomes.'

Case study #7 Kyeamba Creek, southern New South Wales

Kyeamba Creek was one of the case studies conducted for the Murray-Darling Basin Commission's *Catchment Characterisation project*[11]. The following text is based on a report of the case study by Cresswell *et al.*[12]. Text in quotation marks comprises direct quotes from their report.

Catchment description

'The Kyeamba Creek is a third-order tributary feeding the Murrumbidgee River just to the south-east of Wagga Wagga, NSW. The catchment covers 602 km^2, with the sharp relief of the hills to the south contributing to a total land surface of 755 km^2. The catchment has an average (over the last 50 years) rainfall of 650 mm/year, exhibiting a south to north gradient from 800 mm/year over the granite hills to the south, decreasing to 600 mm/year at its confluence with the Murrumbidgee River to the north.'

Groundwater Flow Systems

'The catchment ... lies within an intermediate-scale fractured rock aquifer. Overlying valley fill alluvium represents a shallow secondary local-scale aquifer system. The catchment thus contains a dual aquifer system: upper local-scale alluvial aquifers and an intermediate-scale deeper fractured rock aquifer. These systems commonly have only a small proportion of land area actually salinised, less than two per cent, but can be a major source of salt via saline discharge to streams and larger river systems.'

Nature of the salinity problem and risk

Kyeamba Creek released the second-highest proportion of salt per unit area of the catchments feeding the Murrumbidgee River. An average annual salt load (1975–1995) of 20,400 tonnes flows past Ladysmith, 12 km from the confluence with the Murrumbidgee River. Kyeamba Creek contributes only five per cent of the salt in the Murrumbidgee River passing Wagga Wagga, but is currently exporting roughly 10 times the amount of salt being brought into the catchment via rainfall.

Land salinisation is not a problem in the catchment, constituting less than one per cent of the area. Catchments with similar salt input:output ratios, such as Boorowa and Yass, are facing major land salinisation problems.

Approach

Approaches taken in salinity management plans for Kyeamba Creek appear to focus mainly on containment and adaptation. The Cresswell *et al.* study was undertaken to:

- 'Describe the physical setting and condition of the Kyeamba Creek catchment and aquifer system.
- Examine various data interpretations on the conceptual model of flow processes for recharge and discharge.
- Model the historical and present-day hydraulic head trends.
- Model possible future salinity mitigation scenarios for the aquifer.'

Tactics

Leakage reduction and groundwater management.

Options

Suggested management options include 'revegetation/reafforestation of upper catchments using perennial pastures, native pasture, and native trees, possibly with some groundwater pumping applications.'

'There is a proposal [ca. 2001] to plant up to 13 per cent of the Kyeamba Creek catchment to hard and softwood plantations over the next five years. The primary purpose is wood production. A secondary benefit, however, may be reduction of recharge and some control of land and stream salinisation in Kyeamba Creek.'

Possible outcomes

The Cresswell *et al.* report concludes that:

- 'In-stream EC in Kyeamba Creek is variable, but is generally < 3000 EC and in dynamic equilibrium.
- The main salt delivery mechanism to the Murrumbidgee from the Kyeamba catchment is surface flow from creeks in the alluvium (including Kyeamba Creek).
- 93 per cent of the salt in Kyeamba Creek comes from surface and throughflow in alluvium; the remaining seven per cent comes from salt mobilised upwards to alluvium from fractured rock aquifer.
- High groundwater levels (in the fractured rock aquifer) are in dynamic equilibrium, but are well connected to the alluvium and highly responsive to rainfall events.
- Saline outbreaks are caused by local bedrock highs. Due to climate and responsiveness of the local alluvial system, they could be expected to expand and contract according to rainfall.
- Large scale reforestation in 800 mm rainfall areas would have only local effects over 20 years (limited to within 25 km of the plantations).'

Successful planting of trees and perennials within the Kyeamba catchment to date indicates a rapid response of water levels and encourages more widespread use of this management strategy[13]'.

Optimal salinity management options for the Kyeamba Creek catchment appear to be:

- Maximise recharge reduction in the alluvium through improved cropping and grazing systems to reduce the size of saline outbreaks, and to reduce salt mobilisation and delivery to streams;
- Investigate groundwater pumping at Gumly Gumly in the north of the catchment as a way of reducing salt mobilisation and heads from the fractured rock aquifer upward to Kyeamba Creek.

Possible outcomes of tree and pasture combinations at Boorowa, southern New South Wales

Possible outcomes of tree and pasture combinations in the Boorowa River catchment were investigated by Vaze *et al.*[14] using CATSALT modelling. The long-term average salt load exported from the Boorowa River to the Lachlan is 38,900 tonnes per year. The Boorowa River's mean annual salinity is 681 EC.

The land use change scenarios modelled by Vaze *et al.* were:

- Scenario 1 – all area under annual pasture was changed to perennial pasture, and 30 per cent of the area under cropping was changed to perennial pasture;
- Scenario 2 – in addition to the changes under Scenario 1, tree cover was increased to 20 per cent (scenario 2.1), 30 per cent (scenario 2.2) and 40 per cent (scenario 2.3) of the catchment.

Briefly summarised, Vaze *et al.* concluded:

- 'The Boorowa River catchment is relatively responsive and equilibrates quickly; around 20 years for the catchment, and around 15 years for individual hillslopes.
- Increasing perennial pasture content of the vegetation (Scenario 1) is unlikely to produce substantial benefits with regard to salinity.
- For Scenarios 2.2 and 2.3, reductions in salt loads are almost linear with flow.
- Reductions in average annual Boorowa River salinity were 10 EC for Scenario 1, 150 EC for Scenario 2.1, 170 EC for Scenario 2.2 and 180 EC for Scenario 2.3.
- Above 20 per cent tree cover (Scenario 2.1) does not produce a significant improvement in salinity, but reduces catchment run-off.
- Although 20 per cent tree cover showed the greatest reduction in salt load and salinity for the least loss of water yield for the catchment, there is reason to believe that a much smaller tree cover increase is probably responsible for most of this effect.
- Downstream effects of Scenario 2.1 in the Lachlan after its confluence with the Boorowa River indicate two per cent reduction in flow and a seven per cent reduction in salt load. Estimated reductions in salinity at Cowra for Scenarios 1, 2.1, 2.2 and 2.3 were 2, 18, 20 and 21 EC.

Possible outcomes of tree and pasture combinations at Mandagery Creek, central NSW

Using the same scenarios that were modelled by Vase *et al.* in the Boorowa River catchment, Tuteja *et al.*[15] used CATSALT modelling to predict the effects of land use change on water and salt balance in the 1688 km^2 Mandagery Creek catchment. Mandagery Creek is the last major tributary to join the Lachlan above Forbes, which is the location of salt load and concentration targets for the Lachlan.

Only about 0.5 per cent of the land area of Mandagery Creek catchment is salinised, but the Creek's salinity at Eugowra can reach 2679 EC under low flow conditions, and it is estimated to contribute 23,530 tonnes of salt per year to the Lachlan River. Its mean annual salinity is 665 EC.

Briefly summarised, the project concluded:

- Discharge areas could re-equilibrate in around 20 years for a catchment, and around 15 years for individual hillslopes;
- Increasing perenniality in crops and pastures (Scenario 1) does not produce substantial benefits with regard to salinity;
- Increasing tree cover to 30 per cent would reduce mean annual in-stream salinity by 84 EC (12.6 per cent), and would reduce run-off by up to 22 per cent;
- Increasing tree cover above 30 per cent (Scenario 2.2) does not produce any significant additional benefit with regard to in-stream salinity, but further reduces run-off from the catchment;
- Downstream effects of Scenario 2.2 in the Lachlan after its confluence with Mandagery Creek were a one per cent reduction in flow and four per cent reduction in salt load. Estimated reductions in salinity in the Lachlan at Forbes under Scenarios 1, 2.1 and 2.2 were 2, 6 and 10 EC.

Case study #8 Mid-Macquarie, Central New South Wales

A study commissioned by the Mid-Macquarie Landcare network in central New South Wales and undertaken by the Bureau of Rural Sciences (BRS) and Salient Solutions Australia is an example of how the latest scientific knowledge has been applied at a more local scale to answer key questions that affect producers' decisions about on-farm action.

The following text is based on the BRS/Salient Solutions Australia report[16]. Text in quotation marks comprises direct quotes from the BRS/Salient Solutions Australia report.

Region description

'The Mid-Macquarie region is located in the central west of New South Wales between Burrendong Dam and Dubbo, stretching from Coolah in the east to Molong in the south and encompassing the Bell, Little, Macquarie and Talbragar catchments.'

Groundwater Flow Systems

The study developed and described 17 GFS using a series of rules concerning slope and geology. They are described in detail in Appendix 2 of the BRS/Salient Solutions Australia report. They comprise 16 local GFS, many of which are underlain by 'Intermediate Flow Systems in the Macquarie Alluvium.'

Nature of the salinity problem and risk

'The region is considered to be at risk of dryland salinity, in terms of salinisation of both streams and land. Dryland salinity is ranked as its second-highest natural resource management priority issue with some 50,000 hectares afflicted by it.'

Approach

Existing salinity management plans in the Mid-Macquarie took a 'containment and adaptation' approach. The Mid-Macquarie community commissioned the BRS/Salient Solutions Australia study to assist in it in ensuring that its revised plan 'determines the nature of the problems, quantifies their impacts, evaluates the full range of action to address the problems, and recommends priority actions. Specific questions to be investigated by the study were:

- 'Where is the source of stream salinity in the Mid-Macquarie Catchment?
- What is the major issue – land or stream salinisation?
- How do the four main [sub-] catchments in the Mid-Macquarie region compare with each other?'

Tactics

Leakage reduction and saltland management.

Options

Prior to the BRS/Salient Solutions Australia study, producers across the four sub-catchments were being encouraged to apply 'best bet' options for addressing a range of natural resources management issues on different land management units based on topography, geology, soil type etc. The options included: farm forestry; saline agroforestry; remnant vegetation conservation; riparian zone conservation; perennial pastures; and saline pastures.

The options were recommended for all LMUs of the same type across the four sub-catchments, irrespective of the nature of the salinity problem across the sub-catchments (land or stream salinity) or where it was having most impact[17]. Implementing the recommended options would have required large on-farm investments.

Possible outcomes

The Executive Summary of the BRS/Salient Solutions Australia report notes that:

- 'A proper prioritisation of sub-catchments within the Mid-Macquarie Region is [still] not possible as the data are lacking both in terms of their spatial spread and coverage over time.
- The GFS methodology proved to be a mixed success [in terms of describing land and stream salinisation processes], with many GFS not showing a consistent groundwater or salinity response [to land use and climate].
- The lack of consistent trends in GFS, combined with the limited data, means that current or future salinity distributions cannot be inferred. Further, some sub-catchments are severely affected by land salinisation, yet are not contributing to stream salinity. This implies that the amount of land salinised is not a good indicator of stream salinity.
- Climate [rainfall] variability dominates groundwater level response and salinisation. Land use and management also contribute, but at a much more local scale. Local GFS dominate the region and there are indications that they have reached equilibrium.

Important points

1. The Mid-Macquarie case study by BRS/Salient Solutions Australia demonstrates the importance of accurately defining the nature of the salinity problem at sub-catchment scale. Severe land salinisation in a sub-catchment does not always mean that streams in that sub-catchment are salinised. Some sub-catchments that have salinised land appear to be contributing fresh flows to rivers.

2. The Victorian and NSW case studies profiled in this section of our report and work by Zhang *et al.* on afforestation and catchment water yield suggest that in much of south-eastern Australia achieving salinity outcomes will be more complex than encouraging producers to 'use water where it falls' or to 'adopt farming systems that reduce leakage rates to those that occurred under native vegetation'.

3. Identifying the 'right' mix and level of intervention with leakage reduction options is complex because they need to achieve conflicting outcomes and at different scales. At catchment-scale, the options need to achieve a balance between reducing leakage and maintaining water quantity and quality. At farm-scale, they need to achieve a balance between minimising waterlogging in wet years and running out of stock water in droughts.

- Air photo analysis of land salinisation outbreaks from the 1960s to the present indicate a close relationship between rainfall and the amount of land salinisation to the point where salinised land disappeared during dry periods.
- Groundwater levels have been historically high in some sub-catchments, reflecting natural discharge conditions under previous land cover [original native vegetation].
- For the study period, 50 per cent of the salinity export [downstream] from the Mid-Macquarie region was generated from outside the region upstream of Burrendong Dam.
- [Within the region] the Talbragar River downstream of Elong Elong and the Little River downstream of Obley were the main contributors to stream salinity.
- Conversely, the Bell River [sub-catchment] and the Little River where it flowed through the granite country, were the major contributors of fresh water flow for the region and hence must be preserved. At least one of the sub-catchments within these areas has been identified for salinity management that will stop these freshening flows!'

Possible outcomes of afforestation in the Mid-Macquarie

Researchers in the CRC for Catchment Hydrology[18] modelled the effect on water run-off and salt load of afforestation scenarios in the Mid-Macquarie, where salt exports to the river occur mainly through groundwater discharge. Two scenarios involved tree planting on 22 per cent ('focus' areas) and on 2.6 per cent (targeted locations within 'focus' areas) of the catchment. They found that:

- Under the 22 per cent planting scenario, salt loads would decrease only marginally 50 years following afforestation.
- Due to the long time required for changes in salt load to be expressed in stream salinity, salinity would get worse before it gets better.
- Under the 2.6 per cent planting scenario, salt loads would continue to increase and be only marginally less than the 'do nothing' scenario.

In addition to the BRS/Salient Solutions study, an associated economic analysis of six recommended 'best bet' options in each of the four Mid-Macquarie sub-catchments (24 modelling runs in total) was conducted by WAREC *et al.*[19]

In the 24 modelling runs, none of the 'best bet' options increased long-term returns to producers over existing enterprises in the absence of subsidies for producers to implement to options. With subsidies, only two modelling runs showed an increased long-term return to producers. A subsidy of $150/ha for replacing 250 hectares of annual pastures with perennial pastures in the Bell River increased NPV by $17,000. The same subsidy for replacing 75 ha of annual pastures with perennial pastures in the Mid-Talbragar increased NPV by $9000.

In the worst case scenario, replacing 250 ha of profitable crop area with perennial pastures in the Little River reduced NPV by $345,000 (30 per cent), while replacing 75 ha of profitable crop area with perennial pastures in the Mid-Talbragar reduced NPV by $126,000. A subsidy of $150/ha reduced the NPV loss only marginally in both cases.

5.3.3 Intermediate Groundwater Flow Systems

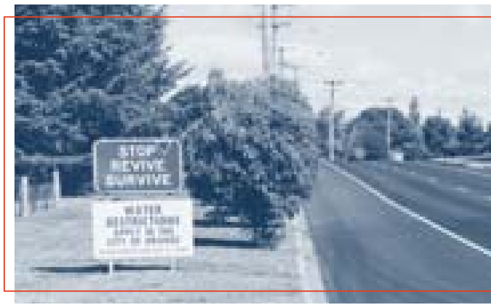
Case study #9 Upper South East, SA

Region description

The Upper South East (USE) region was a focus 'catchment' under NDSP Phase 1. At the time it was nominated, there were serious concerns over economic losses due to dryland salinity, surface flooding and waterlogging.

Groundwater Flow Systems

The *National Classification of Catchments for Land and River Salinity Control*[20] identifies the Upper South East as one of a number of locations within Australia that has intermediate GFS where 'groundwater discharge occurs from intermediate flow systems in low-lying areas as the result of gradual reductions in aquifer transmissivity.'



Leakage reduction options need to achieve a balance between salinity management and water supply objectives, especially during dry periods

Source: John Powell

Nature of the salinity problem and risk

The area affected by rising regional water tables was about 400,000 ha and a further 200,000 ha was threatened. Causes of the rapidly-expanding dryland salinity problem included the clearance of native vegetation, followed by the widespread killing of lucerne by blue-green aphid in the mid 1970s[21].

Approach

The USE Dryland Salinity and Flood Management Plan (see below) emphasises containment and adaptation, with localised recovery of farmland where possible.

Tactics

Leakage reduction, groundwater management and saltland management.

Options

The USE Dryland Salinity and Flood Management Plan involves four key management options: construction of a regional network of drains to control groundwater levels and surface flooding; pasture improvement using salt-tolerant and deep-rooted perennials; revegetation for biodiversity and leakage control; and wetland management.

On-farm measures included establishment of salt-tolerant pastures on salt-affected flats, and perennial pastures (lucerne) on dune rises. In addition, a minimum of 55 per cent perennial plant cover (including woodlots and afforestation) plus a minimum of 20 per cent native vegetation cover were recommended as targets for revegetation[22].

The status of the perennial vegetation and revegetation targets were reviewed internally by the South Australian government in 2002. The results of the review have been incorporated into current flagship programs promoting on-ground actions[23].

The USE has recently introduced a biodiversity trading scheme whereby producers can offset the cost of their drainage levies by entering into management agreements to protect and enhance remnant native vegetation. The scheme aims to improve the management of 64,000 ha of native vegetation for both biodiversity and recharge reduction values[24].

Possible outcomes

In their national review of engineering options, SKM[25] discussed Stage 1 of the **USE drainage works**, the Fairview Drain, which was completed in May 1998. The drain has a dual role in that it provides groundwater control to land adjacent to its 54 km length, and also allows control of surface water flows for the 27,500 ha of land within the drain's catchment.

SKM's reported observations from the Fairview Drain are that groundwater levels have been lowered in areas adjacent to the drain extending 1 to 1.5 km west and 1.5 to 2.5 km east of the drain. The key reason for the wide extent of the drawdown is the very high transmissivity of the limestone and associated calcareous soils into which the drain is excavated.

Disposal of water from the drains occurs into wetlands when the salinity is low enough, i.e. when the majority of flow is from surface run-off. Ultimately the intention is to dispose of drainage water to the sea.

On sandy rises, producers in the USE have used clay spreading to assist re-establishment of **lucerne, other deep-rooted perennials and productive annual crops**. Clay spreading has been a successful salinity management option in the USE, where about 800,000 ha are susceptible to high recharge rates on non-wetting sandy soils.

Clay has been spread on approximately 40,000 ha. At about $150/ha and requiring incorporation into the topsoil, clay spreading is not a cheap option, but it appears to be a one-off expense which can often be recovered in three years through gains in production[26].

Saltland agronomy is widely implemented in the USE, with commonly two-thirds of suitable saline land being established to salt-tolerant pastures[27]. The region hosts a producer network and a research site for the Sustainable Grazing on Saline Lands, which currently leads research into maintenance and utilisation of puccinellias and Balansa clover pastures[26].

Some puccinellia stands in drained areas are beginning to perform poorly as a result of effective drainage[10].

Important point

The findings of the Axe Creek study are not readily transferable to other areas because of the catchment's unique hydrologeological characteristics. The study is included in this report as it was one of the major MDBC *Catchment Characterisation* studies, and because it indicates that in some areas, specific investigations are required to determine the exact nature of the salinity problem and to identify appropriate management approaches.

Case study #10 Axe Creek, Central Victoria

Axe Creek is one of the case studies conducted for the Murray-Darling Basin Commission's *Catchment Characterisation* project[11]. The following text is based on a report of the case study by Hekmeijer and Dawes[28]. Text in quotation marks comprises direct quotes from their report.

Catchment description

'The 33 km^2 study area is located immediately south-east of Bendigo, with drainage towards the north-east, to the Campaspe River. The mean annual rainfall for the study area is 550 mm, with winter and spring rainfall slightly dominant.'

Groundwater flow systems

The GFS is described as 'an Intermediate Flow System in a fractured rock aquifer.' 'A defining feature of the catchment is the Whitelaw Fault that cuts the catchment into two distinct areas. Upslope of the Fault the country is steep with incised streams, shallow soils and a reasonable amount of native tree cover.' 'Downslope the landscape is much flatter with gently rolling terrain and extensive agricultural development.'

Nature of the salinity problem and risk

'Fractured rock aquifers [similar to Axe Creek] may manifest only a small area of surface salinity but result in a highly saline stream that exports a disproportionate amount of salt to the main rivers. Observations in Axe Creek support this.'

'Landholders believe the discharge sites have stabilised in extent. The total affected area is approximately 276 hectares. This is largely topographically controlled so it is unlikely that discharge areas will increase because nearly all the drainage lines down gradient of the [Whitelaw] Fault are already salt-affected. Salt loads exiting the Axe Creek catchment range from 5,000–15,000 tonnes per year, with recent records averaging around 7,000 tonnes annually.'

Approach

Rather than starting with a preferred approach, the study sought to:

- Outline the geological features of this geologically distinctive catchment.
- Conceptualise the groundwater flow processes for recharge and discharge to enable modelling of this part of the Campaspe River system.
- Model the historical and present-day hydraulic head trends in the catchment and relate these to surface discharge features.

Tactics

Leakage reduction and adaptation.

Options

'Management of cropping and grazing systems is required to minimise recharge on the lower slopes, and living with the current stable saline areas are appropriate options.'

Possible outcomes

'FLOWTUBE modelling of recharge reductions of 50 per cent and 80 per cent of the present recharge rates, to represent assumed pre-clearing levels, indicates that only the upper part of the catchment responds with appreciable drops in water levels. These reductions would be achieved in the first 20 to 50 years of recharge reduction, with little change thereafter.' Only the area upstream from the Whitelaw Fault would benefit from recharge reduction, whilst the flatter eastern lowlands would remain largely unchanged.'

5.3.4 Intermediate and Regional Groundwater Flow Systems

Case study #11 Liverpool Plains, Northern New South Wales

The Liverpool Plains case study was one the case studies conducted for the Murray-Darling Basin Commission's *Catchment Characterisation* project[11]. Except for references to a report by Ringrose-Voase *et al*.[29], the following text is based on a report of the *Catchment Characterisation* case study by Stauffacher *et al*.[30] Text in quotation marks comprises direct quotes from the Stauffacher *et al.* report.

Region description

'The study area covers 11,728 km^2 south of the town of Gunnedah. Ephemeral drainage occurs within the sub-catchments of the Liverpool Plains, with ephemeral streams of the Mooki River and Cox's Creek draining to the Namoi River, and into the Murray-Darling River system. Mean annual rainfall varies from just over 1000 mm/year at the top of the Liverpool Ranges in the south, to around 550 mm/year on the plains proper. Rainfall is summer-dominant and highly variable, with high intensity thunderstorms causing flooding on the plains.'

Groundwater Flow Systems

The GFS is 'an intermediate to regional flow system in alluvial deposits. The hydraulic gradient of groundwater flows follows the general topography, from the foothills of the Liverpool Ranges across the plains towards the Mooki River. The main [deep underlying] aquifer is made up of gravel and sand and is locally called the Gunnedah formation, while the semi-confining heavy layer over the top is called the Narrabri Formation.'

Nature of the salinity problem and risk

The Ringrose-Voase *et al.* report[29] notes that 'During the early 1990s it was estimated that up to 30,000 ha with water tables within 2 m of the ground surface suffered declines in crop yields and a larger area of up to 195,000 ha was at risk of water tables within 5 m.'

However, the Ringrose-Voase *et al.* report also notes that 'The area of salt-affected land with > 80 per cent reduction in yields [ca. 2003] is around 500–1000 ha.' This is a much smaller area of salinised land than that predicted in the early 1990s.

Stauffacher *et al.* in 2003 also noted that there are few signs of surface salinity in the sub-catchments of the Liverpool Plains. Only two sub-catchments — Pine Ridge and Lake Goran — are showing signs of dryland salinity. They concluded that 'Only small increases in groundwater heads and levels are likely with no change in land use, and that the main salinity issue is salt export to the river system during flood events.'

Approach

The Liverpool Plains was a focus catchment under NDSP Phase 1 of the. There have been many salinity research and extension activities in the region over the last decade. In view of early predictions that a significant area of the region was at risk of high water tables and salinity, this research and extension effort has focused on containment.

Tactics

Leakage reduction.

Options

Leakage reduction options being promoted are engineered structures to control flooding, opportunity cropping on the plains themselves, and perennial pastures and tree planting on the higher slopes.

Possible outcomes

The Stauffacher *et al.* study did not model a scenario involving the recommended options. However, their report notes that under a 'no-change scenario, there are steady but small increases in groundwater heads mainly in the upper parts of the catchments, and certainly only minor rises near the outlet.'

Important point

The Liverpool Plains case study also demonstrates the importance of accurately defining the nature of the salinity problem. In 1994, salinity risk predictions suggested that significant production losses due to salinised land would occur under a 'no change' scenario. The *containment* approach adopted at the time sought to prevent expansion in the area of salinised land.

The predicted expansion has not occurred, and in 2003, mobilisation of salt and its export to streams during episodic flood events appears to be the priority salinity management issue. This new knowledge supports continuation of the *containment* approach, but shifts its emphasis to containing salt exports.

The primary tactic of recharge reduction on the plains themselves remains valid, but its purpose is to create an unsaturated buffer zone to provide an effective store for floodwaters [to minimise salt mobilisation and export] rather than to lower water tables.

5.3.5 Regional Groundwater Flow Systems

Case study #12 South Loddon Plains, North Central Victoria

The South Loddon Plains was one the case studies conducted for the Murray-Darling Basin Commission's *Catchment Characterisation* project[11]. The following text is based on a report of the case study by Hekmeijer and Dawes[31]. Text in quotation marks comprises direct quotes from their report.

Region description

'The study area is located 40 km north-west of Bendigo, and extends west to the Loddon River and north to the Waranga Western Channel, and area of approximately 600 km^2. The mean annual rainfall for the study area is between 400 and 450 mm, supporting grain cropping and grazing.'

Groundwater Flow Systems

'The South Loddon Plains contains a highly permeable regional-scale alluvial plains aquifer with additional, distinctive features [that include] shoestring sand lenses and spill-over sands, both of which play significant roles in hydrogeological processes, particularly the discharge of groundwater.' 'Recharge to the deep lead aquifer is a combination of leakage from watercourses such as the Loddon River, a low level of diffuse recharge below crops and pastures, and extensive sheet flooding which episodically covers the entire area.'

Nature of the salinity problem and risk

'The discharge areas were mapped in 1991 (based on the presence of salt-tolerant vegetation) as 170 ha at Bears Lagoon and 77 ha at Pompapiel Creek). The area of salt-affected land has remained stable or declined since that time.

Any increase in discharge area is likely to extend to comparable topographically low points on the plains and to localities where shoestring sands (see Groundwater Flow Systems below) can transmit groundwater to the surface.'

Approach

Rather than starting with a preferred approach, the Murray-Darling Basin Commission *Catchment Characterisation* case studies examined the possible outcomes of options to assist stakeholders in choosing approaches. The South Loddon Plains study sought to:

- Outline the hydrogeological features of the South Loddon Plains.
- Conceptualise the groundwater flow processes for recharge and discharge to enable modelling of this part of the Loddon Valley system.
- Quantify the main components of these processes and groundwater resources.
- Model the historic and present-day hydraulic head trends.
- Model current and future [groundwater] pumping scenarios.

Tactics

Groundwater management by pumping.

Options

'Pumping [ground] water from the deep lead aquifer, under conditions with and without recharge within the drawdown zone.'

Possible outcomes

'Pumping fresh groundwater is an efficient and controllable option for reducing groundwater pressure in the main aquifer. While [groundwater pressure] heads would not be reduced below ground level everywhere, up to 10 m of drawdown can be established over the northern half of the study area [possibly 300 km^2] by increasing pumping to current estimated sustainable yield.'

[Groundwater pumping] 'is appropriate to analagous areas where groundwater is relatively fresh, particularly where there are opportunities for utilisation of the extracted water for small irrigated enterprises in otherwise dryland terrain.'

Key message

Groundwater pumping may assist in stabilising water tables in regional-scale alluvial groundwater flow systems along the south western margin of the Great Dividing Range

The study in the regional-scale GFS of the South Loddon Plains by Hekmeijer and Dawes was undertaken to 'identify feasible management options (biological or engineering) for dryland salinity in this and similar groundwater systems.'

They noted that 'Rapid rise in groundwater levels is typical after wet years and the levels remain high in the intervening years, only gradually declining during drought periods. [However] Apparent from the current monitoring bore hydrographs is the downward trend of groundwater levels since 1997, a reflection of both increased pumping and below average rainfall over the last four years [to 2001]. This is the case in both the shallow Shepparton Formation groundwater system and the Calivil Formation 'Deep Lead'.'

In considering the portability of their conceptual groundwater model, tools and results, Hekmeijer and Dawes noted that: 'The Calivil and Shepparton formations are very widespread alluvial aquifer systems in the Murray-Darling Basin [from Shepparton, in the south to Hillston in the north and Renmark in the west] although a high degree of connectivity between sand lenses is not typical throughout the Basin.'

They cautioned that: 'Extension of findings north into Queensland and the Great Artesian Basin, and the north-west of Western Australia, to other regional-scale aquifers is not recommended. Although ultimately similar recommendations may be reached, such as the pragmatic preference of engineering over biological measures, local information and investigation would be required.'

They concluded that: 'Findings and recommendations of this report are generally applicable to the other large alluvial flow systems all along the western margin of the Great Dividing Range.'

5.4 DECIDING ON THE RIGHT APPROACH

Producers and advisors who have used this report as an aid to decision-making for their particular salinity situation, will by now have:

- **Assessed their salinity risk** and clarified the nature of their salinity problem.
- **Short-listed possible approaches** to managing it.
- **Reviewed various tactics** and management options.
- **Considered possible farm to catchment-scale outcomes** from implementing the options.

The above steps should have been undertaken in consultation with the best professional advice available from catchment managers, researchers and other advisors.

The remaining tasks for producers and advisors are to *review* their short-listed approaches and *decide* on the most appropriate approach for them. This key decision can then be used to *confirm* choices in relation to preferred tactics and combinations of options. Choosing the 'do nothing' approach may be valid for the level of information and choice of options currently available.

Reconciling on-farm decisions with catchment objectives

In some instances, farm-scale approaches, tactics and options (e.g. adaptation to land salinisation through saltland management using salt-tolerant pastures) may not coincide with preferred catchment-scale approaches, tactics and options (e.g. containment of river salinisation through leakage reduction using perennial pastures and farm forestry).
This situation could occur in sub-catchments where:

- Water tables have reached or are about to reach dynamic equilibrium, salinised land is a small proportion of the catchment or region, and on-farm impacts are low.
- Salt stores are high and salt balance is not yet in equilibrium and may not be for many decades.
- Saline baseflow into streams is the dominant process governing salt exports from the sub-catchment and increasing stream salinity and/or salt loads is a priority issue.

From the case studies reviewed for this report, these circumstances appear relatively common in south-eastern Australia.

The most appropriate action from the producer's perspective may be to take no further action if they have already increased the perenniality of their systems to the extent that it is profitable, and are maximising productivity from their small areas of saline land.

However, saline baseflow from the sub-catchments may be adding substantial amounts of salt to streams and rivers, which may be compromising downstream salinity and salt load targets. Hence the regional salinity plan or strategy may be seeking substantial changes to farm management practices and/or land use to reduce saline baseflow.

These situations require constructive and inclusive negotiation processes that are informed by the best possible quantification of estimated on and off-farm benefits and costs of all possible options that may reduce saline baseflow. On-farm approaches, tactics and options need to take account of catchment-scale considerations and vice-versa.

6. WHERE TO FROM HERE?

6.1 FUTURE RESEARCH AND INVESTIGATIONS

Section 1.3 of this report identified a series of questions that producers and advisors need to answer in order to decide on appropriate approaches, tactics, and salinity management options. Briefly revisited, these questions are:

- Is the salinity problem severe enough to justify further action?
- If further action is justified, is there sufficient knowledge about salinity processes, impacts, and management options to decide on the best approach and for that approach, the preferred management options?
- Are financial or other assistance measures available for implementing the options and for involving producers and advisors in monitoring the effectiveness of the options?

The last question refers to grants and other incentives that may be available under salinity management strategies and plans. It is beyond the scope of this report, but is within the capacity of catchment managers to answer. Chapters 4 and 5 make as much progress as they can in assisting producers and advisors to answer the earlier questions.

However, the information presented in Chapters 4 and 5 indicates that there is still considerable uncertainty about the likely future extent of salinity and actual level of outcomes that may be possible with different combinations of options and levels of intervention. Even with available local knowledge from catchment managers and researchers, the level of uncertainty is highest at the farm-scale.

Future research is required to reduce this uncertainty to a level where producers can invest in salinity management with a level of confidence that matches the level of investment required.

In the future, as in the past, there will be some knowledge gaps that are better addressed by a national *research* effort, and others of more specific relevance that are better addressed by State to regional and local scale *investigations*.

Possible future priorities at these two scales are briefly outlined below. For the national priorities listed from 6.1.3 to 6.1.7, which all involve further development of the types of salinity management options described in Chapter 4, further research is required not only on the individual options themselves, but also on how combinations of them work together.

6.2 RESEARCH ADDRESSING REGIONAL TO NATIONAL ISSUES

6.2.1 Salinity processes and risk in northern NSW and Queensland

Apart from the northern NSW and Queensland case studies profiled in this report, few areas in these regions have shown extensive signs of salinity until recently. This is probably due to two main factors:

- Clearing for agriculture has occurred later than most areas of southern Australia, so recharge started later.
- Rainfall is summer-dominant, which means that recharge is also less because maximum plant growth occurs during periods of maximum rainfall.

However, in recent years, evidence[1] suggests salinising processes in northern landscapes are complex and may result from water table and non-water table-driven processes.

For example, it appears that clearing and increased leakage below the root zone on sodic/saline soils in northern NSW can trigger the development of an impermeable clay layer close to the land surface. Above the clay layer, seasonal waterlogging mobilises salts and they concentrate at the soil surface as the soil dries out. In this case, salinity is not water table-driven, but the symptoms of plant death and bare land are similar to those expressed in dryland salinity.

Furthermore, as salinity has been seen as an important issue only recently in these regions, the body of monitoring data (e.g. time trends in water levels) and related research that has been conducted into its causes, costs and consequences has been much less developed than the level of research in southern Australia. Climate, land use, and catchment hydrology are different in these regions and research is required to develop options that are appropriate for these conditions.

Leucaena — a forage tree legume for salinity prevention in Queensland

A 250,000 hectare revegetation strategy to prevent dryland salinity and improve water quality is proposed for the Fitzroy Basin catchment. It is based on using the perennial forage tree legume leucaena in conjunction with grass pastures for cattle production.

Scientific and grazier evidence from studies in Queensland and overseas suggests that leucaena will be effective in reducing deep drainage and run-off and will mimic the original native vegetation. The University of Queensland is currently undertaking leakage modelling[2].

6.2.2 Salinity processes and risk in Tasmania

There is a growing body of research in Tasmania, including hydrogeological and salinity work in some areas of the State, by Dell[3], Department of Primary Industries, Water and Environment[4] and Latinovic *et al.*[5], as well as some unpublished work. It does appear from this work that some of the paradigms applying to the mainland do not apply as widely in this State. Nonetheless it still seems clear that many of the tools developed elsewhere will be found useful in Tasmanian conditions.

Currently there is a need to increase the understanding of salinity processes in Tasmania, including where they operate and their relative importance.

6.2.3 Profitable plant-based salinity management options

The CRC for Plant-based Management of Dryland Salinity was established in 2002 to improve our understanding of natural and agricultural ecosystems and to develop new plant-based land use systems that lessen the economic, environmental and social impacts of dryland salinity.

Among other activities underpinning development of programs, a scoping study[6] was conducted to identify research priorities concerning perennial pastures for the recharge areas of southern Australia. The scoping study lists recommendations for research into perennial grasses, perennial legumes, and native and exotic non-leguminous herbs. These are being investigated under the CRC's programs, which include:

- Education and communication.
- Function of natural ecosystems.
- New and better varieties of herbaceous and woody plants.
- Land use systems with balanced water use.
- Economic and social assessment.
- Grazing systems for recharge and discharge pastures.
- Biodiversity.

The *Grazing systems for recharge and discharge pastures* program includes core research being undertaken for the Sustainable Grazing on Saline Lands program referred to in Chapter 4. For more information, see www.crcsalinity.com

6.2.4 Salinity, salt load and water yield outcomes of vegetation management options

The CRC for Catchment Hydrology has been established to deliver to resource managers the capability to assess the hydrologic impact of land use and water management decisions at the whole-of-catchment scale. The CRC is developing a Catchment Modelling Toolkit — a repository of software and supporting documentation intended to improve the efficiency and standard of catchment modelling.

The purpose of the Toolkit is to enable prediction of the multiple outcomes of land and water management decisions. Its use will enable catchment managers to manage catchments better, leading to improved environmental, economic and social outcomes. For more information, see www.catchment.crc.org.au

CRC for Catchment Hydrology scientists have been closely involved in the hydrological modelling work undertaken for the Murray-Darling *Catchment Characterisation* case studies and the National Land & Water Resources Audit case studies profiled in this report.

The CRC for Catchment Hydrology, the Grains Research and Development Corporation, and the Western Australia Department of Agriculture in WA have refined the FLOWTUBE model and constructed a user-friendly version to enable wider use by professionals advising on salinity management. It can be downloaded from www.agric.wa.gov.au

6.2.5 New industries based on tree and woody plant crops

National research findings concerning socio-economic constraints to adoption of changed farming systems, and the findings of the low recharge farming project in WA illustrate the difficulties associated with encouraging producers to adopt changed practices that are more complex and/or risky that their current practices, even where the recommended changes may be only incremental changes on their existing systems.

We can expect, therefore, an even greater level of producer resistance to new land uses that may be 'foreign' to producers' experience and aspirations. Achieving landscape change through farm forestry, as advocated by many governments and catchment management organisations, is therefore particularly challenging, and appears to warrant expanded national research effort.

A major review of the contribution of mid to low rainfall forestry and agroforestry to greenhouse and natural resource management outcomes was conducted in 2001[7]. Among other things, the review findings included:

- 'In mid to low rainfall systems, appropriate forestry and agroforestry design is critical to minimising the risk of drought. Research in Western Australia has shown that access to sufficient soil moisture is a significant factor when considering the risk of drought stress or mortality.
- Identifying new industries based on large-scale tree planting is a high priority for future research. The current scale of research is not commensurate with the scale of the environmental problem that tree planting is being called on to remedy.
- Public-funded research into historical niche industries should be at a level commensurate with the returns. The limited scale of these systems and their restricted impact on managing natural resource issues such as salinity implies that the R&D effort should be relatively low.
- The potential for industries such as oil mallee and charcoal should be investigated as part of the evaluation of new industries based on tree crops.
- The low rainfall native vegetation firewood industry and traditional, durable, hardwood pole and post supplies are likely to be able to use residues from low rainfall, long rotation plantations.'

6.2.6 Engineering options

In contrast to available vegetation management options, which may produce results only in the long-term or be unviable economically, engineering options offer the prospect of immediate results, and depending on the circumstances, cost effectiveness.

The roles of shallow and deep drains, interception banks etc. have been highlighted in this report, especially in sections on WA and SA.

However, problems encountered include the highly variable impact of deep drains, managing saline and acidic groundwater flows, and soil bio-geochemical changes that can occur where drainage lowers water tables. There is also debate about the need for regional drains, and about legal and institutional processes associated with such drainage programs. Requirements for major expenditure on infrastructure further constrain adoption.

With the exception of some groundwater pumping work in Victoria, our knowledge of the effectiveness of engineering options in managing salinity in the eastern States is limited. Research in irrigation and related salt interception schemes are relevant and require review and interpretation in the context of managing dryland salinity.

The effectiveness (and appropriateness) of engineering options cannot be determined objectively without more detailed analysis and assessment on a site-by-site basis. This assessment needs to take into account landscape position, groundwater systems, soils and farming systems. An over-riding requirement is to evaluate engineering options on an integrated landscape/catchment basis, so that all impacts and effects can be considered[8].

6.2.7 Saline resource management options

Collation and reviews of saline resource management systems have identified industry options for managing the substantial areas of land and volumes of water resources that will be salinised for the foreseeable future. However, in comparison to the body of research that has been conducted into preventing or controlling salinity, there has been limited research into the development of productive and profitable saline resource management systems.

Some opportunities exist such as salt water harvesting for aquaculture, desalination, salt harvesting, rare earth 'liquid mines' and related industries. In the long-term, it may be possible to develop salt-tolerant crops. These options require further research.

In the interim, there appears to be significant potential for increasing livestock production from saline land. Producer-driven trials under the Sustainable Grazing on Saline Lands (SGSL) program and research within the CRC for Plant-based Management of Dryland Salinity represent early steps in this direction.

6.3 INVESTIGATIONS ADDRESSING LOCAL TO REGIONAL ISSUES

In addition to national-scale research to further develop the different *types* of salinity management options and how they might work in combination with each other, there is an urgent need for improved tools, knowledge and processes for deciding *why* the options should be applied, *where* they should be applied, and the *scale* (i.e. level of intervention) at which to apply them.

Local to regional investigations are necessary to deliver these tools, knowledge and processes. Some regional salinity management planning processes are well advanced down this path, but others are in their early stages. In these latter areas, producers and their advisers are being impeded in their ability to take active approaches. In their case, the 'do nothing' approach may be justified at present.

6. WHERE TO FROM HERE?

Suggested local to regional-scale investigation priorities (in approximate sequential order) that would assist producers and their advisors to choose more active approaches are:

- Develop the GFS framework so that it can be used below regional scale.
- Develop the capacity to reliably link farm-scale models such as APSIM to catchment-scale models.
- Identify high-value assets at risk of salinity and the nature and timeframe of risk.
- Identify salinity and action targets that would be needed to protect high-value assets.
- Identify trade-offs associated with the action targets, for example trade-offs between water yield, salt load and salt concentration.
- Identify community processes for reviewing asset protection and action targets in the light of any trade-offs.
- Identify locations for priority action by producers and other community groups.
- Identify socio-economic adjustment trajectories of producers and communities in high priority locations.
- Develop salinity management options and assistance measures that are appropriate for the adjustment trajectories identified (including consideration of property rights, duty of care, public conservation services etc).
- Improve processes for implementing assistance measures and monitoring their effectiveness.

ADDITIONAL REGIONAL-SCALE INFORMATION ON SALINITY IMPACTS, PRIORITY SOIL LANDSCAPES OR GROUNDWATER FLOW SYSTEMS FOR ACTION, AND RECOMMENDED OPTIONS

Introduction

The information provided for Western Australia is based on findings of the *Land Monitor* Project and the State's Salinity Investment Framework[1].

Information provided for the other States is based on Tools Regional Information Packages (RIPs)[2] developed for selected regions of the Murray-Darling Basin (see also NDSP *TechNotes*[3]).

Western Australia

Salinity impacts and priority soil landscapes

In WA, the National Land & Water Resources Audit estimated areas with shallow water tables and future hazard. These estimates were updated as part of the *Land Monitor* project, and have been combined in an assessment of priorities for salinity management.

Land Monitor delivered farm-scale maps and estimates of the area of salt-affected land. They showed that a total of 1.047 million hectares was severely salt-affected by 2000. Of this area, 0.821 ha was farmland and the remainder was public land (mainly native vegetation). The time trend in the rate of expansion of saline land was approximately 15,000 ha/year. WA expects to continuously acquire Landsat data on a 5–10 year timeline to update trends in salinity and native vegetation.

Land Monitor also developed a surrogate system for assessing salinity hazard, after first failing to develop a system based on conventional groundwater data and modelling systems (results are described in NLWRA projects called SS2020). The final hazard assessment tool used terrain analysis and decision rules derived to identify valley hazards for subsequent analysis. Between 4.4 m ha (private) and 5.4 m ha (plus public land) of valley hazard was identified using this system.

Using methods defined under the Salinity Investment Framework, the technical feasibility of management options was conducted according to the tactic or combinations of tactics and their effects on the future extent of salinity, using the *recovery*, *containment* and *adaptation* approaches described in the body of this report.

In addition, the probability of adoption was also assessed. An assessment of the urgency (or timing of peak risk) was also assessed based on rates of water table rise and estimated risk. For each soil-landscape zone (used in Western Australia as a surrogate Groundwater Flow System), an estimate of the impact of the tactic or option on salinity was developed (See Table 1).

Finally, estimates of the impact in each zone were then assessed and the economic benefit of management evaluated. Sensitivity analysis was conducted on each of the factors.

For public assets (such as roads, town, biodiversity and water resources) the analysis was used to identify each asset's risk. Assets were then classed by value and threat and specific assets identified for individual analysis.

Important point

Some extracts from the Tools Regional Information Packages presented in this Appendix are more than two years old and may not be consistent with current understanding of salinity processes and of possible outcomes from salinity management options. This situation reflects the dynamic nature of the knowledge-generation environment concerning salinity.

Notwithstanding, the Regional Information Packages represent the most consistent regional-scale set of information available for salinity management in the Murray-Darling Basin. Hence they provide producers and advisors whose circumstances may not be covered by the case studies presented in the body of this report with some guidance as to the most appropriate options for them, based on the Groundwater Flow Systems classification.

Table 1. Analysis of impact of management strategies on the current extent and salinity hazard on agricultural land in Western Australia

REGION	SOIL-LANDSCAPE ZONE	URGENCY	AREA OF TREATMENT IMPACT			EXTENT & HAZARD	
			R	C	A	VALLEY HAZARD	CURRENT SALINITY
SWAN	211 Perth Coastal	5	1,425	0	380	38,000	38,000
	212 Bassendean	5	1,006	1,078	2,156	9,200	4,600
	213 Pinjarra – Dryland	5	4,275	2,344	15,625	40,000	34,000
	(Pinjarra – Irrigated)	5	2,344	1,172	1,094	10,000	7,500
	214 Donnybrook Sunkland	0					
	215 Scott Coastal	0					
	216 Leeuwin	0					
GREENOUGH	221 Geraldton Coastal	2	656	525	625	10,000	2,000
	222 Dandaragan Plateau	4	8,203	25,314	70,313	125,000	16,993
	223 Victoria Plateau	3	800	1,372	18,750	80,000	1,628
	224 Arrowsmith	2	18,750	18,281	37,500	80,000	2,000
	225 Chapman	5	4,519	4,458	4,519	41,314	557
	226 Lockier	3	1,750	1,662	3,063	46,676	2,354
CARNARVON	231 Port Gregory Coastal	0				296	107
	232 Kalbarri Sandplain	3	1,669	1,655	4,290	15,255	121
STIRLING	241 Pallinup	3	19,522	20,659	11,713	83,295	9,841
	242 Albany Sandplain	2	788	2,344	788	12,000	6,000
	243 Jerramungup	4	14,063	9,563	8,438	60,000	26,000
	244 Ravensthorpe	2	1,723	294	1,723	12,249	589
	245 Esperance Sandplain	2	19,688	48,623	39,375	277,058	60,000
	246 Salmon Gums-Mallee	1	1,925	6,575	7,219	191,168	9,803
	248 Stirling Range	5	3,797	1,403	6,328	27,000	5,618
AVON	250 SE Ancient Drainage	2	27,396	21,330	58,705	417,459	92,436
	253 Eastern Darling Range	3	35,204	31,647	42,245	150,204	15,177
	254 Warren-Denmark Southland	5	19,463	29,550	38,925	83,040	20,000
	255 Western Darling Range	4	4,050	4,187	8,100	17,281	2,395
	256 Nrthn Rejuvenated Drainage	3	37,500	26,743	62,500	266,666	76,495
	257 Sthn Rejuvenated Drainage	3	43,506	62,529	72,511	309,378	42,587
	258 Northern Ancient Drainage	2	95,595	45,258	95,595	1,456,679	249,796
	259 SW Ancient Drainage	2	15,985	25,741	57,091	243,587	60,537
KALGOORLIE	261 Southern Cross	1	574	2,117	2,154	57,450	1,006
MURCHISON	271 Irwin River	3	7,577	6,567	34,794	247,426	32,988
			414,546	**444,953**	**750,392**	**4,407,682**	**821,129**

Key

Definitions are based on State Salinity Strategy (2000); Recovery (returned from saline to previous production system), Containment (time taken or land prevented from becoming saline) and Adaptation (saline land under profitable land uses).

Rating Scale – Urgency

0 No significant problems from salinity
1 Most potential salinity after 2075
2 Most potential salinity after 2030 and before 2075
3 Most potential salinity after 2020 and before 2030
4 Most potential salinity after 2010 and before 2020
5 Most potential salinity at or before 2010

Costs and benefits of implementing options

A detailed account of the costs and benefits of salinity management in Western Australia appears in the Salinity Investment Framework.

For agriculture, the Framework shows that investment in salinity management is estimated to eventually generate a stream of additional profits (and losses avoided) for farmers that, in present value terms, equates to $716 million. The analysis can be used to speculate that the annual cost to farmers of forgone profit is around $300 million and the present value of those annual impacts (losses) is around $4 billion.

The following conclusions can be drawn from this analysis:

- Salinity currently affects 0.821 m ha or threatens (4.4 m ha) agricultural land and over 40 towns containing high value infrastructure. Over 3640 km of primary roads are affected or at risk (16,090 km). Of the area at risk, current trends in adoption and analyses of the effectiveness of practices suggest that less than 800,000 ha can be recovered or contained, and a similar area of land managed by systems of adaptation. A large area of the land at risk has no options for management (but may have in the future).
- Most of the benefits (and losses avoided) for farmers from the adoption of factors assessed in this review stem from the containment of salinity. Benefits from recovery of salt-affected areas are imputed to be higher than those for the improved management of saline areas, although this depends on actual costs of recovery. Recovery technologies are poorly developed.
- There is a high degree of variability between the zones where benefits were incurred (or losses avoided), with many eastern zones having a lower return on investment than those to the west. Net return per hectare needs to be considered along with return per zone.
- Improving either the technical feasibility or adoption rate greatly boosts the potential returns on investment in many zones.
- Further analysis of the economics is warranted as this analysis was only undertaken at regional scale and was related to agriculture and infrastructure alone. An analytical tool that allows further sensitivity analysis to be undertaken and regional variations better accounted for, is being developed.

The information below comprises extracts from *Tools* Regional Information Packages for selected regions of the Murray–Darling Basin

South Australian and Victorian Mallee

The region extends from the rolling eastern hills of the Mt Lofty Ranges near Adelaide to the undulating landscapes and plains of the mallee country (extending from South Australia into Victoria), bordered to the south by the Wimmera and uplands of Victoria, and the Upper South East (USE) of South Australia. It includes the lower River Murray from the Victorian/New South Wales border to the Murray mouth at Goolwa.

In 2000, it was estimated that 19,800 ha of the Murray [Geological] Basin was affected by [secondary] dryland salinity. In addition, it was estimated that 250,000 ha in the USE was affected and that this would increase to 324,000 ha by 2020 and 409,000 ha by 2050.

Agricultural productivity is severely curtailed on 6000 ha of salinised land in the Goolwa to Wellington region, which is predicted to increase to 9000 ha within 25 years. Rising water tables have also affected low-lying areas around the Lower Lakes (Alexandrina and Albert) and at the Noora-Yamba groundwater discharge zone near Loxton.

Detailed biological, engineering and 'living with salt' options for the three main GFS in the region (local, local/intermediate, and regional) are set out in pages 20–23 and Table 7 of the SAMDB-Mallee TOOLS RIP.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

For local GFS, recharge reduction using biological control (especially lucerne) is the preferred option. The use of trees also has potential, as belts or small plantations above saline discharge zones.

For the local/intermediate GFS, recharge reduction through biological control (deep-rooted perennials such as phalaris and lucerne, and native vegetation) is an option, although response times may be substantial (10–20 years). Groundwater pumping is probably the most effective engineering option, and pumping may be restricted to protecting high-value assets.

The RIP includes the following statements about best management options for the regional GFS:

- Modifications to existing farming systems were not predicted [in groundwater flow modelling] to significantly reduce River Murray salinity.
- The dominant passage for salt loads entering the lower River Murray is by direct baseflow of groundwater in the regional GFS.
- The regional GFS cannot be realistically managed through a reduction in groundwater recharge.
- Widespread revegetation within 5 km of the River Murray may provide some capacity to avoid future increases in salt loads attributed to recharge in the near-River environment. Beyond 5 km, the time lag for recharge in the Mallee to be expressed as discharge to the River is too great for practical consideration.
- Engineering options are deemed a suitable management option in protecting the lower River Murray from saline baseflow.

Wimmera region, Victoria

The Wimmera region covers about 3 million hectares including the Wimmera River catchment and part of the Millicent Coast Basin adjacent to the South Australian border.

The Wimmera River and its tributaries drain from the Mt Cole-Pyrenees Ranges in the south-east and the Grampians in the south, to the terminal Lakes Hindmarsh and Albacutya.

Dryland salinity affects at least 17,000 ha of the Wimmera. The region is at risk from further dryland salinity due to rising water tables. The NLWRA (2001) suggested that 96,400 ha in the region had high water tables and this was predicted to rise to 160,800 ha by 2050.

Salt export in surface streams including the Wimmera River 100–400 kg/ha/year. Salt exports from the Wimmera through deeper regional aquifers is estimated to be in excess of 200,000 tonnes annually.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 14–40 of the Wimmera *Tools* RIP.

Unlike the other *Tools* RIPs, the Wimmera RIP does not incorporate a broad summary of salinity management options for the region. However, it notes that:

- Challenges ahead include broad-scale land use change and an adaptation of current plans to incorporate new scientific information.
- For example, groundwater and catchment modelling suggests that even best practice grazing and cropping cannot adequately reduce groundwater recharge.

North Central region, Victoria

The region covers about 13 per cent of Victoria, bordered by the River Murray to the north, the central highlands to the south, Mt Camel to the east and to the west by a line west of Swan Hill to Avoca.

The four main river catchments are the Campaspe, Loddon, Avoca and Avon-Richardson. The Loddon and Campaspe Rivers drain directly to the River Murray, while the Avoca reaches the Murray only during floods.'

It was estimated that the North Central region had 124,300 ha affected by high water tables in 1998 and this was predicted to rise to 401,400 ha by 2050. Specific areas at risk from dryland salinity and/or predicted to have shallow water tables include: the break of slope between the uplands of the Great Dividing Range and the northern Victorian Riverine Plains, the middle and lower reaches of the Loddon riverine plain, and the floodplains of the Avon River.

The salt loads exported to the River Murray from the North Central region are believed to be significant. Stream salinity levels of the Avoca, Loddon and Campaspe already exceed or are predicted to exceed the 800 EC and 1500 EC thresholds for water quality.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 17–28 and Table 6 of the North Central *Tools* RIP. The moderate to high priority GFS (i.e. moderate, moderate to high, and high priority) are:

- Regional GFS in alluvial (riverine) plains.
- Local and intermediate GFS in deeply weathered and fractured sedimentary rock.
- Local and intermediate GFS in Cambrian volcanic and sedimentary rock.
- Intermediate GFS in fractured rock.
- Local GFS in fractured rock.
- Local and intermediate GFS in upland alluvium.

The RIP also includes the following information about best management options:

- Improved perennial pastures can assist in controlling recharge in local GFS but they may not be effective in high rainfall areas.
- Permanent native vegetation could be established on the more marginal terrain of the uplands as the dominant salinity mitigation measure.
- The upland terrain is generally suited to a range of 'living with salt' options such as salt-tolerant pastures and saline aquaculture.

Goulburn-Broken region, Victoria

The Goulburn-Broken region covers about 2.4 million hectares, and comprises the Goulburn River catchment (1.6 m ha), the Broken River catchment (0.7 m ha), and a small part of the Murray Valley.

About 4500 ha of the region is affected by saline groundwater discharge and this is predicted to increase to 38,000 ha by 2050. The NLWRA (2001) estimated that over 123,000 ha was affected by shallow water tables in 1998 and this was predicted to expand to 740,000 ha by 2050. The major area predicted to have shallow water tables is the break of slope between the uplands of the Ranges and the Riverine Plains.

Salt exported from the dryland part of the catchment to the irrigation region or the River Murray averages 180,000 tonnes per year, which is likely to double in 50 years if corrective action is not taken.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 19–25 and Table 8 of the Goulburn-Broken *Tools* RIP. The moderate and high priority GFS (i.e. low to high, moderate, and high priority) are:

- Regional GFS in alluvial plains.
- Local and intermediate GFS in fractured sedimentary rock.
- Local GFS in granites and acid volcanic rocks.

The RIP also includes the following information about best management options:

- Improved perennial pastures may not be able to control recharge in high rainfall areas.
- Permanent native vegetation could be established on the more marginal terrain of the uplands as the dominant salinity mitigation measure.
- The upland terrain is generally suited to a range of 'living with salt' options such as salt-tolerant pastures and saline aquaculture.
- The northern Riverine Plains are dominated by regional GFS, which are very difficult to manage using biological systems to control groundwater recharge.
- Engineering options have demonstrated their effectiveness within the regional GFS of the Riverine Plains. They can be particularly useful where their high cost is offset by an immediate need to preserve high-value assets.

North East region, Victoria

The North East region covers about 1.98 million hectares. It is bounded by the NSW border to the north, the Goulburn-Broken region to the west, and Gippsland to the south.

The three main river catchments are the Upper Murray, Kiewa and Ovens. Dryland salinity occurs in all three catchments. In 1998, 40,400 ha of land was estimated to have shallow water tables < 2 m from the land surface. This was predicted to increase to 68,100 ha by 2050.

However, given that groundwater salinity is low, problems in these catchments will result as much from waterlogging as from salinisation.

In 1997 it was estimated that 180,000 tonnes of salt was being exported annually to the River Murray from the North East, and this load was predicted to increase to about 245,000 tonnes annually by 2027.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 18–30 and Table 8 of the North East *Tools* RIP. The moderate to high priority GFS (i.e. moderate priority, moderate to high priority and high priority) are:

- Local GFS in fractured sedimentary and metamorphic rocks.
- Local GFS in glacial sediments.
- Regional and local GFS in broad alluvial plains.
- Dual GFS in colluvium and fractured rock.
- Local GFS in deeply weathered fractured rocks.
- Local GFS in Tertiary sediments (cappings).
- Local GFS in weathered granites and adjacent metamorphic aureoles.

The RIP also includes the following statements about best management options:

- The Riverine Plains contain large regional GFS that pose a significant salinity risk. Throughout the steeper terrain of the uplands, smaller localised GFS are common where saline discharges occur around the break of slope.
- The large regional aquifers of the Riverine Plains are very difficult to manage by recharge control. Irrespective of the cause of salinity in the Plains, the best opportunity to effectively limit groundwater recharge is by incorporating several years of deep-rooted perennial pastures within the crop rotation.
- Strategic placement of woody vegetation is an option but is limited by the difficulty of locating zones of preferential recharge. A well-managed lucerne pasture over large areas is likely to use more water than much smaller stands of strategically located woody vegetation.
- In the southern uplands, where local GFS exist and groundwater is mostly of low salinity, recharge control options should focus on perennial vegetation systems.
- Permanent woody vegetation could be considered for the marginal upland terrain, however caution is advised in higher rainfall regions where a reduction in run-off may result in high stream salinity.

Important point

The New South Wales Government is progressing development of modelling techniques for improving farm to catchment-scale salinity decision-making. These new techniques may result in changes to the information from Regional Information Packages presented below.

The government has provided the following information:

'The effects of land use change on water and salt balance in the The Mooki River catchment [in northern NSW] were modelled with CATSALT using the same methodology as described by Tuteja *et al.* (2003) as part of nine case studies throughout NSW.

The results of APSIM simulations presented in Ringrose-Voase *et al.* (2003) were used to parameterise landuse efficiencies in CATSALT to provide estimates of landuse change on stream water yield, saltload and salinity.

PERFECT model simulations used in NSW recharge mapping (Littleboy and Heron 2003) were subsequently used in CATSALT simulations for the 150 catchments that had been previously analysed in the MDB [Murray-Darling Basin] and Hunter River salinity Audits. PERFECT model results were consistent with APSIM simulations reported by Ringrose-Voase *et al.* (2003) and this work has effectively extrapolated the APSIM simulations to the whole of the Barwon catchment.

The results of CATSALT modelling on the 150 catchments have been embedded within the NSW Land Use Options Simulator (LUOS) decision support tool and have been supplied to Catchment Management Authorities and agency staff. Results are also being analysed within the IQQM framework to examine basin-wide effects.'

Murray region, NSW

The region covers 3,535,000 ha in southern NSW including the 1,394,000 ha Billabong Creek catchment. The region is bounded by the River Murray to the south, the Murrumbidgee River catchment to the north, the Great Dividing Range to the east, and the convergence of the Murray and Murrumbidgee Rivers to the west.

Tributaries to the Murray include the Edward-Wakool System and Billabong Creek.

The NLWRA (2001) estimated that 39,526 ha in the Murray region has water tables < 2 m from the ground surface [including irrigation areas]. This is predicted to increase to 293,191 ha by 2050. The Upper Murray and south-west slopes (including Billabong Creek) have the highest salinity risk in the catchment.

About 126,000 tonnes of salt is exported to the River Murray annually from the Murray catchment. This is predicted to increase to 167,000 tonnes by 2020. The Upper Murray and south-west slopes contribute 80 per cent of total salt exports. About 17 per cent comes from irrigation areas.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 19–28 and Table 7 of the Murray *Tools* RIP. The moderate to high priority GFS are:

- Local and intermediate GFS in low relief fractured rock (non-granite).
- Intermediate and regional GFS in Murray Basin sediments (Shepparton Formation).

The RIP includes the following information about best management options:

- Uplands system involve fractured rock aquifers, colluvial fans, and ancient landscapes that function poorly as aquifers but contain vast amounts of salt.
- Improved perennial pastures are most suitable in managing local GFS common to the upland areas, but there are limitations in managing them for optimum water use, particularly in high rainfall areas.
- Permanent native vegetation could be established on the more marginal terrain of the uplands as the dominant salinity mitigation measure, particularly in high recharge zones.
- The uplands and the Riverine Plains are generally suited to 'living with salt' options such as salt-tolerant pastures and saline aquaculture.

Murrumbidgee region, New South Wales

The Murrumbidgee RIP covers the catchment of the Murrumbidgee River, which extends for 1600 km from the edge of the Great Dividing Range in Kosciuszko National Park to its junction with the Murray downstream of Swan Hill.

Tributaries to the Murrumbidgee include the Tumut River, Yass River, Goodradigbee River, Jugiong Creek, Tarcutta Creek, Billabung Creek, Old Man Creek and Yanco Creek.

It is estimated that within the Murrumbidgee region 58,000 ha of land is affected by shallow water tables. This is predicted to expand to 469,500 ha by 2050, mostly in the upper and mid sub-catchments.

The salt load in the Murrumbidgee at Balranald was 139,000 t/yr in 2000 and is predicted to rise to 180,500 tonnes/year by 2050. Salinity in the River is relatively low at < 300 EC, however upstream tributaries such as Jugiong Creek regularly exceed 800 EC and at times 1500 EC.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 18–30 and Table 7 of the Murrumbidgee *Tools* RIP. The moderate to high priority systems are all local, and include:

- High relief fractured sedimentary rocks.
- Low relief fractured sedimentary rocks.
- Low relief granites.
- Low relief Silurian/Devonian acid volcanics.

The RIP includes the following statements concerning best management options:

- Improved perennial pastures, while suitable for a range of GFS identified for the region, do not always offer the best strategy for controlling recharge because of difficulties in managing them for optimum water use, particularly in high rainfall areas.
- The Riverine Plains are dominated by regional GFS, which are very difficult to manage using biological systems that control groundwater recharge.
- The areas that are best suited to on-farm revegetation are the uplands which support local GFS.

Central West and Lachlan region, NSW

The Central West and Lachlan RIP covers the Castlereagh, Macquarie/Bogan, and Lachlan Rivers.

A large area of this region is affected by shallow water tables or dryland salinity. The NLWRA (2001) predicted substantial increases the area affected, with the greatest increase predicted for the Lachlan and Castlereagh catchments.

The NLWRA also predicted that Macquarie River salinity would rise from about 600 EC in 2000 to 1700 EC in 2050. Similarly, the NSW Salinity Strategy (Department of Land & Water Conservation, 2000) noted that several rivers already exceed 1500 EC and that others will exceed the 800 EC threshold for drinking water within 50 years.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 21–36 and Table 8 of the Central West and Lachlan RIP.

Not all GFS in the region pose a salinity risk. For example, the Fractured Basalts Local and Intermediate GFS and Limestone Local and Intermediate GFS contain fresh groundwater that can be a valuable resource for consumptive use or as fresh baseflow to streams and rivers. In these areas, recharge management may not be necessary or appropriate.

The high to moderate salinity risk GFS are:

- Regional (and Local) including unconsolidated alluvium — irrigation over prior stream sediments.
- Intermediate, including Fractured rock.
- Local and intermediate, including Alluvium within upland valleys.
- Local, including Alluvial Plains, High relief fractured rock, low relief fractured rock (Paleozoic), Permian and Triassic Rock, Weathered Granite, Colluvial Slopes (Rhyollite), and Layered Sedimentary Rocks (Cretaceous).

The RIP includes the following statements concerning best management options:

- The large regional aquifers of the Riverine Plains are very difficult to manage by recharge control because the major source of recharge is leakage of water from rivers, particularly during floods.
- In the eastern uplands, recharge control should focus on perennial vegetation. However, perennial pastures are not always successful in the higher rainfall areas. Permanent woody vegetation could be considered for the marginal upland terrain.
- To protect [built] assets, engineering options, particularly groundwater pumping, can be effective but groundwater yields and disposal are limiting factors for both local and regional GFS.
- Where circumstances permit, salt-affected land or water may be used as potential resources.

Barwon region, New South Wales

The Barwon RIP covers the Border River, Gwydir and Namoi catchments of the northern MDB.

Dryland salinity has not been extensively studied within most of the Barwon region. The main difficulty is in describing how GFS function in sub-tropical climates where much of the rainfall occurs during the growing season.

In 2000, the NLWRA estimated that the Barwon region had 6696 ha of land with water tables < 2 m from the surface; this was predicted to rise to 98,034 ha by 2050. Dryland salinity on the Liverpool Plains is of particular concern. Currently 47,000 ha are affected by dryland salinity; this is expected to increase to 175,000 ha by 2025. Salinity in the Namoi River is expected to exceed the 800 EC drinking water threshold within 20 years and 1500 EC within 50 years.

The RIP also includes a detailed statement of salinity impact costs, including costs to agricultural producers.

Detailed biological, engineering and 'living with salt' options for GFS in the region are set out in pages 22–32 and Table 10 of the Barwon *Tools* RIP. The GFS are:

- Regional, including Surat Basin, Western Plains, Upland Alluvial Aquifer (Upper Namoi).
- Intermediate, including Alluvial Fans (Pilliga Outwash).
- Local and intermediate, including Permian and Triassic Rocks, Basaltic Rocks, Fractured Rocks and Carboniferous metasediments, Fractured Rocks-Accretionary Wedge Sub-system (Devonian).
- Local, including Upland Alluvium (Narrabri Formation), Central Volcanic Complexes, Low-relief Granites, High-relief Granites, Fractured Volcanic Rocks (Permian).

The RIP also includes the following statements about best management options:

- The three regional GFS are unlikely to impact on [cause] dryland salinity outbreaks.
- Management options on the floodplains covered by the Upland Alluvium include response cropping, perennial pastures, salt-tolerant grasses and halophytes (e.g. saltbush) and possibly in limited instances localised water table control through groundwater pumping.

- The most appropriate management strategy for local and intermediate GFS (Permian-Triassic Rocks) involves the protection and enhancement of native vegetation on recharge areas.
- Salinity mitigation in basaltic rock GFS (local and intermediate) depends on the scale of [water] flow. Options include managing native vegetation, perennial grasses, grazing management, groundwater pumping (from fractured basaltic rocks) and surface water management.
- Options for mitigation of groundwater recharge in low relief granite GFS (local) include either introduced or native perennial pastures, targeted plantings of woody perennial vegetation, salt-tolerant pastures and surface drainage and groundwater pumping.
- Options in local and intermediate fractured rock GFS include perennial pastures, restricted cropping, alternative products and re-introducing native vegetation.
- Salinity management of central volcanic complexes (local GFS) is not considered a high priority, but includes native vegetation retention and reintroduction, grazing management, greater adoption of perennial grasses, land-class fencing, groundwater interception plantations and greater use of dryland lucerne.
- Intermediate GFS (alluvial fans) pose a low but significant risk; 'living with salt' through adoption of either salt-tolerant grasses or halophytes is suggested.

References and further reading

1. Anon, 2003, *Salinity Investment Framework Interim Report – Phase 1, Salinity and Land Use Impacts*, Report No 32. Department of Environment, Perth, Western Australia
2. Tools Regional Information Packages, Murray-Darling Basin Commission, Canberra
3. NDSP *TechNotes – Tools to investigate and plan for improved management of dryland salinity in the Murray-Darling Basin*

REVIEWS OF THE EFFECTIVENESS OF ENGINEERING OPTIONS

1. Sinclair Knight Merz (SKM)

Sinclair Knight Merz has reported on an exhaustive investigation into engineering options for dryland salinity[1]. See also NDSP *TechNotes*[2].

Of 300 research abstracts considered, only 17 case studies had relevant information on the application of engineering options in a dryland context. Most of these were from **Western Australia**.

The project confirmed that the following engineering options can be effective in dryland salinity management:

- Groundwater pumping.
- Shallow surface drains (for recharge control).
- Deep surface drains (for water table management).
- Sub-surface drainage systems.
- Construction approaches (e.g. corrosion-resistant materials and standards).

The effectiveness of any particular option varies with local conditions such as GFS, discharge sites, local environmental conditions and the economics of an option.

A detailed description (with illustrations) of the above options is included in the full report of the study at pages 5–31 of SKM (2001). Table 1–2 of the full report lists a comprehensive range of possible engineering options for different GFS.

The SKM project reported on an earlier study in Western Australia (Coles *et al.* 1999), which reviewed 25 sites where deep surface drains had been installed. In all cases the drains were installed to control local discharge on-farm. The general opinion of the landholders involved was that 'the drains work', but the degree of effectiveness varied widely.

An economic evaluation concluded that it would be necessary to reclaim/protect a strip extending between 25 and 90 metres on either side of a drain to break even. In most cases, the impacts generally extended no more than 20 m from the drain, and rarely exceeded 40 m, suggesting that they are generally not economically viable.

Drains having the greatest impact were generally those installed at the break of slope. This was either because their location was at a point of stronger upward flow, the discharge areas were small, and/or there was an interaction with dykes or other geological constraints.

It was further concluded that drains constructed in low, flat valley floors appeared to be less successful and that shallow surface drains aimed at reducing surface waterlogging may be the most economic option in these situations.

A wide range of investigations was seen as necessary before adopting any large-scale drainage system. Wide community consultation was also seen as important [given the implications of disposing of saline flow].

In their national review of engineering options, SKM discussed Stage 1 of the drainage works, the Fairview Drain, which was completed in May 1998. The drain has a dual role in that it provides groundwater control to land adjacent to the 54 km length of the drain, and also allows control of surface water flows for the 27,500 ha of land within the drain's catchment.

In **South Australia**, SKM reported preliminary observations from the Fairview drainage trial that groundwater levels have been lowered in areas adjacent to the drain extending 1 to 1.5 km west of the drain and 1.5 to 2.5 km east of the drain. The key reason for the wide extent of the drawdown is the very high transmissivity of the limestone and associated calcareous soils into which the drain is excavated.

Disposal of water is into wetlands (when the salinity is low enough – i.e. when the majority of flow is from surface run-off), and ultimately the intention is to dispose of drainage water to the sea.

2. Water and Rivers Commission

A more recent review of engineering and safe disposal options in Western Australia was conducted by the Water and Rivers Commission[3]. The review found that, across the State:

- There is considerable variation in discharge water quality and quantity, which is likely to have widely varying impacts on receiving sites.
- High salinity, low volumes, low pH, dissolved heavy metals, nutrients and sediment loading are the main water quality problems that pose significant risks to downstream land productivity and ecological values.

The review highlighted the following critical points:

- It is not considered possible to compile maps to guide implementation of engineering works for use at farm-scales. Additional projects to characterise the different hydrogeological provinces in terms of the effectiveness of engineering work in managing salinity at farm-scale will not substitute for detailed site-specific studies; and similarly
- It is not considered possible to compile maps of suitable safe disposal sites for use at farm and sub-catchment scales. Regional characterisation of safe disposal sites in natural rivers, lakes and wetlands is no substitute for detailed site-specific assessments.

The review recommended for further work to clarify risks with disposal in natural systems, to explore limitations to disposal in constructed basins and productive uses, and to improve information on the costs and benefits of all disposal options. These are discussed further below under 'What more do we need to know?'

3. CSIRO Land and Water

CSIRO (see NDSP *TechNotes*[4]) is (as at January 2004) formally assessing the impacts of deep open drains on shallow and deep groundwater in a 70 km system of existing and new drains in the Wakeman catchment upstream of Narembeen in WA. Its objectives are to:

- Assess the impacts of deep open drains on shallow and deep groundwater at the farm-scale level.
- Determine the areal extent of the effectiveness of deep open drains in the Wakeman sub-catchment.
- Compare and illuminate the differences in the hydrology of drained and undrained areas and assess the groundwater dynamics and interactions between shallow and deep groundwater.

Results from three seasons' monitoring to date indicate that:

- The drains are generating large groundwater discharges (1–4 megalitres per day) with high salt loads (200–600 tonnes per day).
- Groundwater levels are controlled to great distances away from the drains (> 200 m and > 400 m at places).
- Following drain construction, water levels can fall very quickly at distance.
- The groundwater is strongly acid and carries high levels of iron, aluminium and manganese.
- Soils within 100 m of the drain are freshening [desalinising] to below the published thresholds for barley.
- Crops are being grown on land not farmed for decades due to salinisation.
- The drains, as designed, tend to silt up following rains and require significant maintenance to maintain effectiveness.

References and further reading

1. SKM, 2001, Assessment of the *Efficacy of Engineering Options for the Management of Dryland Salinity*, Research Report Final — December 2001, Land and Water Resources Research and Development Corporation, Canberra, ACT
2. NDSP *TechNotes* — Evaluating the efficacy of engineering options
3. Dogramaci S. and Degens B., 2003, *Review of Engineering and Safe Disposal Options*, Water and Rivers Commission Salinity and Land Use Impacts Series, Report No SLUI 20, Water and Rivers Commission, Perth, Western Australia
4. NDSP *TechNotes — Evaluating the impacts of deep drains on crop productivity and the environment*

Where to get help

This chapter provides some direction on where to get help when it is required. It describes networks that you can join or tap into, databases, maps, web-sites, publications, contact lists and other useful information. Details are listed in alphabetical order within sections.

NATIONAL DRYLAND SALINITY PROGRAM

All NDSP information and resources are available on www.ndsp.gov.au.

Engineering options

A CD-ROM from the South Australian Dryland Salinity Committee's 2003 forum *To Drain or not to Drain* features:

- abstracts and PowerPoint presentations from the forum
- the 90 Mb NDSP *Engineering Options* decision support tool
- six fact sheets from that NDSP project
- abstracts and PowerPoint presentations from two papers delivered to the NDSP Technical Forum (*Evaluating the Impacts of Deep Drains on Crop Productivity* and *Environment and Engineering Options for Dryland Salinity Management*)
- a draft *Review of Engineering Options for Salinity Management* by the WA Water Resources Commission.

It is available from CanPrint Communications (freecall 1800 776 616).

Focus on Salt

Focus on Salt newsletter is produced three to four times a year for technical advisors, planners and researchers. The stories on projects and issues always have a contact listed, so you can follow up if needing additional information. Back issues may also be relevant, as many of the projects discussed operate over several years.

Local Government project

The *Local Government* project produced a CD-ROM for councils containing an information kit on dryland salinity and key contacts. Additional local government contacts are available on the CD-ROM[1] produced by the Murray Darling Association from the conference *National Local Government Salinity Summit – Community-based solutions*, held in Echuca-Moama in 2001.

NDSP web-site www.ndsp.gov.au

If you're looking for anything on dryland salinity management in Australia, then the NDSP web-site is a good place to start. The web-site has been updated to provide the best possible service to users with easy access to *Key Messages, Catchment and Property* level information and *Networking* resources.

On-line forum

The NDSP on-line forum, accessed from the web-site, provides an opportunity to explore salinity issues with colleagues and peers. Subscribers can initiate topics or participate in existing discussions, can be alerted to any responses to their post and can establish closed forums that are accessible only to nominated subscribers.

Options for Productive Use of Saline Land (OPUS)

The NDSP *OPUS* project investigated about 140 different innovations and enterprises built around the utilisation of saline land or water, and created a database containing a brief synopsis of each innovation. The database includes key contacts for further information and is easily accessible from the NDSP web-site.

Practical Index of Salinity Models (PRISM)

PRISM is a comprehensive collection of natural resource and salinity management modelling tools and frameworks, now available on CD-ROM as a single electronic resource. It is available from CanPrint Communications (freecall 1800 776 616).

Salt magazine

Salt magazine provides case study examples of dryland salinity management problems and solutions from across Australia. While it primarily targets farmers, many of the stories have a broader catchment dimension. Each story has a contact so you can follow up on further information. Recent editions feature short by-lines by researchers who bring the scientist's perspective to issues on the farm.

Saltlist

Saltlist is an e-mail-based network where about 600 subscribers share information about salinity research and management. You might like to join if you are a researcher, extension provider (government or private), in local government, a land manager, environmentalist, project officer, landcare group, policy advisor or educator.\

The minimum level of participation is to read your e-mail from time to time. The facility has thrived because many people use it to:

- Promote events (field days, seminars, conferences, etc.)
- Alert others to new research, developments or discoveries
- Raise questions
- Contribute answers or references to these questions
- Engage in debate.

Saltlist is a moderated list, which means someone controls who is on it and the messages they can send, protecting participants from viruses, e-mail avalanches, irrelevant and unwanted messages. Subscribe by e-mailing majordomo@list.senet.com.au with the message <<subscribe saltlist>>.

TechNotes

NDSP *TechNotes* are fact sheets that represent a valuable summary of each project undertaken through the NDSP. They can be downloaded directly from the web-page.

TECH NOTE 001 – **Structural adjustment in agriculture and capacity to implement catchment plans**
Project Team: Read Sturgess and Associates; Neil Barr, Victorian Department of Sustainability & Environment

TECH NOTE 002 – **Predicting the combined environmental impact of catchment management regimes on dryland salinity**
Project Manager: Lu Zhang, CSIRO

TECH NOTE 003 – **Appraisal of infrastructure assets under threat**
Project Team: Mike Young, CSIRO/Dames and Moore with RECC/PPK

TECH NOTE 004 – **Technical assessment of desalination technologies in Australia**
Project Manager: Geoff Moyle, URS Australia

TECH NOTE 005 – **Evaluating the efficacy of engineering options**
Project Manager: Chris McAuley and Martin Robinson, Sinclair Knight Merz

TECH NOTE 006 – **Risk and restoration potential for remnant vegetation in salinising landscapes**
Project Manager: Richard Hobbs, Murdoch University

TECH NOTE 007 – **Biogeochemical and physical processes in saline soils and potential reversibility**
Project Manager: Rob Fitzpatrick, CSIRO

TECH NOTE 008 – **Understanding the recruitment biology of vegetation communities on saline soils**
Project Manager: Michelle Carey, Murdoch University

TECH NOTE 009 – **Determining the costs of dryland salinity in the Murray–Darling Basin**
Project Team: Dr Suzanne Wilson, Wilson Land Management Services and Richard Ivey, Ivey ATP

TECH NOTE 010 – **Generation and delivery of salt and water to streams on a catchment scale**
Project Manager: Hamish Cresswell, CSIRO

TECH NOTES 011 – **Evaluating the impacts of deep drains on crop productivity and the environment**
Project Manager: Tom Hatton, CSIRO

TECH NOTE 012 – **Catchment classification for salinity management**
Project Team Leader: Glen Walker, CSIRO

TECH NOTES 013 – **Developing a national evaluation framework for dryland salinity management**
Project Manager: Jane Coram, Bureau of Rural Sciences

TECH NOTES 014 – **Delineation of potential salinity hazard in Queensland cropping lands**
Project Manager: Ian Gordon, Qld Dept of Natural Resources

TECH NOTES 015 – **Water table change in Western Slopes cropping areas of NSW**
Project Manager: Richard Cresswell, Bureau of Rural Sciences

TECH NOTES 016 – **Enhancing institutional support for managing dryland salinity**
Project Manager: Greg Hayes, Virtual Consulting Group

TECH NOTE 017 – **Assessment of a system to predict the loss of aquatic biodiversity from changes in salinity**
Project Manager: Ben Kefford, RMIT University

TECH NOTE 018 – **Farming systems with lower recharge for Western Australia**
Project Manager: Jon Warren, Western Australian Department of Agriculture

TECH NOTE 019 – **Million Hectares for the Future**
Project Team: Jon Warren, Western Australian Department of Agriculture; Jay Cummins, Primary Industries and Resources South Australia

TECH NOTE 020 – **Options for the Productive Use of Salinity (OPUS)**
Project Team: Stephanie Bolt, Parsons Brinckerhoff (formerly PPK)

TECH NOTE 021 – **Simple device for monitoring deep drainage**
Project Manager: Paul Hutchinson, CSIRO

TECH NOTE 022 – **Tools to Investigate and Plan for Improved Management of Dryland Salinity in the Murray–Darling Basin**
Project Team: Darrel Brewin, Darrel Brewin and Associates; Stephanie Bolt, Parsons Brinckerhoff (formerly PPK) and Phil Dyson, Phil Dyson and Associates

TECH NOTE 23 – **Enhancing the capacity of Local Government to contribute to the management of dryland salinity**
Project Manager: Trevor Budge, Research, Planning and Design Group

TECH NOTE 24 – **FLOWTUBE rapid catchment appraisal model**
Project Manager: Christopher Clarke, Murdoch University

Tools information packages

The *Tools information packages* provide key contacts for dryland salinity management. The *Salinity Information Package* contains over 40 information sheets, which provide a step-by-step framework to understand the complex relationships between salinity, socio-economics, land systems and management options. *Regional Information Packages* have been structured on the *Groundwater Flow Systems Framework* to provide regional stakeholders with access to the best scientific information about their groundwater flow systems.

NATIONAL LAND & WATER RESOURCES AUDIT

The Atlas

The Australian Government Department of the Environment and Heritage (www.deh.gov.au/atlas) manages the *Australian Natural Resources Atlas* (the Atlas) on behalf of the National Land and Water Resources Audit (www.nlwra.gov.au), an internet-based 'one-stop-shop' for information on Australia's natural resources. The Atlas provides summary data and information at National, State and regional scales and the full *Australian Dryland Salinity Assessment 2000* report.

Audit Phase II (2002–07) will build on existing data, maps and information. Its Strategic Plan2 is available via the web-site.

STATE RESOURCES

New South Wales

Catchment Management Authorities (CMA)

The catchment blueprints are advisory "whole-of-government" plans for integrated catchment management that will guide the long term management of natural resources in NSW for the next 10 years. Prepared by catchment management boards, the Hunter Catchment Management Trust, the Coxs River and Wollondilly Catchment Management Committees and the Hawkesbury Nepean Local Government Advisory Group, the blueprints set overarching priorities for investment in natural resource management, consistent with NSW and Commonwealth Government policy.

Border Rivers/Gwydir	(02) 6764 5906; Adrian.Harte@dipnr.nsw.gov.au
Central West	(02) 6393 4322; Kate.Lorimer-Ward@dipnr.nsw.gov.au
Hawkesbury-Nepean	(02) 4828 6702; Bernie.Bugden@dipnr.nsw.gov.au
Hunter/Central Rivers	(02) 4930 1030; g.evans@hcmt.org.au
Lachlan	(02) 6341 9311; Peter.Sparkes@dipnr.nsw.gov.au
Lower Murray Darling	(03) 5881 9205; Kaye.Dalton@dipnr.nsw.gov.au
Murray	(03) 5881 9205; Kaye.Dalton@dipnr.nsw.gov.au
Murrumbidgee	(02) 6923 0439; John.Searson@dipnr.nsw.gov.au
Namoi	(02) 6764 5915; Tony.Page@dipnr.nsw.gov.au
Northern Rivers	(02) 6640 2183; Michael.Pitt@dipnr.nsw.gov.au
Southern Rivers	(02) 4224 9606; Noel.Kesby@dipnr.nsw.gov.au
Sydney Metro	(02) 9895 7536; Peter.Dixon@dipnr.nsw.gov.au
Western	(02) 6883 3046; Daryl.Green@dipnr.nsw.gov.au

Centre for Salinity Assessment and Management (CSAM)

CSAM (www.agric.usyd.edu.au/csam/index.html) has been established within the University of Sydney, conducting research into generic aspects of salinity such as mapping and assessment techniques, as well as focusing on aspects of dryland, irrigation and urban salinity. The education program aims to teach the causes of soil and water salinity and options for management and will provide education resources for both secondary and tertiary education sectors.

Community Access to Natural Resource Information (CANRI)

The CANRI web-site, www.canri.nsw.gov.au, combines environmental information from NSW Government agencies and other organisations tailored for community-based local and regional environmental management. It is the first program of its kind to offer integrated access to maps and other data held at various internet sites by a diverse group of natural resource agencies and other stakeholders.

Department of Environment and Conservation

The *National Parks and Wildlife Service* (NPWS) (tel: (02) 9585 6444; www.nationalparks.nsw.gov.au) is part of the *Department of Environment and Conservation* – the main government conservation agency in New South Wales. NPWS is conducting projects on Aboriginal heritage and salinity and the impacts of salinity on biodiversity.

Department of Infrastructure, Planning and Natural Resources (DIPNR)

DIPNR (tel: (02) 9762 8044; www.dipnr.nsw.gov.au) coordinates land use and transport planning, infrastructure development and natural resource management. The DIPNR web-site contains information on types of salinity, as well as the causes, impacts and management options in both rural and urban areas. It contains information on the NSW Salinity Strategy, with a number of downloadable research reports and an extensive reference list.

Department of State and Regional Development

DSRD (tel: (02) 9228 3111; www.business.nsw.gov.au) has developed a Salinity Business Development Program to encourage and assist businesses to take advantage of opportunities arising from productive uses of salt-affected land and water. Information about the program and potential business opportunities arising from salinity in fields such as agriculture, forestry, aquaculture and salt harvesting is available on the web-site. The report *A Solution to Urban Salinity* is on the web-site – search for salinity.

NSW Agriculture

NSW Agriculture (tel: (02) 6391 3100; www.agric.nsw.gov.au/reader/salinity) is involved in agricultural research, advisory services, education and regulation and provides practical farm production solutions for profitable agriculture and a better environment. The web-site contains information on some of the measures that have been implemented to manage both dryland and irrigation salinity.

A Strategic Framework for Salinity Research and Development in NSW, a *Register of Existing Salinity R&D Projects* and *NSW Salinity R&D Investment Portfolio* are all available from the web-site.

Queensland

Consortium for Integrated Resource Management (CIRM)

CIRM (tel: (07) 3896 9471; www.cirm.org.au) aims to facilitate collaborative research across and beyond its consortium of seven organisations – three government departments (DPI&F, EPA and NRM&E), three universities (Griffith, University of Queensland and Central Queensland University) and CSIRO.

Department of Natural Resources, Mines and Energy (NRM&E)

NRM&E (tel: (07) 3896 9645; www.nrm.qld.gov.au) plays a critical role in the stewardship of Queensland's natural resources. The department manages and allocates the State's land, water, mineral and petroleum resources, and manages native vegetation and the control of pest plants and animals. The web-site www.nrm.qld.gov.au/salinity has salinity fact sheets, hazard maps and information about the National Action Plan for Salinity and Water Quality.

Regional NRM Bodies

Fifteen Community-based NRM bodies have been established in Queensland. Each NRM group is currently developing a natural resource management plan that aims to achieve the best and most effective NRM results for their region. These plans and associated investment strategies will be loaded on to a Queensland Whole-of-Government web site to be released in April.

The NRM bodies are:

Burdekin Dry Tropics Board	(07) 4724 3544;	kim@burdekindrytropics.org.au
Burnett-Mary Regional Group	(07) 4132 8324;	deborah.scott@burnettmarynrm.org.au
Cape York	(07) 4046 6767;	bruce.rampton@env.qld.gov.au
Condamine Alliance	(07) 4620 0101;	kathryngalea@netspace.net.au
Desert Channels	(07) 4658 0600;	leanne.kohler@nrm.qld.gov.au
FNQ NRM Ltd	(07) 4061 6477;	nrmboard@znet.net.au
Fitzroy Basin Association	(07) 4921 2843;	s.m.Christensen@cqu.edu.au
Mackay Whitsunday	(07) 4957 9526;	julia@mwnrm.org.au
Northern Gulf	(07) 4031 3432;	mitchell@cypda.com.au
Qld Murray Darling Committee	(07) 4637 6276;	g.penton@landcare.org.au
SEQ Inc	(07) 3211 4404;	adrian@nrmseq.com
SEQ Western Catchments	(07) 3816 9713;	operations@seqwcq.com.au
Southern Gulf Catchments	(07) 4749 4805;	ccurry@southerngulfcatchments.com.au
South West NRM	(07) 4654 7382;	exec.officer@southwestnrm.org.au
Torres Strait	(07) 4069 1446;	victor.mcgrath@icc.qld.gov.au

South Australia

Department of Water, Land & Biodiversity Conservation (DWLBC)

DWLBC (tel: (08) 8463 6800; www.dwlbc.sa.gov.au) is the lead agency with responsibility for the Natural Resources Management Bill 2003, the River Murray Act and the Upper South East Dryland Salinity & Flood Management (USE DS&FM) Act. It also provides executive support to the SA Dryland Salinity Committee (tel: (08) 8303 9345). The DWLBC web-site gives access to information on dryland salinity and how it is being addressed in SA – go to *Natural Resources* then *Soil*. It carries numerous fact sheets that are also available on the SA DSC web-site (www.saltcontrolsa.com).

The Centre for Natural Resource Management (tel: (08) 8303 9703) undertakes research-related roles, including oversight of the South Australian R&D component of the National Action Plan for Salinity and Water Quality. It facilitates and encourages collaboration amongst researchers and supports regional delivery of improved on-ground outcomes. The Centre identifies and negotiates supplementary funding sources for NRM research, from both the public and private sectors, with the aim of leveraging NAP research funding.

Department for Environment and Heritage (DEH)

DEH (tel: (08) 8204 9000; www.environment.sa.gov.au) has a particular interest in the impact of salt-affected land and water on biodiversity. It provides technical support to the wetlands conservation component of the USE DS&FM Program and its biodiversity trading model. The Environment Protection Authority (EPA) presents the State of the Environment Report for SA, outlining the current state or condition of South Australia's environment, the pressures on it and trends over time.

Integrated Natural Resource Management (INRM) Boards

Community based INRM groups have been established in eight regions covering the entire State. Each INRM group has developed or is currently developing a natural resource management plan that aims to achieve the best and most effective NRM results for their region. These plans, and associated investment strategies, where they have been developed, can be accessed at www.nrm.sa.gov.au.

The NRM regions are:

Aboriginal Lands	(08) 8260 0266; jhammat@alt.sa.gov.au
Eyre Peninsula	(08) 8680 2653; wnacrisp@bigpond.com
Kangaroo Island	(08) 8553 3136; richards@kin.net.au
Mt Lofty Ranges & Greater Adelaide	(08) 8391 7501; Burston.Jim@saugov.sa.gov.au
Murray–Darling Basin	(08) 8532 1432; mdbinrm@lm.net.au
Northern and Yorke Agricultural District	(08) 8842 6253; Stanley.trudie@saugov.sa.gov.au
Rangelands	(08) 8648 5194; white.andrew2@saugov.sa.gov.au
South East	(08) 8723 1057; senrcc@lcrdb.com

Primary Industries and Resources SA (PIRSA)

SA Research & Development Institute (SARDI) (tel: (08) 8303 9577; www.sardi.sa.gov.au) undertakes research into pastures, soils and sustainable resources including their relationship to dryland salinity. SARDI is a major participant in the CRC for Plant-based Management of Dryland Salinity with research undertaken at the Waite Institute and at Struan.

Rural Solutions SA (tel: (08) 8568 6418; www.pir.sa.gov.au), the service provider arm of PIRSA, is actively involved in salinity management through the SALTSMART Program (Salinity Management Action Response Team). The SALTSMART team undertakes:

- Regional and catchment planning for salinity management within INRM (see www.saltcontrolsa.com)
- Implementation of catchment plans using a multi-disciplinary skills base
- Salinity mapping and monitoring
- Salinity research
- Identifying new opportunities and formulating investment strategies
- Catchment and groundwater modelling
- Training and education programs.

South Australian Dryland Salinity Committee (SA DSC)

The SA DSC (tel: (08) 8303 9345; www.saltcontrolsa.com) oversees implementation and periodic review of the *SA Dryland Salinity Strategy*. This strategy can be found on the web-site www.saltcontrolsa.com that also features updates on State salinity projects such as Salt Mapping, the USE DS&FM Program, Sustainable Grazing on Saline Lands, individual catchment salinity plans, and numerous fact sheets.

Tasmania

Department of Primary Industries Water and Environment (DPIWE)

DPIWE (tel: (03) 6233 8011; www.dpiwe.tas.gov.au) is the lead agency for salinity management in Tasmania, being responsible at State level for the National Action Plan (NAP) for Salinity and Water Quality, and supporting Regional NRM Committees and the NAP Working Group.

It also facilitates dryland salinity management through industry development, natural resource management, land information services, environmental protection, policy development and the conservation of natural heritage and other salinity prevention and management activities.

Mineral Resources Tasmania

Mineral Resources Tasmania (tel: (03) 6233 8377; www.mrt.tas.gov.au) provides essential information for land management (geological, groundwater geophysical data and information) and salinity project support.

Regional NRM organisations

These organisations are responsible for the development and implementation of regional NRM plans in Tasmania:

NRM North	(03) 6336 5219; www.nrmtas.com.au
NRM South	(03) 6234 2248; www.nrmtas.com.au
NRM NW	(03) 6431 7186; www.nrmtas.com.au

The National Action Plan for Salinity and Water Quality Joint Working Group

This is a joint committee of the Northern and Southern regions that develop and deliver strategies to address specific salinity and water quality issues in the Tasmanian NAP region. It can be contacted through the NRM North or NRM South regional organizations (www.naptas.com.au).

Victoria

Catchment Management Authorities (CMA)

Victoria has an integrated catchment management system established under the *Catchment and Land Protection Act 1994* (the CaLP Act). Under the CaLP Act, Victoria is divided into 10 catchment regions and a Catchment Management Authority established for each.

CMA Boards are responsible for the development of strategic direction for land and water management. They set priorities, evaluate the effectiveness of outcomes, monitor the external and internal environment and identify opportunities.

Implementation Committees are the conduits for local community input, and are responsible for development of detailed work programs and oversight of on-ground program delivery for specific issues or sub-catchments.

CMA staff oversee development and implementation of programs and liaise with the community, government and other catchment-focused organisations.

Corangamite	(03) 5232 9100; www.ccma.vic.gov.au
East Gippsland	(03) 5153 0462; www.egcma.vic.gov.au
Glenelg-Hopkins	(03) 5571 2526; www.glenelg-hopkins.vic.gov.au
Goulburn-Broken	(03) 5822 2288; www.gbcma.vic.gov.au
Mallee	(03) 5051 4377; www.malleecma.vic.gov.au
North Central	(03) 5448 7124; www.nccma.vic.gov.au
North East	(02) 6043 7600; www.necma.vic.gov.au
Port Phillip & Westernport	(03) 9785 0183; www.ppwcma.vic.gov.au
West Gippsland	(03) 5175 7800; www.wgcma.vic.gov.au
Wimmera	(03) 5382 1544; www.wcma.vic.gov.au

Department of Primary Industries (DPI)

DPI's Agriculture Division (tel: 136 186, e-mail: customer.service@dpi.vic.gov.au; www.dpi.vic.gov.au) is concerned with improving the profitability and market competitiveness of agricultural industries while ensuring that such operations remain sustainable and environmentally responsible. The Department aims to achieve this through research, industry development and extension activities. The web-site has extensive information on salinity – go to *Agriculture & Food* and then *Soil and Water.*

Primary Industries Research Victoria (PIRVic) is the R&D division within DPI with capabilities in specific fields of science including: plant production sciences, landscape systems and soil and water sciences. PIRVic centres undertaking dryland salinity R&D are:

- Bendigo Centre (tel: (03) 5430 4444; www.dpi.vic.gov.au/clpr) specialising in natural resource management including salinity and land capability
- Rutherglen Centre (tel: (02) 6030 4500; www.dpi.vic.gov.au/rutherglen) with expertise in modelling, farming systems and landscapes for production and environmental gains
- Hamilton Centre (tel: (03) 5573 0900; www.dpi.vic.gov.au) developing and evaluating annual and perennial plant species and livestock systems for recharge and discharge management.

Department of Sustainability and Environment (DSE)

DSE (tel: 136 186, e-mail: customer.service@dse.vic.gov.au; www.dse.vic.gov.au) is responsible for managing Victoria's natural and built environments and for providing a policy focus on sustainability. Its responsibilities include catchment management; conservation, recreation and public land stewardship; water sector development and services; forests and fire management; sustainability policy and programs; sustainable cities and regions; biodiversity; heritage; parks and Crown land; land information; greenhouse and sustainable energy policy.

The NAP/NHT office is located in the DSE at Epsom in Bendigo (tel: (03) 5430 4432, e-mail: NAP.NHT@dse.vic.gov.au).

Western Australia

Department of Agriculture (DAWA)

DAWA (tel: (08) 9368 3333; www.agric.wa.gov.au) is responsible for policy, research and information provision on dryland salinity affecting agricultural areas and rural towns. Main project areas include engineering water management, chemical and sediment export, land use assessment and farming systems including sustainable grazing on saline lands. The web-site has a large number of reports and fact sheets dealing with salinity – go to *Land Water + Environment*. The State branches of the Natural Heritage Trust and National Landcare Program are located within the South Perth head office.

Department of Conservation and Land Management (CALM)

CALM (tel: (08) 9334 0333; www.calm.wa.gov.au) deals with conservation of ecosystems, oil mallee research, wetlands, biodiversity and other issues. The web-site has many reports on these issues – search for *salinity*.

Department of Environment

This department (tel: (08) 9278 0300; www.environment.wa.gov.au) brings together the former Department of Environmental Protection (DEP) and the Water and Rivers Commission (WRC).

WA's key regulatory body, it manages water quality, particularly for irrigation water and stream flows, and administers the Salinity Investment Framework. The web-site has salinity information under the following headings:

- Dealing with Salinity in Wheatbelt Valleys
- Engineering Evaluation Initiative
- Salinity and Land Use Impacts Series
- Salinity Engineering Newsletter.

Forest Products Commission (FPC)

FPC (tel: (08) 9475 8888; www.fpc.wa.gov.au) is WA's trading enterprise for plantation management and commercial production from renewable timber resources. It manages tree-planting programs, sometimes in association with private landholders (e.g. the Infinitree Program which aims to increase tree planting rates to 20,000 ha per annum, partly with the aim of addressing salinity). FPC has a dedicated research program which has identified tree and shrub species with the ability to withstand defined salt levels.

Natural Resource Management Office

This aims to co-ordinate State Government activities across agencies in the natural resource management field. It is located at the Department of Agriculture (tel: (08) 9368 3164) and has close links to the regional NRM groups which are recognised for funding applications through the Natural Heritage Trust, National Action Plan for Salinity and Water Quality and the National Landcare Program. The regional groups are (from north to south):

- Rangelands NRM Coordinating Group — (08) 9455 5477; kelvin.baldock@greenbase.com.au
- Northern Agricultural Catchments — (08) 9954 3354; www.calci.org Council (NACC)
- Avon Catchment Council (ACC) — (08) 9690 2251; www.avonicm.org.au
- Swan Catchment Council (SCC) — (08) 9374 3309; www.wrc.wa.gov.au/swanavon
- South West Catchments Council (SWCC) — (08) 9780 6168; swcc@agric.wa.gov.au
- South Coast Regional Initiative — (08) 9892 8537; Planning Team (SCRIPT) www.script.asn.au

NATIONAL INSTITUTIONS

Australian Bureau of Agriculture and Resource Economics (ABARE)

ABARE (tel: (02) 6272 2000) provides quarterly forecasts for the full range of export commodities. Its recent research on the economics of salinity control and related policy issues has made an important contribution to the development of the Murray–Darling Basin Salinity Strategy (www.abareconomics.com/research/landwater/salinity.html). ABARE has also provided insights into the problem of salinity control that will be considered in regional plans being developed under the National Action Plan for Salinity and Water Quality.

WHERE TO GET HELP

Australian Government Departments of Agriculture, Fisheries and Forestry (DAFF) and Department of the Environment and Heritage (DEH)

DAFF and DEH jointly administer the National Action Plan for Salinity and Water Quality (NAP). The web-site (www.napswq.gov.au/index.html) provides information on the history of the NAP and lists current events. Fact sheets, reports, maps, discussion papers and media releases can be accessed. Links are provided to a range of useful web-sites and an e-mail subscription service is available.

Australian Government Department of Transport and Regional Services (DOTARS)

The DOTARS web-site (www.dotars.gov.au) lists dryland salinity among a range of environmental issues affecting regional Australia. Its corporate plan acknowledges 'the increasing importance of environment issues, particularly salinity and global warming, and the need to factor environmental impacts into decision making.'

Australian Greenhouse Office (AGO)

The AGO's web-site (www.greenhouse.gov.au) provides information on the implications of climate change on agriculture and other industries. A range of fact sheets and other publications can be downloaded from the web-site.

Australian Landcare Council (ALC)

The ALC (tel: (02) 6295 8199; www.daff.gov.au and search for landcare) is the Australian Government's key advisory body on landcare policy. It provides advice on issues relevant to the sustainable management of natural resources including salinity, sustainable agriculture, catchment management, greenhouse and weed management.

Australian Wool Innovation (AWI) Limited

AWI Limited (tel: (02) 9299 5155; www.wool.com.au) is a fully independent public company owned by Australian woolgrowers. Almost 25 per cent of wool producers say that salinity is an on-farm issue. A five-year research partnership between AWI and Land & Water Australia aims to find productive and sustainable solutions to salinity and other natural resource management issues for wool producers. Part of the program involves new research on maximising farm returns through the Land, Water and Wool *Sustainable Grazing on Saline Lands (SGSL) sub-program*. Further information can be found at www.landwaterwool.gov.au. *Beyond the Bale* is AWI's free bi-monthly newspaper providing project and technical information for woolgrowers, including updates on research, trials, farmer activities and case studies.

Bureau of Rural Sciences (BRS)

The BRS (tel: (02) 6272 4282; www.daff.gov.au then following the link under the specialist areas menu) is the scientific bureau within the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). BRS provides nationally focused scientific advice to support evidence-based policy development and decision-making by government. The Bureau's Salinity Risk Management Sciences Program provides data on land condition to support the NAP. Multi-disciplinary research techniques, including airborne geophysical survey techniques, are used to develop models to predict the outcomes of various salinity management scenarios.

CSIRO

CSIRO Forestry & Forest Products (tel: (02) 6281 8211; www.ffp.csiro.au) researches forestry, wood and paper sciences. Some of this research is relevant to recharge management and productive use of saline land.

CSIRO Land and Water (tel: (02) 6246 5700; www.clw.csiro.au) and its partners seek to develop innovative solutions to Australia's land and water management challenges. Land and Water's skill base includes expertise in hydrology, hydrogeology, soil science, biology, ecology, atmospheric science, remote sensing, physics, chemistry, economics and social science.

CSIRO Plant Industry (tel: (02) 6246 4911; www.pi.csiro.au) applies strategic research in the plant sciences to promote profitable and sustainable agri-food, fibre and horticultural industries, develop novel plant products and improve natural resource management.

CSIRO Sustainable Ecosystems (tel: (02) 6242 1600; www.cse.csiro.au) focuses on research to underpin the sustainable development of rural and regional Australia.

These Divisions of CSIRO are active and important participants in research currently conducted by the CRC for Plant-based Management of Dryland Salinity.

Grains Research and Development Corporation (GRDC)

GRDC (tel: (02) 6272 5525; www.grdc.com.au) is responsible for planning, investing and overseeing research and development, and delivering improvements in production, sustainability and profitability across the Australian grains industry. Information on dryland salinity on the web-site is organised into topics of interest relevant to growers, researchers and consumers. GRDC's quarterly newsletter *Groundcover* brings grain growers some research information on salinity management.

Land & Water Australia (LWA)

LWA (tel: (02) 6257 3379; www.lwa.gov.au) invests in more than 20 R&D programs in five arenas: sustainable primary industries; rivers; vegetation; future landscapes; and cross-cutting activities. The NDSP is one of these R&D programs, but many others are relevant to salinity and its impacts. LWA has a comprehensive database of stakeholders in dryland salinity management, used by NDSP to distribute *Salt* magazine and *Focus on Salt*.

Meat and Livestock Australia (MLA)

MLA (tel: (02) 9463 9333; www.mla.com.au) provides research and development, market information and marketing to benefit the red meat industry. MLA's *Sustainable Grazing Systems (SGS)* program developed *The Professional Producer's Guide* that incorporates a comprehensive collection of best farming practices including management of soil, water resources and pastures. Also from SGS is *Tips & Tools*, practical and easy to follow information sheets on a range of topics including pastures and grazing management, and natural resource management. A monthly newsletter *Feedback*, sometimes profiles grazing issues related to salinity.

Rural Industries Research & Development Corporation (RIRDC)

RIRDC (tel: (02) 6272 4539; www.rirdc.gov.au) manages and funds research and translates results into practical outcomes for industry development. Salinity risk and management issues are investigated under the *Resilient Agricultural Systems Research Program* that aims to foster the development of agri-business systems that have sufficient diversity, integration, flexibility and robustness to be resilient enough to respond opportunistically to change. Fact sheets and a range of free research publications are available from the web-site. RIRDC is also a major partner in the Joint Venture Agroforestry Program (JVAP).

The JVAP (www.rirdc.gov.au/programs/aft.htm) has the following key roles:

- Initiating, coordinating and communicating agroforestry research and development
- Assisting in the removal of policy and institutional impediments
- Assisting in the development of new tree-based industries
- Designing large-scale commercial agroforestry systems in lower rainfall areas to address environmental issues.

JVAP communicates research via its Agroforestry Guideline Series, a Manual Series (which includes *Trees, water and salt: an Australian guide to using trees for healthy catchments and productive farms*), the Master TreeGrower training program and Research Reports & Updates, Short Reports and Newsletters.

MURRAY–DARLING BASIN COMMISSION

The Murray–Darling Basin Commission (tel: (02) 6279 0100; www.mdbc.gov.au) has a charter 'to promote and co-ordinate effective planning and management for the equitable, efficient and sustainable use of water, land and environmental resources of the Murray–Darling Basin'. *The Basin Salinity Management Strategy 2001–2015* guides communities and governments in working together to control salinity and protect key natural resource values within their catchments, consistent with principles of the *Integrated Catchment Management Policy Statement*. It establishes targets for the river salinity of each tributary valley and the Murray–Darling system itself, that reflect the shared responsibility for action both between valley communities and between States.

Many MDBC publications and reports can be downloaded from the web-site (go to *Publications*) or ordered on-line.

Basin Salinity Network

Basin Salinity Network (www.ndsp.gov.au/salinity/tools/) links people across the Murray–Darling Basin who require support for local and regional salinity planning or can offer experienced salinity management advice. The aim is to develop stronger links so that people can gain access to information, technical advice and support. Members of the network come from a broad range of backgrounds.

LOCAL GOVERNMENT

Australian Local Government Association (ALGA)

ALGA (tel: (02) 6122 9400; www.alga.asn.au) is a federation of associations in each of Australia's six States and two Territories. It is a member of the Council of Australian Governments, alongside the Commonwealth, States and Territories, as well as numerous ministerial councils and intergovernmental committees. Local government is also an active partner in a range of national strategies for environmental management. Information on ALGA and its role in dryland salinity management can be found at its web-site.

Murray Darling Association (MDA)

The MDA (tel: (08) 8226 0582; www.mda.asn.au) has developed a Dryland Salinity Project as a pilot project to provide local government with data and information on the impact of salinity. This encourages local government to undertake salinity risk assessment and provides management tools.

COOPERATIVE RESEARCH CENTRES

CRC for Catchment Hydrology

This CRC (tel: (03) 9905 2704; www.catchment.crc.org.au) provides land and water managers with capability to predict, in an operating environment of high climatic variability, the hydrologic impacts of catchment management. It runs six multi-disciplinary research programs:

- Predicting catchment behaviour
- Land use impacts on rivers
- Sustainable water allocation
- Urban stormwater quality
- Climate variability
- River restoration.

CRC for Freshwater Ecology

The CRC for Freshwater Ecology (tel: (02) 6201 5168; www.environmentdirectory.com.au) is a national research centre specialising in temperate river and wetland ecology. The CRC develops ecological understanding to improve and protect Australia's inland waterways by collaborative research, education, resource management, policy advice and community liaison.

CRC for Landscape Environments and Mineral Exploration (CRC LEME)

CRC LEME (tel: (08) 6436 8695; http://leme.anu.edu.au) has four core research programs:

- Regolith geoscience
- Mineral exploration in areas of cover
- Environmental applications of regolith geoscience
- Salinity mapping and hazard assessment.

CRC for Plant-based Management of Dryland Salinity

This CRC (tel: (08) 6488 8559; www.crcsalinity.com) focuses on developing profitable and sustainable farming systems to manage both recharge and discharge. The CRC brings together research effort from six State government agencies, three universities and CSIRO to address these issues through seven research programs:

- Education
- Function of natural ecosystems
- New and improved plant species
- New farming systems
- Economic and social assessment
- Animal systems
- Biodiversity.

These research programs are outlined in the strategic report *Research Portfolio 2002/3*[3] that can be found at the web-site.

NON-GOVERNMENT ORGANISATIONS

Australian Association of Natural Resource Management (AANRM)

AANRM (tel: (02) 6247 4137; www.soil-water.org.au) is a network of groups and individuals with a common interest in natural resource management including salinity. It publishes a journal and maintains a web-site.

Australian Salinity Action Network (ASAN)

ASAN (www.asan.net.au) seeks to coordinate and share information between all stakeholders involved in addressing the impact of salinity. It provides members with:

- Networking
- Information sharing
- Advisory services and problem solving
- Promotion of technologies
- Trialing and testing salinity initiatives
- An advocacy group for emerging industries
- Community education and awareness raising campaigns
- Salinity-based research

Greening Australia

Greening Australia (tel: (02) 6281 8585; www.greeningaustralia.org.au) is a national organisation with a network of over 300 staff in 80 locations. Many of these are involved in on-ground and strategic dryland salinity management planning and management at regional, State and National levels. The national web-site is a good source of information and contacts.

Greening Australia has an initiative called *Changing lives + landscapes* that aims to achieve river and landscape repairs worth $10 million. It will use its regional networks to bring farmers, indigenous communities and scientists together to tackle land and water degradation. Land & Water Australia, CSIRO and the CRC for Freshwater Ecology will provide the scientific back-up for public participation programs.

Australian Conservation Foundation (ACF)

The ACF (tel: (03) 9345 1111; www.acfonline.org.au) has an alliance with leading winemaker Southcorp Ltd to raise awareness of salinity. An output of this alliance is a community information kit *Salt: Nature in the Balance* that can be ordered on-line. The ACF has campaigned for a national policy and investment response to salinity, including biodiversity conservation and commitment of necessary funding.

WWF Australia

WWF Australia (tel: 1800 032 551; www.wwf.org.au), formerly known as World Wildlife Fund and World Wide Fund For Nature, works to help protect and sustain biologically diverse environments via on-ground field projects and seeks to influence policy formulation.

National Farmers' Federation (NFF)

The NFF (tel: (02) 6273 3855; www.nff.org.au) is the peak lobby group for Australian farmers and farmer organisations.

OTHER RESOURCES

Australian Landcare Magazine

Australian Landcare Magazine is published quarterly and features regular articles from LWA (including the NDSP), MDBC, RIRDC and AANRM. Selected articles are available at www.australianlandcaremagazine.com.au.

Glossary

Airborne geophysics	Remote sensing from the air of geophysical properties using electromagnetic induction, magnetics or radiometrics.
Agronomy	Biophysical science supporting agricultural production.
Agroforestry	A land management system enabling the production of trees and agriculture products from the same land unit.
Alley (farming)	A farming system in which belts of perennial vegetation (e.g. trees, saltbush) are interspersed with alleys of land, for productive use of annual species (crops, understorey).
Alluvium	Unconsolidated sediments (clay, gravel, sand) deposited by rivers in low-lying areas and flood plains.
Annuals	Plants that live for one growing season only.
Aquaculture	Farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants.
Aquifer	A layer of rock or unconsolidated sediments which holds and allows water to move through.
Aquifer, confined	An aquifer overlain by a confining bed (e.g. clay).
Aquifer, perched	An aquifer above and separated from a major aquifer by an impermeable layer of rock or sediment (clay).
Aquifer, unconfined	An aquifer in which there is no confining bed between the groundwater and the soil surface. The water table is the upper boundary of the groundwater.
Aquifer transmissivity	The ability of an aquifer to transmit groundwater.
Bedrock	Unweathered hard rock at the base of a soil profile.
Biodiversity	The variety of life forms – the different plants, animals and microorganisms, the genes they contain and ecosystems they may form.
Biophysical	Relating to biological and physical processes.
Break of slope	The line across a landscape at which the surface slope is reduced and where the hydraulic conductivity of the underlying material or the hydraulic gradient decrease.
Capillary rise	The drawing up of groundwater through soil pores caused by evaporation and the upward pull of surface tension forces overcoming the downward pull of gravity.
Catchment	The area of land drained by a river and its tributaries.
Colluvial (deposits)	Deposits of loose material that have been carried by gravity and are usually found at the foot of slopes or cliff lines.
Crop rotation	The growing of different crops and pastures on the same paddock in annual succession. e.g. pasture-grain-legume or pulse-legume-grain; etc.
Deep drainage	Water that drains from below the root-zone into underlying aquifer systems. Also called leakage. In some States the term 'deep drain' is used to describe an engineered drain that intercept lateral flow, through-flow or base-flow.
Desalination	Removal of salt from water.
Direct seeding	Sowing seeds directly into the ground for revegetation.
Discharge	Seepage of groundwater into streams and/or to the land surface, actively from springs or passively by evaporation.
Discharge area	Area affected by groundwater discharge.
Drainage paths	Naturally defined pathways through which run-off flows. Generally used to describe drainage depressions, gullies, drainage lines, creeks and rivers.
Drawdown	Lowering of the water table due to drainage or groundwater pumping.
Dryland salinity	Expression of salt at the soil surface or within capillary range, concentrated by the evaporation of saline groundwater discharging as a result of land use or land management.
Ecological zonation	Distribution of plant species across ecological zones because of variations in the environment (e.g. soil salinity, waterlogging and inundation).
Ecosystem	A community of organisms, interacting with each other, and including the environment in which they live.
Electrical conductivity (EC)	Ability of a substance to conduct electricity, used as a measure of water salinity. See conversion table at end of Glossary.

Electromagnetic induction	Process whereby a changing magnetic field causes an electric current to flow in conductive material (e.g. saline soil or groundwater).
End-of-valley target	A 'big picture' goal indicating how much salt will be discharged at the end of major catchments when management strategies are implemented.
Episodic recharge	Recharge as a result of unusually intense or prolonged rainfall events.
Evaporation basin	A shallow pond into which saline water is discharged to evaporate, leaving a residue of salt.
Evapotranspiration	Loss of water resulting from both transpiration by plants and evaporation.
Extension	The process of advising and providing information to land and water managers.
Geomorphology	Science of describing and interpreting landform patterns and processes of landscape formation.
GIS	Geographic Information System.
Ground truthing	A system where remotely sensed data is tested against direct measurements conducted on the ground.
Groundwater	Water beneath the surface held in or moving through saturated layers of soil, sediment or rock.
Groundwater base-flow	Stream flow that results from groundwater seepage.
Groundwater flow system (GFS)	A conceptual model to describe the response of groundwater to recharge.
Groundwater through-flow	Lateral movement of perched groundwater, often in a non-permanently saturated zone.
Halophytes	Salt-tolerant plants.
Hard water	Water containing high concentrations of calcium and magnesium salts. Hard water makes soap difficult to lather and may cause scaling or corrosion in water pipes, boilers, water heaters and other appliances, and industrial equipment.
Hydraulic conductivity	The physical property of the aquifer which determines the rate of movement of water.
Hydraulic gradient	The slope of the water table (change in hydraulic pressure over distance in the direction of flow) which helps determine the rate of movement of groundwater.
Hydraulic pressure	The pressure exerted by groundwater in an elevated part of the aquifer. This usually causes groundwater movement, possibly resulting in lateral or upward discharge.
Hydrogeology	The study of groundwater movement through soil, sediment or rock under natural or induced conditions.
Hydrology	The study of water movement.
Hypersaline	More saline than seawater.
Infiltration	The process by which surface water from rainfall, streams and irrigation channels enters the soil and is added to the groundwater.
Integrated catchment management	A process through which people develop a vision, agree on shared values and behaviours, make informed decisions and act together to manage the natural resources of their catchment.
Inundation	A condition in which free standing water occurs above the soil surface (sometimes called flooding). Waterlogging usually coincides with inundation, but many waterlogged soils are not inundated.
Land managers/holders	Those who manage land, including farmers, graziers, irrigators, cultural and environmental land holders, councils and government agencies.
Landscape	An area of land and its physical features.
Lateral flow	Groundwater flowing parallel to the natural surface. Normally confined to near-surface movement above the main aquifer.
Leaf area index (LAI)	The ratio of leaf area in a plant canopy to the area of the land beneath that canopy.
Leakage	The movement of water (rainfall or irrigation) below the root zone. In eastern Australia, deep drainage has been used interchangeably with leakage
Local groundwater system	Aquifer with a flow length of only a few kilometres.
Magnetics	Magnetic data can reveal buried drainage patterns, dykes, faults, fractures and deeper structural geology that assist our understanding of the hydrogeology of catchments.
Model	Conceptual models allow us to simplify complex systems (such as groundwater) and predict qualitatively their behaviour under various conditions. Computer models assign numerical values to many of the features of the model, input water as recharge then calculate the output (in time and space) as discharge.

Opportunity cropping	Sowing a crop only when climatic conditions present a suitable opportunity.
Percolation	The downward movement of water through soil.
Perennial	Plant that lives for several years (annuals live for only one growing season).
Permeability	The capacity of a substance (for example, soil or rock) to allow water to pass through it. Sand, for example, is said to have high permeability.
Phase-farming	Alternating farming land uses over time between annual and perennial vegetation (e.g. annual crops-lucerne-annual crops).
Piezometer	A tube (usually PVC, slotted and screened at the bottom) inserted into a confined aquifer to measure the relative groundwater pressure.
Porosity	Permeability by water, air or similar through small holes, or pores.
Radiometrics	Radiometrics detect radiation from the upper 30cm of the soil which may provide information about different types of clays or drainage patterns linked to areas where salt outbreaks occur.
Recharge	The process that replenishes groundwater, usually by rainfall infiltrating from the ground surface (river or lake bed) to the water table.
Recharge area	The area in which surface water (from rainfall, irrigation or streams) infiltrates into the soil and is added to the groundwater (c.f. discharge area).
Regional groundwater system	Aquifer with a flow length from recharge area to discharge area of hundreds of kilometres.
Regolith	Weathered or sedimentary material between the ground surface and bedrock.
Remote sensing	Collecting data using instruments remote from the data source, such as satellites or aircraft, but also ground-based instruments that collect sub-surface data.
Remnant vegetation	Native vegetation remaining after an area has been cleared.
Residual salt	Salt that is left in the landscape after the water has evaporated or receded.
Revegetation	Replacing the plants in an area which have previously been cleared.
Riparian	Belonging to the bank or shore of a river, stream or lake.
Root zone	Near-surface part of a soil profile where roots are active.
Salinisation	The accumulation of salts via the actions of water in the soil to a level that causes degradation of the soil.
Salinity hazard	Salt which, if mobilised has the potential to cause harm by discharging on the land surface and/or in streams. (See page 8 of '*Catchment Management*')
Salinity management	Intervention needed to mitigate or control salinity. Can be biophysical (plants) or engineering (e.g. drains).
Salinity mitigation	Any activity that reduces the salinity problem. For example, revegetation, improved cropping practices, reducing fallow and cultivation, planting salt tolerant species, and so on.
Salinity province	That part of the landscape in which a particular GFS (or several GFSs of the same type) operates.
Salinity risk	The probability of salt (salinity hazard) being mobilised and affecting natural, cultural or man-made assets. (See page 8 of '*Catchment Management*')
Salt, salts	'Salt' is a general term for many soluble chemical compounds, of which sodium chloride is generally the most abundant. Some salts cause hardness in water while others, in the right concentration, can be beneficial.
Salt accumulation	Salt deposited on the land from groundwater discharge or evaporated surface water.
Salt concentration	Level of salts on the land surface or in soil, rocks or water.
Salt interception scheme	Pumping or drainage that lower the water table by discharging groundwater into evaporation basins or elsewhere, thereby intercepting salt before it enters a river or reaches the soil surface.
Salt load	The amount of salt carried in water flow in rivers, groundwater or off the soil surface, in a given time period.
Salt scald	An area of land where the ground surface has been left bare after salt has destroyed the vegetation.
Seepage	The process by which water percolates downwards and/or laterally through the soil, often emerging at ground or stream level lower down the slope.
Sodicity	A measure of the amount of 'exchangeable' sodium ions in the soil. As sodicity increases so does the likelihood of soil structure decline, waterlogging and erosion.
Soil profile	A vertical section of earth from the soil surface to parent rock material, that shows the different soil horizons.

Soil water	Moisture stored in soil pores.
Sub-surface flow	Water moving laterally beneath the surface of the soil.
Sustainability	Managing our natural resources in a way that maintains their environmental, economic and cultural values, so that they continue to be available in the long-term.
Topography	The detailed description and analysis of the surface features of the landscape.
Transmission zones	Areas where water moves from recharge areas to discharge areas.
Total dissolved solids (TDS)	A measure of the salinity of water, sometimes referred to as total dissolved salts usually expressed in milligrams per litre (mg/L). An alternative measure is total soluble salts (TSS) (See Electrical conductivity (EC).
Transpiration	The process by which water is extracted from the soil, transmitted through plants, evaporated from the leaves and enters the atmosphere.
Tributaries	Watercourses (rivers, creeks, streams) which flow into another watercourse.
Water balance	A state of equilibrium when rainfall or irrigation water in a landscape is accounted for by the sum of run-off, plant water use, evaporation, recharge and changes in soil moisture content.
Waterlogging	Waterlogging will occur when the water table is at or close to the surface. Soil pores are then filled with water, plant roots become starved of oxygen, and plant growth is inhibited or even ceases.
Water table	The water table is the upper surface of groundwater. The soil profile is fully saturated below the water table and unsaturated above it.
Weathering	Chemical, physical and biological decomposition of rocks that can result in formation of a soil profile.
Wetlands	An area that is permanently, periodically or occasionally covered by fresh, brackish or saline water to a shallow depth. They support a unique range of plants and animals.
Woodlot	A small area devoted to growing trees, usually on a farm for firewood and posts.

Salinity unit conversion table

↓Start here	mS/m EC	dS/m EC	uS/cm** EC	mS/cm EC	mg/L (ppm)* TDS	gpg* TDS
1 mS/m =	1	0.01	10	0.01	5.5	0.38
1 dS/m =	100	1	1000	1	550	38
1 uS/cm** =	0.1	0.001	1	0.001	0.55	0.038
1 mS/cm =	100	1	1000	1	550	38
1 mg/L (ppm)* =	0.18	0.00018	1.8	0.0018	1	0.06
1 gpg* =	2.63	0.0263	26.3	26,300	14.3	1

* Conversion from Electrical Conductivity (EC) to Total Dissolved Salts (TDS) varies depending on the salts present and concentration. These figures are a guide only.

** Eastern States of Australia often refer to 1 uS/cm as an EC Unit

This glossary was prepared with reference to:

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National DRYLAND SALINITY Program

Know-how
to tackle salinity