# A Revolution in Land Use:

## Emerging Land Use Systems for Managing Dryland Salinity

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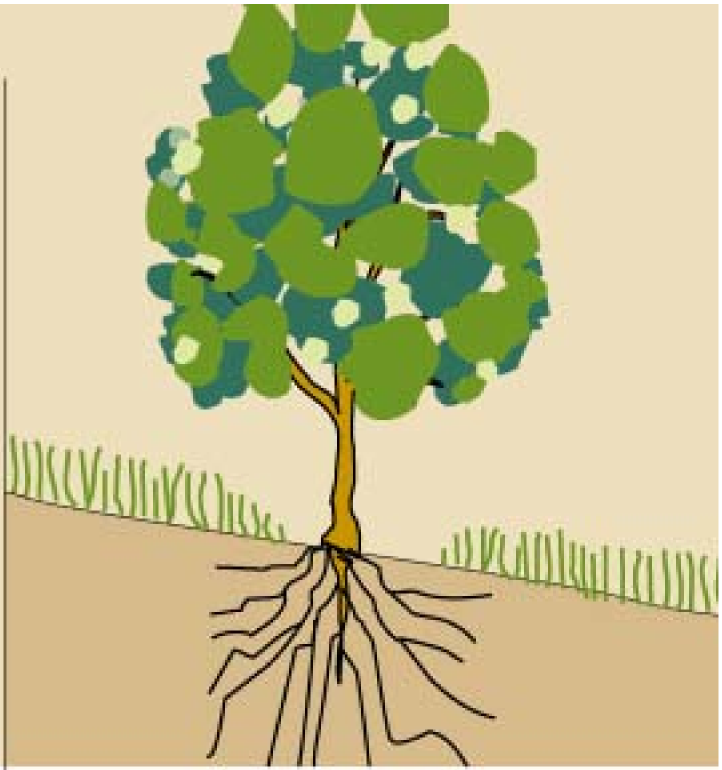
Dryland salinity is a serious problem affecting many parts of Australia, including the Murray-Darling Basin, one of our most important river systems. In 1999, CSIRO Land and Water released a report for the Murray Darling Basin Commission called *Effectiveness of Current Farming Systems in the Control of Dryland Salinity*. It outlined the causes and extent of salinity in the Basin and identified that for much of the Basin, current farming systems, even when implemented with best practice, cannot control salinity. This report continues the story by investigating the capability of various options to deal with salinity and the prospects for new solutions from research, development and innovation. Such innovative solutions, which may lead to revolutionary new ways to use our land, will need to be incorporated into the landscape not only to help counter the growing problem of salinity but also to maintain native biodiversity and community well-being.



# What will it take to save the Basin?

No single land-use option will halt the growth of salinity and the loss of native biodiversity in our land and rivers. We need to develop and deploy a suite of novel land uses that are matched to the diverse climate, soils, and hydrological conditions of the Basin. These land uses, in combination, need to deliver leakage rates past the root zone that approach those of natural vegetation. This will require radical change to land use, incorporating the following features.

- Commercially driven tree production systems and/or new tree species, to be developed for large areas of the current crop and pasture zones of the Basin. These would include trees to produce fruits, nuts, oils, pharmaceuticals, bush foods and forestry products such as specialty timbers, charcoal, and biomass energy.

- New farming systems made up of novel mixes of all the best current annual and perennial plants, the best agronomy, companion plantings, rotations and combinations.

- New forms of cereals, pulses, oilseeds and forages selected or bred for characteristics that substantially reduce deep drainage and nitrogen leakage.

- Refined land assessment tools that best locate trees, other perennial plants, high-value annuals, and native species to meet water quantity and

- New tools for land managers to monitor leakage past the root zone, and change land use accordingly.

To realise this vision, we will need to pioneer the development of a new landscape, a mosaic of tree crops driven by large-scale industrial markets such as biomass fuels and high-value annual crops, as well as mixed perennial-annual cropping systems, and areas devoted to maintaining those elements of native biota dependent on native vegetation. Devising the optimal placement of these land uses in terms of salinity control, productivity and maintenance of native biodiversity will require a robust understanding of landscape process and ecosystem function, and good maps of landscape properties, particularly salt storage and groundwater flow.

While a vision for the Basin is emerging, many of the components described above do not yet exist. A substantial new research and development effort is needed that tackles the redesign of farming systems and their integration into the landscape as a whole. This needs to combine biophysical and economic studies that deliver innovative designs well matched to soil, climate and catchment circumstances including biodiversity; on-farm measurement and improved land assessment techniques; modern genetic improvement techniques; and a participatory process that

# Current options and future prospects for managing dryland salinity

There is no single, viable, land-use system capable of controlling leakage over the Basin as a whole. The following list summarises various options that can help control leakage. Some are available now and others, as noted, have realistic prospects but require additional research. Further to successfully integrate these options into the landscape as a whole will demand a significant research effort in the maintenance and restoration of the native biota and of ecosystem function. Research is also essential to develop incentives for incorporating maintenance and restoration of biodiversity into these current options and future prospects.

## Annual cropping

This is the preferred economic option but it is ineffective in attaining leakage targets except in a small proportion of the Basin. There is little opportunity for agronomic research to reduce leakage by the magnitude required.

## Opportunity cropping

Rotations of winter and summer crops that are sensitive to the water conditions of soil make a useful contribution in those parts of the Basin with significant summer rainfall. Opportunity cropping is a relatively mature area in research agronomy. An applied research effort over the next 5–10 years on suitable crop/soil/rainfall combinations could yield improved systems in terms of salinity control and profitability.

## Phase farming

This is effective when the lucerne phase is long enough to dry the subsoil and the cropping phase is terminated before leakage recommences. Reductions in leakage of 50–70% are associated with reduced profitability. This is a mature area of agronomic research and systems are well advanced and available. Research over the next five years should overcome dependence on lucerne and fine-tune the application of phase farming to improve profitability and drainage outcomes.

## Companion farming

Over-sowing annual cereals into perennial forages/pastures holds promise of significantly reducing leakage beneath the root zone. Research is needed over at least 5–10 years on species and agronomic practice to provide viable systems.

## New agricultural plants

Some potential exists to select or breed long season, perennial and/or deep-rooted cultivars of current crop and fodder plants that may substantially reduce deep drainage, and to fit these plants into new farming systems. This will require a substantial and well-focused research effort over the next 5–25 years.

## Organic farming

While the demand for organic produce is growing in the marketplace, organic farming is not necessarily any more effective than annual cropping in controlling leakage beneath the root zone. However phase farming, companion farming and agroforestry practices that reduce leakage are in harmony with the organic philosophy and are therefore more likely to be adopted.

## High rainfall tree products

These products are effective in reducing leakage, and profitable, but their proven potential is currently limited to a small proportion of the Basin. Long-term research (10–30 years) is needed to extend profitable forestry to a larger proportion of the Basin in a way that maintains water yield.

## Low rainfall tree products

While this is potentially the most effective land-use option for managing salinity by reducing leakage, it is not commercially viable due to a lack of markets to drive reforestation and/or re-vegetation at the necessary scale. A very significant, well-focused research effort over the next 30 years will be essential to develop: new markets; tree crops to produce fruits, nuts, oils, pharmaceuticals; bush foods; and forestry products including specialty timbers, charcoal, carbon credits and bio-mass energy applications.

## Agroforestry

Agroforestry can be more profitable than tree crops alone, but its effectiveness depends on the proportion planted to trees, and on the skill of locating trees in the right parts of the landscape. Further research is needed to determine which tree/crop/pasture mixtures can reduce leakage to acceptable levels and continue to give economic return. This research should provide solutions over the next 30 years. It will build on and benefit from work essential to the development of commercial tree crops and new agricultural plants.

## Perennial pastures

Perennial pastures leak less water beneath the root zone than annuals, but higher rainfall, winter dominance, acid and shallow soils, and grazing pressure all compromise their potential across the southern half of the Basin. Research and development should focus on ameliorating subsoil and on deeper rooting species.

## Saltland farming

Saltland farming allows for soil stabilisation and provision of stock feed but makes little long-term contribution to managing the watertable, reducing salt loads to rivers and therefore to water quality. Identifying species and management practices that make best use of such land is important because of the huge areas that will be affected by salt, but the impact of this research on controlling land and river salinisation will be relatively small.

# Why we need a revolution in land use

Five years ago the salt problem was just another topic for scientific meetings and loss of biodiversity was regarded as a nature conservation issue. Today, it is front-page news and high on the political agenda. This prominence has elicited different responses. Hydrologists are relieved that the community is at last beginning to share the burden of their message on salinity. Landholders have the disquiet of knowing that they may be both responsible and the major casualty. Agricultural scientists find the doom and gloom a bit much. The dedication and skill of their predecessors has seen many seemingly intractable problems overcome in the past. Why not this one? Ecologists have documented the decline and loss of biodiversity and the change in ecosystem processes and are concerned that salinity and loss of biodiversity are often treated as completely separate issues. They are not, as salinity is an extremely visual manifestation of the loss of major elements of biodiversity and change in ecosystem process.

Agriculture has flourished over much of the world for thousands of years, despite the changes wrought when virgin land comes under the plough. But in southern Australia, the signs of an uncertain future surfaced within ten years of the first trees being ring-barked. Railway engineers found that the reservoirs they constructed to supply water to locomotives became too salty to use.

By 1897, astute observers were making the connection between clearing native vegetation and fresh creeks becoming salty. Twenty years later, an analysis was published that described the relationship between clearing and salinisation with surprising clarity, although the underlying processes were somewhat misunderstood. A description of the problem that accurately captured the fundamental issues was published in 1924.

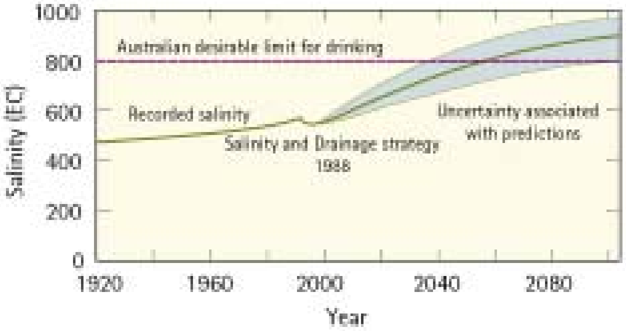


**Figure 1. The salinity in the Murray River at Morgan (close to the off-take for Adelaide's water) has been rising slowly for 80 years and is forecast to rise more quickly over the next 100 years.**
Source: Murray–Darling Basin Ministerial Council (1999)

This newfound understanding was not translated into action. Agriculture continued to expand and became the foundation of a prosperous economy. At the same time, more water has been leaking below annual crops than the aquifers can deliver to rivers. As aquifers fill and watertables rise, the deep and ancient stores of salt are lifted to the soil surface, killing much of the remaining native vegetation and its associated fauna, while the salt is carried into rivers.

This publication does not go back over the causes of the salinity problem. They are well dealt with in its predecessor report, *Effectiveness of current farming systems in the control of dryland salinity*, which concluded that:

- current farming systems are the fundamental cause of the dryland salinity problem;
- under best management practice, the leakage from most agricultural land still far exceeds the capacity of the landscape to shed the excess water;
- for most of the country we do not have profitable systems to replace existing land use; and
- even if we did introduce very different farming systems immediately, it will be a long time before we see an improvement in salt trends.

This volume looks to the next 20 to 50 years. If today's agriculture is the root cause of dryland salinity, can we envisage a new agriculture in better harmony with Australia's unique landscape?

# Lessons from ecology

We often hear that Australian farmers imposed a European agriculture completely unsuited to Australian soils and climate. This is not entirely fair. All human societies that have forsaken a hunter-gatherer existence have based their civilisations on annual seed-bearing plants such as wheat, rice and maize. It is not the European heritage of agriculture that is at odds with this land, but the replacement of native perennial plants with annuals.

The strategy of the annual plant is to match its life cycle perfectly with the favourable growing season and to survive the harsh times as seed. This made the annual a perfect candidate for domestication because its large seeds favour the survival of the next generation. For example, the wheat plant packages half its total biomass as starch and 70% of its nitrogen as protein in its seed. Perennial plants cannot match this bounty. The strategy of the perennial is to survive, not sit out, the hard times. They need deep roots to tap the last of the water and frequently, woody stems so that they can lift their canopies above their annual competitors.

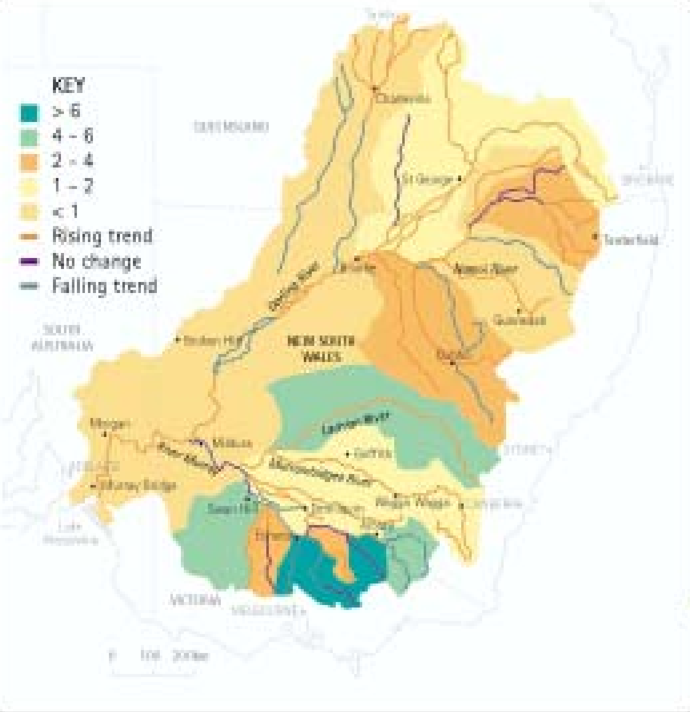


**Figure 2. Salt exports and trends in river salinities 1975–95: tonnes per km² per annum. The salt levels in many major river systems are rising.**
Source: Murray–Darling Basin Ministerial Council (1999)

Perennials have to survive greater pressures from parasites and grazers. Many perennial plants produce structures and chemicals as protection. This investment in infrastructure and defence, and its associated maintenance requirement, diverts resources that could be used for new growth. Even though a perennial may capture more water and nutrients than an annual, the harvestable proportion of digestible energy and protein falls short.

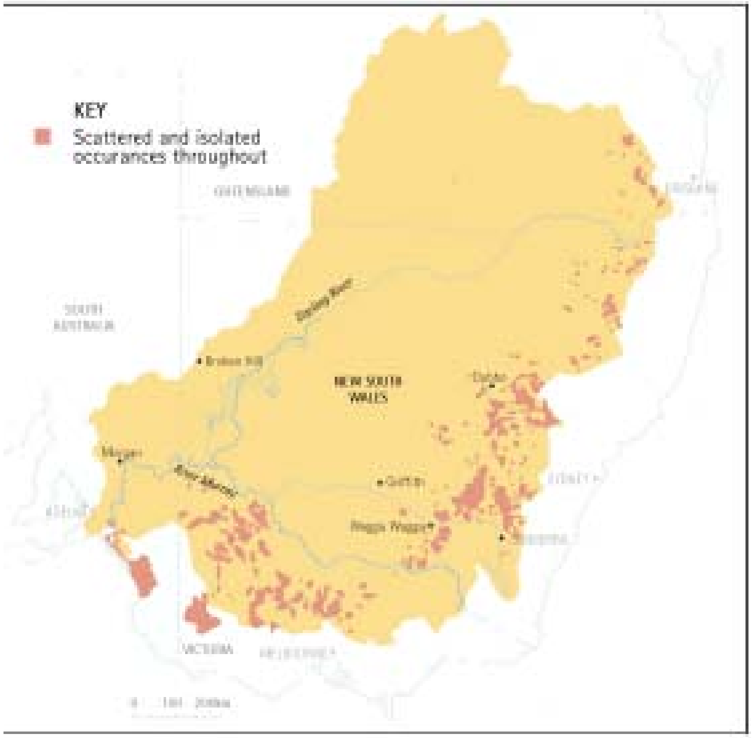


**Figure 3. Areas threatened by dryland salinity.**
Source: Land and Water Resources Research and Development Corporation (1998)

The annual is more suited to intensive agriculture. Ploughing and herbicides remove competitors and allow a perfect match between the season and the plant's requirements. The productivity of the annual and its apparent wastefulness are linked. Typically 5–15% of the long-term average rainfall gets past the roots of annual plants, whereas less than 1% escapes the native perennial vegetation.

For most landscapes, leakage past the root zone of native vegetation approaches the capacity of the groundwater systems to deliver water to rivers (discharge capacity). For the annual cropping zone of the Basin, leakage beneath the root zone for annual crops and pastures translates to between 15 and 130 mm per year, while the landscape capacity to drain groundwater to rivers is of the order of 0.5–10 mm per year.

# Agriculture and the environment

The removal of vast areas of native vegetation (in some cases over 95% of areal extent) has resulted in 5–15% of rainfall leaking past the root zone over agricultural land. This has caused the changes in land and river salinity shown in Figures 1, 2 and 3 and the widespread loss of biodiversity, and changes to ecosystem processes. The salinity level of waters of the Loddon and Avoca rivers is already above the desirable Australian limits for drinking for most of the year. The Warrego, Condamine-Balonne, Border, Macquarie and Namoi rivers are predicted to join this category in 20 years, and the Lachlan, Castlereagh and Murray (at Murray Bridge) within 50 years.

The paucity of data makes it difficult to predict the area of land expected to be salinised or what of our natural heritage we stand to lose. Groundwater monitoring has been conducted over almost half the 107 million ha Basin. Groundwater is rising under at least 15 million ha of the Basin. About 0.3 million ha of land were salt-affected by 1996, and this is expected to rise to 6–9 million ha before a new hydrologic equilibrium is reached.

If we are to have any impact on these trends, we will need to introduce perennial species into agricultural landscapes. Given that perennials are less conducive to intensive agriculture, the task will be difficult. In the following pages we examine the options and their prospects.

However, before looking at the options, we need to be clear about the targets we set ourselves over the next 20 to 50 years. We also need a comprehensive assessment of leakage rates under current farming systems and how they vary throughout the Basin.

# Setting targets

No strategy can work until we have set targets to measure its performance. Three suggested targets are described below.

## Mimic the bush

A first target is to try to reach the leakage rates of the original vegetation. This is the target required to avoid and/or reverse salinisation. We aim to retain a productive landscape by mimicking the hydrological function of native vegetation with economically viable species.

Due to the vast quantities of salt already mobilised by rising water tables, reversing the salt trend to the state that existed before clearing is not possible. We can limit the spread of salinity by creating a productive landscape that mimics the water use patterns of the original bush. However without profitable tree crops, especially in low rainfall areas, the only way to do this is to revert to native vegetation with serious implications for agriculture and rural communities.

Nevertheless native vegetation and re-vegetation has a most important role in salinity control. Maintenance of remnant native vegetation throughout the basin is a key target in order to conserve and maintain biodiversity and ecosystem services in conjunction with salinity control. The integration of native vegetation into landscape design is critical to halting further loss of species and ecosystem function. On our present path we can expect to lose 50% of avifauna from the basin over the next 50–100 years. Solutions, which mimic the ecosystem functions of the bush, will be important to both salinity control and protection of landscape biodiversity and function.

## Protect the land

A second target is to ensure that recharge levels remain less than the discharge capacity of a catchment. The discharge capacity is the amount of water that the groundwater aquifers can carry — water that will eventually be delivered to a stream. The discharge capacity is set at the point of lowest transmissivity, where the aquifer becomes shallow, narrows or decreases in permeability. As long as the recharge rate is less than the discharge capacity, watertables will not rise to the surface, and land and infrastructure will not be lost to salinity.

This target is made difficult by our inability to measure both leakage and discharge capacity with reasonable accuracy. Discharge capacities have been calculated for only a few catchments, and fall somewhere between one half and one tenth of our best estimates of current leakage rates beneath land used for agriculture.

## Protect the rivers

A third target is to keep the salinity of the streams below a certain threshold, say 800 EC, which is the Australian limit for desirable drinking water.

This target is the most relevant for the Basin, and also the easiest to measure. Even though millions of hectares of farmland are threatened by salinity, the major cost to the community will come from declining river quality for domestic water supply and irrigation.

Individual leakage targets would have to be determined for each catchment, but for most, targets should not exceed the catchment's discharge capacity, which will rarely exceed about 1% of rainfall. For the Basin, this means leakage rates beneath the root zone of land use should be less than 0.5–10 mm per year, depending on the amount of rainfall, its distribution, and catchment properties. Any increase or decrease in recharge affects stream salinity, and the size of the impact will depend on the salinity of the groundwater.

It is essential to consider time lags within the system. In many areas, the salt discharge is rising and will continue to rise even after recharge has been reduced. In local-scale groundwater systems, the salt discharge may continue to rise for a decade or more. In larger intermediate and regional-scale systems, the rise could extend to hundreds of years no matter what we do (Figure 6). Unfortunately, large-scale groundwater systems dominate the Basin (Figure 4).

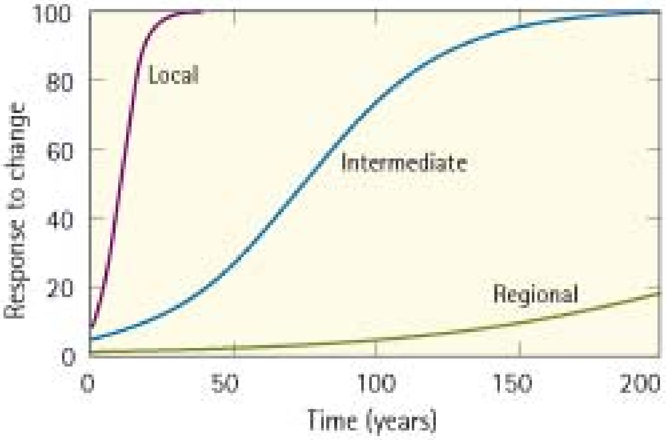


**Figure 5. There is a time lag between a change in vegetation and the response of the groundwater.**

There is an important distinction between salt from dryland and irrigation sources. The Salinity and Drainage Strategy for irrigation areas includes a system of salt credits, which are tradeable pollution rights. If managers of an irrigation area need to put more salt into the river from drainage systems, they are responsible for the cost of engineering works that can intercept a similar quantity of salt downstream.

*The Salinity Audit* published by MDBC in 1999 predicts that most of the future salt discharge into river systems will come from dryland catchment sources, undermining existing plans to protect irrigation areas. For this reason the following pages focus on land-use options for dryland catchments.

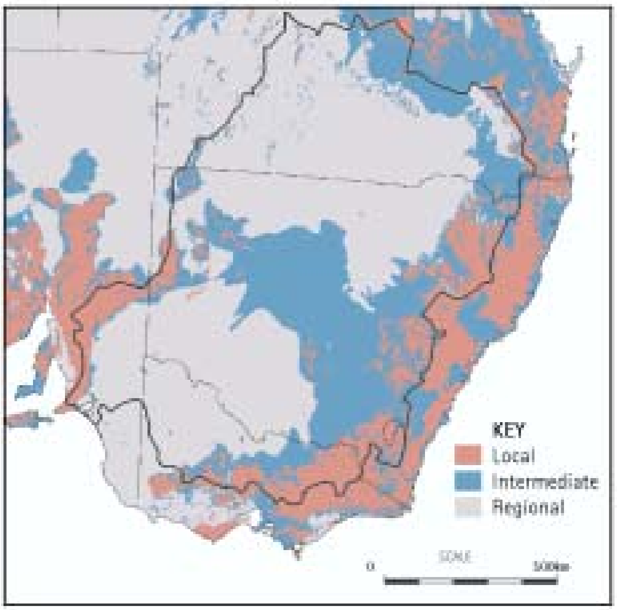


**Figure 6. Distribution of local, intermediate and regional scale aquifers in the Basin.**
Source: National Land and Water Resources Audit (2000)

Figure 7 summarises the problem we face. If dryland agriculture as we know it today does not change, land and native biodiversity will continue to be lost to salinity and rivers will become saline — path A in Figure 7. If we push current land-use systems to their limit of efficiency, we are likely to follow path B — buying time but ultimately losing the battle. We already recognise that path D, a return to the pristine state, is unattainable. On the following pages we briefly evaluate the potential of improving current systems before examining the options for moving down path C.

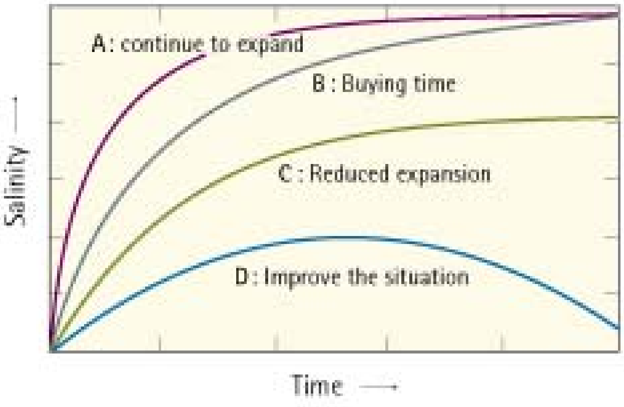


**Figure 7. Which path do we take?**
Source: Walker et al (1999). *Effectiveness of Current Farming Systems in the Control of Dryland Salinity*

The better managed crops had higher yield and also left the soil around 20 mm drier. Such improvements are in line with model predictions shown in Figure 9, and again fall short of what is required over most of the cropping zone.

The best hopes for cropping systems are to concentrate on soils with high water-holding capacity, and to introduce summer crops or perennial pastures into rotations according to the amount of water stored in the soil.

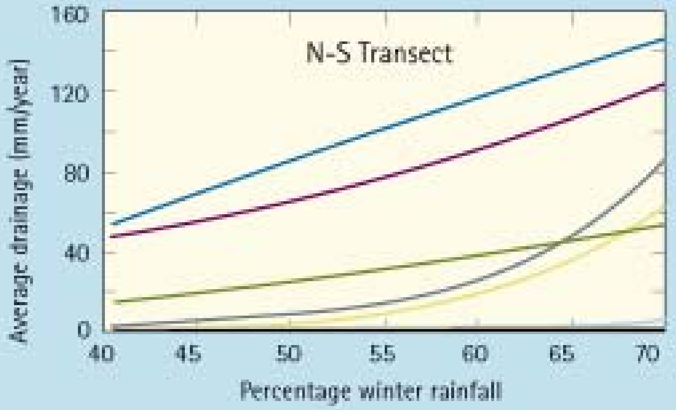


**Figure 10. Predicted leakage with increasing winter dominance for a range of current land use options and for future prospects (see key Figure 9).**

# Joint Venture Agroforestry Program

## (RIRDC/LWRRDC/FWPRDC)

Since 1993, JVAP has led Australia in the development and dissemination of research and practical information to underpin new sustainable farming systems incorporating perennial woody vegetation.

The program focuses on commercially driven tree production systems for addressing land degradation issues. It is developing new tree-based industries for integration into low to medium rainfall farming systems. The program aims to deliver cost-effective multi-purpose agroforestry systems to meet commercial and environmental objectives.

# Opportunity cropping

One option to increase water use by annual cropping systems is to sow crops opportunistically in both winter and summer, when rainfall and soil water conditions allow. This is a useful strategy, particularly in the northern half of the Basin, when summer rainfall is more significant and soil water storage generally greater (Figures 9, 10).

In the northern part of the Basin, soils with high water-holding capacity coincide with sufficient summer rain to allow cropping at almost any time of the year. The modelled volume of drainage from a catchment under current management was nearly six times that of the native vegetation. Opportunity cropping yields a leakage volume less than twice that of native vegetation (Figure 11). However, on soils formed from sedimentary rocks, the difference between current and best practice is smaller, and both leak considerably more than the native system.

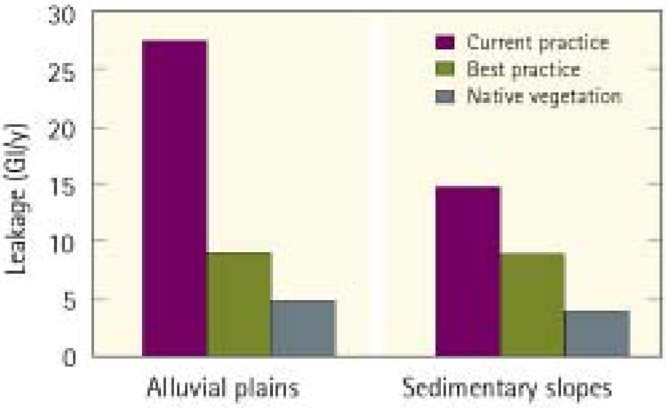


**Figure 11. Modelled leakage under current practice, best practice and the native vegetation in a catchment in northern NSW.**

Source: Ringrose-Voase and Cresswell (2000)

The greatest obstacle to controlling leakage in annual cropping systems is season-to-season variability in rainfall. Average leakage may be 50 mm/y, but developing farming systems that use an extra 50 mm/y would not solve the problem. The wetter-than-average years contribute most to drainage and any sustainable system must have the capacity to deal with such years. This can only be achieved using perennials.

Annual crops can be made to behave in a more perennial fashion using *phase farming* or *companion farming*, combining and alternating perennials with annual crops.

# Annual cropping

Most of the Basin with rainfall greater than 400 mm has been cleared for agriculture, predominantly for annual crops and pastures. In this section we present an overview of the expected leakage of water below annual crops across the Basin. The estimates below are from field-calibrated simulation modelling of annual cropping, but the same principles apply to annual plant-based pasture systems.

Two transects are explored (Figure 8). The first considers the *amount* of rainfall; the second the *timing* of rainfall. These simulations are for a deep well-drained soil using weather data collected over the past 40 years.

**Figure 8. Simulations were carried out across N–S and E–W transects.**

The E–W transect runs across the Basin at approximately 33°S, taking in towns such as Condobolin, Parkes and Orange. Annual rainfall ranges from 320 mm in the west to 870 mm in the east. Rainfall at this latitude is slightly winter dominant (55% of the annual total).

The estimates of average annual leakage for a wheat cropping system increase from almost nothing in the west to well over 200 mm in the east (Figure 9). The simulations also show that higher input farming has had a large effect on yield, but not on drainage. Doubling nitrogen fertiliser (N) from 40 to 80 kg/ha increased yield by 20–40% but only reduced annual leakage by about 25 mm (Figure 9). Bigger crops with more leaves mean more transpiration and interception, but this is largely at the expense of soil evaporation, not leakage below the root zone.

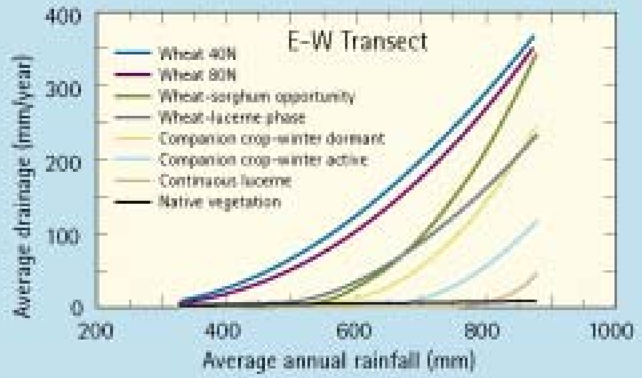


**Figure 9. Predicted leakage with increasing rainfall along the E–W transect for a range of current land-use options and future prospects.**

The N–S transect, which explores the impact of winter and summer rainfall dominance, runs roughly along the 575 mm rainfall isohyet (range 550–600 mm), extending from Roma in Queensland, through Moree, Dubbo and Parkes in New South Wales, and ending with Rutherglen and Bendigo in Victoria. The proportion of annual rainfall received in the winter months increased from 40% in Queensland to 70% in Victoria.

The N–S transect highlights the influence of winter-dominant rainfall on leakage (Figure 10). As winter dominance increases, so too does the leakage associated with annual cropping. This is because more of the rainfall occurs in the cooler part of the year, when potential water use by vegetation and loss via soil evaporation is reduced.

While the targets for leakage will need to be specific to catchments or landscapes, they are almost certainly well below 20 mm/y. Therefore, based on these simulations and complementary experimental work, annual cropping systems fall a long way short of acceptable leakage targets. Yet some would argue that this is not the last word.

There has been continuous change in farming systems since the land was first cleared. In trials across southern NSW, wheat crops grown under practices common in the 1990s were compared to a best management package that included disease-break crops or nitrogen top-dressed crops.

# Phase farming

In phase farming, a deep-rooted perennial like lucerne can create a dry soil buffer of 200 mm or more. This means that it can prevent leakage most years, and also protect subsequent crops in a rotation. The introduction of a perennial deep-rooted pasture phase that can dry the soil to 3 m depth into a cropping rotation (three years pasture followed by three years wheat) across the 575 mm isohyet, drops leakage by 70% or more (Figure 10).

A key element of farming system design that controls leakage is the ability to cope with rainfall variability. For instance, long-term simulation of continuous cropping in central NSW, with 614 mm annual rainfall, produced an average leakage of 107 mm. In 31% of years, the leakage was less than 50 mm, so the cropping phase could occur for at least four years after lucerne. However, in 17% of years, the annual drainage was greater than 200 mm. Such a year, coinciding with a depleted buffer, would lead to unacceptably high leakage (Figure 12).

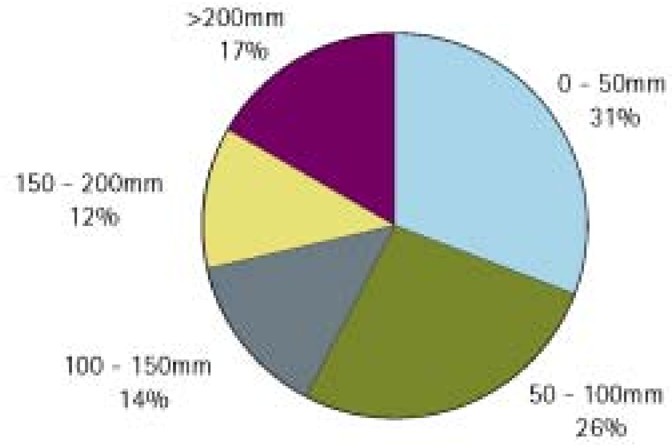


**Figure 12. The modelled probability of getting different amounts of leakage under continuous cropping in central NSW.**

# Companion farming

Companion farming is an emerging concept in which annual cereals are oversown into a perennial pasture system, ideally one that exhibits a strong degree of winter and spring dormancy. The perennial pastures may be native grasslands, like those being trialed by innovative farmers in northern NSW, or deep-rooted legumes such as lucerne or other novel species. Oversowing annuals into winter dormant perennial pastures may be a way of getting around the issue of year-to-year variability in leakage and the technical difficulty of changing phase.

These systems have been explored in calibrated simulation models (see Figures 9, 10) and appear to be potentially more effective than phase farming in controlling leakage, with at least the same grain-yield production possibilities. However, there may be a trade-off in production through competition for water and problems with obtaining a clean harvest.

This option could be implemented over the short term (three to five years), with well-targeted on-farm research and development.

# New agricultural plants

Our current crop and forage species have been bred and/or selected for yield and desirable agronomic characters. Little or no attention has been given to their ability to use water and nitrogen and restrict dryland salinisation.

The immediate opportunities lie in longer season cultivars and species. Good prospects exist to develop winter wheat and canola varieties that can be sown as early as February, if rainfall conditions allow, and grazed in May. They then regrow to produce a grain yield over the normal spring–early summer period.

Longer term, opportunities lie in the use of both improvements in conventional plants and developments in biotechnology to develop new plants with more extensive root systems, greater perenniality, and different degrees of winter and summer activity. Other traits such as enhanced early vigour, waterlogging tolerance and disease resistance would also improve their use of water.

It may be possible to add 'resurrection genes' to annual crops, giving them the ability to re-sprout after harvest in the event of summer rain. At the extreme, it might even be possible to produce perennial grain crops, although it is highly likely that there will be a trade-off between productivity and persistence. This research frontier has been examined as part of a new research and development program entitled 'Redesigning Agriculture for Australian Landscapes' (see below). Some results can be expected in the next five years, but most of the developments mentioned above will require 5 to 25 years of focused research.

# Redesigning Agriculture for Australian Landscapes

The Redesigning Agriculture for Australian Landscapes (RAAL) Research and Development Program is a joint initiative of the Land and Water Resources Research and Development Corporation and CSIRO. The program is researching how agricultural systems in Australia can be redesigned to address a range of sustainability issues. It has four objectives:

- To understand, by comparison, the key biophysical processes affecting leakage of water and nutrients in cropping, grazing and natural systems.
- To benchmark criteria for redesigning agricultural systems in Australian landscapes.
- To develop a toolbox of redesign options to modify current, or develop new, agricultural systems for Australian landscapes.
- To facilitate implementation of redesign options in priority Australian landscapes by exploring the socio-economic, institutional, policy, marketing and technological requirements and implications of each option.

This design approach has potential to be applied through:

- selection and plant breeding — including molecular genetics — for our commercial crops, pastures and native plants to manipulate their phenology, canopy development, rooting function, distribution and temperature response.
- rotating and mixing, in space and time, innovative configurations of plants including: annual and perennial crops, pastures, forest and horticultural trees, native plants and bush foods, in alleys, blocks, windbreaks and clusters, over rotations of months or years.

Recognising the diverse skills and inputs necessary to achieve its mission and objectives, the RAAL Program will actively seek opportunities to collaborate, focusing on:

- integrating RAAL with a range of other redesign initiatives, and
- incorporating RAAL outputs into other research and development initiatives.

# Organic farming

Organic farming is increasing in importance due to rapidly growing market preference. Organic farming uses crop rotations and diversity to replace agrochemicals, but this does not necessarily mean a shift to greater use of perennial plants. A similar reliance on annual species will expose organic farming to the same risk of leakage as conventional agriculture. Research to give greater emphasis to deep-rooted perennials in phase planting or as companion plants is attractive because organic farmers are well disposed towards and skilled in the complexities of crop/pasture/tree management.

**Belts of Eucalypts pruned for sawlog production, planted into high rainfall pasture.** Photo: Richard Moore.

# High rainfall tree products

Forestry for sawlogs and pulpwood is a potentially valuable land use where annual rainfall exceeds 800 mm. Where rainfall is below this limit, forestry is more difficult, although it is being attempted. There are two major constraints to high rainfall tree crops as a tool for managing salinity in the Basin. First, only 6% of the Basin receives more than 800 mm of rainfall per year, and some of this is already under forest cover. Second, timber production has to be balanced with another major product of this zone — fresh water. In North Eastern Victoria, for example, the catchments of the Kiewa, King and Ovens rivers make up only 2% of the Basin yet contribute 38% of the total river flows each year.

While planting trees would probably improve water quality, the volume of runoff would certainly decline due to increased evapotranspiration by the trees. In catchments that currently yield high-quality water, the value of that water may well be greater than the value of the timber. One estimate puts the decline in mean annual runoff after planting at up to 220 mm for eucalypts and 290 mm for pines, where annual rainfall is 1000 mm (Figure 13). The magnitude of surface overland flow during storm events in areas under re-afforestation is open to manipulation; it should not be assumed that water yield is determined by evapotranspiration alone. This area of research is critical to managing re-afforestation in the Basin. To manage this trade-off, forestry needs to be researched and implemented with great care in catchments of the Basin with their heavily allocated flows.

Afforestation in medium–high rainfall areas will also affect the magnitude and distribution of flows over time and reduce the incidence and severity of flooding.

Field measurements show that flood peaks associated with low and intermediate storm events would be roughly halved by pine afforestation, with lesser reductions likely for large storm events. However some perennial streams may become intermittent.

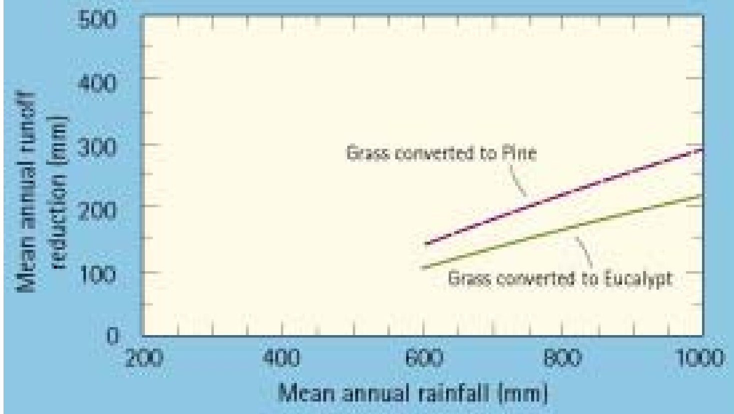


**Figure 13. The reduction in runoff when moving from grass to trees.** Source: Vertessy R (2000) in *Afforestation impacts on catchment runoff.* Presented to Plantations, Farm Forests and Water: a national workshop organised by CSIRO, Agriculture, Fisheries and Forestry – Australia, and the RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program.

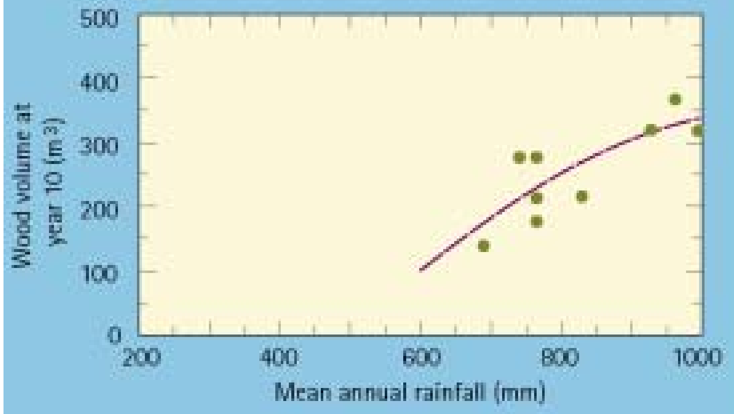
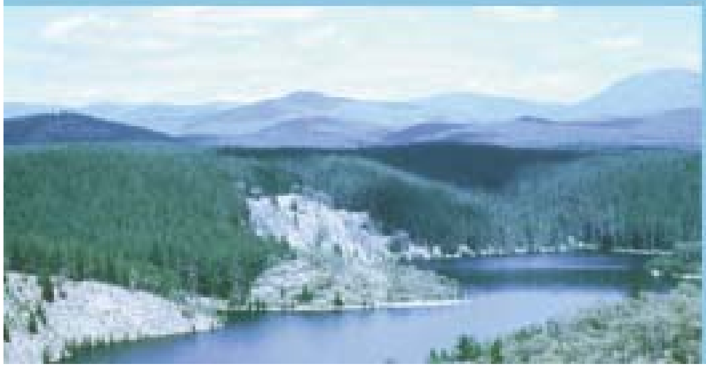


**Figure 14. Relationship between wood volume and annual rainfall**

Source: Wong J, Baker T, Duncan M, McGuire D and Bulman P (2000). *Forecasting Growth of Key Agroforestry Species in south-eastern Australia. A report for the RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program,* RIRDC Publication No 00/68.



Source: CSIRO Forestry and Forest P

# Low rainfall tree products

As the growth rates of trees decline with rainfall, their commercial viability depends increasingly on high-value/low-volume products. Historically, this has included industries in the Basin based on specialty timbers, essential oils and tannin from native wattle and pine. More recently, there has been market interest in native shrubs and trees for foods, flowers, oils and pharmaceuticals, as well as for a suite of exotic species including carob, jojoba, olives and nut trees.

One emerging industry utilises Australian native species to produce food. Most of the native foods that are harvested come from the wild, but there are increasing efforts to cultivate these plants, which include both trees and perennial shrubs. Thus far, the main aims have been to reduce the demand on wild stands, and to increase the reliability and quality of supply. Species for which product demand exceeds supply include quandong, Acacia (for wattle seed), native citrus, mountain pepper, riberry (clove lillypilly) and lemon aspen. The list includes some arid zone species and others from higher rainfall areas in eastern Australia. These species are relatively widespread in the native flora and some, such as *Acacia pycnantha,* are found in the understorey. Knowledge on best practice for cultivating these plants is in its infancy, but growing.

Producing food from native trees offers medium-to-high returns. Data on gross margins and economic analyses are beginning to emerge. The capacity of trees such as Acacia (grown for seed) to contribute to solving salinity problems has not yet been explored, but they appear to be good candidates.

The problem with specialty products such as native foods is that small markets can be readily satisfied with a small area of trees. Australian imports of tannin could be replaced with some 25 000–50 000 ha of acacias. Similarly, imports of carob bean gum worth A$10 million each year could be replaced with 5000 hectares of carob trees. If salinity targets are going to be met, requiring millions of hectares of new perennial vegetation in the medium-to-low rainfall zone, this approach would need an enormous number of different commodities suited to low rainfall areas.

**Harvesting melaleuca for essential oil production.** Source: Australian Plantations Pty. Ltd.

A new approach that is being developed involves multi-purpose harvesting of native trees for industrial products. Mallee eucalypts, similar to those that once occupied large areas in the south west of the Basin, are harvested at ground level on a two-to-four-year rotation and streamed into three products. Pelletised charcoal for use in water filtration and gold mining is made from the wood, the essential oil cineole is extracted from the leaves for use as an industrial solvent, and the waste is used to drive the oil distillation and to generate electricity for sale into the grid.

**Figure 15. Harvesting tea tree.**
Source: Australian Plantations Pty. Ltd.

It is not profitable to produce any of these products alone. Put together, the value of mallees may come close to returns from cropping on lighter land, precisely the areas that leak the most under current agriculture. With a world market for activated carbon of 700 000 tonnes a year and competitive price for electricity, such generalist products are likely to be applicable to large areas. Yields of between 5 and 7 tonnes per hectare have been achieved from oil mallees in the Murray Darling Basin on an annual harvesting cycle.

The likely structure for such an industry is cells based on major regional centres with plants capable of processing several hundred thousand tonnes of trees a year, requiring some 10 000 ha of trees within a 100 km radius.

The production of ethanol and methanol as replacements for fossil fuels is potentially a large industrial use for tree crops. Modelling has suggested that 30 million hectares of trees and shrubs would be required if Australia were to make the transition to an ethanol fuel-based transport system. This would provide 50 jobs in each of 1000 regionally based production plants and 200 000 jobs in growing and delivering the feedstock.

It would also reduce carbon dioxide emissions by 500 million tonnes a year.

The costs of producing ethanol from woody biomass 'crops' is likely to be significantly more expensive than current transport fuels (maybe by a factor of two to three). However, government excise policies (or other incentives) may make such land uses economically feasible in the medium term. A pilot plan is being established in NSW to explore ethanol production from woody biomass. In addition, the Federal Government has a taskforce currently exploring options for increasing the renewable energy component of Australia's transport fuels.

Finally, any attempts at costing the production of biomass fuels should factor in the benefits mentioned above: improving land and water quality, converting to a carbon-neutral fuel cycle, increasing regional employment and replacing imports of fossil fuels.

# Tactical deployment of trees

Trees are profitable in high rainfall areas, but this is only a small fraction of the Basin. However, trees can be grown profitably in drier regions in landscape positions where they can capture more water than annual rainfall. A second way to introduce trees is to identify parts of cropped areas where crops routinely perform poorly. Identifying niches in the landscape particularly suited to trees or unsuited to cropping is a way of shifting the balance to woody perennials at least cost to the landholder.

## Niche locations of trees

Where slopes exceed 3–5%, water can move horizontally across the landscape. Hillslopes that are convergent or concave tend to contain wet areas. Such areas may be problematic in that they are prone to waterlogging, salinisation and erosion. They may also be ideal locations for tree planting.

Tree belts are particularly suited to the high rainfall pasture zone, where it is clear that pastures do not use all the rainfall. For local groundwater systems, the excess water may move laterally over impermeable soil layers or shallow bedrock, and will often be fresh (Figures 16,17).

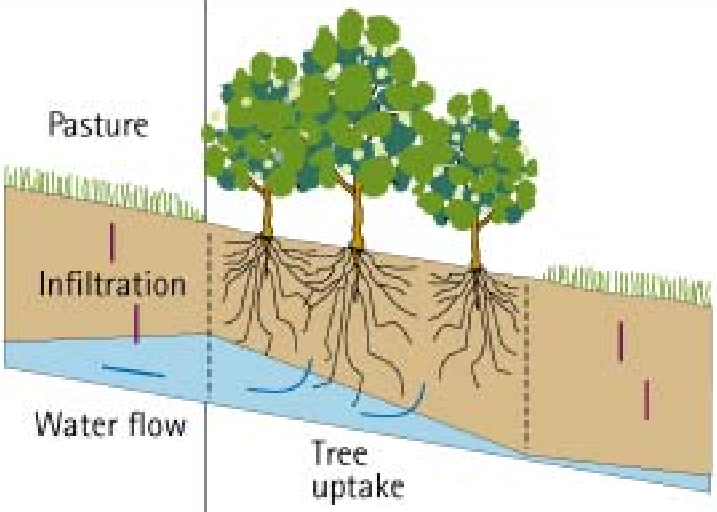
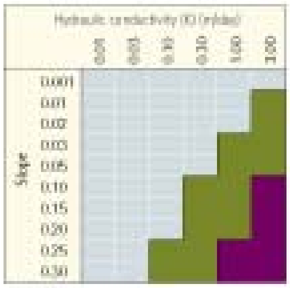


**Figure 16. Trees can intercept water moving laterally across the landscape.**

Source: From Silberstein R et al (*in prep*) in *Trees, Water and Salt, an Australian guide to using trees in achieving healthy catchments and productive farms.*

In southern Australia, trees have the potential to use around 1000–1400 mm of water per year, so the excess water would certainly enhance tree productivity and possibly reduce waterlogging down slope. However, suitable locations represent a small area of the Basin.

A second way to deploy trees tactically is to site them over areas with particularly large salt stores so that this salt is not mobilised. New techniques are being developed to identify such areas.



| Slope | 0.01 | 0.03 | 0.10 | 0.30 | 1.00 | 3.00 |
|---|---|---|---|---|---|---|
| 0.001 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
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**Figure 17. The combination of slope and soil conductivity required for significant lateral movement of water to tree belts (purple — good lateral movement), green — some lateral movement, grey — insufficient lateral movement.**
Source: From Silberstein R et al(*in prep*). in *Trees, Water and Salt, an Australian guide to using trees in achieving healthy catchments and productive farms.*

## Selective removal of crops

Yield mapping — the real-time measurement of grain yield during harvesting — has revealed enormous variability across single paddocks. When yield maps are turned into gross margin maps, we see that most of the profit comes from a small proportion of the paddock and some areas even lose money. The bad spots can be season specific, such as low-lying areas in wet years that may outperform other areas in dry seasons. The bad spots can also be due to shallow soil, sodicity or other toxicities that consistently reduce crop yield.

Such areas may never be profitable under cropping. Revegetation with perennial vegetation that is suited to the particular impediment would reduce both recharge and the variable costs associated with cropping. It also provides opportunity for creation of habitat for the maintenance of native biodiversity.

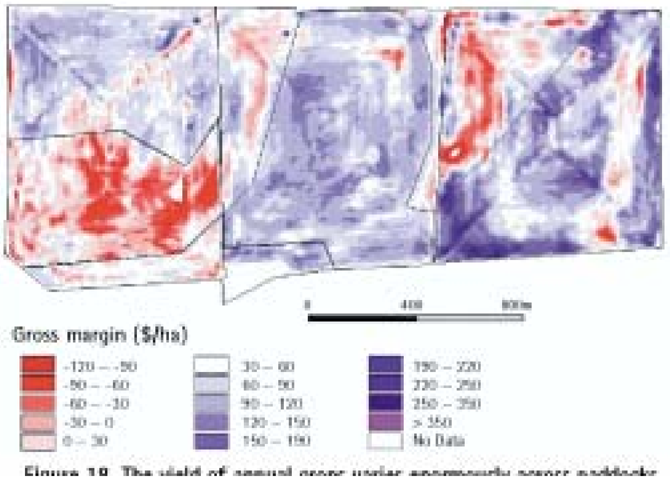

**Figure 18. The yield of annual crops varies enormously across paddocks**

# Agroforestry

Over most of the Basin, water does not move laterally. A plantation will only stop leakage over the area of land it occupies. The situation is different for spaced trees or tree belts in cropping or pasture land. Spaced trees can scavenge water from an area far beyond their canopies, and use water left behind by crops and pastures. Thus fewer trees can achieve a greater impact on leakage. A spaced tree is likely to grow faster than its counterpart in a plantation because of the extra resources available.

Mixing trees and crops introduces the problem of competition for light, water and nutrients. Tree/crop combinations (agroforestry) will only be profitable if the value of tree products and any benefits from shelter exceed the value of displaced crops and decline in crop yield through competition (Figure 22).

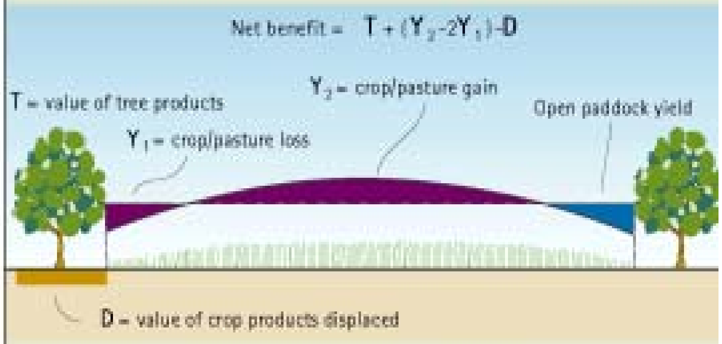

**Figure 19. The net benefit of tree belts is a combination of the value of the tree product plus yield enhancement due to shelter less the area of land displaced and the crop lost to competition**
Source: Redrawn from Lefroy EC and Scott PR (1994). Alley farming: new vision for western Australian farmland. *Western Australian Journal of Agriculture* 35: 119–126

Most studies have shown that the increase in crop yield resulting from nearby shelter hardly compensates for the loss of crops closer to a row of trees. Since the value of trees is less than that of the crop, this usually makes agroforestry uneconomic. Edge rows of tree belts have shown enhanced growth, but edge rows also require more silvicultural management.

Win-win situations, where drainage is reduced and profitability is increased, are therefore rare. However, mixtures of trees and crops can be a better way of reaching a target reduction in leakage than having part of a catchment in plantation and the rest in crop. This represents a trade-off between environmental service and profitability. Belts of trees may be more cost effective than plantations but are less profitable than pure cropping.

The aim of agroforestry is for the trees to use water that would have contributed to leakage, not water that would have been used by the crop. This balancing act is difficult to achieve in a variable climate. In wetter-than-average years there will be more water than the tree/crop mixture can cope with and leakage will continue. In dry years there will not be any excess resources and the tree, by virtue of its perennial root infrastructure, is likely to be a stronger competitor for water than the crop, resulting in crop failure.

Agroforestry may be more suitable in wetter pasture regions. Competition in pastures may be lower than for crops, partly because there is more rainfall and partly because pastures that comprise several different species and exhibit different growth patterns spread the period over which competition can be tolerated. Fodder shrubs may also provide feed when the supply from annuals it at its lowest.

The best prospects for successful agroforestry or pasture mixtures occur when the tree component has a direct economic value. As the value of tree products approaches that of annual products, the problem of competition between trees and crops dissipates.

**Note the denser foliage of trees where they meet with cropped land.**

# Perennial pastures

While profitable tree cropping for the less than 800 mm rainfall zone remains an unproven option, herbaceous perennial plants — lucerne and perennial grasses — are already part of current farming systems. To what extent can a herbaceous perennial match the water use of a woody perennial?

Perennial grass pastures are capable of using higher rates of water than trees in the short term (days), but cannot match the performance of trees over the medium or longer term. The reason is that perennial grasses seldom have roots below 2 m, whereas tree roots frequently reach below 6 m.

Although they are a great improvement on annual pastures, perennial grass-based pastures cannot meet recharge targets where rainfall exceeds 600 mm and is winter dominant. Evapotranspiration can be 20–100 mm less than annual rainfall, making this zone responsible for large salt discharges to rivers. However, in some areas, particularly over duplex soils, much of the excess water leaves as runoff and contributes fresh water for rivers.

Perennial pastures suffer two further impediments. Acid sub-soils limit the distribution and performance of the most favourable species, and heavy grazing can severely compromise their water use.

There have been few comparisons of introduced and native perennial grasses. The major difference, at least with *Themeda* grasslands, is that the native grasses use less water in winter and spring and more in summer — thus the annual evapotranspiration is similar. There is some evidence that native grasses have greater surface runoff than introduced grasses and thereby reduce the leakage beneath the root zone.

**The perennial pastures remains green while annuals are dying off.**

Lucerne has proved to be a herbaceous perennial in a class of its own, frequently drying the soil profile to 3 m and more. The main interest in lucerne in recent times is due to its role in phase farming, as discussed on page 11. However, the perennial phase suffers two impediments at farm level. First, the marginal return decreases as the proportion of the farm under lucerne increases, as there is a limit to the area of well-suited soils. Second, the value of the perennial must either be similar to the annual, or the area planted to the perennial must protect a large area of land currently under annuals (Figure 20). Generally, neither is the case.

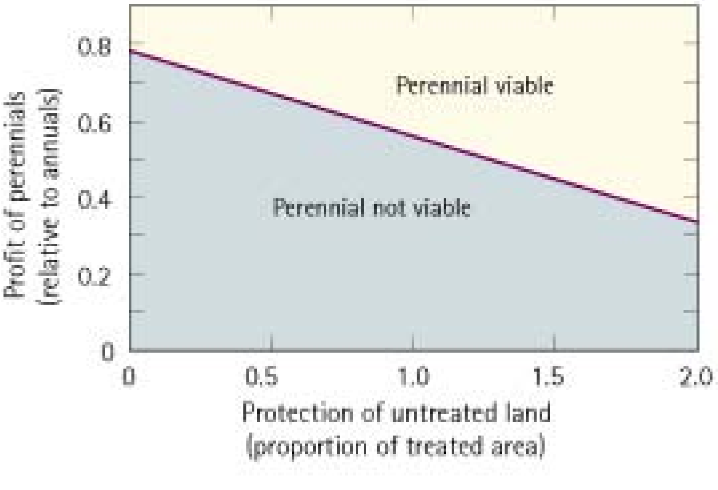

**Figure 20. The required value of the perennial species depends on the area of land it protects beyond the area over which it is planted. For details see Bathgate and Pannell (2000) at www.general.uwa.edu.au/u/dpannell/dpap0005.htm**
Source: Bathgate A and Pannell DJ (2000). *Economics of deep-rooted perennials in Southern Australia.*

# Saltland farming

Current predictions state that the Basin will contain 6–9 million ha of salt-affected land. Salt-affected land is defined not as a white landscape devoid of plants, but as land where the yield of traditional crops and pastures is no longer economic.

Salt makes water less available to plants so that they experience the stress of drought in a wet soil and their growth rate is reduced. When salt gets into a plant it causes progressive leaf fall and ultimately, death. However, some plants and trees can exclude most of the salt at the root surface and tolerate a high concentration of salt in their leaves.

On the rare occasions when groundwater is fresh, plants can obtain up to half of their daily requirement from the watertable. As the salinity increases to above 5000-10 000 EC, the amount of groundwater use falls dramatically, even by salt tolerant vegetation. Unfortunately, groundwater salinities above this value are all too common in Australia.

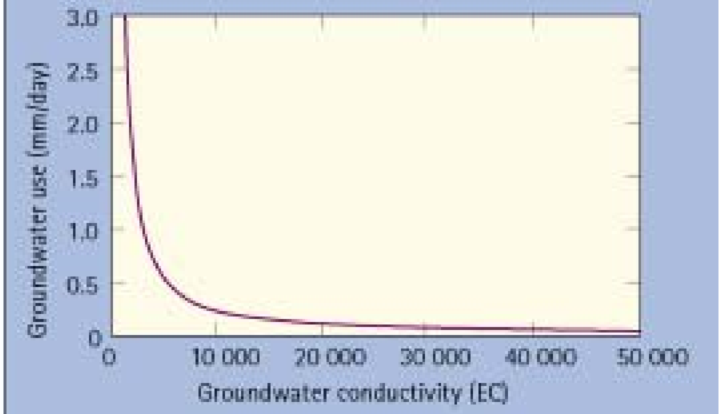

**Figure 21. The use of saline groundwater by trees falls rapidly as the salinity of the groundwater increases.**
Source: Thorburn PJ (1996). *Can shallow watertables be controlled by the revegetation of saline lands?*

On the other hand, plants using only small amounts of groundwater can have a large effect on the depth of the watertable. If plants can maintain a net groundwater use of just 0.1 mm/d over a year, a watertable would drop by 30–60 cm. This rather optimistic picture is tempered by the fact that salt becomes concentrated in the soil above saline groundwater. Since plants use essentially fresh water, the excluded salt is left behind in the soil. The freshwater transpired is continuously replaced by salty groundwater. Even if the groundwater starts off slightly saline, the concentration of salt in the root zone will approach that of seawater, thus precluding further uptake.

There are success stories where farmers have made good use of or even reclaimed saline land. These are likely to be hydrogeological settings where the accumulated salt can be flushed out of the soil and transported to rivers. Thus rarely does reclaiming saline areas assist in controlling salinity in rivers. Success in one location is not necessarily transferable to another.

Planting discharge areas with salt tolerant vegetation remains an important strategy for reducing the risk of spreading localised salinity, reducing the visual impact of salted land, reducing soil erosion and maybe salt transport to creeks, and for obtaining some productivity from salt tolerant grasses and shrubs. Small-scale groundwater systems may be ameliorated, but salt will continue to accumulate above larger-scale systems.

Once the salt concentration exceeds the threshold of the tree to take up water, the very process that brought the watertable within range of the tree roots will continue to operate and drown the trees in low-lying discharge areas, unless the salt can be removed. From a hydrological perspective, trees in discharge areas are not a substitute for planting recharge areas in most cases. At best, the strategies are complementary. They do little to halt the transport of salt to rivers and creeks.

# Land assessment

Our existing maps and databases of land resources in the Murray-Darling Basin do not provide enough information for targeting where land use should be changed for maximum benefit. We need good maps of land suitability for the emerging systems of land use. This requires a much better understanding of variations in regolith hydrology and salt storage throughout the landscape. It also requires good understanding of the relative performance of these land uses across a range of soils and climates. Current surveys do not have the necessary resolution to support the type of landscape planning implied in this report. They also fail to integrate our understanding of the hydrology of farming systems into the landscape processes and functioning as a whole. New methods of land resource assessment must be developed if we are to provide a scientific basis for the revolution in land use described here. Methods for mapping land resources have to be integrated with procedures for simulation modelling, and these in turn have to be supported with strategic programs of natural resource monitoring.

**Sheep grazing in saltbush pastures.**
**Note the dead tree.**
W. van Aken © CSIRO

# Report card

This section reviews the options described in the previous pages on the basis of four criteria:

1. *relevance* to the Basin in terms of the area of suitable land
2. *effectiveness* in terms of each option's ability to reduce leakage
3. *robustness* in terms of the ability of land users to achieve the potential in (2) above, and
4. *profitability* relative to current land use.

Ten broad options are rated in Table 1. The rainfall limits on forestry, perennial pastures and cropping are more flexible than suggested in Figure 22 and Table 1, yet rainfall still imposes severe limits on the relevance of an option.

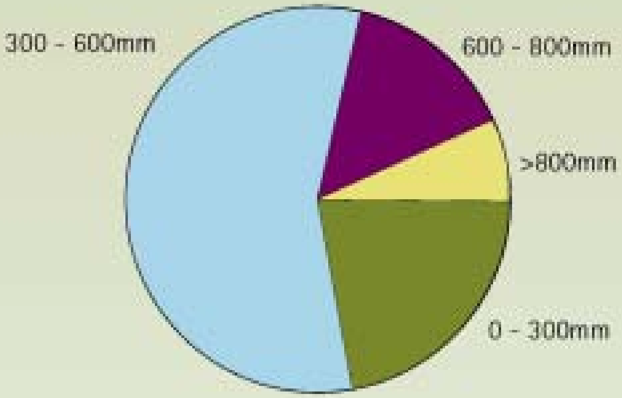

**Figure 22. Proportion of the Basin in different rainfall classes.**

Effectiveness depends on the perenniality and rooting depth of the plants in each system. The long-term average leakage from the system is determined by the proportion of land under perennial vegetation and the ability of this vegetation to use water. Options that are potentially effective may not be robust enough to obtain a desirable outcome due to the lack of required technology because rainfall variability makes them difficult to manage. Where we consider effectiveness to be low, we do not give robustness a rating. Profitability is relative to current land use.

## Annual cropping

Cropping rates 'high' (see Table 1) in relevance and profitability because of the large land area under crop and its status as the preferred economic option. However the effectiveness of annuals in attaining recharge targets is low.

## Opportunity cropping

Opportunity cropping is profitable, robust and moderately effective where summer-dominant rainfall coincides with soils that have high water-holding capacity (e.g. the northern parts of the Basin). However, it has a lower rating on relevance since such areas represent only about one third of the cropping zone.

## Phase/companion farming

Phase farming is effective when the lucerne phase is long enough to dry the subsoil and the cropping phase is terminated before leakage recommences. Its relevance is rated as medium because lucerne is limited to areas with suitably deep non-acid soils. The robustness is medium because it depends on the land manager's skill in timing the change of phase. Profitability is likely to be reduced in phase farming due to the lower average returns from animal production in the lucerne phase.

Oversowing annuals into perennial pastures is emerging as a variant of phase farming that may be more effective and robust, but it might also have productivity trade-offs. Further investigations are needed.

## New agricultural plants

New crops or forages that restrict drainage may be moderately effective and are potentially profitable components of new farming systems. The relevance and robustness of such species and/or cultivars are unknown at this stage, and depend largely on the success of the plant breeders in developing new cultivars with novel characteristics.

|  | Annual crops | Opportunity cropping | Phase farming/ companion farming | New agricultural plants | Organic farming | Perennial pastures | High rainfall tree products | Low rainfall tree products | Agro-forestry | Saltland farming |
|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall (mm) | 300–600 | 500–600 | 300–600 | 300–800 | 300–800 | 600–800 | > 800 | 300–800 | 300–800 | 300–800 |
| Relevance | High | Medium | Medium | Medium | Medium | Medium | Low | High | High | Medium |
| Effectiveness | Low | High | High | Medium | Medium | Medium | High | High | Medium | Low |
| Robustness | – | Medium | Medium | Medium | – | Medium | High | High | Medium | – |
| Profitability | High | High | Medium | High | High | Medium | High | Low | Medium | Low |

**Table 1. Options for managing dryland salinity.**

## Organic farming

Organic farming is not necessarily any more effective than annual cropping. However, the rapidly growing demand for organic produce, particularly from overseas markets, means this is an increasingly relevant option. If good prices can be maintained for organic produce then profitability could be high. Profitability combined with the land stewardship ethic that characterises the organic farming movement could translate into a larger area of any one farm devoted to non-commercial vegetation that is high in water use.

## Perennial pastures

Perennial pastures use more water than annuals, but they are not necessarily effective in the grazing zone east of the cropping belt. Higher rainfall, acid and shallow soils and grazing pressure all compromise their potential. The moderate profitability of the grazing industry limits investment in liming, pasture improvement and grazing management, thus reducing the robustness of this option. The shallow roots of perennial grasses compared to lucerne or woody perennials may thwart attempts to make annual crops perennial through genetic manipulation.

## High rainfall tree products

The strategy of developing high rainfall tree products is profitable, but its relevance is low, simply because the proven range of products is limited to a very small area of the Basin. The effectiveness of this strategy in reducing leakage is better than for any other land use. However, some high rainfall catchments are already flushed of salt, making them more valuable as contributors of fresh water in their cleared state.

## Low rainfall tree products

Developing low rainfall tree products is potentially the most relevant, effective and robust land-use option for managing salinity. However, with the exception of a few niche industries, low rainfall forestry does not exist in a commercially viable form. The major obstacle is finding markets of sufficient size and value to drive reforestation and the use of native plants at the necessary scale. The transition from a fossil fuel to a bio-fuel transport economy is the scale of change required for this to happen.

## Agroforestry

In the absence of forestry that is as profitable as cropping, the careful location and arrangement of trees can increase their water access and growth rates and minimise the displacement of more valuable crops. Tree/crop mixtures are therefore highly relevant and more profitable than tree crops alone. Their effectiveness will depend on the area planted to trees, and on the skill of locating trees in the right parts of the landscape. Finding trees that are complementarity to cropping or pastures remains a major obstacle.

## Saltland farming

Plants use water from saline aquifers at very low rates. As the area of salt affected land increases, commercial rehabilitation with salt tolerant vegetation will become important for stabilising soil and providing stock feed, but it will contribute very little to managing the watertable, salt loads to rivers, and therefore to water quality.

# Summary

No land-use option rates highly in every respect for relevance, effectiveness, robustness and profitability. Whereas certain land-use options in the right location and in expert hands can satisfy these four criteria, we do not yet have viable land-use systems capable of controlling leakage over the Basin as a whole.

The most obvious need is for a wider range of commercially viable, deep-rooted perennial plants, including trees, shrubs and herbaceous plants. The second need is to refine land assessment techniques to pinpoint the best locations for agroforestry and high-value annuals. The third is to develop ways of rotating and mixing perennial plants with current crops and new agricultural plants, and to invent tools for land managers to monitor leakage and change land use accordingly.

Many of these components do not yet exist. The revolution in land use that is required to control dryland salinity in the Basin cannot happen without a well-targeted program of research, development and innovation that supplies new land-use solutions designed specifically for the Australian landscape.

# Acknowledgements

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We acknowledge in particular two books from which many of the ideas are drawn: *Agriculture as a mimic of natural ecosystems* (1999), Lefroy EC, Hobbs RJ, O'Connor MH, Pate JS (Eds) (Kluwer Academic Publishers: Dordrecht) and *Trees, Water and Salt: an Australian guide for using trees to achieve healthy catchments and productive farms,* Stirzaker RJ, Vertessy RA and Sarre A (Eds) (*in prep*), RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program. Released in November 2000.

# Further reading

Further reading

Angus JF, Gault RR, Peoples MB, Stapper M, van Herwaarden AF (submitted). *Soil water extraction by dryland crops, annual pastures and lucerne in south-eastern Australia*. *Aust. J. Agric. Res.*

Bennett B (1998). *Dealing with Dryland Salinity*. ECOS, 96, CSIRO Publishing, 9–28.

Clarke D and Downes R (2000). *Scoping Study – Opportunities to Breed, Select, Bioengineer Plant Species to Control Deep Drainage and Nitrogen Leakage*. Report for LWRRDC Redesigning Agriculture for Australian Landscapes, LWRRDC Occasional Paper (in press).

Dunin FX, Williams J, Verburg K and Keating BA (1999). Can agricultural management emulate natural ecosystems in recharge control in south eastern Australia? *Agroforestry Systems* 45: 343–364.

Ellis TW, Hatton TJ, Nuberg IK (1999). A simple method for estimating recharge from low rainfall agroforestry systems, *Environwater99*, 2nd Inter-Regional Conference on Environment – Water, 1–4 September, Lausanne, Switzerland.

Foran B and Mardon C (1999). *Beyond 2025: Transitions to a biomass-alcohol economy using ethanol and methanol*. Working Paper Series 99/07. A consultancy report for the National Dryland Salinity Program of the Land and Water Resources Research and Development Corporation (CSIRO Wildlife and Ecology: Canberra).

Hatton TJ and Nulsen RA (1999). Towards achieving functional ecosystem mimicry with respect to water cycling in southern Australian agriculture. In EC Lefroy, RJ Hobbs, MH O'Connor and JS Pate (eds.), *Agriculture as a Mimic of Natural Systems*. Kluwer Academic Publishers, Netherlands.

Hatton T and Salama R (1999). Is it feasible to restore the salinity affected rivers of the Western Australian wheatbelt? *In* I Rutherfurd and R Bartley (eds.), *Proceedings of Second Australian Stream Management Conference* Vol 1., Adelaide, pp 313–317.

Hobbs RJ and Saunders DA (1993). *Reintegrating Fragmented Landscapes: Towards Sustainable Production and Nature Conservation*. Springer-Verlag, New York.

Hume IH, Mitchell DC, Milthorpe PL, Yea M, O'Connell M, Zhang L (1998). *Episodic recharge under crops and shrubs in the Mallee zone*. Final Report, Project No. M4025, Natural Resources Management Strategy, NSW Agriculture.

George RJ, McFarlane DJ and Speed RJ (1995). *The consequences of a changing hydrologic environment in southwestern Australia*. Pp 9–22 in Saunders DA, Craig JL and Mattiske EM (Eds.), Nature Conservation 4: The Role of Networks. Surrey Beatty & Sons, Chipping Norton, NSW.

Keating BA, McCown RL and Cresswell HP (1995). Paddock-scale models and catchment scale problems: The role for APSIM in the Liverpool Plains. In P Binning, H Bridgman and B Williams (Eds.), *Proceedings of the International Congress on Modelling and Simulation, Volume 1: Agriculture, Catchment Hydrology and Industry*. pp158–165 November 27–30,The University of Newcastle.

Lefroy EC, Hobbs RJ, O'Connor MH and Pate JS (Eds.) (1999). *Agriculture as a Mimic of Natural Systems*. Kluwer Academic Publishers, Netherlands.

Lefroy EC and Scot PR (1994). Alley farming: new vision for western Australian farmland. *Western Australian Journal of Agriculture* 35: 119–126

McCown RL, Hammer GL, Hargreaves JNG, Holzworth DP and Freebairn DM (1996). APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. *Agric. Sys.* 50: 255–271.

Murray-Darling Basin Ministerial Council (1999). *The Salinity Audit of the Murray-Darling Basin: a 100-year perspective*. Murray-Darling Basin Commission, Canberra.

Nambier S, Cromer R and Brown Alan (2000). *Restoring Tree Cover in the Murray-Darling Basin*. CSIRO Forestry and Forest Products, Canberra, ACT, Australia.

Pannell D, McFarlane D, Ferdowsian R (1999). *Reassessing the importance of off-site impacts for dryland salinity in Western Australia*. SEA Working Paper 99/11b (Agricultural and Resource Economics, The University of Western Australia: Perth).

Paydar Z, Ringrose-Voase AJ, Huth NI, Young RR, Bernardi AL, Keating BA, Cresswell HP, Holland JF and Daniels I (1999). Modelling deep drainage under different land use systems. 1. Verification and systems comparison. In *Proceedings of MODSIM'99*, Hamilton, New Zealand, December 6–9 1999. (In press).

Petheram C, Zhang L and Walker G (1999). Towards a predictive framework for land use impacts on recharge: A review of recharge studies in Australia. In *Proceeding of Murray-Darling Basin Groundwater Workshop*, Griffith.

PMSEIC (1999). *Dryland Salinity and its impact on Rural Industries and the Landscape*. Prime Minister's Science, Engineering and Innovation Council Occasional Paper No. 1, Department of Industry, Science and Resources, Canberra.

Race D, Curtis A, Booth W (1999). Carob agroforestry industry: an assessment of its potential for the low-medium rainfall Murray Valley region. *Australian Journal of Experimental Agriculture* 39: 325–334.

Ridley AM, White RE, Simpson RJ, Callinan L (1997). Water use and drainage under phalaris, cocksfoot, and annual ryegrass pastures. *Australian Journal of Agricultural Research* 48: 1011–1023.

Ringrose-Voase AJ and Cresswell HP (2000). *Measurement and Prediction of Deep Drainage under Current and Alternative Farming Practice*. A final report prepared for the Land and Water Resources Research and Development Corporation, CSIRO Land and Water Consultancy Report.

Smith CJ, Dunin FX, Zegelin SJ, Poss R (1998). Nitrate leaching from a Riverine clay soil under cereal rotation. *Australian Journal of Agricultural Research* 48: 379–389.

Thorburn PJ (1996). Can shallow watertables be controlled by the revegetation of saline lands? *Australian Journal of Soil and Water Conservation* 9: 45–50.

Walker GR, Gilfedder M and Williams J (1999). *Effectiveness of Current Farming Systems in the Control of Dryland Salinity*. CSIRO Land and Water, Canberra, 16pp.

Walker GR, Blom RM, Kennett-Smith AK (1992). *Preliminary results of recharge investigations in the upper South-East region of South Australia*. Report No. 47, Centre for Groundwater Studies and CSIRO Division of Water Resources.

Ward PR, Dunin FX and Micin SF (1999). Water balance of annual and perennial pastures on duplex soils in a Mediterranean environment, *Australian Journal of Agricultural Research*. (In press).

White RE, Helyar KR, Ridley AM, Chen D, Heng LK, Evans J, Fisher R, Hirth JR, Mele PM, Morrison GR, Cresswell HP, Paydar Z, Dunin FX, Dove H, Simpson RJ (2000). Soil factors affecting the sustainability and productivity of perennial and annual pastures in the high rainfall zone of south eastern Australia. *Australian Journal of Experimental Agriculture* 40: 267–283.

Williams J (1999). *Farming without Harming: can we do it?* Paper for the Regional Australia Summit Theme 12, Canberra 27–29 October 1999.http://www.dotrs.gov.au/regional/summit/program/background/pdf/williams_paper.pdf

Wood WE (1924). Increase in salt and streams following destruction of the native vegetation. *Journal of the Royal Society of Western Australia* 10: 35–47.

Zhang L and GR Walker (series Eds.) (1998), *Studies in catchment hydrology: The basics of recharge and discharge*. CSIRO Publishing.

Zhang L, Dawes WR, Hatton TJ, Hume H, O'Connell MG, Mitchell DC, Milthorpe PL and Yee M (1999), *Estimating Episodic Recharge Under Different Crop/Pasture Rotations in the Mallee Region: 2 Recharge Control by Agronomic Practices*. Agricultural Water Management 42(2), 241–254.

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