Presidential Address, 45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide, 23-25 January 2001

Dryland Salinity: Inevitable, Inequitable, Intractable?

David J. Pannell*

Agricultural and Resource Economics, University of Western Australia, Crawley WA 6009

Abstract

New information about the hydrogeology of Australia's agricultural regions has profound implications for the economics of salinity management and the design of policy. This paper reviews a broad range of information relevant to the salinity problem in order to critically evaluate existing and prospective policy responses. It brings together issues of hydrogeology, farmer perceptions and preferences, farm-level economics of salinity management practices, external benefits and costs from salinity management, and politics. The technical challenge of preventing salinity is far greater than previously recognised. The farm-level economics of currently available management practices for salinity prevention are adverse in many situations. The off-site benefits from these on-farm practices are often small and long delayed. A conclusion of the paper is that past national salinity policies have been seriously flawed, and that the 2000 National Action Plan has positive elements but has not sufficiently escaped from the past. The two most important broad areas of change identified in this review are better targeting and more rigorous analyses of proposed public investments and a greater emphasis on the development of improved technologies, both for salinity prevention and for adaptation to a saline environment.

1. Introduction

Dryland salinity is seen as one of Australia's most serious environmental and resource management problems. There have been major government progammes in place for over a decade aiming to increase farmers' adoption of management practices for salinity prevention. Farmers have responded, although not on the scale recommended by hydrologists, and salinity is continuing to worsen. Recent hydrological studies have shown that even if farmers had responded on the scale recommended, salinity would be continuing to worsen.

The political profile of salinity has increased dramatically in recent years, with extensive media coverage and the release of reports by the Prime Minister's Science, Engineering and Innovation Council (PMSEIC 1999), The Salinity Audit of the Murray Darling Basin (Murray Darling Basin Ministerial Council 1999), and salinity strategies by the governments of each of the four most seriously affected states: Western Australia (State Salinity Council 2000), South Australia (Primary Industries and Resources South Australia 2000), New South Wales (New South Wales Government 2000), and Victoria. In 2000, The National Farmers Federation and the Australian Conservation Foundation commissioned consultants to calculate the cost of fully preventing and repairing land degradation in Australia. They estimated that it would require expenditures of $65 billion over 10 years, with the majority of these funds being required for salinity (Madden et al. 2000). The Commonwealth Government's response to these developing pressures has been a new National Action Plan, announced in November 2000, including Commonwealth and state expenditures of $1.4 billion over seven years.

This paper provides a broad review of the problems of forming sound policy for management of dryland salinity in Australia. It brings together consideration of hydrogeology, farmer perceptions and preferences, farm-level economics of salinity management practices, external benefits and costs from salinity management, and the politics of salinity.

* I am grateful to Don McFarlane, Tom Hatton, Laura McCann, and Colin Mues for comments they provided on a draft of this paper, and to the many others who have contributed in various ways to my salinity education, particularly Ruhi Ferdowsian, John Bartle and Richard George. Funding assistance from Grains Research and Development Corporation is gratefully acknowledged.

2. Technical Background

2.1 Causes

Salt, mainly sodium chloride, occurs naturally at high levels in the subsoils of most Australian agricultural land. It has been carried inland from the oceans on prevailing winds and deposited in small amounts (20-200 kg/ha/year) with rainfall and dust (Hingston and Gailitis 1976). Over tens of thousands of years, it has accumulated in sub-soils and in Western Australia, for example, it is commonly measured at levels between 100 and 15,000 tonnes per ha.

Prior to European settlement, groundwater tables in Australia were in long-term equilibrium. In agricultural regions, settlers cleared most of the native vegetation and replaced it with annual crop and pasture species, which allow a larger proportion of rainfall to remain unused by plants and to enter the groundwater (Walker et al. 1999). As a result, groundwater tables have risen, bringing dissolved accumulated salt to the surface (Anonymous 1996). Patterns and rates of groundwater change vary widely but most bores show a rising trend, except where they have already reached the surface or during periods of low rainfall. Common rates of rise are 10 to 30 cm/year (e.g. Ferdowsian et al. 2001). Given the geological history and characteristics of the Australian continent, large-scale salinisation of land and water resources following clearing for agriculture was inevitable.

2.2 Impacts and extent

Forecasts of the eventual extent and impacts of dryland salinity if left unmanaged test the imagination. The National Land and Water Resources Audit (2000b) estimates that the area of land in Australia with shallow watertables (i.e. likely to be salt affected) is currently 5.7 million ha and will exceed 17 million ha by 2050. Western Australia has by far the greatest affected area, with 80 percent of current national total, and 50 percent of the 2050 forecast area. The proportion of agricultural land affected to some extent will exceed 30 percent in Western Australia and 15 percent nationally.

In the Murray Darling River system, average salinity at Morgan will exceed the WHO desirable limit for drinking (800 EC) between 2050 and 2100 (Murray Darling Basin Ministerial Council 1999). Salinity is rising in most rivers of southern Australia (Hatton and Salama 1999).

According to George et al. (1999b), in Western Australia, without massive intervention, most or all of the wetland, dampland and woodland communities on heavier soils in the lower halves of catchments will be lost to salinity. There are at least 450 plant species and an unknown number of invertebrates which occur only in these environments and are at high risk of extinction (State Salinity Council 2000; Keighery, 2000). Similarly, major impacts on environmental assets in the Murray Darling Basin have been forecast (Murray Darling Basin Ministerial Council 1999), including wetlands which have been internationally recognised under the Ramsar Convention.

Increased flood risks have been studied for only a small number of case studies (e.g. Bowman and Ruprecht 2000). Extrapolating from these, George et al. (1999b) concluded that, with the predicted three- to four-fold increase in area of wheatbelt land with shallow watertables, there will be a three- to four-fold increase in flood flows.

Infrastructure at risk has also been identified and valued in case studies. For example, Campbell et al. (2001) estimated for a sub-region of south-west Western Australia that 1200 buildings (15 percent of all buildings in the region), 3,300 km of roads (26 percent) and 16,000 farm dams (44 percent) face damage or destruction from salinity.

2.3 Treatments

The above impact forecasts are generally based on a “business as usual” scenario. Three broad types of salinity management are relevant to this review: prevention, remediation and adaptation.

Prevention

The scales of treatments recommended by hydrologists for preventing the various impacts of dryland salinity are daunting. In recent years, we have lost earlier hopes that large-scale preventative impacts on salinity could be achieved by clever selection and placement of relatively small-scale treatments, or by changes to the management of traditional annual crops and pastures. The new consensus is that large proportions of land in threatened catchments would need to be revegetated with deep-rooted perennial plants (shrubs, perennial pastures or trees) for at least part of the time. The perennials would need to be integrated with engineering works, particularly shallow drainage for surface water management. Table 1 shows several systems of perennial vegetation designed by Stauffacher et al. (2000) for Wanilla Catchment on the Eyre Peninsula of South Australia. All six scenarios involve establishment of perennials on well over 50 percent of land in the catchment. Similarly dramatic changes in land use are envisaged by Stirzaker et al. (2000) for the Murray Darling Basin and by Campbell et al. (2001) for Western Australia.

Table 1. Low-recharge land use scenarios for Wanilla Catchment, Eyre Peninsula, South Australia

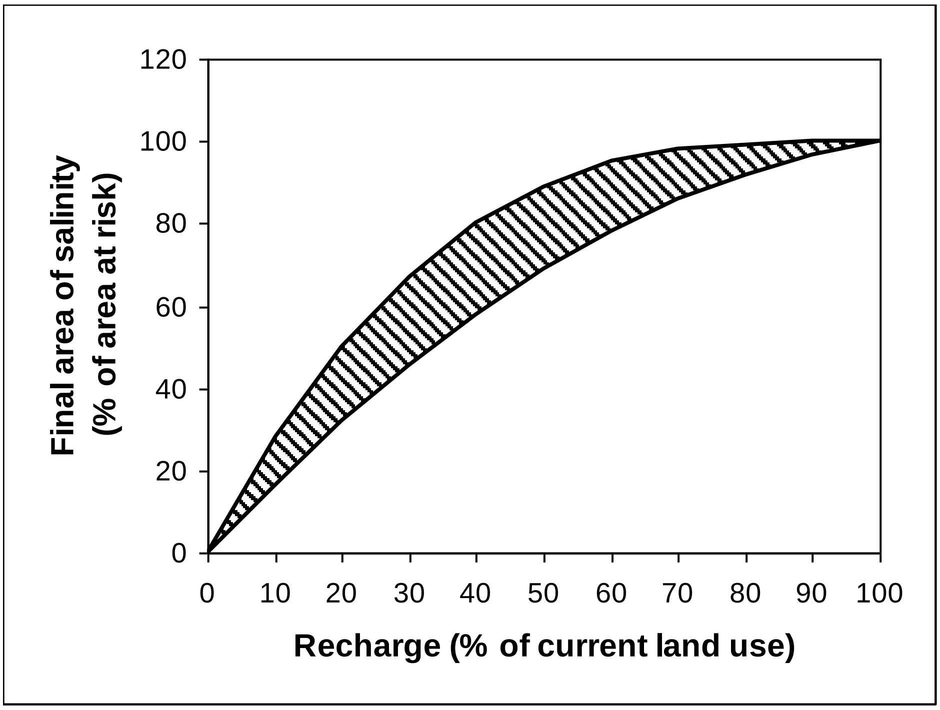
Scenario	Upper Catchment Land Use	Lower Catchment Land Use	Reduction in Recharge (%)	Area Lost to Salt (%)
Status quo	Retain existing land-use	Retain existing land-use	0%	15%
A	100% trees	50% crops, 50% lucerne	49%	12%
B	50% trees, 25% crops, 25% lucerne	50% crops, 50% lucerne	33%	13%
C	100% trees	50% crops, 50% deep-rooted lucerne	59%	9%
D	50% trees, 25% crops, 25% deep-rooted lucerne	50% crops, 50% deep-rooted lucerne	47%	12%
E	100% trees	50% trees, 25% crops, 25% lucerne	74%	5%
F	50% trees, 25% crops, 25% lucerne	50% trees, 25% crops, 25% lucerne	42%	12%

Source: Stauffacher et al. (2000) cited in Hajkowicz and Young (2000)

Despite the massive scale of intervention involved in these management scenarios, their impacts on salinity are surprisingly modest. For example, the last column of Table 1 shows the forecasts of Stauffacher et al. (2000) for the Wanilla catchment. Strategies involving establishment of perennial vegetation on very large proportions of agricultural land (not just the land threatened with salinity) would prevent, at best, 10 percent of land from going saline within a 20-year time frame. Similarly, Figure 1 shows the range of results for several catchments in Western Australia (Campbell et al. 2001). If recharge across a catchment were reduced by 50 percent, implying perennials on approximately 50 percent of the land, the final equilibrium area of salinity in the catchment would be reduced by 10 to 40 percent (i.e. to between 60 and 90 percent of the area at risk). Assuming that 30 percent of the catchment would have gone saline (consistent with Ferdowsian et al. 1996), the area protected would be 3 to 12 percent of the catchment. Impacts of treatments within the Murray Darling Basin would be broadly similar in relative scale.

The timing of treatment impacts is also important. On the positive side, even where equilibrium areas of salinity are reduced little, the implementation of large-scale revegetation programs is likely to delay the process of reaching that equilibrium by several decades (Campbell et al. 2001). On the negative side, given the slow rate of development of salinity, the benefits of treatments implemented now may be well into the future. Although local reductions in watertables can be achieved within a year or two (George et al. 1999a), catchment-scale impacts, such as reductions of saline discharges into waterways, will be very much slower. In catchments having regional groundwater flow systems, the benefits will probably be a century or more in the future (Hatton and Nulsen 1999; Hatton and Salama 1999; Heaney, Beare and Bell 2000).

Figure 1. Final equilibrium area of saline land (as a percentage of the area for a "business as usual" scenario) in a range of catchment types of Western Australia as a function of reducing recharge to groundwater as a result of revegetation and engineering works.



Even with massive intervention, continuing salinisation of resources is inevitable and unpreventable. For example, in Western Australia hydrologists have estimated that, if radical large-scale changes to farming practices are made immediately, the area of saline land would increase by at least two million ha from current levels before stabilising. Without such radical changes the area would increase by approximately four million ha.

Engineering methods may provide an alternative or a supplement to perennial vegetation. Pumping of saline groundwater into evaporation basins is expensive and has only local effects on groundwater, but it may be a viable strategy where particularly valuable assets are at stake (e.g. the infrastructure of a town, or an important environmental asset). In situations where a valuable asset is located in a catchment where the process of watertable rise is well advanced, the benefits of revegetating the catchment may be too little and too late to save the asset. In these cases, pumping is the only strategy available with the technical capacity to protect the asset (Campbell et al. 2001). The Murray Darling Basin Commission is using pumping extensively to intercept saline groundwaters before they discharge into waterways.

Attempts to prevent salinity by revegetation are further complicated by the impacts of perennial vegetation on surface water flows. One of the advantages of perennial vegetation is that it avoids predicted increases in flood risk, which it does by reducing runoff of surface water[1]. (With deeper watertables, rainfall is more likely to infiltrate the soil). However in catchments where the waterways provide water resources for the community or the environment, the reduction in runoff following revegetation also creates an external cost. This issue is further discussed below in the context of external benefits and costs of revegetation.

Remediation and Adaptation

Clearly, once the hydrological balance of a catchment is disturbed, prevention of salinity is very difficult. Once land is salinised, returning a catchment to an non-saline state is even more difficult. Chemical changes in salinised soil reduce the ability of water to pass through the soil and flush out salts. Even without these chemical changes, it is easier for watertables in a catchment to rise than to fall. A rising watertable only requires water to move a relatively

[1] Salt tolerant vegetation growing in salt-affected valleys can also contribute to flood mitigation by providing a physical barrier to slow water flows and thereby reduce peak flows.

small vertical distance under the pull of gravity (from the ground surface to the water table). On the other hand, a falling watertable requires lateral water movement over much greater distances and over slopes much lower than 90 degrees (from recharge areas high in the catchment to discharge areas low in the catchment).

Rather than remediation, adaptation is generally a much more practical and realistic strategy. Farmers in Western Australia with large areas of salt-affected land are already trialling and implementing farming systems based on salt-tolerant species. Many farmers are also implementing deep open drains on salinised land, intending to lower watertables locally and allow a continuation or resumption of traditional agricultural practices between the drains. Although very expensive to implement and maintain and despite evidence of poor drain performance in some situations (e.g., Ferdowsian et al. 1997; Speed and Simons 1992) many farmers feel that such drains offer their best option in response to salinisation of land.

Where water resources are salinised, adaptation in the form of desalination is another option which appears to warrant further investigation. Other situations where engineering methods to adapt to adverse developments may conceivably be economically more efficient than prevention include engineering works for flood mitigation, and replacement of damaged infrastructure with structures designed to better withstand salinity. A variation on the theme of "adaptation" is pumping to intercept rising saline groundwaters before they discharge into rivers or sites of biodiversity. In this way, impacts can be reduced without successfully treating the underlying cause of salinity.

Finally, an option which is available to landholders is to allow salinity to occur unchecked and make do with smaller productive areas, perhaps with some intensification of production. In situations where treatments are expensive and/or slow to show benefits, and the assets at risk are not sufficiently valuable, such an option may conceivably be the most efficient course of action, not just for the farmer but also for society more generally.

3. The Farmer's Perspective

3.1 Farmer responses to salinity

Encouraged by policies such as the National Landcare Program, many farmers have been making personal sacrifices and financial commitments to salinity prevention under the impression that the treatments have been officially sanctioned[2] and will be sufficient. Although the sacrifices of time, labour and finance loom large to these farmers, we now know that the treatments implemented are too small by an order of magnitude or more to significantly reduce eventual areas of shallow watertables, although local effects providing worthwhile delays are likely. In salinity-prone regions there are only localised areas where the watertable has been brought under control.

To illustrate further, consider the Upper Kent catchment in Western Australia. This is a "Water Resource Recovery Catchment" in the state's Salinity Action Plan. It was selected as a "Focus Catchment" in the National Dryland Salinity Program (phase 1) and provided with relatively high funding and intensive scientific study. However, a survey conducted after the completion of the NDSP initiative (Kington and Pannell 2001) found that 75 percent of farmers had established less than 50 hectares of perennials. Almost all farmers had implemented at least one new practice in response to land degradation, but the average scale of implementation was small. Disturbingly, over 50 percent of farmers reported that they had not observed any benefit at all from their land conservation investment, so the prospects for much larger investments would appear very poor.

Curtis et al. (2000) found in the Goulburn Broken Catchment that most farmers responding to a survey were not concerned about the potential economic, environmental or social impacts of rising watertables. Although a majority of farmers had implemented perceived "best management practices" for salinity to some extent, the average scale of adoption was modest.

3.2 The adoption problem

In recent years there has been an emphasis on encouraging farmers to monitor their groundwater tables (Pannell and Glenn 2000; Marsh et al. 2000), to raise awareness of salinity and encourage greater adoption of practices for salinity prevention. While awareness is relatively easily achieved, the adoption problem is too complex and multifaceted to allow it to be solved by monitoring alone.

---

[2] In some situations, catchment plans developed by farmer groups have in fact been officially accredited.

I have elsewhere discussed and reviewed reasons for low adoption by farmers of salinity treatments (Pannell 1999a, 1999b, 2000), commenting that:

> Lack of awareness of salinity is probably not a major factor explaining slow and low adoption of the recommended practices. Rather, the major factors relate to the economic costs and benefits of current treatment options, the difficulties of trialling the options, long time scales, externalities, and social issues. This combination of factors means that the problem in many regions is extremely adverse to rapid adoption, probably more so than for any other agricultural issue in Australia. In other words, farmer reluctance to adopt the radical changes being recommended is completely understandable and, indeed, reasonable from the farmers' perspectives. (Pannell 2000).

Curtis et al. (2000) emphasised lack of financial capacity as the greatest impediment to change within the Goulburn Broken Catchment. Others have highlighted the profitability of an innovation as being a particularly important factor influencing its attractiveness to farmers (Lindner 1987; Cary and Wilkinson 1997). This is addressed further in the next section.

4. Economics of Salinity Management

Shallow saline groundwaters have a multitude of costly consequences, as summarised in Table 2. Although traditionally seen primarily as an agricultural problem, it is now appreciated that the non-agricultural costs are likely to be at least as significant. Protection of water resources, in particular, has increasingly been seen as paramount.

Table 2. Examples of costs caused by dryland salinity

Type of salinity cost	Agricultural impacts	Non-agricultural impacts
Preventative action	Costs of establishing preventative treatments: areas of perennial plants, surface drainage.	Costs of engineering works (pumps, drains, evaporation basins) and revegetation to protect buildings, roads, bridges and other infrastructure
Replacement, repairs and maintenance	Repairs to buildings, replacement of dams, establishment of deep drains to lower saline groundwater	Repairs to houses and other buildings, desalination of water resources, repairs to infrastructure, restoration of natural environments
Direct losses	Reduced agricultural production, reduced flexibility of farm management	Extinctions, loss of biodiversity, loss of amenity, loss of aesthetic values, loss of water resources, eutrophication of waterways, loss of development opportunities on flood plains

Benefits and costs related to salinity management are considered here in two broad groups: agricultural and non-agricultural benefits and costs. Where treatments implemented by private land managers result in non-agricultural benefits or costs (e.g. column 3 of Table 2), these externalities or spillovers may be particularly important in shaping appropriate government policies. This aspect of the salinity problem has dominated economists' thinking, although it is not the only relevant cause of market failure (see Section 5) and, perhaps, not the most important (Pannell et al. 2001).

4.1 Agricultural benefits and costs

Preventative management: direct benefits and costs

The overall assessment of public investments in salinity management depends in part on the on-farm economics of the treatments (private costs and benefits are a subset of social costs and benefits). The less costly are perennials to farmers, the more likely it is that mechanisms or institutions to reduce external impacts will generate social benefits.

Some examples of profitable perennial-based farming systems can be identified.

- Tasmanian blue gums (*Eucalyptus globulus*) in the south west of Western Australia are profitable in the right environments, with suitable soils and rainfall (Burdass *et al*. 1998)
- Oil mallees appear likely to become profitable for farms located within the transport limits of processing plants/power generators (Cooper 1999; Herbert 2000). A pilot plant is currently in the planning phase for the town of Narrogin.
- The perennial pasture plant, lucerne (*Medicago sativa*), is currently profitable in suitable environments (e.g., Bathgate and Pannell 2001).

Unfortunately, these positive results apply to particular niches in particular regions, which tend to be higher rainfall regions. For the majority of land that is at risk of dryland salinity, no profitable perennial plant options are currently available. In many situations, the sacrifice of profit involved in growing perennials appears very great (e.g. Herbert 1999; Hajkowicz and Young 2000). This creates serious difficulties for attempts to devise efficient policies to enhance prevention of land salinisation.

Preventative management: indirect benefits and costs

It has been widely assumed that, even if perennials are not directly profitable in terms of their harvested products and farming system benefits, their ability to prevent salinity would make them financially attractive to those farmers with long-term planning horizons. However, the results reported in Table 1 and Figure 1 reveal that the financial benefits to farmers from salinity prevention are unlikely to be high.

To illustrate further, Figure 2 shows results from a simple Net Present Value model (adapted from Bathgate and Pannell 2001) based on the following assumptions.

- The planning horizon is 100 years.
- The real discount rate is 10 percent.
- After a time lag, all of the land in question would become immediately salinised if left in traditional farming systems. Result are shown for time lags of 10, 20, 30 and 50 years.
- "Treated" land is land on which perennials are established. "Protected" land is saved from salinisation as a result of the perennials. The area of protected land may be more or less than the area of treated land.
- If perennials are established immediately and "Land protected" is at least one, treated land is permanently protected from salinity. At the proportion 1.0 (marked by a dashed line), only treated land is protected.
- The net profitability of production from salinised land is 20 percent of the profitability of non-saline land.

Figure 2. Break-even levels of direct profit from perennial-based farming system required to match long-run financial performance of traditional annuals, allowing for salinity-prevention benefits of perennials.

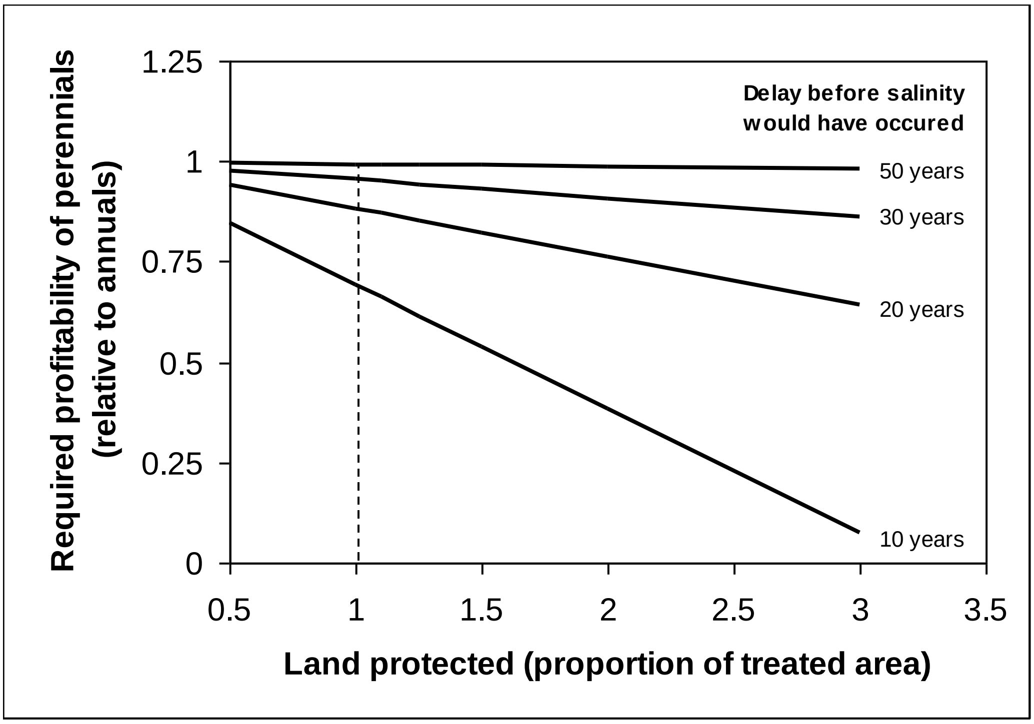


Figure 2 shows how much direct profit would be required from the perennials to justify their inclusion on the farm, from a narrow financial perspective. If no additional untreated land is protected, the perennial would need to generate profits at least 70 percent as large as the traditional agricultural enterprise grown on the land in question (assuming a 10-year lag before the onset of salinity). In other words, to avoid an 80 percent profit decline due to salinity in years 11 to 100, it is worth sacrificing 30 percent of the profitability of traditional agriculture over years 1 to 100.

As the protection of additional untreated land increases, there is a fall in the profitability required to break even, while longer time lags before salinity result in a greater profit requirement. In most situations, protection of untreated land will be low (see earlier), so where agricultural land is the only asset at risk, the relevant portions of the graphs probably do not extend far to the right than the dashed line.

It is striking that, even in the most favourable situation modelled, perennials must do better than covering their input costs. They must also cover a proportion of the short-term opportunity cost of traditional (annual) crop or pasture production on the land in question. For time lags of 20 years or more (which are relevant to most of the land currently at risk), the profitability of perennials must very nearly equal that of traditional farming enterprises. Even at lower discount rates than used to generate these results, the present value of salinity prevention 20 years hence is relatively small. Overall, the results show that, for realistic assumptions about treatment impacts and lags, the indirect benefits of perennials due to salinity prevention will be small relative to their direct, short-term benefits and costs. Thus a relatively narrow and short-term measure of on-farm profitability will be very important in determining the likely net social benefits of revegetation.

Overall Figure 2 indicates that on-farm benefits from salinity prevention are likely to contribute little to the economic attractiveness to farmers of perennial-based farming systems. Thus the consideration of salinity prevention does not change the earlier broad conclusion that the on-farm economics of current perennial options are adverse in most locations.

Management of salinised resources

With its history of land salinisation, there have long been efforts in Western Australia to develop farming systems which can make productive use of saline and/or waterlogged areas (e.g. Malcolm and Pol 1986). A number of farmers appear to have been successful in implementing such systems on commercial scales. There is also a growing interest in methods which will make use of saline water (e.g. salt-water fish farming) and in technologies to extract relatively valuable products, such as magnesium, from saline groundwaters.

There appears to have been little economic analysis of these practices (which seems an important oversight). However, there is reason to expect that they will become of considerable economic importance. Much of the forecast salinisation of land is not technically avoidable without implausibly large changes in land use. A feature of salinised land is that it has a low opportunity cost, in contrast to much of the land on which perennials would need to be established for effective salinity prevention. Therefore, provided that up-front establishment costs are low enough, the prospects for widespread adoption of new salt-tolerant plants for economic production off salt-affected land appear good. Such plants suffer few of the adoption difficulties highlighted by Pannell (2000) for preventative perennials.

These approaches involve acceptance of and adaptation to salinisation of land. The other approach to management of salinised land is amelioration by engineering means. For farmers, the primary method of interest is deep open drainage. Although very expensive, many farmers in Western Australia with salt-affected areas have been investing heavily in networks of deep drains. This has been an area of considerable controversy, firstly because the disposal of saline waters collected in these drains can cause external costs. Secondly, the claims made by farmers and drainage contractors regarding the effectiveness of deep drains greatly exceed measurements which have been made by hydrologists for at least some situations (e.g. Speed and Simons 1992; Ferdowsian et al. 1997). An economic evaluation of deep drains based on those measurements reached predictably negative conclusions (Ferdowsian et al. 1997). Nevertheless, the enthusiasm of some farmers continues, and there is a renewed interest among hydrologists in evaluating deep drains more broadly.

Despite this range of technologies for using or repairing saline land, it continues to pose significant management problems and financial burdens on farmers. Some farmers and scientists view these approaches as “defeatist” and for use as a last resort when preventative measures fail. On the other hand, they might equally well be considered as alternatives to prevention. Clearly, the more profitable are the available uses for saline land, the less financially attractive are methods for salinity prevention.

The technologies which make use of saline groundwaters (e.g. extractive uses or saline aquaculture) are different to those discussed above in that their economic attractiveness is not closely related to any worsening or improvement in the salinity problem. The technologies are not intensive users of land (salinised or otherwise) and their usage of saline water is not sufficient to lower watertables over large areas. Where valuable assets are highly localised (e.g. within a town), extraction and commercial use of saline groundwaters may provide sufficient benefits to affect the cost-effectiveness of a salinity management strategy. For example, in the Western Australian wheatbelt town of Merredin, saline groundwater will be pumped to lower the watertable, then desalinated to provide potable water for the town. On agricultural land, the evaluation of these technologies seems to be largely separate from the main concerns raised by salinity. This is not to say that the methods are necessarily unattractive to land holders, just that their attractiveness neither depends on nor helps to reduce other salinity problems on the property.

Another potential avenue to improve efficient management of salinised land is establishment of systems to ease transfer of ownership. Salinised land may offer opportunities to more innovative and entrepreneurial managers or potentially to environmentalists which are not realisable while the land remains legally tied to larger parcels of non-saline land.

4.2 Non-agricultural benefits and costs

Reduced saline discharges

Saline discharges are the primary causes of most of the non-agricultural costs in Table 2, although surface waters are relevant in some cases (see below). Pannell et al. (2001) outlined six reasons why external costs from off-site discharges of saline groundwater are less important in Western Australia than has been commonly perceived.

(a) For a proportion of the landscape, little groundwater moves across farm boundaries. Hydrological flow systems are localised in many situations (National Land and Water Resources Audit 2000a).

(b) Even in regional flow systems, it can be possible for treatments to be effective locally, at least temporarily. This is particularly relevant to landscapes with low slopes and low transmissivity of soils, such as the wheatbelt valleys of Western Australia.

(c) Damage to key rivers will continue for many years (centuries in some cases) even if large-scale revegetation programs are implemented (Hatton and Salama 1999).

(d) As the process of farm consolidation and enlargement continues, it is increasingly likely that discharge and recharge sites occur within the same farm. In other words, fewer farmers are suffering from saline discharges that originated outside their own farm.

(e) Discounting of future benefits and costs is necessary to allow valid comparison of economic impacts occurring at different times. Given the slowness of some key off-site benefits from perennial plants, discounting causes the significance of these benefits in present day terms to be small.

(f) Given the adverse economics of currently available perennial plant systems (particularly in drier regions), the optimal balance between the costs and benefits of salinity prevention measures may involve very little prevention of salinity, even when off-farm benefits are considered. The findings reported earlier about the large scale of revegetation needed to prevent salinity on relatively small areas of land (Stauffacher et al. 2000; Campbell et al. 2001) and the discussion surrounding Figure 2 reinforce the finding that external benefits per hectare of treatment are low.

For some public assets, the greatest need and justification is for highly localised treatments, within or adjacent to the assets themselves, rather than treatments dispersed across surrounding agricultural land. The impacts of dispersed, catchment-wide treatments alone would be too little, too late to prevent severe damage to the assets. In some cases this is because the primary cause of rising groundwaters is recharge on the site of the non-agricultural asset, rather than recharge in the surrounding catchment. This applies to some rural towns in Western Australia which have been evaluated under the state's Rural Towns Program (e.g. Matta 1999). The broader point about placement of treatments adjacent to threatened assets is relevant to the Murray Darling River system, where the Murray Darling Basin Commission is investing heavily in pumping schemes to intercept saline water before it enters waterways.

Nevertheless, there is variation in both the responsiveness of off-site impacts to treatments (National Land and Water Resources Audit 2000a) and in the value of the off-site resources at risk (environmental, economic and perhaps social). In some locations, the combination of hydrological responsiveness and asset values at risk will be such that the public benefits of on-farm treatments are high. However, it is now clear that this will apply to only a minority of agricultural land.

Surface water flows

Heaney et al. (2000) noted that revegetation with perennials results in a reduction in surface water runoff and emphasised the importance of this effect in the Murray Darling Basin. Fresh water from runoff in the Basin provides domestic water for the city of Adelaide and other towns, irrigation water for important intensive agricultural industries, and environmental services of various kinds. In an analysis of the Macquarie-Bogan catchment, Heaney et al. (2000) found that perennials may have higher external costs due to reduced runoff than their external benefits due to groundwater management. This is, in part, because the impacts of revegetation on runoff are rapid, while the impacts on discharge of saline groundwaters are often very slow.

Runoff increases disproportionately with rainfall. Stirzaker et al. (2000) noted that 38 percent of runoff entering the Murray-Darling river system is collected from just two percent of the land area of the catchment. Therefore, the result noted by Heaney et al. (2000) is more likely to occur in high rainfall zones. Unfortunately, woody perennials are more likely to be economically viable in these zones (Heaney et al. 2000; Stirzaker et al. 2000), creating an additional tension between public benefits and the incentives faced by private land managers. It seems a cruel irony that where trees are most needed to manage groundwaters, their private economic performance is relatively poor, while in some locations where they are more economically attractive to private landholders, establishing trees may reduce overall social welfare.

Additional benefits from salinity management

We have seen that the economic value of reducing saline discharges by revegetation with perennials is often lower than many might expect. However, it is important to recognise that perennials have a range of additional benefits, both public and private.

- Carbon sequestration, particularly by woody perennials.

- Biodiversity. Protection of native flora and fauna from salt encroachment is encompassed in the benefits already considered. However, where a diversity of native species are used for the revegetation (e.g. oil mallees - Bartle 1999; Cooper 1999), there are direct benefits from increased biodiversity and provision of habitat.
- Reductions in wind and water erosion.
- Diversification of farm income.
- Farming systems benefits, such as use of perennial pastures in a strategy to manage herbicide resistant weeds (e.g. Pannell et al. 2001).
- Regional development and regional employment, particularly where woody perennials are processed in rural areas.
- Aesthetics and amenity value. Rural and urban populations appear to value the prevention of land and water salinisation for both aesthetic and amenity related reasons (van Bueren and Bennett 2001)

Whether these benefits are sufficient to justify greater areas of perennials is an empirical question about which evidence is limited and patchy.

4.3 Bringing together public and private benefits and costs

It has commonly been assumed that market failure due to external costs from salinity is pervasive across all agricultural land. However, the economics of public investment in reducing saline discharges will be sensitive to a number of factors already discussed, including level and timing of treatment impacts, the value of assets at risk, and the farm-level economics of the treatments. Figure 3 shows how the traditional economic model of marginal benefits and costs of pollution abatement might be adapted to the problem of salinity prevention.

Suppose that in each catchment, a similar proportion of land is to be converted to perennials. The net cost to farmers of doing so varies widely. In some catchments, perennials may be profitable independent of salinity considerations (i.e. a negative marginal cost) while in others the cost is very high. Ranking the catchments from lowest to highest revegetation cost produces the hypothetical marginal cost curve shown in Figure 3. It shows marginal cost in the sense that the catchment in question is marginal.

On the benefit side, based on the earlier discussion, one would expect a highly skewed distribution. A small number of catchments would contain highly valuable assets and responsive groundwater flow systems, so that benefits of revegetation are high. However in the majority of catchments, off-site benefits of revegetation are low. Ranking catchments from highest to lowest marginal benefit results in the curve shown in Figure 3.

In catchments 1 to 10, perennials are more profitable than existing land uses and will eventually be adopted by most farmers. For catchments 20 to 100, the off-site benefits of revegetation are smaller than the on-site costs. Only in catchments 11 to 19 is there a potential for a policy mechanism to generate off-site benefits of revegetation in excess of the on-site costs. If the external benefits of revegetating catchments 11 to 19 could be fully reflected in the incentives confronting farmers (i.e. if the externalities were “internalised”), the net social benefit of doing so is represented by the shaded area, assuming zero transaction costs of implementing the scheme.

There is a problem with the application of this standard model to salinity, due to the spatially specific nature of benefits and costs. It is not realistic to expect that the catchment with the greatest benefits from revegetation will be that with the lowest costs. Indeed there is likely to be a weak relationship, if any, between benefits and costs across different catchments. Figure 4 shows a graph with the same set of benefits and costs as in Figure 3, but with benefits and costs distributed independently among the catchments.

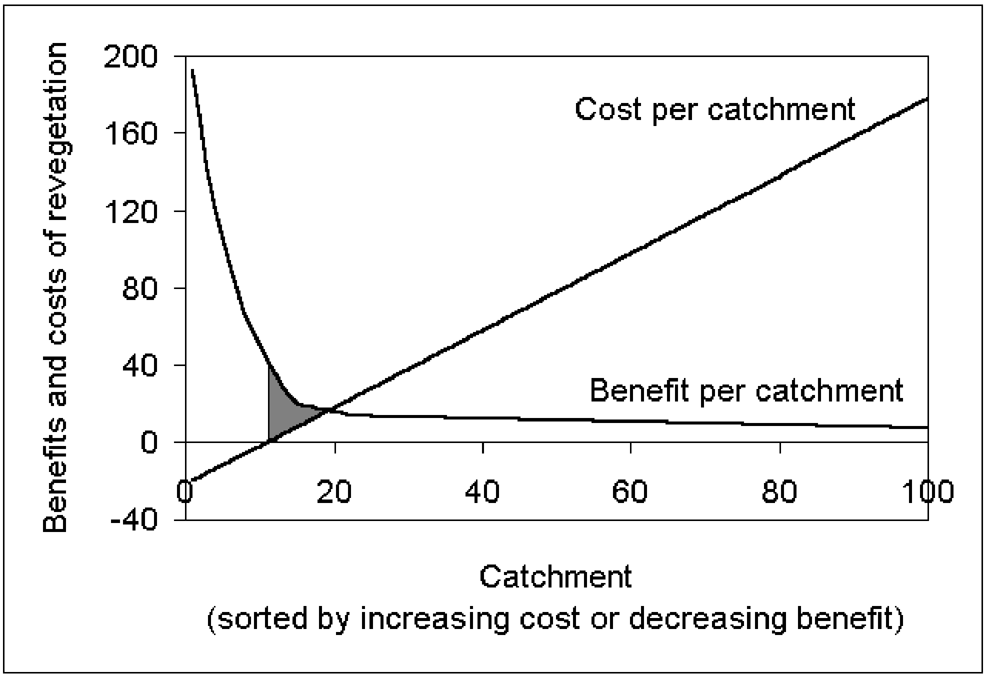


Figure 3. Hypothetical model of marginal costs and benefits of salinity prevention across 100 catchments.

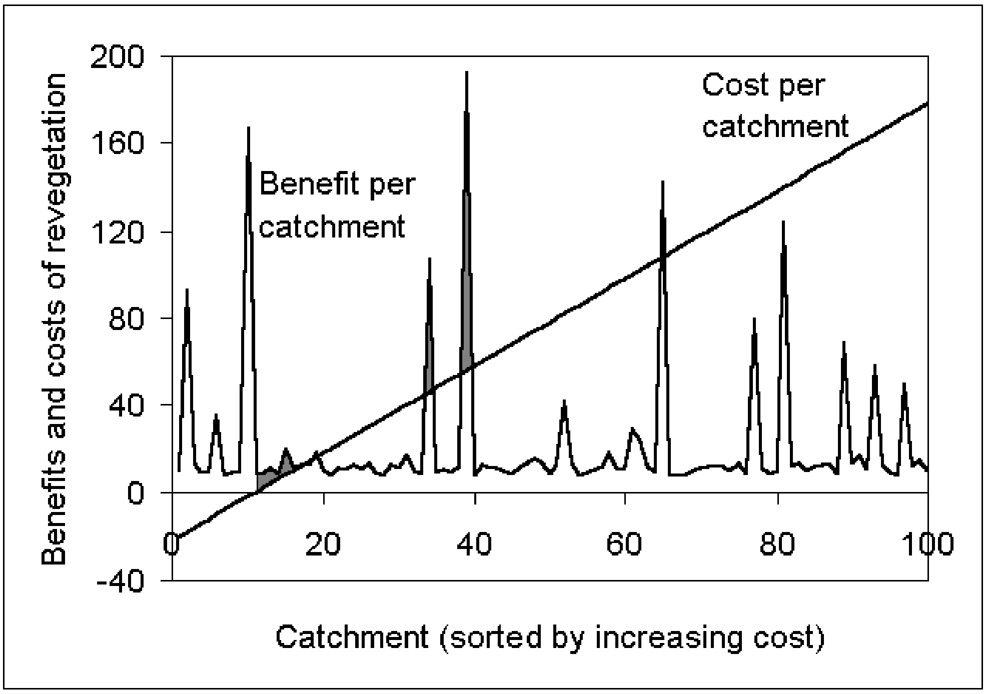


Figure 4. Hypothetical model of marginal costs and benefits of salinity prevention across 100 catchments, where benefits are independent of costs.

This hypothetical graph illustrates some important differences to the standard model.

- A number of catchments with high off-site benefits from revegetation also have high on-site costs. In some catchments with high off-site benefits, internalisation of externalities would generate positive net social benefits (catchments 34, 39 and 65) while in others the costs would exceed the benefits (77, 81).

- Some catchments with low off-site benefits have sufficiently low costs of revegetation to potentially justify policy efforts to directly address external impacts (catchments 11 to 16). However, the net benefits of doing so would be small, especially when one considers transaction costs, which are not included in Figure 4.

The catchments where the net benefits of revegetation would be high will be particular, readily identifiable individual catchments, no doubt containing assets of exceptional value. This model suggests that, apart from these catchments, the potential social gains from internalising externalities from salinity are not great. This has important implications for policy.

5. Salinity Policy

5.1 An Appropriate Role for Government in Salinity Management

As noted earlier, resource economists in Australia have tended to focus on internalisation of externalities as being the most important role for government in relation to salinity (e.g. Hayes 1997). This is reflected, for example, in a considerable interest in use of economic policy instruments, such as tradable emissions permits, auction-based systems for allocating rights, charges and subsidies (e.g. Bell et al. 2000). These approaches have been given priority for further investigation in the National Dryland Salinity Program, in the Commonwealth Government's National Action Plan and in at least two of the state salinity strategies. While market-based instruments do, no doubt, have a role to play in promoting change on farms, recent developments in our understanding, as reflected in Figure 4, reveal that it is likely to be a somewhat limited role. The main benefits will be in a small proportion of locations where off-site benefits from on-farm revegetation are outstandingly high. For the majority of agricultural land, off-site benefits from revegetation are low, or on site costs are high, or both. In these situations, use of market-based instruments are unlikely to be effective in altering farm management on the scale needed for technical effectiveness unless the incentives created are greater than the off-site benefits which are the object of the exercise. The use of such large incentives would actually reduce economic efficiency, rather than increase it, because they would encourage adoption of perennials in situations where the total costs exceed the total benefits.

This also has implications for other policy approaches, such as command-and-control regulation, and use of moral suasion. To the extent that these are successful in altering farmers' management strategies, they run the risk of reducing social welfare unless carefully targeted to situations where off-site benefits are greater than on-site costs.

Although externalities from salinity seem less important as a cause of market failure than previously thought, there are a number of other aspects of salinity for which market failure seems likely.

- Divergence between public and private discount rates (Tietenberg 1996). Given the long time scales involved in achieving some of the benefits from salinity mitigation, any divergence between social and private discount rates may have a substantial impact on evaluation of investment decisions. A key example is investment in R&D to develop improved farming systems based on perennial plants. Time scales on such R&D can be long, and must be added to the time lag between establishment of perennials and avoidance of saline discharges.

- Divergence between public and private attitudes to risk. Bell et al. (2000) emphasised the considerable uncertainties that remain regarding the links between specific salinity treatments and specific salinity mitigation benefits. These uncertainties are difficult to reduce because of the long time lags involved and the geological complexity and diversity of catchments. For farmers, the normal route to reducing uncertainty about an innovation is a small-scale trial, but for several reasons outlined by Pannell (2000) the value of information about salinity effects from such a trial is likely to be low. Uncertainty about long term prices of products from woody perennials may also be higher than for traditional agricultural products, even if only because the products are less familiar to farmers. These uncertainties are highly likely to inhibit farmer adoption of new perennial-based farming systems, even in situations where the perennials would, in fact, be beneficial to the farmers (Pannell 1999a, 1999b). High uncertainty about payoffs is also a feature of long-term R&D, and may have contributed to the very limited private investment in development of commercial perennials for low-to-medium rainfall areas. On the other hand, Arrow and Lind (1970) argue that as long as a public investment is small relative to national income, its risks will normally be offset by uncorrelated returns from other investments. Decisions about public investments can therefore be based on the expected value of net benefits.

- Information and some environmental benefits are "public goods" which may not be adequately provided by the market. In the case of information, this argument is commonly proposed as a potential justification for government investment in R&D and information provision services such as agricultural extension (e.g. Alston et al. 1995; Marsh and Pannell 2000). For salinity the argument is reinforced because some of the benefits at stake are themselves public goods. In particular, non-market environmental values are under threat. Despite the limited available evidence, there are reasons to expect that in some locations the values at stake are high.

In some situations this last issue points to an externality problem, where on-farm management is needed to protect an environmental asset. However, in others, the greater requirement is for direct government management of the public assets under its care and control. Protection of physical public infrastructure can also fall into this category of requiring government action because the management problem is already predominantly within the sphere of government. They have responsibility for the asset, and the socially optimal salinity management strategy does not require actions by others in the community (e.g. drainage in a roadside reserve to protect the road).

5.2 Past and Present Policies

There are numerous government programs in place across Australia which are intended to promote conservation of land and water resources (e.g. Industry Commission 1997). Although salinity is one of a number of causes of resource degradation, it has increasingly been seen as the most serious and important of them, as reflected in the growth of major policies and programs targeted specifically at salinity. This subsection is a brief review of only the major policies relevant to dryland salinity over the past decade, including the new National Action Plan.

National Landcare Program and Natural Heritage Trust

Concerted efforts to address salinity in Australia began with the National Landcare Program (NLP), launched in 1989 from the foundation of the National Soil Conservation Program. The NLP started with the premise that land degradation in agriculture could be solved by awareness-raising, education, and catchment planning processes for groups of farmers (Curtis and De Lacy 1997; Vanclay 1997). A stewardship ethic was to be cultivated among farmers. For over a decade, this paradigm has been the dominant force shaping resource management policies for agriculture. The NLP approach has been very successful in raising awareness of resource conservation issues among farmers, and in some cases this awareness has led to changes in farming practices. It has also clearly had benefits in areas other than salinity. However, for dryland salinity, the changes achieved have been too small to prevent ongoing resource degradation. To be fair, the land use changes required to effectively prevent salinity are now known to be very much more substantial than was believed when the Landcare program was conceived. However, the contributors to Lockie and Vanclay (1997) identified a range of problems with the objectives and underlying assumptions of the NLP. Barr (1999) notes the inadequacies of relying on voluntarism and a stewardship ethic: "There is a significant body of research that demonstrates that links between environmental beliefs and environmental behaviour are tenuous," (p. 134).

The primary instruments used within the Landcare program have been provision of paid facilitators and organisers for Landcare groups, often without strong agricultural or technical backgrounds, the development of catchment plans, and subsidies for partial funding of relatively small-scale on-ground works. The NLP was subsumed within the Natural Heritage Trust (NHT) in 1997. The basic approach and philosophy of Landcare has continued and has also been applied to other programs within NHT such as Bushcare.

Although reported levels of membership of Landcare groups are high, farmers are increasingly jaded with the Landcare approach. Many are dismissive of the unrealistic expectations embodied in the Landcare program. Landcare coordinators and committed farmers are frustrated at the difficulty of involving the broader farming community in Landcare efforts.

A concern is that, despite this, and despite our new understanding of the salinity problem, some areas of government continue to advocate the Landcare paradigm for salinity management. Although "empowerment" and "participation" (buzzwords within Landcare) are important elements of good extension practice, they are not sufficient weapons against salinity. After a decade of exhorting farmers to action on the basis that "every little bit helps", it will be difficult indeed for those deeply wedded to the Landcare program to accept that it may not. Given what we now know, continuation of the Landcare policy approach to address salinity is, in many situations, inequitable, inefficient, and perhaps legally risky.

If, as mooted, the Natural Heritage Trust is continued into a second phase, it is to be hoped that there are major changes to its operation. One important change would be for an emphasis on enhancing the technical and agricultural knowledge of the group coordinators employed by the program, so that they can contribute more directly to the development and testing of the farming innovations that are needed. Another would be a commitment to full and honest disclosure to farmers about the problem and the results of high quality evaluations of the treatments. Honesty needs to temper the spirit of forced optimism which has fuelled the Landcare program to date.

Integrated Catchment Management

Ghassemi et al. (1995) observed that, "In Australia, since the early 1980s an emerging enthusiasm for the concept of integrated management of water and land resources on a catchment-wide scale has become evident" (p. 84). Most of the national and state salinity policies have included so-called "Integrated Catchment Management" (ICM) as a prominent theme. The mantra of ICM has had a strong influence on thinking about salinity and its management. One outcome has been a common belief among farmers, agricultural extension agents and others that localised management activities will not generate benefits unless replicated across the entire catchment. Pannell et al. (2001) have argued on several grounds that in Western Australia this is frequently a misconception, and the National Land and Water Resources Audit (2000a) has revealed that some of the arguments also apply in the Murray Darling Basin. One issue is that surface water catchments (on which group boundaries and catchment plans are based) may differ substantially from groundwater catchments.

The concept of ICM has also influenced planning processes, at least in the sense of them being spatially inclusive of entire (surface water) catchments. However, the task of integrating all elements of the salinity problem into a meaningful planning process at the catchment scale seems intractable. It would entail consideration of hydrology, economics, social impacts, environment, agriculture, spatial variability, and timing. The perceived requirement for consultation and participation would not ease this burden. In practice, most plans developed for agricultural catchments *have* involved consultation and participation but have been technically weak. They have also lacked mechanisms to achieve implementation, beyond the Landcare approach outlined above.

National Action Plan

The 2000 National Action Plan is an evolution from Landcare and ICM. The document released to announce the program, *"Our Vital Resources – National Action Plan for Salinity and Water Quality"*, emphasises "Integrated Catchment/Region Management Plans" to be developed "by the community". The community is to be supported in this by the existing facilitator and coordinator support network, by skills development programs, by extension of technical information, and by a major public communication program "to promote behaviour change and community support". In all this, the program sounds disappointingly similar to the existing programs.

Novel elements of the National Action Plan include that it requires targets for salinity to be set and that funding to achieve these targets is directed to community-based groups in the regions. The setting of targets for each catchment or region raises a number of issues. If they are not based on detailed analyses which account for the hydrological and economic realities of the catchment, targets might easily define outcomes which are inferior to a business as usual approach. If they are based on scientifically credible analyses, targets for the available budget will be very modest, even allowing for unrealistic expectations about the sacrifices to be made by farmers. As noted earlier, likely responses in river salinity to major revegetation activities in the Murray Darling Basin are 100 years or more. This means that achievement of short to medium term water quality targets for the rivers in the Basin will probably depend on the viability of engineering schemes, such as pumping/evaporation to intercept saline groundwaters. The option of desalinating water for domestic consumption in Adelaide may also become attractive.

It is apparently intended that targets should enhance accountability, which has been a serious weakness in previous programs. However, long time lags and scientific uncertainty erode this advantage. Many of the benefits from the policy, if they occur, will be decades in the future. Even a retrospective evaluation of the policy at that time will be difficult because of uncertainty about what would have happened without it, and achievement or otherwise of the specified targets will provide only a loose indication of success or failure.

The regional groups to which funds are to be channeled will find it very difficult not to spread much of the money thinly and non-strategically amongst farmers. The groups will need very high levels of information and leadership if they are not to allocate the money in ways that will be socially and politically attractive but technically and economically inefficient. It may be expecting too much of them to make the difficult but necessary decisions about priorities, especially where it involves fewer funds going directly to farmer members of their communities, many of whom are suffering financial hardship. Provision of high levels of technical information from government and research organisations will be essential for the process to operate effectively.

The plan does allow for technical and economic evaluations to be conducted to back agreements with regional groups (and ABARE has already conducted modelling studies for parts of the Murray Darling Basin, Heaney et al. 2000). It remains to be seen how influential these evaluations will be on the contents of the agreed plans.

The other relatively new element in the plan is an improved “governance framework”, including clarification of property rights for water, limits on land clearing and greater use of economic policy instruments (salinity credits, subsidy payments, etc.). These changes seem broadly positive, although I have argued earlier that achievement of benefits from use of economic policy instruments is likely to be highly site specific.

A high profile component of the plan is airborne geophysics using electro-magnetics and other techniques to identify salt deposits and flows. While information from these methods no doubt has some value for diagnosis and planning, it does not in itself address the core problem in most locations of lack of viable technologies for salinity prevention.

5.3 Policy Needs

The technical and economic information presented earlier in this paper and the experience from policy measures over the past decade point to the need for a clear change of policy approach. Key implications for policy from the foregoing discussion are outlined below.

In most locations across the agricultural regions of Australia, the salinity-related benefits from perennials are small relative to their costs and direct production-related benefits. It is therefore unlikely that policy instruments to provide incentives for adoption of perennials, whether economic or regulatory, would be socially desirable except in one of two situations. Either the perennials would need to be almost as economically attractive as existing farm enterprises (which is currently only true in a minority of situations) or they would need to be in locations where they provide protection to assets of outstanding value.

This points to the need for direct public investments in salinity prevention to be carefully targeted and site specific, rather than distributed broadly across rural areas (Heaney et al. 2000). A proportion of this targeted investment would not be directed to farmers, and much of it will be directed to engineering works. This conclusion has consequences which are likely to be highly unattractive to some politicians and to those with a stake in the existing approach. Farmers are already concerned that salinity money is not all spent on farms (Industry Commission 1997), and farming lobby groups have regularly stated that it should be.

The other way that public money could be targeted to achieve benefits from salinity prevention would be by investment in development of new farming systems based on profitable production of perennials. This option has been neglected in past funding decisions. Its attractions include the following.

- Scientists believe that substantial improvements in the range and scope of profitable perennials are achievable. The current paucity of profitable perennials reflects a low investment in development rather than intractability of the task.
- Some benefits are probably only achievable if profitable perennials became available (e.g. diffuse benefits such as avoidance of flood risk, protection of remnant native vegetation on farms, watertable control in regional flow systems).
- Where subsidies for perennials on farms are used, the subsidy can be reduced by any profit improvement. Less costly perennials increase the area over which economic policy instruments could be beneficial.
- In the case of woody perennials, profitable options will attract private sector finance to meet the establishment costs, which are beyond the means of many farmers.

Of course, the challenges involved in creating a new perennial-based industry are formidable. The tasks required vary from one case to another, but for shrubs, for example, they would include screening of plant species, identifying potential products, developing harvesting and processing technologies, conducting market research, establishing marketing bodies, obtaining finance, and establishing perennials over large areas. For perennials pastures, the technical challenges of development are probably less, but the reliance on livestock to convert plant biomass to marketable products may be seen as a weakness, particularly at present. So this strategy involves delays and uncertainties. However, perennials are the only prospect for prevention of salinity on most of the threatened agricultural land. The community may consider that the value of protecting agricultural land in the very long term is not adequately reflected in discounted Net Present Values. Investment in development of profitable perennials is likely to be the most efficient and effective way of achieving this protection.

Inevitably there will be large increases in the area of salt-affected land. Investment in development of improved systems for making productive agricultural use of saline land appears certain to be attractive. Like development of perennials, this too has been under-resourced in past and present programs.

Engineering methods for use on-farm are already attractive to farmers. There are methods relevant to prevention, adaptation and remediation. R&D to improve and better understand the available methods is another priority which has been neglected.

Aspects of the existing plans deserving of support include: protection of remaining native vegetation, economic policy instruments (if carefully targeted), and management of flows of fresh and saline waters in the Murray Darling and other water resource catchments (including limits on placement of perennials). Given their current roles, the investment in the network of coordinators and facilitators appears hard to defend, but a reorientation towards advice about resource management technologies and participatory research may see them make a valuable contribution.

6. Conclusion

The emphasis of salinity policy has developed in waves, with different ideas or approaches periodically coming to prominence. The scientific and economic basis for much of the policy design has historically been poor and the quality of decision making about policy approaches has suffered accordingly. We are now reaching an understanding of the hydrogeology of Australia's agricultural regions which has profound implications for the economics of salinity management and the design of policy.

The experience with salinity highlights the critical importance of high quality scientific information to guide policy design. It also reinforces the importance of bringing together the perspectives of different disciplines to properly address such a complex and multifaceted problem. Pronouncements about what is needed for salinity policy have been made by physical scientists, biological scientists, social scientists and economists (among many other groups). In cases where the protagonists from any one of these discipline areas have failed to adequately consider the other disciplines, their contributions to the debate have been limited, at best, or even counterproductive. There has been a lack of rigour and critical evaluation in the policy process, perhaps to avoid conflicting with "the spirit of forced optimism" which pervades natural resource management policy in Australia.

Although the 2000 National Action Plan carries strong vestiges of the past, it does contain positive elements. The public documentation for the plan appears rooted in the Landcare paradigm, but there are signs of recognition that change is needed. It will be interesting to see whether the necessary change can be achieved, given some of the unfortunate constraints which appear to have been built into the plan. If not, there is a serious risk that large and growing amounts of public money will be poorly spent.

The two most important broad areas of change identified in this review are (a) better targeting and more rigorous analyses of proposed public investments (along the lines of Heaney et al. 2000), and (b) a greater emphasis on the development of technologies, both for salinity prevention (e.g. perennial plants, engineering methods) and adaptation to a saline environment (e.g. salt-tolerant plants, engineering, commercial use of saline water resources).

References

Alston, J.M., Norton, G.W. and Pardey, P.G. 1995, *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*, Cornell University Press, Ithaca.

Anonymous 1996, *Salinity: A Situation Statement for Western Australia*, A Report to the Minister for Primary Industry, Minister for the Environment, Government of Western Australia, Perth, 46 pp.

Arrow, K.J. and Lind, R.C. 1970, 'Uncertainty and the evaluation of public investment decisions', *American Economic Review*, vol. 60, no. 3, pp. 364-78.

Barr, N, 1999, Social aspects of rural natural resource management, in *Outlook 99, Proceedings of the National Agricultural and resources Outlook Conference*, Canberra, 17-18 March, vol. 1, Commodity Markets and Resource Management, ABARE, Canberra, pp. 133-140.

Bartle, J.R. 1999, Why oil mallee? *Proceedings of Oil Mallee Profitable Landcare Seminar*, Oil Mallee Association, Perth, pp. 4-10.

Bathgate, A. and Pannell, D.J. 2001, Economics of deep-rooted perennials in southern Australia. *Agroforestry Systems* (in press).

Bell, R., Mues, C. and Beare, S. 2000, Salinity management: Some public policy issues in the Murray Darling Basin, In: *Proceedings of the National Outlook Conference, 29 February – 2 March 2000,* Australian Bureau of Agricultural and Resource Economics, Canberra.

Bowman, S. and Ruprecht, J.K. 2000, *Blackwood River Catchment Flood Risk Study*. Water and Rivers Commission Report No. SWH 29. Western Australian Government, East Perth, WA.

Burdass, J., Grieve, R. and Robinson, B. 1998, An integrated catchment management plan for the Upper Kent River Catchment. Report to the Kent Steering Committee, unpublished report

Campbell, N., George, R., Hatton, T., McFarlane, T., Pannell, D., Van Bueren, M., Caccetta, P., Clarke, C., Evans, F., Ferdowsian, R. and Hodgson, G. 2001, *Using Natural Resource Inventory Data to Improve the Management of Dryland Salinity in the Great Southern, Western Australia,* National Land and Water Resources Audit, Implementation Project 2, Theme 2 – Dryland Salinity. (in press).

Cary, J.W. and Wilkinson, R.L. 1997, Perceived profitability and farmers' conservation behaviour, *Journal of Agricultural Economics* 48, 13-21.

Cooper, D. 1999, *An Economic Analysis of Oil Mallee Industries in the Wheatbelt of Western Australia*, Unpublished thesis, Master of Science in Natural Resource Management, Faculty of Agriculture, The University of Western Australia.

Curtis, A. and De Lacy, T. 1997, Examining the assumptions underlying Landcare, In: S. Lockie and F. Vanclay (eds.) *Critical Landcare*, Key Papers Series 5, Centre for Rural Social Research, Charles Sturt University, Wagga Wagga, pp. 185-199.

Curtis, A., MacKay, J., Van Nouhuys, M., Lockwood, M., Byron, I. and Graham, M. 2000, *Exploring Landholder Willingness and Capacity to Manage Dryland Salinity: The Goulburn Broken Catchment*, Johnstone Centre Report No. 138, Charles Sturt University, Albury, NSW.

Ferdowsian, R., George, R., Lewis, F., McFarlane, D., Short, R. and Speed, R. 1996, The extent of dryland salinity in Western Australia. *Proceedings, 4th National Conference and Workshop on the Productive Use and Rehabilitation of Saline Lands*, Albany, Western Australia, 25-30 March 1996, Promaco Conventions: Perth, Western Australia, pp. 89-97.

Ferdowsian, R., Ryder, A. and Kelly, J. 1997, *Evaluation of Deep Open Drains in the North Stirlings Area*, Resource Management Technical Report 161, April 1997, Agriculture Western Australia, South Perth.

Ferdowsian, R., Pannell, D.J., McCaron, C., Ryder, A. and Crossing, L. 2001, Explaining groundwater hydrographs: Separating atypical rainfall events from time trends, *Australian Journal of Soil Research* 39(4): (in press).

George, R.J., Nulsen, R.A., Ferdowsian, R. and Raper, G.P. 1999a, 'Interactions between trees and groundwaters in recharge and discharge areas - a survey of Western Australian sites', *Agricultural Water Management*, vol. 39, pp. 91-113.

George, R., Clarke, C., Hatton, T., Reggiani, P., Herbert, A., Ruprecht, J., Bowman, S. and Keighery, G. 1999b, The effect of recharge management on the extent of dryland salinity, flood risk and biodiversity in Western Australia. Preliminary computer modelling, assessment and financial analysis. Unpublished report to State Salinity Council of Western Australia.

Ghassemi, F., Jakeman, A.J. and Nix, H.A. 1995, Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. University of New South Wales Press, Sydney

Greiner R 1997, Integrated catchment management for dryland salinity control in the Liverpool Plains Catchment: a preliminary study from an economic perspective. Occasional Paper No 12/97 LWRRDC, Canberra, 51 pp

Hajkowicz S and Young M 2000, An Economic Analysis and Cost sharing Assessment for Dryland Salinity Management A Case Study of the Lower Eyre Peninsula in South Australia. Policy and Economic Research Unit, CSIRO Land and Water, Adelaide

Hatton, T.J. and Nulsen, R.A. 1999, 'Towards achieving functional ecosystem mimicry with respect to water cycling in southern Australian agriculture', *Agroforestry Systems*, vol. 45, pp. 203-14.

Hatton, T. and Salama, R. 1999, 'Is it feasible to restore the salinity affected rivers of the Western Australian wheatbelt?' in Rutherford, I. and Bartley, R. (eds.), *Proceedings of the 2nd Australian Stream Management Conference, Adelaide, 8-11 February 1999*, pp. 313-18.

Hayes, G. 1997, *An Assessment of the National Dryland Salinity R, D & E Program,* LWRRDC Occasional Paper No 16/97, Land and Water Resources Research and Development Corporation, Canberra.

Heaney, A., Beare, S. and Bell, R. 2000, Targeting reforestation for salinity management, *Australian Commodities*, vol. 7, pp. 511-518.

Herbert A 1999, Fence Road Focus Catchment: A benefit cost analysis. Bulletin 4370, Agriculture Western Australia, South Perth, WA

Herbert A 2000, Economics of Oil Mallees. Marketing, Economics and Rural Adjustment Service, Economic Series 99.9, Agriculture Western Australia, Perth.

Hingston, F.J. and Gailitis, V. 1976, The geographic variation of salt precipitation over Western Australia, *Australian Journal of Soil Research* vol. 14, pp. 319-335.

Industry Commission 1997, *A Full Repairing Lease: Inquiry into Ecologically Sustainable Land Management, Draft Report, September 1997*, Industry Commission, Canberra.

Keighery, G. 2000, Wheatbelt wonders under threat, *Landscope,* Summer 2000-2001.

Kington, E.A. and Pannell, D.J. 2001, 'Dryland salinity in the upper Kent River catchment of Western Australia: Farmer perceptions and practices', *Journal of Environmental Management,* (submitted).

Lindner, R.K. 1987, 'Adoption and diffusion of technology: an overview', in Champ, B.R. Highley, E. and Remenyi, J.V. (eds.), *Technological Change in Postharvest Handling and Transportation of Grains in the Humid Tropics*, ACIAR Proceedings No. 19, pp. 144-151.

Lockie, S. and Vanclay, F. (eds.) 1997, *Critical Landcare*, Key Papers Series 5, Centre for Rural Social Research, Charles Sturt University, Wagga Wagga, 238 pp.

Madden, B., Hayes, G. and Duggan, K. 2000, *National Investment in Rural Landscapes: An Investment Scenario for NFF and ACF with the Assistance of LWRRDC*, Virtual Consulting Group, Albury NSW, 44 pp.

Malcolm, C.V. and Pol, J.E., 1986, Grazing and management of saltland shrubs, *Journal of Agriculture, Western Australia* 27, 59-63.

Marsh, S.P. and Pannell, D.J. 2000, Agricultural extension policy in Australia: The good, the bad and the misguided. *Australian Journal of Agricultural and Resource Economics* 44(4): 605-627.

Marsh, S.P., Burton, M.P. and Pannell,D.J. 2000, 'Understanding monitoring of "sustainability indicators" by farmers: A case study of groundwater monitoring under threat of dryland salinity', in Conacher, A. (ed.), *Land Degradation*, Kluwer, Dordrecht, (in press).

Matta, J. 1999, *The Rural Towns Program, Groundwater Modelling, The Merredin Catchment,* Agriculture Western Australia, Perth.

Murray Darling Basin Ministerial Council 1999, *The Salinity Audit of the Murray-Darling Basin, A 100 Year Perspective, 1999,* Murray-Darling Basin Commission, Canberra, 39 pp.

National Land and Water Resources Audit 2000a, *Australian Groundwater Flow Systems Contributing to Dryland Salinity,* CD-ROM, National Land and Water Resources Audit, Canberra.

National Land and Water Resources Audit 2000b, *Dryland Salinity in Australia – Key Findings*, Fast Facts 21, National Land and Water Resources Audit, Canberra.

New South Wales Government 2000, *Taking on the Challenge: NSW Salinity Strategy,* NSW Department of Land and Water Conservation, Sydney, 79 pp.

Pannell D.J. 1999a, Social and economic challenges in the development of complex farming systems. *Agroforestry Systems* 45: 393-409

Pannell, D.J. 1999b, Uncertainty and Adoption of Sustainable Farming Systems, Paper presented at the 43rd Annual Conference of the Australian Agricultural and Resource Economics Society, Christchurch, New Zealand, January 20-22 1999.

Pannell D.J. 2000, Explaining non-adoption of practices to prevent dryland salinity in Western Australia: Implications for policy. In:Conacher A (ed) Land Degradation, Kluwer, Dordrecht. (in press).

Pannell D.J. and Glenn N.A. 2000, A Framework for Economic Evaluation and Selection of Sustainability Indicators in Agriculture, *Ecological Economics* 33(1): 135-149.

Pannell, D.J., McFarlane, D.J. and Ferdowsian, R. 2001, Rethinking the externality issue for dryland salinity in Western Australia. Australian Journal of Agricultural and Resource Economics (in press)

Primary Industries and Resources South Australia, 2000, *Draft State Dryland Salinity Strategy, South Australia*, Soil Conservation Council of South Australia and Government of South Australia, Adelaide.

Prime Minister's Science, Engineering and Innovation Council 1999, *Dryland Salinity and its Impact on Rural Industries and the Landscape*, Prime Minister's Science, Engineering and Innovation Council, Occasional Paper Number 1, Department of Industry, Science and Resources, Canberra.

Speed, R.J. and Simons, J.A.S. 1992, *Deep Drains – A Case Study and Discussion*. Division of Resource Management Technical Report 133. Department of Agriculture Western Australia, South Perth.

State Salinity Council 2000, *Natural Resource Management in Western Australia: The Salinity Strategy*, Government of Western Australia, Perth, 72 pp.

Stauffacher, M., Bond, W., Bradford, A., Coram, J., Cresswell, H., Dawes, W., Gilfedder, M., Huth, N., Keating, B., Moore, A., Paydar, Z., Probert, M., Simpson, R., Stefanski, A., and Walker, G. 2000, Assessment of Salinity Management Options for Wanilla, Eyre Peninsula: Groundwater and Crop Water Balance Modelling. Technical Report 1/00, CSIRO Land & Water, Canberra, Bureau of Rural Sciences, Canberra.

Stirzaker, R., Lefroy, T., Keating, B. and Williams, J. 2000, *A Revolution in Land Use: Emerging Land Use Systems for Managing Dryland Salinity*, CSIRO, Canberra, 24 pp.

Tietenberg, T. 1996, *Environmental and Natural Resource Economics, 4th ed.*, Harper Collins, New York, 614 pp.

Van Bueren, M.S. and Bennett, J. 2001. Towards the development of a transferable set of value estimates for environmental attributes, Unpublished paper presented at the 45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide, 23-25 January 2001.

Vanclay, F. 1997, 'The social basis of environmental management in agriculture: A background for understanding Landcare', in Lockie, S. and Vanclay, F. (eds.) *Critical Landcare,* Key Papers Series 5, Centre for Rural Social Research, Charles Sturt University, Wagga Wagga, pp. 9-27.

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