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DRYLAND SALINITY: SPATIAL IMPACTS AND FARMERS' OPTIONS

Dr Ross Kingwell

WA Department of Agriculture & The University of WA

Abstract

The salinisation of farmland in Australia is a major natural resource management problem. Over the next 20 years a further 1.1 million hectares of broadacre farmland is predicted to become salt-affected. This paper firstly explores the spatial ramifications of the spread of salinity in Australia's agricultural regions. Some of the nation's most profitable grain growing regions will become seriously affected by salinity over the next 20 years.

Secondly this paper outlines the nature, uptake and profitability of various salinity management options available to Australian farmers. These options include preventative and containment measures, such as engineering solutions and adoption of deep-rooted perennials, and other options involving adaptation to more saline environments such as commercial use of saline water and salt tolerant fodder plants.

[illegible] significant impact on the rate of spread of salinity on farmland, or the rate of increase of saltload in rivers and streams.

Introduction[37]

Dryland salinity is a growing environmental problem affecting water catchments, river systems, native vegetation, farm land, transport infrastructure and regional towns in many parts of Australia (PMSEIC 1999, MDBMC 1999, SSC 2000, NLWRA 2001). The causes and science of the problem are increasingly well understood and documented (Ghassemi *et al*. 1995, George *et al*. 1997, Walker *et al*. 1999, Hatton and Salama 1999, Frost *et al*. 2001,). In simple terms broadacre agricultural development in Australia has involved massive clearing of temperate woodlands, followed by planting of annual crops and pastures. In Western Australia, for example, in the 1960s a million acres of natural bushland was released each year for farming. The agricultural species that were planted across vast tracts of cleared land used much less water than the deeper-rooted native trees and perennial shrubs they replaced. The result has been a gradual rise in water tables, bringing to the soil surface or within the root zone of agricultural plants dissolved salts originally stored deeper in soil profiles. These salts brought near or to the surface restrict plant growth, increase salt loads

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[37] This paper draws heavily from material recently published in Kingwell *et al*. (2003)

in streams and rivers and weaken the chemical structure of road bases and building foundations (Maas and Hoffman 1977, Williamson 1998, Keighery 2000, Dames and Moore 2001).

The salt concentration of rising water tables, the rate of rise of water tables, landscape topology and seasonal conditions, all interact to influence the spatial impact of dryland salinity. Variation in spatial impacts can mean that farms and even whole regions are differently affected by salinity. Yet because agricultural activity underpins the economies of many inland rural regions of Australia it is important to understand the nature and size of the spatial impacts of salinity. Accordingly, this paper firstly explores the spatial impacts of salinity in major grain growing regions of Australia. The paper is restricted to considering direct on-farm ramifications of salinity, although noting that the off-farm ramifications of salinity on water quality, native vegetation and infrastructure are serious issues in their own right.

A second section of this paper outlines the nature, uptake and profitability of various salinity management options available to Australian farmers. These options include preventative and containment measures, such as engineering solutions and adoption of deep-rooted perennials, and other options involving adaptation to more saline environments such as commercial use of saline water and salt tolerant fodder plants. A final section draws conclusions about farmers' management of salinity and some possible implications for R&D priorities for salinity management.

Section 1: Spatial Impacts of Dryland Salinity

In the 1990s dryland salinity became a major community issue in Australia (Beresford *et al*. 2001). The first national State of the Environment report (SEAC, 1996) identified extensive deterioration of natural resources due to dryland salinisation and was part of the stimulus to subsequent salinity reviews and management plans (GWA 1996 & 1998, McRobert and Foley 1999, MDBMC 1999, PMSEIC 1999, NLWA 2001, Frost *et al*. 2001).

The forecasts or estimates of the spatial extent of dryland salinity in Australia generated by major reviews of salinity are listed in Table 1. The differences in these estimates relate mostly to definitional differences of salinity. For example the NLWRA (2001) define salinity area as the area at risk of salinisation, based on water table heights. By contrast ABS (2002) use farmers' assessments of the areas on farms already showing signs of salinity. Farmers' estimates of areas affected by salinity are generally the lowest which may mean their perception of the problem understates its real impact or conversely, that the scientific community over-states its importance. The former explanation seems more plausible based on earlier evidence from a 1989 regional survey of farmers in which farmers identified only 443,000 ha of land being salt affected. However satellite imaging used just after this survey revealed the extent of salinisation was 2 to 3 times larger than farmers estimated.

Table 1. A comparison of estimates of salinity extent

State	Kingwell *et al.* (2003) Area affected by salinity '000ha	PMSEIC (1999) Area affected by salinity '000ha	NLWRA (2001) Area at risk of salinity '000ha	ABS (2002) Area showing signs of salinity '000ha
WA	1890	1802	4363	1241
NSW	105	120	181	124
Vic/SA	575	522	1060	489
Qld	33	10	na	106
Total	2603	2454	5604[a]	1960

[a] excludes Queensland as estimates were not available

Kingwell *et al*. (2003) drew on revised and standardised NLWRA datasets to generate estimates of areas affected by salinity at both a State and regional level. The regional classification they used were agro-ecological zones as defined by the Grains Research and Development Corporation (GRDC). Figure 1 shows the GRDC agro-ecological zones and Table 2 lists the estimated current extent of salinity in each GRDC agro-ecological zone and the anticipated growth in salinity area in each zone by 2020.

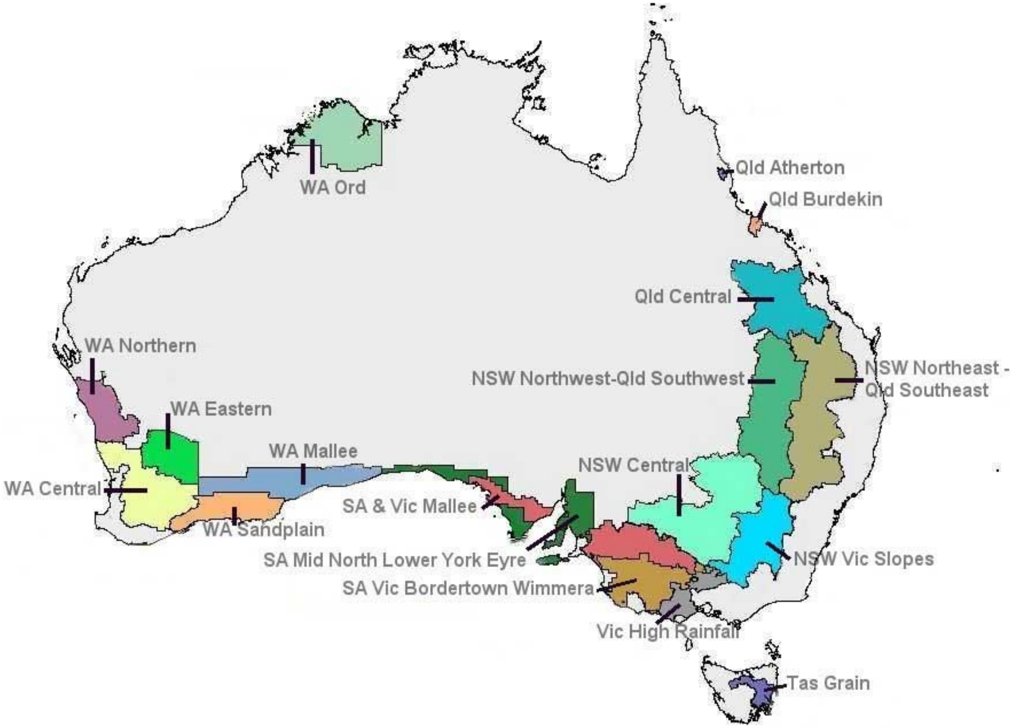

Figure 1: GRDC Agro-ecological Zones

Table 2. Area of salt affected land in 2000 and 2020

GRDC Zone	Saline Area ('000 ha) 2000	2020	Area Increase ('000 ha)	Increase (x Area)
NSW Central	4	32	28	7.4
NSW Northeast - Qld Southeast	38	88	50	1.3
NSW Northwest-Qld Southwest	2	6	5	2.9
NSW Vic Slopes	61	203	142	2.3
Qld Atherton	1	2	2	2.2
Qld Burdekin		1	1	180.3
Qld Central	32	71	39	1.2
SA & Vic Mallee	108	145	37	0.3
SA Mid-North Lower York Eyre	118	118		
SA Vic Bordertown Wimmera	277	488	211	0.8
Tas Grain	18	24	6	0.3
Vic High Rainfall	72	228	155	2.1
WA Central	961	1,142	181	0.2
WA Eastern	374	374		
WA Northern	280	280		
WA Sandplain	275	522	247	0.9
Total	2,620	3,723	1,123	0.4

[a] No significant areas of salinity are recorded for the WA Mallee Zone or the WA Ord Zone.

Zones with large increases in areas affected by salinity include the WA Sandplain, SA Vic Bordertown Wimmera, NSW Vic Slopes, the WA Central and the Vic High Rainfall. Over 60 per cent of the additional area of salinity forecast to occur from 2000 to 2020 will be in the GRDC Western Region, in particular the WA Sandplain zone and the WA Central zone. A range of rates of increase in salinity area is forecast. In general higher rates are observed where salinity is newly emerging, such as in the NSW Central and NSW Northeast - Qld Southeast/Southwest zones. In the GRDC zones listed in Table 2 an additional 1.1 million hectares of salinity are anticipated to emerge by 2020.

In the zones WA Eastern, WA Northern and SA Mid-North Lower York Eyre, new hydrological equilibria appear to have been reached as no further increases in the area of salt affected land are forecast. In these zones the investment issues are the recovery of salt affected land and/or more productive uses of saline land. In most other zones the additional investment issue is the containment of the spread of salinity.

Some GRDC zones, such as the WA Sandplain and WA Central, are already major grain-growing regions so their forecast large increases in salt affected areas toward 2020 will impact on national crop production. Across all the GRDC zones, if only half the forecast additional area to be salt affected is normally sown to crops, this represents at worst a potential loss of around 0.5 million hectares of crop land. In practice, there is a continuum of yield loss due to salinity, with some paddocks becoming bare salt scalds while others experience slight or infrequent reductions in production due to salt.

In many zones, the low-lying parts of the landscape at risk of salinisation are often the more fertile, high-yielding soil classes. Crop production on these soils can be a main source of farm profit. Hence, although these soils only form part of many farms, nonetheless salt damage to these soils can lead to substantial impacts on overall farm profit through reduced yields and reduced areas sown to crops on these once fertile soils.

Zones forecast to experience large salinity problems over the next 20 years (WA Sandplain, SA Vic Bordertown Wimmera, NSW Vic Slopes, the WA Central and the Vic High Rainfall) are, with the exception of the Vic High Rainfall zone, also main sources of Australian farm profit (see data in Table 3). Hence, declines in farm profit due to salinity within these zones could potentially have damaging consequences for overall grain industry profits. The macroeconomic impact of the foregone profit, especially within regional economies, could be significant. This spatial impact of salinity on farm profit is explored further in the next sub-section.

Table 3. Estimated farm profit at full equity summed within GRDC zones for 2001/02[38] ($'000)

[38] Based on landuse patterns and input usage in 1996/97 updated with 2001/02 costs and prices.

GRDC Zone	Profit at Full Equity ($'000) 5yr average[2]	Profit ranking[1]	Salinity area Increase towards 2020 ('000 ha)
NSW Central	-102,800	17	28
NSW Northeast - Qld Southeast	645,993	1	50
NSW Northwest-Qld Southwest	-121,588	18	5
NSW Vic Slopes	433,119	3	142
Qld Atherton	7,318	13	2
Qld Burdekin	2,794	14	1
Qld Central	64,922	9	39
SA & Vic Mallee	53,881	10	37
SA Mid-North Lower York Eyre	289,044	4	
SA Vic Bordertown Wimmera	142,442	5	211
Tas Grain	-18,449	16	6
Vic High Rainfall	27,262	11	155
WA Central	477,144	2	181
WA Eastern	75,998	6	
WA Mallee	-875	15	
WA Northern	64,996	8	
WA Ord	11,377	12	

WA Sandplain	65,591	7	247
Total	**2,118,169**		**1,123**

[1] Regions are ranked from 1 (=highest profit) to 18 (=least profit)

[2] Average of years 1992/3 to 1996/7

A Conceptual Model of Salinity Impact

Figure 2 shows alternative scenarios for profit at full equity in the grains industries resulting from salinity outcomes over the next twenty years. If salinity remains unchecked then, with current technologies and price relativities, farm profit will decline as shown by the downward sloping "unchecked" line. If salinity is unchecked and profits decline then this lower profit can be considered the impact cost. The shaded area in Figure 2 represents the present value of the impact cost over the 20 year period to 2020. The net loss in profits over the 20 years, due to worsening salinity, is the potential farm-level impact cost of salinity.

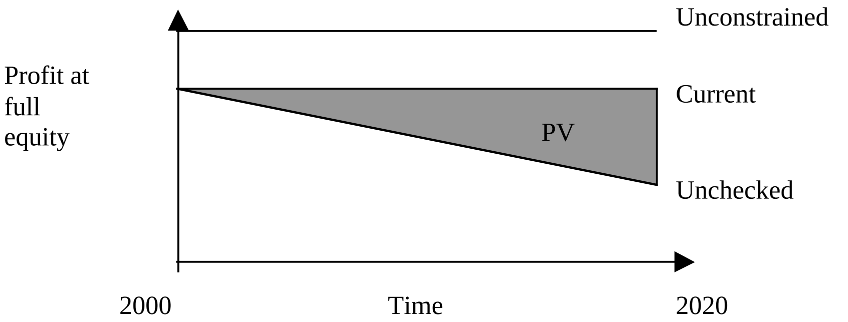

Figure 2. Conceptual model of salinity costs over time

If salinity was costlessly and completely ameliorated then profits would rise to the unconstrained level, which equates to the notion of potential gross benefit from salinity amelioration. However, clearly a costless 'fix' of salinity is not possible, and the costs would need to be compared against the benefits in evaluating remedial projects. In other words, it's almost certain that all potential gross benefits of salinity amelioration will not be generated.

It is worth noting that the "unchecked" line represents a worst-case scenario. In practice, farmers will respond to worsening salinity problems through improved management practices, new technologies and enterprise switches. This will have the effect of reducing the present value of costs.

To determine the present value of salinity costs in perpetuity, it is assumed that profits to not decline below their 2020 levels. In other words, when the unchecked line in Figure 8 reaches 2020 it continues horizontally into the future.

Impact Cost of Salinity

Impact cost is defined as the decrease in profit at full equity due to worsening salinity extent and severity over the period 2000 to 2020. It is represented by the 'unchecked' line in Figure 2. The impact cost over the 20-year period (the shaded area in Figure 2) can be expressed as a present value.

The spatial impact cost of salinity was estimated by applying the conceptual model shown in Figure 2, based on a 1 km^2 grid across the GRDC zones. A single land use was assigned to each 1 km^2 grid cell, based on 1996/7 landuse data from the NLWRA, and amended where necessary to ensure consistent regional aggregation and regional specificity in the production of some commodities (e.g. cotton and rice). The landuse dataset then was complemented with relative yield surfaces generated by participants in theme two of the NLWRA (2000). These surfaces showed the impact of increased salinisation on the relative yields of crops and pastures. For each 1 km^2 grid cell, assuming no change in land use within the cell and assuming a linear decrease in profits, the impact cost can be determined by:

$$\pi_{\text{current}} = pq - c \qquad (1)$$

$$\pi_{2020} = pq\frac{\alpha_2}{\alpha_1} - c \qquad (2)$$

Where:

α_1 = relative yield in 2000, where relative yield is actual yield divided by potential yield
α_2 = relative yield in 2020
p = agricultural commodity price in 2000/01 dollar terms
c = production costs for the agricultural commodity in 2000/01constant dollar terms
q = commodity production

$$\pi_{\text{current}} - \pi_{2020} = pq\left(1 - \frac{\alpha_2}{\alpha_1}\right) \qquad (3)$$

The simplified impact cost in equation (3) can be re-expressed in full form of the impact cost as in equation (4). Equation (4) includes livestock turn-off rate and the relationship between variable costs and fixed costs.

$$\text{Impact Cost} = \prod_{\text{Current}} - \prod_{2020} = \beta q_1 \left(p_1 - v - \frac{\alpha_2 (p_1 + v)}{\alpha_1} \right) \quad (4)$$

Where:
π_{Current} = current profit at full equity
π_{2020} = profit at full equity in 2020
α_1 = relative yield in 2000
α_2 = relative yield in 2020 (note: $\alpha_2 \leq \alpha_1$ due to worsening salinity)
β = turn off rate (ratio) for livestock
v = variable costs of producing agricultural commodity
p_1 = farm gate price ($/ha or $/DSE)
q_1 = yield or stocking rate ($/ha or $/DSE)

Using equation (4), and aggregating the 1 km^2 cells within the various GRDC zones, generates estimates of the impact cost of worsening salinity over the next 20 years by GRDC zone, as shown in Table 4 and Figure 3.

Table 4. Impact costs of worsening salinity from 2000 to 2020 (in 2001/02 prices)

GRDC Zone	Impact Cost ($000)[1]	Mean Impact Cost ($/ha)	Present value for 20 years ($000)[2]	Present value in perpetuity ($000)[3]	Decrease in PFE[4] (%)
NSW Central	1,154	0.1	4,552	7,417	1
NSW Northeast - Qld Southeast	4,329	0.3	17,081	27,832	1
NSW Northwest-Qld Southwest	173	0	684	1,115	0
NSW Vic Slopes	11,036	1.4	43,542	70,947	3
Qld Atherton	143	3	563	917	2
Qld Burdekin	1	0	4	7	0
Qld Central	2,624	0.3	10,353	16,869	10
SA & Vic Mallee	2,073	0.3	8,179	13,327	2
SA Mid-North Lower York Eyre	2	0	10	16	0
SA Vic Bordertown Wimmera	14,910	2.6	58,825	95,849	7
Tas Grain	204	0.3	807	1,315	1
Vic High Rainfall	5,385	2.3	21,246	34,618	307
WA Central	9,946	1.1	39,242	63,941	2
WA Sandplain	8,206	3.7	32,378	52,756	10
All Zones[5]	**60,188**	**-**	**237,464**	**386,922**	**3**

1. As defined by equation (4). 2. Determined using an 8% discount rate and assuming a linear increase in salinity extent and severity over the 20-year period (2000-2020). 3. Determined using an 8% discount rate and assuming a linear increase in salinity extent and severity over the 20-year period (2000 to 2020). The impact cost is then held at the 2020 level in perpetuity. 4. Impact cost expressed as percentage decline in profit at full equity (PFE) for grains related industries. 5. The GRDC regions of WA Eastern zone, WA Mallee zone, WA Northern zone, WA Ord zone were found to have impact costs of zero.

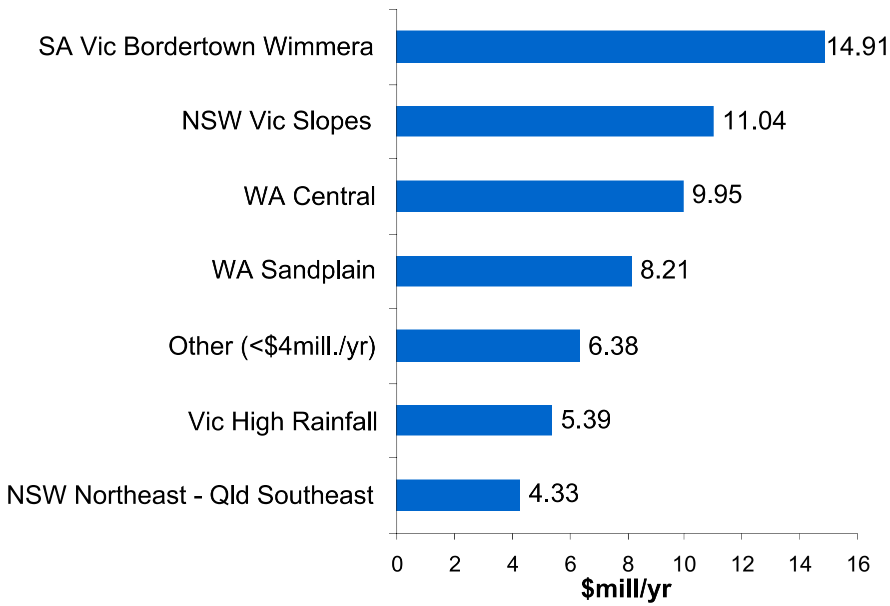

Figure 3. Impact costs of worsening salinity from 2000 to 2020 ($mill/yr, 2001/02 prices)

The zones identified as likely to experience substantial profit reductions due to salinity are SA Vic Bordertown Wimmera, NSW Vic Slopes, the WA Central, WA Sandplain and the Vic High Rainfall. Including perpetuity costs worsens the impact costs of salinity in these zones (see column 5 in Table 4). The SA Vic Bordertown Wimmera and WA Sandplain zones are particularly affected with percentage annual reductions in farm profit due to salinity forecast to be 7 and 10 percent respectively. To overcome such reductions in profit, especially in the face of a likely continuance of adverse cost-price movements, large increases in enterprise productivity or new profitable enterprises will need to be introduced. By contrast, in the NSW Vic Slopes and WA Central zones combating the negative impact of salinity is a more feasible challenge as the forecast annual reductions in profit due to salinity are only 3 and 2 percent respectively. The marked differences between zones in the forecast impacts of salinity mean there are also differences in the size of the challenge to farming systems in these zones. The profitability of some farm businesses in some zones will be very reliant on salinity management innovations. If these innovations do not emerge to protect or boost farm profit then the viability of these businesses will be quickly threatened.

The estimates of spatial costs of salinity in Table 4 can be compared to the estimate generated by Heaney *et al*. (2001) for the Murray Darling basin. Their estimate of the agricultural cost of salinity in the Murray Darling basin, expressed as an annualised cost, was $28 million. The equivalent annualised cost reported here for the GRDC zones lying within the basin is $20 million. The difference between the estimates arises from the different modelling approaches and datasets used. However, both studies are in agreement that the cost to agriculture of salinity is generally far less than is commonly portrayed.

Section 2: Salinity Management Options

To lessen the impact of salinisation farmers are trialing a range of management options. There are ground-based engineering works such as deep open drains; agro-forestry opportunities including blue gums, maritime pines and oil mallees; deep-rooted perennial fodder crops such as lucerne and tagasaste; and the planting of salt tolerant species such as saltbush and bluebush. Aquaculture and other commercial uses of salt water are also of interest to some farmers.

Plant-based Options

In 2002 over 20,000 farm establishments participated in a salinity survey (ABS 2002). The farmers were selected because they had already indicated they had land affected by salinity or they used salinity management strategies. The Australian Bureau of Statistics (ABS) applied sampling techniques to generalise findings to all farmers. For dryland farms the ABS found that many farms were using a variety of salinity management strategies. Table 5 presents some key findings for crop and pasture salinity management strategies while Table 6 lists findings for tree planting.

Table 5. Dryland farm numbers and areas subject to various crop and pasture salinity management strategies in 2002

State	Salt tolerant	Lucerne	Deep-rooted	Salt tolerant	Saltbush,	Other fodder
No. of farms						
NSW/ACT	321	2038	1059	398	233[a]	128
Vic	263	1153[a]	1367	927	259	93
Qld	299[a]	349[a]	117	72	25	61[a]
SA	235	576[a]	127	600	931[a]	110[a]
WA	1406	1031	504	1160	1455	956
Tas	-	9[a]	100[a]	92[a]	-	4[a]
NT	1	3[a]	1	1	1	-
Total	2526	5158	3276	3250	2905	1353
Area ('000 ha)						
NSW/ACT	47	457	266	16	25[a]	4[a]
Vic	44	83	349[a]	58[a]	5	3[a]
Qld	25[a]	32[a]	157	27[a]	2[a]	60[a]
SA	32	122	27[a]	76	61[a]	5[a]
WA	266	74	51	61	123	39
Tas	-	-	4[a]	-	-	-
NT	1	5[a]	-	-	-	-
Total	416	773	854	238	216	110[a]

[a] These estimates have high relative standard errors and so are unreliable.

Source: ABS (2002), Bulletin 4615.0

Lucerne is planted for salinity management on more farms than any other plant option. Lucerne is popular in NSW, SA and Vic; with large areas grown in NSW and moderate areas in SA. Deep-rooted perennials, other than lucerne, are popular in Vic and are grown on a moderate scale in that State and in NSW. As may be expected, in WA saltbush and bluebush are popular; yet are grown on a limited scale. Salt tolerant crops, particularly barley, are grown on a moderate scale only in WA.

Although many thousands of farms indicate they have planted trees to aid salinity management, in fact the area planted nation-wide is less than the area planted to lucerne for salinity management. WA leads by far other States in the area planted to trees to combat salinity. Almost half a million hectares of farmland have been planted to trees for salinity management in WA which in that State is an area greater than that sown to oats and much greater than the areas sown to pulse crops (apart from lupins).

Table 6. Dryland farm numbers and areas subject to tree planting for salinity management in 2002

State	No. of	Area of trees
NSW/ACT	1301	72
Vic	2078	32
Qld	266	109
SA	792	13
WA	4112	496
Tas	32	2[a]
NT	na	-
Total	**8582**	**724**

[a] These estimates have high relative standard errors and so are unreliable. na not available

Source: ABS (2002), Bulletin 4615.0

The planting of deep-rooted plant species is an attempt to mimic the low groundwater recharge of native bushland. By reducing groundwater recharge on agricultural land watertables fall and salts are drawn away from the soil surface and plant root-zone. In other situations where salinity is already evident, plants better suited to saline or waterlogged soils bolster profits from these soils. In some cases these plants might also lower watertables and eventually establish a less saline soil surface.

The economic assessment of these plant options for managing salinity has received increased attention in recent years, as shown in Figure 4. The number of studies has escalated since the 1990s, yet it is often difficult to compare the findings from these studies due to their different price, cost and discount rate assumptions as well as fundamental methodology differences.

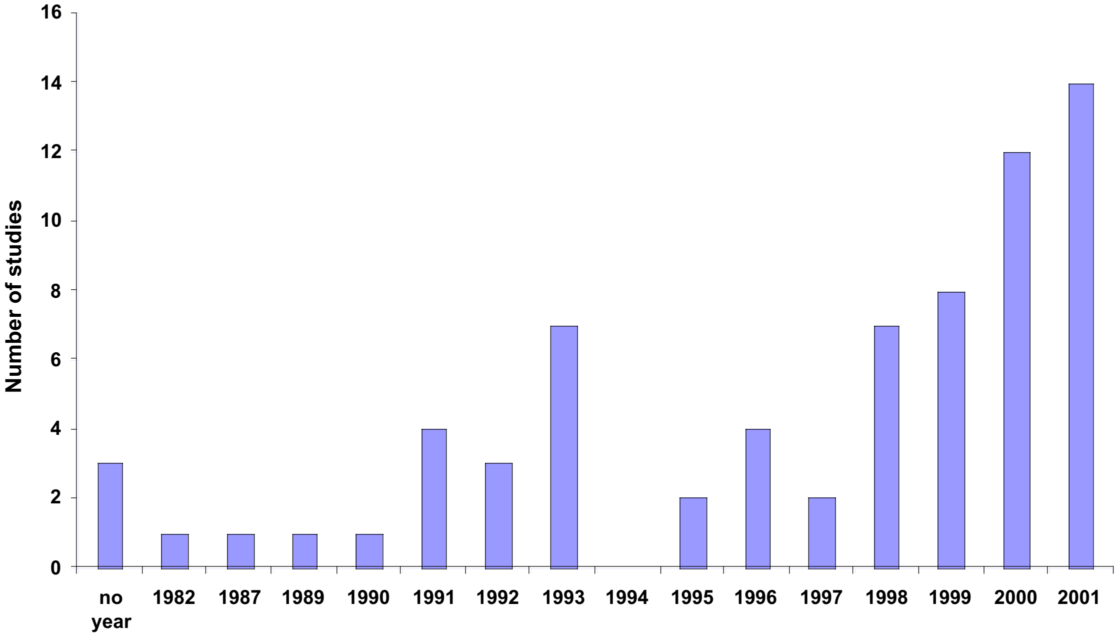

Figure 4. The distribution of economic studies of plant-based salinity management options, according to date of publication, up until 2001.

Source: Kingwell et al. (2003)

To generate a more consistent set of comparative analyses, Kingwell *et al*. (2003) conducted a suite of over 40 case study and regional analyses underpinned by a uniform set of commodity prices, the same discount rate (8 percent) and a consistent reporting framework. Sensitivity analyses were applied to the various case study and regional investigations to test the robustness of findings. The profitability of the various options was reported mostly as the addition to whole farm profit, expressed as profit at full equity per hectare of arable area. A summary of their findings is listed in Table 7.

Table 7. A summary of case study and regional analyses

Name of option	GRDC Zone	SLA	Change in profit at full equity ($/ha/yr)
Lucerne	SA & Vic Mallee	Mildura	32[a]
		Loddon (1)	12
		Loddon (2)	12
		Buloke	60
	SA Vic Bordertown Wimmera	Loddon	12
		Hindmarsh	22
	NSW Vic Slopes	Corowa (A)	29
	NSW Central	Lachlan	31
		Corowa	5
	Vic High Rainfall	Shepparton	44
	WA Northern	Dalwallinu (1)	33
		Dalwallinu (2)	13
	WA Central	Quairading	1
		Wickepin	-4
		Meckering	2
		Kojonup	12
	WA Sandplain	Esperance & Ravensthorpe	12
Opportunistic	NSW Northeast	Quirindi	35
Saltland pastures	WA Central	Quairading	3
		Kojonup	6
		Merredin	4
	WA Sandplain	Esperance & Ravensthorpe	5
	NSW Central	Lachlan	2

Sequential perennials	SA Vic Bordertown Wimmera	Tintinara	135[b]
	SA Mid-North Lower York	Cummins	139[b]
Pasture cropping	NSW Northeast	Mudgee	20
Phalaris	NSW Vic Slopes	Young	48
Cell grazing	NSW Central	Narromine	39
Jojoba	NSW Central	Lachlan	69
Oil Mallees	WA Northern (1)	Coroow	9
	WA Northern (2)	Coroow	-1
	NSW Central	Lachlan	17
Broombush	Vic High Rainfall	Strathbogie	-78
	SA Vic Bordertown Wimmera	Central Gold field	-67
Maritime pine	SA Vic Bordertown Wimmera	Central Gold field	-67
	SA Vic Bordertown Wimmera	Horsham	-92
Eucalyptus	NSW Northeast	Mudgee	66
Red river gum	NSW Central	Corowa	-29
	NSW Northeast	Mudgee	-40
	NSW Vic Slopes	Young	-117
	NSW Northeast	Quirindi	-17
Firewood	Vic High Rainfall	Strathbogie	-92

[a] Includes removal of long fallow [b] This is the profit difference after a decade of sequential use of deep-rooted perennials. It represents the profit difference between a system that has become saline versus a system that prevents saline impacts.

A common difficulty facing Kingwell *et al* was the paucity of data regarding the impact of the various management options upon recharge. Accordingly, the analysts concentrated on assessing the current profitability of the various options, noting that their exact impacts upon reducing recharge were unknown in most of the situations.

The key findings from the over 40 case study and regional analyses, supported by other recent studies (e.g. Abadi *et al*. 2003, O'Connell and Young 2002), were:

(i) Lucerne is comprehensively a profitable inclusion in farming systems in a range of GRDC zones. Phase rotations that incorporate lucerne, or lucerne rows with crop interrows, were both profitable systems. In most situations inclusion of lucerne boosted annual farm profit by between 2 to 33 $/ha of farm arable area, in spite of lucerne usually only being planted on a small portion of the farm. Although the profit generated per hectare of lucerne could be around $100 or more per hectare, to adopt lucerne farmers need to be aware of its management requirements and that on each farm there is an optimal area of lucerne. Planting additional areas beyond that area will only decrease farm profit.

(ii) Where land is already saline then incorporation of saltland pastures into the farming system is shown to be profitable in all case studies examined by Kingwell *et al*. Saltland pastures boost farm profits through a more productive use of saline areas. In the situations examined inclusion of saltland pastures boosted annual farm profit by between 2 to 6 $/ha of farm arable area, in spite of the small portion of the farm devoted to these pastures. The saltland that formed the basis of analysis was mostly of reasonable quality, sufficient to support productive stands of salt tolerant fodder species. The profit generated per hectare of these stands of pasture was as high as $120 per hectare.

(iii) In relative terms, lucerne usually generates more profit for most farm businesses than saltland pastures because in many situations it prevents salinisation and allows highly profitable crops to be grown either as interrows or between the phases of lucerne production. Once the productivity potential of a soil is lost through salinisation then the introduction of saltland pastures, at best, only improves farm profit from a reduced profit base due to salinity impacts.

(iv) In some circumstances, because only relatively small areas on a farm will be sown to lucerne or other profitable deep-rooted perennials (eg tagasaste), their contribution to countering the overall salinity threat will be minor.

(v) The use of native perennials and the replacement of bare fallows also offers opportunities for additional profit and greater water use. However, in many situations farmers eventually will need to consider engineering and tree-based options.

(vi) A dilemma for many farmers, in spite of tree planting efforts to date, is that there are no readily available profitable tree options for widescale planting in most grain-growing areas. Analyses of many tree options show, in general, they are yet to be a more profitable extensive use of agricultural land than current crop and pasture options. There are a few exceptions, such as oil mallees and *eucalyptus radiata* (Abadi *et al*. 2003), in some situations.

(vii) Tree options may be extremely effective in improving hydrological balances in soils at risk of salinisation, yet their comparatively low profitabilities and long payback periods militate against their adoption.

(viii) Most of the farmers participating in the analyses were unaware of just how profitable were the changes in their farm management to address salinity concerns. Also most were not sure, in prospect, of how effectively recharge would be reduced and the consequential impact on the spread of salinity.

(ix) Perennial fodder species appear to offer the best short to medium term prospect of providing a means of managing salinity in most agricultural zones. However, in many situations they may not be profitable *at the scale* required to have a significant impact on the rate of spread of salinity on farmland, or the rate of increase of saltload in rivers and streams. Hence, although profitable inclusions in farming systems, in many situations, they may only slow or delay the onset of salinity.

Engineering Options

The ABS (2002) also reported farmers' utilization of engineering options. As shown in Table 8 surface drains and deep open drains are very popular in WA. As watertables rise in other grain growing zones, affected grain farmers increasingly will consider these sorts of drainage options.

Table 8. Earthworks for salinity management

State	Levees/ banks	Shallow open drains	Deep open drains	Subsurface drains
No. of farms				
NSW/ACT	921	756	82	158
Vic	440	894	158	250
Qld	492	63	18	21
SA	197	284	62	18
WA	3356	1992	1370	184
Tas	20	141	33	12
NT	4	-	1	-
Total	5429	4130	1724	643
Length ('000 km)				
NSW/ACT	10	2	-	2
Vic	2	3	-	1
Qld	10	1	-	1
SA	2	2	-	5
WA	67	17	11	1
Tas	-	1	-	-
NT	-	-	-	-
Total	92	25	13	11

Source: ABS (2002), Bulletin 4615.0

Coles *et al*. (1999) is one of few economic analyses of drainage options for farmers. They report on the efficacy of deep open drains in the wheatbelt of Western Australia and list the factors affecting the profitability of drainage. The list includes the cost of drain construction and maintenance, the frequency of maintenance, the timing, duration and extent of land reclamation, the increase in average returns after reclamation and the interest rate on borrowings (or the opportunity cost of funds used to finance the earthworks). They show that deep open drains which cost around $5000 per kilometre to construct usually need to reclaim a minimum of 5 hectares per kilometre of drain in order to break even. In many of the cases they reviewed the area reclaimed was less than 4 hectares per kilometre and rarely exceeded 8 hectares per kilometre.

Another engineering option for some farmers is groundwater pumping. Its purpose is to lower watertables and thereby lessen the risk of trees, shrubs, pastures and crops being affected either by waterlogging or rising saline watertables. The economic aim of pumping is to maximise the benefits from a fall in watertable while spending the least possible on pumping.
The effectiveness of pumping crucially depends on the nature of the water-bearing formations (aquifers) that are subject to groundwater pumping. There are three major aquifer categories: confined, unconfined and semi-confined. Semi-confined aquifers represent the majority of deep aquifers in the main grain growing zones of WA. By contrast, unconfined aquifers are much more common in grain growing zones of the Murray-Darling Basin. Hence, the many case studies of groundwater pumping in the Murray Darling Basin are of limited relevance to farms in the GRDC Western Region.

The other aspect of aquifers that is important for groundwater pumping is their hydraulic properties. The ability of aquifers to transmit water (rather than just their ability to hold water) is called hydraulic conductivity. This property affects the effectiveness of groundwater pumping in lowering water tables in unconfined aquifers, and the hydraulic head in confined and semi-confined aquifers (Dogramaci 2002). Determining if pumping is cost effective is often a complex task due to variation in the scale or nature of the groundwater problem.

In 2001 cost-benefit analyses of groundwater pumping were carried out for six rural towns in the WA Central and Northern zones (Brookton, Corrigin, Cranbrook, Katanning, Merredin and Morawa). The main conclusions were that the groundwater pumping was expensive and difficult to justify when compared to the local damage cost (Dames and Moore 2001). Of the six rural towns reviewed, the Katanning town site had the most saline-affected land and potential damage to infrastructure and buildings due to rising groundwater. The predicted damage bill of $6.9 million for this town equated to approximately $1800 per resident and exceeded the combined potential damage costs for the other five towns in the study. To meet the damage costs without controlling and lowering the groundwater tables would cost the town approximately $6.9 million (discounted at 7 per cent). In contrast to this, the estimated control cost to prevent further rise and lower existing groundwater levels by groundwater pumping would cost the town approximately $7.6 million (discounted at 7 per cent). Hence, even in this case where the threatened damage to town infrastructure was high, the groundwater pumping remedy would cost residents even more.

For farmland which has much less asset value per hectare compared to townsites, pumping to combat the impact of farmland dryland salinity will rarely be cost-effective on the scale needed to address the widespread salinity problem. In specific situations where the assets being protected have high value and where aquifer characteristics make pumping highly effective, then pumping might be economic.

As saline watertables rise, demands for deep open drains and surface water management will increase. The safe removal of water from farmland will become an increasingly important and potentially vexatious issue, potentially made worse by government failure to regulate degradation of farm, water and natural landscapes.

In some situations farmers may opt to discharge groundwater and surface water at expense to downstream wetlands where the salinity, salt load and hydroperiod of the receiving wetlands increases. The altered ecology of the wetlands will affect the ecological services they provide. Hence, establishing safe disposal sites for saline waters harvested from farms will become vital to the environmental viability of surface water management and deep open drains as salinity management options.

Commercial Use of Saline Water

The main options to use saline water for commercial purposes in agricultural regions involve aquaculture, desalinisation, energy generation and mineral harvesting. George and Coleman (2001) outline the nature and current commercial attractiveness of these options.

Aquaculture

Aquaculture can involve minimal capital investment, as a sideline enterprise, or substantial capital investment as a specialized activity. Currently, aquaculture has good potential for recovery of its infrastructure costs (Actis 1999). Depending on the salinity of the groundwater, various finfish species can be produced such as rainbow trout, barramundi, bream and snapper (Lawrence 1996). However, its labour intensive nature makes aquaculture relatively unattractive for a majority of grain growers. This is not to say that groups of farmers forming co-operatives or companies, or establishing joint venture arrangements with private companies, may not be feasible ways of developing these enterprises. However, the transaction costs of forming these arrangements limit their likelihood of widespread adoption in farming areas.

Desalinisation

Winter *et al* (2002) review desalinisation methods and costs. They reported costs of desalinating water, using current technologies, of between $0.80/kL to $2.10/kL, depending upon the process, location and the potential for blending with marginal quality groundwater. These costs, however, did not include disposal or distribution costs. In grain growing regions of Australia disposal of brine inland presents some difficulties as it may either exacerbate groundwater salinity (Fath, 1998; Buros, 1999), or result in an additional disposal expenses (for example, lined evaporation basins or impounding underground). In some cases the brine may have an economic value (for example, as chemical salt) but the potential scale of this would probably be small relative to the production of brine if desalination became a major source of fresh water (Water Corporation, 2000). Little information is available on the environmental impacts caused by desalination processes (Squire *et al*. 1996).

The cost of desalting is determined mostly by the feedwater salinity level, energy costs and economies of size. Reverse osmosis is currently the most economical in many situations due to its lower energy consumption. Its cost per unit of desalted water is primarily determined by membrane life and energy cost (Ericsson *et al* 1987, Wade 1987). Winter *et al* (2002) point out that currently in most countries (including Australia) prices charged for traditional water supplies are generally cheaper than the full cost of desalinating water. However, it is likely that the gap will diminish due to the higher costs of finding, maintaining and delivering new fresh water supplies; combined with technological improvements that improve the efficiency or prolong the effective life of membranes.

Where major fresh water supplies are being threatened by salinity and the costs of its prevention are very large (as in the Murray-Darling basin), then desalinisation may eventually be a cheaper engineering option.

Mineral Extraction

Mineral extraction can lessen salt loads by removing saleable quantities of halite (common salt) and magnesium, calcium and potassium salts. Halite makes up over 50% of the salts in most brines but not all of this is recoverable. Halite is extracted by allowing brine in ponds to evaporate to saturation (at near ten times seawater concentration). The saturated brine is then pumped or gravitates into specially prepared ponds. After the crystals of salt have formed they are then mechanically harvested and processed. Processing may include washing, drying and sorting before being bagged ready for sale. The remaining minerals such as the magnesium salts can then be extracted using a patented process such as SAL-PROC (Ahmed *et al*. 2000) or sold as a road base additive or dust suppressant.

Although several relatively small halite-based ventures exist in grain growing regions (e.g. Kalannie, Corrigin) most mineral extraction processes require very large inputs of brine to be profitable. For instance, the standard SAL-PROC process requires an annual brine supply of more than 2,000 ML. Only by targeting niche markets is it possible to support smaller production systems.

To convert saline groundwater into a range of mineral products requires a range of conditions and technical and managerial abilities. For example, a high level of technical and managerial skill, as well as capital investment in cleaning and drying processes, is needed to produce quality salt that requires the salt to be over 99.9% pure and for the salt crystals to be of a uniform large size. Yet even quality salt only attracts a price of $A60 per tonne. Given this low value of a final product, any cost or loss through setup and/or processing can rapidly make salt mineral extraction non-commercial.

Electricity Generation

Solar brine ponds can be constructed to generate electricity (Ahmed *et al*. 2000). Several environmental and economic conditions must be satisfied to ensure such commercial ventures are profitable (PPK 2001). The generation of heat requires a large pond with a large salinity gradient from the top to bottom. In Australia, most solar ponds service small communities or are mainly experimental. The generation of solar pond energy can be matched to desalinisation. Disposal of waste brine from a desalinisation unit can be used in the solar energy plant. It has been estimated that a ten-hectare solar energy salt pond will generate 200,000 KWh of low grade energy ($130,000) per year in northern Victoria at a capital cost of $300,000 (Akbarzadeh and Earl 1992). The operating costs have not been stated but they would be significant. Accordingly, the market environment for electricity generation means that solar pond energy will only become widely established if there are some policy or market changes to provide additional incentive for provision of solar pond energy.

Section 3: Concluding Remarks and R&D Priorities

This paper has explored the spatial ramifications of the spread of salinity in Australia's agricultural regions. Over the next 20 years a further 1.1 million hectares of farmland is forecast to become salt-affected, yet there are marked regional differences in the size and rate of this spread. Some grain growing regions such as the WA Sandplain, SA Vic Bordertown Wimmera, NSW Vic Slopes, WA Central and Vic High Rainfall zones will experience large increases in areas affected by salinity. Many of these zones are main sources of Australian farm profit. Hence, declines in farm profit due to salinity within these zones could potentially have damaging consequences for overall grain industry profits. Further, of these zones the SA Vic Bordertown Wimmera and WA Sandplain zones face major salinity challenges as the impact costs of salinity equate to forecast percentage annual reductions in farm profit of 7 and 10 percent respectively. To overcome such reductions in profit, especially in the face of a likely continuance of adverse cost-price movements, large increases in enterprise productivity or new profitable enterprises will need to be introduced.

By contrast, in the other two zones particularly affected by salinity, NSW Vic Slopes and WA Central zones, combating the negative impact of salinity is a more feasible challenge. The forecast annual reductions in profit due to salinity in these two zones are only 3 and 2 percent respectively. The marked differences between zones in the forecast impacts of salinity mean there are also differences in the size of the challenge to farming systems in these zones. The profitability of some farm businesses in some zones will be very reliant on salinity management innovations. If these innovations do not emerge to protect or boost farm profit then the viability of these businesses will be eroded quickly.

The farm-level profitability of a range of options for salinity management was assessed. A main finding was that deep-rooted perennial fodder species appear to offer the best short to medium term prospect for managing salinity in most agricultural zones. This finding helps counter a common view that perennials are less profitable than traditional enterprises. For example, Pannell *et al.* (2001) mention 'the very adverse profitability of current perennial plant options' (p. 469). However, other comments of Pannell *et al* are consistent with conclusions of Kingwell *et al.* (2003) that often perennials may not be profitable *at the scale* required to have a significant impact on the rate of spread of salinity on farmland, or the rate of increase of saltload in rivers and streams. Hence, although profitable inclusions in farming systems, in many situations, they may only slow or delay the onset of salinity. So the central R&D challenge for salinity management remains the need to:

(i) discover new species or improve the relative profitability of existing species that reduce recharge while being profitable wide-scale inclusions in farming systems;

(ii) develop cost-effective appropriate engineering options, including desalinisation technologies and
(iii) develop profitable farming systems that incorporate salt-affected land.

When considering how to manage the salinity threat on their farm, farmers are often unsure about:
(i) how rapid will be the onset of salinity on their farm or what type and scale of response across their farm is required to negate the threat of salinity.
(ii) whether the current and future actions of neighbours will be a main influence upon the easing or worsening of their own salinity situation. The extent to which coordinated catchment-based action complements the actions of an individual farmer is often uncertain. The long lag between farmer action and hydrological response at the catchment level can compound the difficulty of knowing what is a sound, profitable investment decision.
(iii) whether profits foregone in investing in large scale salinity management will be greater than the future costs of salinity upon land productivity.

In making investment choices often a farmer is mostly concerned with the relative profitability of current alternative land uses. A farmer needs to know how alternative systems compare given current conditions as well as how the systems may fare in the future. To invest in managing salinity problems, ideally a farmer needs to know the nature of the emerging salinity threat on his farm, the efficacy of alternative systems in reducing salinity problems and their current and future relative profitabilities. At times much of the required information is site-specific and subject to uncertainty. Hence, an overarching R&D challenge is to generate or provide information and principles or rules of thumb relevant to different settings that might facilitate farmers' decisions about investment alternatives for salinity management.

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