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Economic and physical attributes of dryland salinity in NSW: A review

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Recently the funds allocated to combat the increase in dryland salinity have been increased substantially. A small proportion of these funds will be used to undertake economic analyses. As part of the NSW salinity strategy economic studies will be undertaken to determine the viability of management options. The complexity of the problem demands a sophisticated approach to quantifying the benefits of management. During the past 15 years a range of economic modelling studies have been completed in different areas of the state, and extensive effort has been undertaken to collect physical data to characterise the problem and the options for salinity management. It is appropriate, therefore, that the nature of the salinity problem, the issues that have been studied, and the methods applied by reviewed to explore the economic significance of the problem and gaps in current knowledge. This information may assist in determining future priorities for economic analysis type of methods that could be employed.

Keywords: dryland salinity, salinity management, economic analysis

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1 Introduction

The implementation of the NSW Salinity Strategy has seen funds allocated to develop economic models to examine the benefits of managing salinity. Models are to be developed at the farm and catchment scale. Until the implementation of the strategy state agencies in NSW had dedicated few resources to salinity economics. However a number of quantitative studies have been undertaken throughout Australia to examine the economics of dryland salinity and many of these have focussed on the issue in NSW.

Quantifying the social welfare implications of salinity management is a seemingly intractable problem. A number of factors may have significant influence on the net benefits of proposed action or set of actions. These are: the physical nature of the problem, spatial variability of underlying relationships, impacts on multiple stakeholders and the trade-offs between their multiple objectives, institutional influences on stakeholder behaviour and incentives, and the impact of potential mixes of amelioration practices. This complexity means that sophisticated quantitative methods of analysis are potentially important in influencing approaches to salinity management, policy development and the allocation of public resources.

The aim of this paper is to review the quantitative economic studies undertaken for NSW to determine the methods applied, the nature of the problems analysed and the regions and stakeholders targeted. The influence of the nature of the salinity problem and the application of economic models is discussed and gaps in current knowledge identified. This may provide some insights into where economists might most usefully focus future effort.

A comprehensive review of regional economic studies of dryland salinity was undertaken by van Bueren and Pannell (1999). They described the features of the reviewed work and the strength, limitations and relevance. This review differs in that it focuses on fewer studies, primarily those undertaken in NSW, describes them in more detail and includes more recent work. The issues examined by the studies are also discussed with a view to providing insights into the gaps in current knowledge and what future work is needed in NSW.

Section 2 provides an overview of the problem of dryland salinity in NSW and the associated economic implications. Section 3 reviews a number of modelling studies undertaken in NSW and

Section 4 discusses the economic significance of secondary salinity and the implications for economic modelling of the problem. Section 5 outlines the conclusions of the paper.

2 Nature of salinity problem in NSW.

2.1 Extent of the problem in NSW

Approximately 180,000 hectares of land in NSW is affected by watertables within 2 metres of the soil surface or soil salinity. This is predicted to increase to 1.3 million hectares by the year 2050, out of a total of 17 million hectares nationally. Of the total predicted increase, over 750,000 hectares of saltland is likely to occur in the Murrumbidgee and Murray River catchments. Over 400,000 hectares of saltland is likely to occur in the Lachlan, Castlereagh and Macquarie catchments (National Land and Water Resources Audit, 2001).

Of the total area currently with shallow watertables, around 75% is pasture land. Pasture land is of much lower economic value than other land uses, so the potential benefits of ameliorating or reducing the rate of spread are relatively low. Only around 15% of the areas predicted to be salt affected is cropping land. The remaining 10% is made up of towns, infrastructure, such as roads and bridges, and environmental assets. The area of land predicted to have shallow watertables by 2050 as a proportion of total landscape, is around 1.5%.

In comparison to other States, dryland salinity appears to be much less of a problem. Victoria, Queensland and Western Australia are expected to have affected areas greater than double the affected area of NSW. It is predicted that WA could have up to 30% of agricultural land affected by salinity in the future.

However, according to some specialists a significant proportion of the problem of rising saline groundwater in NSW occurs in catchments where the surface expression of rising watertables is discharge into rivers, rather than the soil surface. Saltloads of major rivers in NSW are predicted to more than double and the salinity levels could increase by up to three times the current levels. This could have severe implications for down stream users, such as householders, manufacturing businesses, irrigators and environmentally sensitive assets.

It is pertinent to note that these predictions are substantially less than earlier estimates (Bradd, J and Gates 1995 cited Greiner and Cacho) and current predictions may also overestimate the future extent of the problem. A major determinant of the expression of rising watertables is the catchment topography. Past predictions have taken no account of topography, due to the lack of suitable tools.

2.2 Causes of salinity and potential solutions

The causes of salinity are well understood and well documented (eg Coram *et al* 2001, Petheram 2000). Clearing of native vegetation and the introduction of shallow rooted annual species have increased accessions of rainfall to groundwater. Annual species are less efficient at using soil water than the perennial species they replaced. They cannot access water deeper in the soil profile and they grow slowly in the cooler months when rainfall is high and evaporation low. They are also unable to use water that falls after senescence unlike perennial species (Coram 2001). Native perennial species are better able to extract soil water in the cooler months and utilise summer rain when it falls.

Higher recharge occurring under annual plant species causes a rise in groundwater levels. Rising groundwater mobilises salt that has accumulated in the soil profile as a result of deposits by wind and rain over hundreds of thousands of years. Eventually saline water is discharged on the soil surface or directly into streams, causing a decline in production of affected soils, damage to infrastructure and public and environmental assets. This results in significant costs to businesses, government and the community.

Management solutions to salinity can be broadly classified into two groups: recharge management and discharge management. Recharge management is aimed at reducing accessions to the watertable thereby slowing or preventing further rise. This will reduce the outbreak of salt on the soil surface and/or prevent adverse affects of high saline watertables on plant production and infrastructure. Planting perennial plant species that better utilise the available soil water is the primary means of achieving this.

A complementary strategy is to reduce the discharge of saline water into streams or to the soil surface by extracting water from the watertable. Salt tolerant plants may have a role in rehabilitating saltland by limiting the rise in groundwater. Alternatively engineering works aimed at draining shallow watertables or pumping of groundwater may provide solutions. Saline water removed from the aquifer could be used in a range of productive activities including aquaculture and power generation.

2.3 Economic significance

The economic significance of the problem depends on the costs of implementing management strategies and the benefits that will accrue by reducing the rise of saline groundwater. The factors influencing the costs of and benefits of salinity management are summarised below:

Benefits

- Reduction in the rate of recharge
    - Area of salinity prevented (at a point in time)
        - Economic value of land prevented from going saline
        - Value of environmental asset saved
        - Reduce repairs and maintenance of infrastructure and assets
        - Costs of reduced life of assets
    - Reduction in saltload and salt concentration in rivers
        - Value of environmental asset saved
        - Reduced repairs and maintenance of infrastructure and assets
        - Costs of reduced life of assets
        - Reduced production costs of businesses (eg irrigators and manufacturers)
        - Increased production of businesses
- Time lag in response to management
- Additional benefits of management (such as reducing other forms of soil degradation or provision of environment services)

Costs

- Scale of management required
- Up-front investment required to adopt practice
- Annual maintenance costs of salinity management practices
- Forgone profits from management changes

In assessing the priorities for action it has been suggested than 3 criteria are applied:

1. Only where high value assets are at risk
2. Management practices are profitable or near profitable

3. Response times to management are short

Where these criteria are met it is more likely the problem is economically significant, in that the net benefits of preventative action will be positive. The criteria are largely dependent on the physical factors above. The following discussion focuses on the physical nature of dryland salinity in NSW and the economic implications.

2.3.1 Physical characteristics of catchments

Coram (2001) characterised catchments according to their size and the capacity to store water and ease with which groundwater can flow through the subsoil. They defined three categories of groundwater systems: local, intermediate and regional.

Local systems

Local systems are small in size with high relief. The extent of groundwater flow may be up to 5km so recharge and discharge occurs within a relatively short distance of each other. Groundwater flows do not occur across catchment boundaries so the impact of management on the watertable is confined to the immediate area of the catchment. Once cleared, catchments with local groundwater systems generally reach a new hydrological equilibrium within 3 decades and the impact of reducing recharge on the watertable can be expected to take from 5 to 20 years. The effectiveness of different management strategies depends on the geology and the geomorphology of the catchment, which influence size of recharge areas, depth and speed of lateral flows of groundwater and area of discharge. Typically, introducing perennials to the landscape provides a feasible means of reducing the rise of saline groundwater.

The outbreak of salinity on farmland in local systems is likely to be a result of management decisions of the landholder, rather than his/her neighbour. However this does not imply that the socially optimal area of salinity will be the same as the private optimum because the rising watertable may also discharge salt into streams. Third parties cannot be excluded from capturing the benefits of salinity management actions in this case, so farmers may under invest in salinity reduction. The extent of under investment is dependent on the off-site benefits of reducing stream salinity compared with costs of changing land use.

In NSW the dominant groundwater flow systems where the risk of dryland salinity is high are local (Evans, R. pers comm and Nicholson, A. pers comm). The area of soil salinity is frequently very small, while the expression of rising saline groundwater is mainly in the rivers. River salinity costs downstream users from the non-agricultural sector as much as $6.3 million annually in the Central West region of NSW (Wilson 2001). This figure is $4.1 million for the Murrumbidgee and $3.4 million for the Lachlan. Additional costs are borne by government by way of infrastructure repairs and maintenance and decreased crop yields in irrigation areas. It is unclear to what extent these costs can be reduced but the dominance of local groundwater systems offers some potential to reduce salinity impacts at relatively low cost.

Intermediate systems

Intermediate groundwater systems may also be confined to a single catchment or may flow between small catchments. They usually occur in valleys in regions of low relief and the points of discharge and recharge be separated by up to 10km. The larger distance and lower relief tend to reduce the rates of lateral flow. Changes in management aimed at decreasing recharge may have a delayed impact of between 50 and 100 years.

Perennial species typically need to be planted over an extensive area to reduce recharge sufficiently to affect the rise in watertable. The reduction in the area of salinity would be small relative to the scale of the management changes required. The distance between points of recharge and discharge mean that farmer actions may affect the area of salinity of his neighbour(s). The slow response times to management means that discounting will substantially reduce future benefits. Therefore the optimal area of salinity for the community will be similar to the private optimum. Net benefits derived from action within the zone influencing the hydrology will often be insignificant after discounting for the time value of money. This is demonstrated (Heaney *et al* 2001), when they examined the net benefits of targeted reafforestation assuming time lags to a new equilibrium of at least 50 years. The net benefits of reducing recharge were generally very small or negative except were groundwater salinity was over 5000 mg/l. Salinity levels in NSW are generally lower than this (Coram *et al* 2001). Recharge management is, therefore, likely to be socially optimal only where perennial plant species are more profitable than current production options. In NSW intermediate groundwater systems are much less dominant than local systems in those areas where there is a risk of high watertables.

Regional systems

Regional systems occur in areas of very low relief and occur over broad areas. Regional aquifers are extensive and can occur over 100km or more. In some case they may underlie local and intermediate systems. Because the distance between recharge and discharge is so large it may take 100 years or more to reach a new hydrological equilibrium after clearing. Response time to management is of a similar order. It is very unlikely in these systems that the external influences of farmer action will be economically significant. That is to say the social and private optimum areas of salinity are very likely to be coincident. Regional and intermediate groundwater systems are influential in around 30% of the landscape where there is a high risk of salinity in NSW.

2.3.2 Trends in salinity

The area (and levels in rivers) of salinity prevented will be the difference between the increase in the absence of salinity management and the change resulting from the adoption of management practices. In general, salinity levels in rivers and the area of high water tables are expected to increase for many decades. However it is not universally the case. It is reasonable to expect that watertables in many catchments have already reached the maximum level. Most regions where salinity is a risk have been farmed for many decades and the equilibrium response times of local groundwater systems are much shorter than this. There is some evidence to support this. For example, measurements of the area of salinity taken on a farm in the Central West of NSW indicate the long-term trend for the area of salinity is flat. In the medium term the area of salinity changes according to rainfall. Figure 1 shows the cumulative rainfall for a farm relative to the long-term average. The arrows indicate points where the area of salinity was assessed. The upward arrows indicate an increase in area of salinity and the downward arrows indicate a decrease in the salinity area.

To determine the benefits of recharge management it is necessary to understand the impact of decreased recharge on the cyclical salinity levels. It is possible that quantifying the benefits according to the change in the average level of salinity is not reflective of the actual benefits. If so, it will have implications for the optimal level of salinity management.

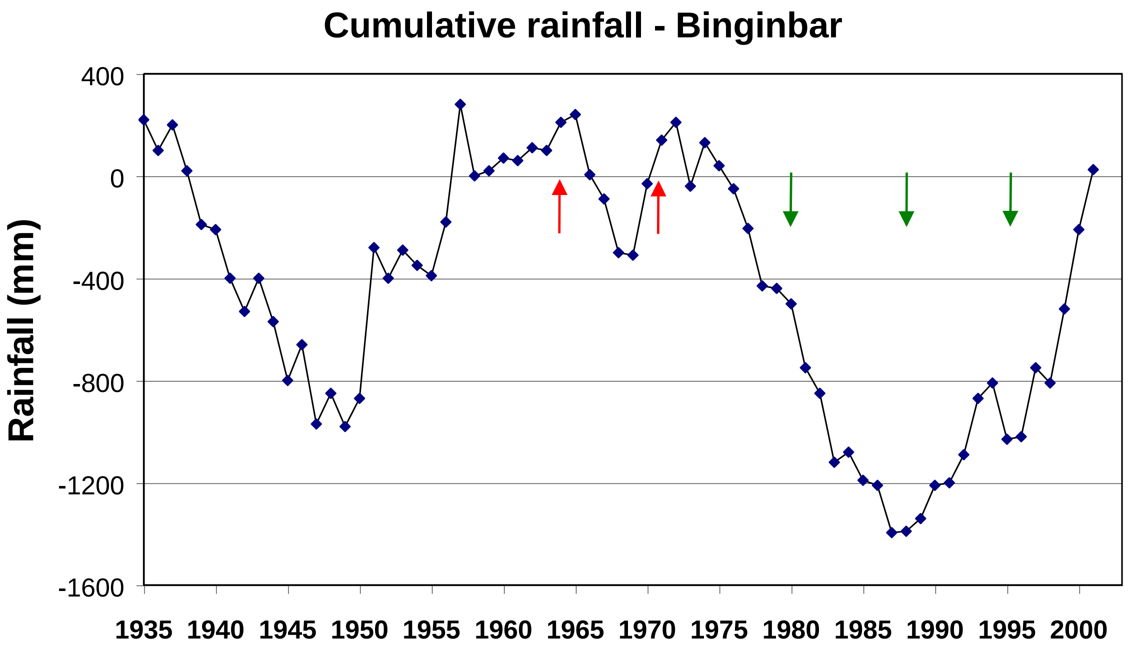

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Figure 1. Cumulative rainfall from 1935 to 2000. Arrows show point at which estimates of the area of salinity were made and the change in trend.

2.3.3 Spatial variability

Soils

Soil characteristics will also have an important influence on the economic significance of the salinity. Soils are a primary determinant of the suitability (profitability) of different plant species that may be employed to manage salinity. Also, the nature of the soil affects the amount of water that leaks past the root zone that may end up as recharge. There is a large variation in recharge between soils (Petheram *et al* 2000); sandy soils contribute more to recharge than do clay soils for a given level of rainfall. The relationship is only general, however, as differences occur within soil types, depending on factors such as the depth the watertable and presence of preferred pathways. These are channels or cracks in the subsoil that enable water to flow vertically more rapidly

(Petheram *et al* 2000). Cost effective management will depend on identifying those soils that contribute most to recharge and their spatial distribution within the catchment. Spatially variability of soil types (and hence recharge) can be large within a catchment.

Run-off of surface water into streams is also a consideration for determining effective management. It too is partly dependent on soil properties. Establishing perennial vegetation will reduce run-off and hence the yield of water in rivers, on which irrigators, businesses and communities are reliant. A key economic consideration is that run-off is reduced more quickly than discharge. Therefore the salinity level of rivers may rise initially increasing the cost to downstream users. Land managers need to target those areas of the catchment where the impact of management on run-off is low relative to its impact on discharge.

Saltstores

Salt accumulation in the soil profile is not uniform across the landscape. Similarly the levels of salt in groundwater can vary over short distances. Figure 2 shows the salinity level in the Talbragar River, a tributary of the Macquarie River in the Central West of NSW. The *x* axis is the distance along the river from the junction with the Macquarie River. The point of interest is where there is a marked increase in the salinity levels at around 80km upriver of the Macquarie. This indicates the catchment at this point of the river is a major contributor to saltload in the Talbragar River or a minor contributor to run-off. These differences also exist between catchments. Data collected in 1998 for the Macquarie (Beale *et al* 2000) show that the Bell River catchment and Buckinbah Creek catchment (a tributary of the Little River) contribute a greater proportion of salt to the Macquarie River than they do run-off. The variation of the geology and geomorphology between co-located local catchments indicate that this variation also exists at a smaller scale.

Heaney *et al* (2001) showed the importance of groundwater salinity to the benefits of recharge reduction. Reducing discharge from a catchment with high salinity will reduce the costs to downstream users to a greater amount than a catchment with lower salinity. Identifying catchments with local groundwater systems and high saltstores is likely to be an important step to the implementation of salinity management strategies that are cost effective.

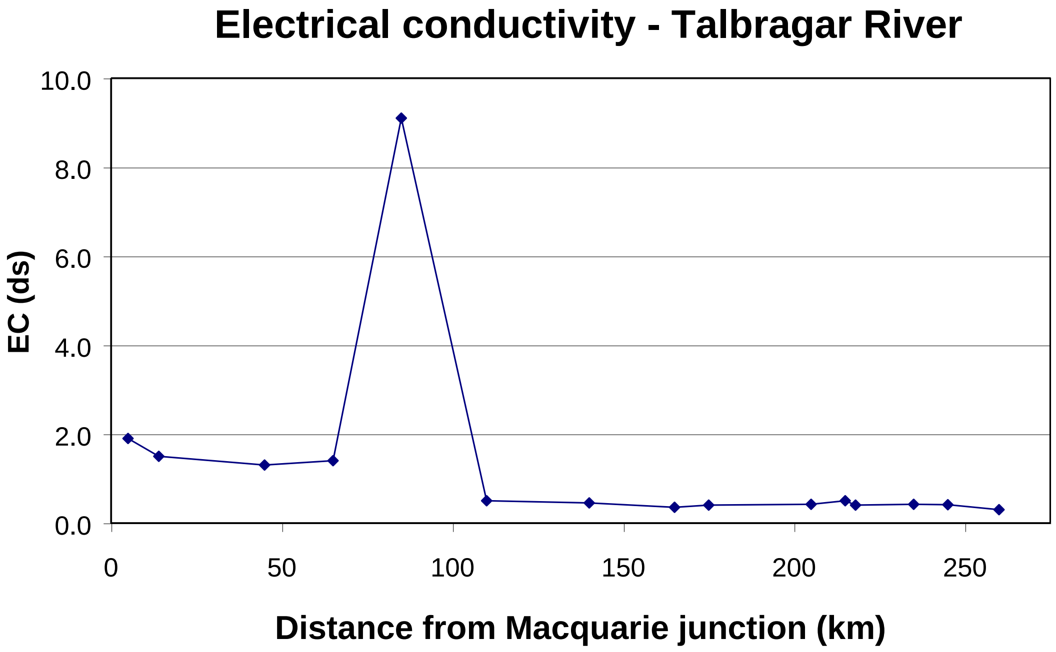

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Figure 2. Salinity levels of the Talbragar River at increasing distance from the junction with the Macquarie River

2.3.4 Management options

In the presence of market failure, adoption of salinity control strategies may be beneficial even when they are less profitable than current practices. However, these strategies must at least cover establishment and maintenance costs and contribute to net revenue. The level of net revenue needed to ensure positive net benefits will depend on the size of the off-site benefits (Bathgate and Pannell, 2002).

Lucerne is one of few options that offer some potential to significantly reduce recharge. It was grown on large areas during the 1970's, however its persistence was adversely affected by lack of resistance to insects. While newer varieties have improved production and persistence the adoption remains below past levels. Field staff have estimated that between 5 and 20% of the land in catchments in the Central West is currently sown to lucerne (A. Nicholsen, pers comm). For many farmers it is likely that larger areas of lucerne would improve profits. Adoption is not higher because of past low wool prices, the capital required for establishment, higher requirement for management compared to current species and increasing soil acidity (C. Hertel, pers comm).

3 Review of economic studies

A large range of analytical methods has been applied to the studies reviewed. They can broadly be classified into simulation and optimisation models. Simulation models can represent a greater level of complexity than optimisation models, however the strategies have to be specified for each run. The profitability and salinity impact of different strategies can be compared by undertaking multiple runs. Determining the strategy that best meets the objective of decision-makers (such as land managers) can be time consuming and require a large number of runs.

Optimisation models have an advantage in that a range of strategies can be compared in a single model solution. Resources limiting production are readily identified and information on the relative profitability of sub-optimal strategies is provided for each run. However, problems need to be specified accordingly to strict rules and this limits flexibility. In general, the complexity of managing, running and interpreting results of models increases exponentially as the number of variables increase. This often means trade-offs are made in how different components of the problem are specified. For example, dynamic models may simplify spatial aspects of the problem to accommodate the temporal aspects.

Some studies have applied both optimisation and simulation methods (eg Heaney *et al* 2001, Greiner and Hall 1997)

3.1 Simulation

The simulation studies have been further categorised into process and budgeting models. The term process is used loosely here describing those models that have represented biological and/or physical aspects of the problem explicitly using generalised mathematical functions (Gorddard forthcoming, Heaney et al. 2001, Heaney et al. 2000, Wilson 1994, Dumsday and Oram, 1998). This enables the models to be readily parameterised for different regions.

Gorddard, (forthcoming) describes a novel modelling approach that could be used to explore the effects of land use change on multiple stakeholders. A prototype was developed for the Lachlan catchment that is yet to be fully validated. It is designed to assess social, environmental and economic consequences of land use change that may result from new policies or technologies. These consequences are tracked over 300 decision units within the catchment over a 20 year period.

Data for the decision units are derived from a number of sources. Production information is typically generated using simulation models. The model is designed to address a range of issues and considers a large set of stakeholders groups. Its focus is broad level analysis that quantifies trends over time of a number of variables.

Heaney et al. (2000) and related studies (Heaney et al. 2000, Heaney and Levantis 2001) use a simulation model developed at ABARE for the Murray Darling Basin. Catchments are divided into "blocks" to reflect regions with similar hydrogeological characteristics. Ground and surface water responses to changes in land management are described for each block. This enables the marginal benefits of recharge and discharge reduction for each catchment to be quantified. The Basin wide implications of salinity management can also be assessed. Representative farm models within each block are solved using an optimising routine to determine the production implications of increased salinity. These are linked to the simulation model to determine the economic implications of land use change at the catchment and basin scale. The studies reported in the literature that have used this model have determined the net benefits of targeted reafforestation in different catchments and for different hydrological characteristics.

Wilson (1994) and Dumsday and Oram (1998) use a farm level simulation (SOILEC) to determine the profitability of salinity management options. Dumsday and Oram (1998) apply SOILEC to the Liverpool Plains catchment to determine the private costs and benefits of salinity management. The catchment level implications of land use change are not explored because of data limitations. However, other case studies described in the same report applied a regional optimisation model to catchment level issues. Wilson (1994) accounts for the offsite impacts of salinity management strategies in the Kyeamba Valley by employing a simplified simulation model of the catchment. The model (SCASSE) quantifies the off-site costs of reduced water yield in rivers and the benefits of salinity reduction. These are added to the gross margins generated by SOILEC to determine the net social benefits of salinity management.

Five other studies have been completed that could be classified as simulation approaches (URS Australia 2001, Jerrems and Hill 1999, Smith forthcoming, Hill 1996, Read 2001). The first three of these used a long-term budgeting framework to quantify the net benefits of catchment scale plans. The studies considered the multiple benefits from ameliorating a range of degradation problems. The primary aim of these studies was to provide information to the community on the potential benefits to the catchment of implementing a particular management plan. Hill (1996) also applied a similar framework but was confined to looking at the benefits of salinity management. Information was obtained from the community where possible. The impact of proposed strategies on reducing degradation were based on expert opinion.

Read (2001) used spreadsheets to import data and undertake the necessary calculations using a damage cost function to compare the benefits and costs of salinity management. GIS information was used to determine the physical scale of salinity impacts and data obtained from simulation models was used to represent the hydrology of the catchment.

Advantages of budgeting models

The budgeting approach is much less costly to apply, in general, mainly because it is much less demanding of data. Point estimates of production functions (or damage functions) are used rather than estimating parameter values for generalised function. The former is more readily available and easier to estimate where unavailable.

Advantages of process style models

Process style models have an advantage in the ease with which they can be parameterised for other regions. This is not to imply that obtaining parameter values is straightforward, but these models provide a framework to undertake analyses that are consistent between regions. Whilst such models offer the potential of transferability, many are not. Poorly structured models or inadequate documentation frequently mean that such models are not applied beyond the region initially described in the model and often only by the developer or a small number of users. The costs of development to improve the ease transferability can be a factor that inhibits wider application.

A further advantage is that sensitivity analyses can usually be readily undertaken. Therefore the influence of different parameter values on the model results can be more easily tested. This provides an inquiring user a greater understanding of the factors that are most important in assessing the viability of salinity management options and the influence of policy on farmer behaviour.

3.2 Optimisation

A range of different approaches were applied to problems addressed by the optimisation studies reviewed. Different modelling methods were applied and different approaches to linking farm level decisions to salinity outcomes and net benefits of management at the catchment scale.

The representative farm models linked to the ABARE model (described in detail by Bell and Heaney 2001) used quadratic programming to assess the profitability of broadly defined farm enterprises and the impact of salinity on production. Quadratic programming differs from linear programming only in that the objective function is specified as a quadratic function. Production and resource constraints are specified as linear equations.

Quiggin (1991)used linear programming to solve farm level models to assess the implications of an open access regime of water extraction on the quality (asset value) of the Murray River. The analysis was repeated using a dynamic programming approach to determine the differences in resource usage that may result if the asset value was maximised. The sequential nature of water extraction from the river by farms in different regions enabled this problem to be formulated as a dynamic programming problem. The difference in asset value between the two approaches provided an estimate of the value of externality created by the open access regime.

Greiner (1996) developed a multi-period linear programming model for the Liverpool Plains of NSW to “investigate best land management and financial strategies” for farms affected by salinity. The hydrological relationships between farms were described to capture the catchment level responses of salinity to changes in practices. A discrete stochastic programming approach was adopted to describe climate variability between seasons.

Later studies undertaken for the Liverpool Plains combined a partial spatial equilibrium model with simulation routines within an LP framework (SMAC) to explore issues such as:

(i) role of forestry in salinity management (Cacho et al. 2001, Greiner 1998)
(ii) the influence of changes in property rights (Ullah and Cacho, 2001)
(iii) the optimal use of land and water resources in the face of salinisation (Greiner and Cacho, 2001) and
(iv) management responses to dryland salinity (Greiner and Hall 1997)

Aggregation in regional models

Optimisation models reviewed typically describe farms that are representative of a region. Within each region the production relationships and constraints are assumed to be similar. However, the degree to which the farms within a defined area are homogenous (in production, financial and physical characteristics) is tested for only one model (Greiner, 1996).

Hazell and Norton (1986) caution against the grouping of dissimilar farms. The main impact of aggregation errors is to over-estimate the mobility of resources on farms in the region. In reality, farms in a heterogeneous region will be less responsive to shocks, such as changes in prices and technology, than the representative model suggests. Responsiveness of farms may also be overstated if farm models do not adequately represent the constraints on resource use faced by farm businesses (ie too few constraints are specified).

Another potential cause of bias in farm models is the oversimplification of biological relationships that underpin farm production. In Australia farms typically produce multiple outputs. This occurs primarily because farmers are able to exploit complementarities between enterprises to increase profit. An understanding of these interactions forms an important component of business decisions. Failure to represent the interactions between enterprises has led to misleading results in some instances.

Pannell (1987) demonstrated that a model of farming systems in the WA low rainfall wheatbelt overstated the area of crop if the interactions between pasture and crop were not described. The extent to which this happens for other regions of Australia has not been tested. However, one study undertaken for the South Coast of WA examined the relative importance of different factors in the optimal area of lucerne (Bathgate and Blennerhasset 2000). Explicit consideration of a number of factors was shown to be important in assessing the profitability lucerne. The results contradicted those of previous less rigorous studies in the region.

Despite its potential importance, the appropriate level of complexity in a farm model is not easy to resolve. This is particularly so if temporal aspects of the problem are modelled, as would be expected for resource management issues. Two or more models of the same farm would need to be developed and the results compared. This can be time consuming and expensive to undertake. Funding for economic studies rarely provide the opportunity for such luxury. There is the added difficulty of increasing the complexity of optimisation models, as discussed above. The benefits of keeping models as simple as possible includes the reduced risk of introducing and/or detecting errors that may themselves have a significant impact on model output. Despite these difficulties it is apparent that the issue warrants further attention.

3.3 General results

Four studies indicated that conservation actions would result in net economic benefits. One of the studies of the Kyeamba Valley (Jerrems and Hill 1999) indicated a shift to perennial pasture would result in substantial increases in farm profit. Only 15% of the total benefits accrued as a result of reducing off-site costs. This included the benefits of reducing other forms of soil degradation resulting from the adoption of the proposed management plan. These results were consistent with the study by Wilson (1994) where it was found that farm income could be increased by adopting lucerne. In addition, the net benefits of reducing off-site impacts were found to insufficient to alter farm practices.

The Liverpool Plains investment analysis (URS Australia, 2001) showed that the benefit cost ratio of implementing a comprehensive catchment management plan would be marginally higher than one. As with the Kyeamba Valley studies the greatest proportion were on-site benefits in this study resulted accrued on-site. However production increases in this case were due to the amelioration of a range of degradation problems.

Heaney et al. (2000) determined the net benefits of targeted reafforestation in the Macquarie-Bogan catchment and concluded that it may be a cost effective strategy for reducing soil and river salinity. This is despite the reduction in surface water yield and the costs it imposes on downstream users. Two key determinants of the net benefits were the level of groundwater salinity and the responsiveness of aquifers to changes in management. Greiner (1998) and Cacho *et al*. (2001) also found that establishing trees in areas of high recharge was economically efficient from a catchment perspective. The benefits of increased production resulting from reducing the area of discharge outweighed the reduction of profit incurred by farmers in recharge areas. In other words the major benefits were the reduction in external costs of higher rates of recharge. Quiggin (1991) also found that the external costs association with salinity were economically significant, although the particular focus of this study was the allocation of water to irrigators and urban users.

Other studies (Smith forthcoming, Jerrems and Hill 1999, Read 2001) found that extensive changes in land use would generate insufficient benefits to cover costs of adoption and forgone income resulting from less profitable practices. In the case of the Billabong Creek study (Read 2001) the potential area of salinity was small and the area of recharge very large. Subsequently the benefits of the decrease in the area of salinity and reduced saltload in the Murrumbidgee were insufficient to compensate farmers for less profitable land use patterns.

Sensitivity analysis

Most optimisation studies conducted sensitivity analysis to explore the impact of different parameter values on the model results. For example, Heaney *et al* (2000) examined the impact of different levels of groundwater salinity and the time lag of the response of groundwater to management on the net benefits of reafforestation. Other studies determined the sensitivity of the optimal rate of salinity encroachment to land values and the rate of rise of groundwater (eg Greiner and Hall 1997) initial depth to groundwater, credit constraints, interest rates and recharge rates (Cacho *et al*, 2001). The majority of sensitivity analyses reported in the reviewed studies were conducted on aspects of the hydrology. The uncertainty of the hydrological characteristics of most catchments is likely to have influenced the priorities for analysis.

By testing different parameter values it can be determined how the optimal solution changes under different circumstances and how much worse off decision-makers would be if these different circumstances were ignored (Pannell 1996). Uncertainty is one of the main reasons sensitivity analysis is useful to decision-makers as it gives insight into the robustness of a strategy or plan and how broadly a policy or strategy might be applicable. This means that sensitivity analysis is a powerful tool for researchers that are often faced with specifying a model with limited data.

Given uncertainty is likely to be a key factor determining modelling priorities, it is interesting that none of the studies reviewed examined the impact of commodity prices on the optimal levels of salinity management. Much of the focus of salinity management is on perennial plant species, particularly pastures. Which of these species are adopted by farmers will depend largely the profitability of livestock that graze pastures. Changes in relative commodity prices may have a marked impact on the extent to which farmers are willing to adopt practices that reduce groundwater recharge.

4 Implications

4.1 Economic significance of salinity in NSW

Given the nature of the problem in NSW and the dominance of local groundwater systems in regions at risk from salinity, it is possible that external costs are economically significant in a large number of catchments. Salinity of the major rivers is a result of processes that occur in catchments that respond quickly to management, so benefits will be realised in the medium term. The high annual costs associated with river salinity in some regions (Wilson 2001) suggest that the major rivers are high value assets. In many regions, where saline discharge into rivers cause significant costs to downstream users, there is at least one management option that may be profitable (or close to profitable) on a large proportion of the landscape.

4.2 Economic modelling

The argument for the existence of market failure in at least some catchments is supported by results of some of the studies reviewed. Improved understanding of the extent to which the externality issue is a primary cause of salinity would come from focussing economic resources in regions that have to date received little attention. Identification of areas that can profitably grow lucerne (or other perennial species) is major limitation of existing data. An examination of the role of prices in affecting the optimal area may also provide information about the future potential value of correcting market failure where it is identified.

The complexity of the salinity problem and the variability between catchments limits what can be said about its economic significance. A number of studies have explored economic questions about salinity. Primarily they have focused on determining optimal management strategies. Some have explored the potential of different policies, in a general way, to address issues of market failure. The results have been useful in developing principles for salinity management and determining factors that are important in decision making. However, the general applicability of the results is limited. This is a reflection mainly of the paucity of data and relatively poor understanding of processes for specific locations. Development of more complex hydrological models alone will not improve this understanding in the absence of better data to determine the values of key parameters.

One means of attempting to address the uncertainty is for economists to participate in more collaborative work with hydrologists. This may improve the likelihood of obtaining data that better meets the requirements of economists and more reliably describes specific catchments. It may also reduce the need for economists to develop more complex hydrological models of catchments by utilising models already developed and decoupling the hydrology and the biology. This could provide a solution to the comprise between simplification and model size.

For some locations studied it has been shown that the majority of benefits accrue to those implementing salinity management strategies (Greiner and Cacho, Hill 1996). Yet the extent of adoption remains limited. Where strategies are adopted it is mostly confined to areas that receive financial assistance to implement on-ground works, despite good economic analysis suggesting that farmers will be better off. The lack of confidence about which areas within a catchment to target and the size future benefits from action (Pannell 2001) will mitigate against widespread adoption. Likewise, off-site stakeholders adversely affected by salinity will be unwilling to pursue negotiations along the lines suggested by Coase (see Randall, 1987), given the uncertainty of the impact of mitigation strategies. While the lack of information (and associated uncertainty) does not provide a comprehensive reason for why farmers do not adopt optimal strategies (Greiner and Cacho, 2001) it is likely to be a substantial one.

A major reason for the lack of specific knowledge about most catchments is the cost of collecting data and the time scales necessary to establish ‘scientific’ relationships. Delays in the implementation of management plans could significantly reduce benefits. Alternatively, implementation of strategies without more specific knowledge of the catchment is likely to lead to inappropriate actions and targeting of actions, thereby reducing their effectiveness.

The lack of site specific information has long been recognised as a cause of non-adoption of control strategies (eg Quiggin 1987). In apparent ignorance of this governments have allocated substantial funding for on-ground works. These works are very likely to be implemented with little detailed understanding on-site processes. The focus of attention of government spending programs has been decried by a number of economists (eg Pannell 2001). Yet the potential benefit of improved information about catchment characteristics appears to have received little attention in the economic literature.

At least 2 studies have been completed, with mixed results. George *et al* (2000) conducted a benefit cost analysis to determine the potential net benefits of airborne geophysics data in Lake Toolibin catchment in Western Australia. The benefits were assumed to accrue only as a result of improved adoption of recommended practices. They found that the potential benefit of airbourne geophysics data was significant, determining that the benefit cost ratio was 7.8:1.

Dumsday and Oram (1998) examined the impact of changing assumptions about the spatial distribution of recharge in one catchment on the profitability of salinity management options. They found little difference between the two solutions. However, it is reasonable to expect large differences between catchments, based on the spatial variability of physical attributes. Both studies above have been useful in providing an estimate of the potential benefit of more detailed physical data. However, it is apparent that further work is necessary to refine the methods of analysis and to broaden the scope of this work. This is likely to provide insights into where it may be useful to collect more information and what level of detail is appropriate.

5 Conclusions

Two key issues arise from the study of the nature of salinity in NSW. Firstly, externalities may well be a significant underlying cause of salinity in many catchments of NSW. Secondly, there remains a large degree of uncertainty in the knowledge of site specific processes. This will limit the extent to which the results of economic analysis can be generalised, and perhaps the ability to influence farmer adoption of control practices and the policy debate. However, improving knowledge of catchment characteristics is costly and the benefits uncertain. It seems economists may well contribute usefully to helping provide a better understanding of the value of further research in this area.

The complexity of the issues; namely the nature of the problem, the number of stakeholders and related natural resource problems, require a sophisticated approach to modelling. Integrating information to describe these problems is a challenging task. An integrative framework requires components of the system to be simplified to be manageable. The compromises have associated costs. Issues such as the impact of level of model detail and aggregation bias on model results warrant further attention. Perhaps one means of addressing this problem is to explore ways of decoupling the hydrology and the biological components of the model. One would provide input to the other rather than being run together.

The scope of the reviewed studies varied greatly. In general, the studies focussed on one or two stakeholder groups. While this may have been appropriate given the nature of the problems examined, there are many regions where multiple groups have a vested interest. In this respect future work should consider the need for a broader focus.

Studies also tended not to describe the issues related to salinity management. These include soil acidity, sodicity, erosion control and environmental services, such as carbon sequestration or enhancement of biodiversity. Work in this area is also warranted, particularly given the interest in environmental services schemes.

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