Mapping the regional benefits and costs of strategies for controlling dryland salinity[1]

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Abstract

Hydrologists predict that salinity in the agricultural region of Western Australia will eventually affect an average of 30 percent of the landscape if nothing is done to reduce current levels of recharge. The scale of tree planting and other works thought to be required for controlling salinity represent a radical departure from the traditional agricultural system practised in WA. The objective of the research presented in this paper was to assess whether a large investment in salinity control is warranted at a regional level and, if so, who are the winners and losers. A geographic information system (GIS), together with maps of predicted salinity, were used to facilitate the economic analysis. The GIS served as a systematic way of identifying and quantifying the areas of agricultural land and off-farm public assets that are at risk from salinity. Area statistics from the GIS were coupled to a spreadsheet model that simulated costs and benefits over a 20 year period. Net present values were then passed back to the GIS for mapping. The procedure described in this paper is a useful way to gain an initial appraisal of the relative size and spatial distribution of economic impacts associated with a particular control program.

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Introduction

Dryland salinity is a growing problem in many agricultural regions of Australia. The incidence of salinity is greatest in Western Australia, where approximately 10 per cent of land is currently affected. Salinisation is predicted to continue until a new hydrological equilibrium is reached in 100 years or more, at which point the total area of land affected is expected to be in the order 30 per cent (State Salinity Council, 1998). Dryland salinity is also forecast to become a major problem in other states. A recent audit by the Murray Darling Basin Ministerial Council reports that up to nine million hectares (or 8.5 percent) of agricultural land in the Basin could become salt-affected by the time a new equilibrium is established (MDBMC, 1999).

Whilst the processes governing salinity are complex and difficult to model, there is an emerging consensus among hydrologists that the most effective way of delaying the advancement of salinity at a regional level is to plant substantial areas of deep-rooted perennials. They predict that to have a major impact on salinity, perennials will need to be planted on 50 to 70 percent of the landscape (George, et. al. 1999). This represents a radical departure from the traditional agricultural system practised in much of southern Australia and begs a raft of questions about policy and the economics of such a strategy. Achieving an adjustment of this scale would require a large amount of public and private investment "up-front" in return for an uncertain benefit some time in the future.

Many existing economic studies of salinity have concentrated on quantifying costs of lost production, either from an *ex post* or *ex ante* perspective (see van Bueren and Pannell, 1999). While cost information is indicative of the magnitude of the issue, it is not sufficient for making investment decisions. In fact, it can be quite misleading and dangerous as it could lead to a misallocation of resources. Sound policies for salinity management should, instead, be founded on a thorough analysis of the costs and benefits likely to accrue to all stakeholders affected by a policy.

The objective of this paper is to demonstrate how a spatial model of salinity within a Geographic Information System (GIS) can be linked to an economic model to evaluate the net benefits of control strategies at a regional scale. Until recently, hydrological information has been relatively scarce and, consequently, few analyses of this type appear in the literature. However, new modelling work by the CSIRO in Perth is producing maps at a scale of 1:100,000 showing the predicted, future extent of salinity under various assumed levels of recharge to ground water. This information provides economists with the opportunity to investigate the approximate magnitude of economic impacts resulting from a range of possible control programs, and to map their spatial distribution.

The methods developed in this paper build upon work by Smyth and Young (1997) and Walpole and Sinden (1996). These earlier studies applied a GIS framework to examine, respectively, the on-farm costs of soil erosion and the cost-benefit ratios of controlling erosion. The techniques developed by these applications are not directly suited to analysing salinity, as the process of salinisation is inherently more complex than erosion. Two major differences are the considerably longer time lags involved with salinity and the spatial separation of causes and effects. By comparison, the benefits of controlling soil erosion are generally internalised and realised within a shorter time frame.

The content of this paper represents "work in progress" as the hydrological modelling is not yet complete. However, the paper details our methodological approach, and critically assesses the value of the technique as a tool for quantifying the economic costs and benefits of salinity management. In a preliminary investigation, the method is applied to a 30,000 hectare region in southern Western Australia.

Methods

Scenarios

Two types of scenarios were examined. They were a "business as usual" scenario and a set of defined "treatment" scenarios which involved one or a combination of practices for reducing recharge to the ground water table. Two such alternatives included farm forestry and phase cropping with lucerne. The analysis did not examine the benefit-cost of rehabilitating discharge areas with saltland agronomy. Neither were engineering works, such as pumping and draining, considered by the analysis. A planning horizon of 20 years was used for both scenarios.

The magnitude of salinity costs suffered under the "business as usual" scenario were equated to future losses in the net value of agricultural production relative to an arbitrary benchmark, namely the current profitability of agriculture. This *ex ante* analysis produces an upper-bound estimate of the size of future economic returns at risk from salinity. In calculating potential future losses, the analysis allowed for the possibility of adaptive management by including a value for salt-land. This was considered important because it is reasonable to expect ways will be developed to use salt-land efficiently as the scale of affected land increases.

The cost estimate calculated for the “business as usual” scenario indicates the magnitude of salinity impact but does not convey any information about the economic merits of controlling salinity. A second analysis was performed to estimate the net benefits associated with a given treatment scenario. Net returns to a treatment were evaluated relative to the economic losses predicted to eventuate under the "business as usual" (BAU) scenario. The direct costs of treatments were included in the analysis but the transaction costs of involved in ensuring implementation of each control program were not considered. Furthermore, it was assumed that all treatments were implemented in the first year of the planning horizon.

Impacts of scenarios

The majority of on-farm (or private) impacts associated with salinity and its control consist of changes in farm income. This paper focuses primarily on these costs and benefits, which are summarised in Table 1. However, the impacts of salinity also include damage to farm infrastructure such as roads, buildings and dams. In addition, impacts frequently extend beyond the "farm gate": Water resources, urban infrastructure and environmental assets are often jeopardised by rising water tables. A comprehensive listing of potential impacts can be found in Martin and Metcalfe (1998).

The methodology developed in this paper is capable of quantifying the extent of physical damage caused to main roads, farm buildings, farm dams, wetlands and remnant vegetation under each scenario but does not estimate the economic consequences. In order to weigh up the relative significance of these unquantified impacts, a technique known as Threshold Value Analysis could be employed. This technique examines the minimum (or threshold) size of benefits that would need to be realised to make a control program break even. The researcher can then judge whether or not the threshold is exceeded by examining the estimated amount of physical damage that is prevented by implementing a treatment.

Table 1: Summary of the ways in which scenarios impact on farm income.

Business as usual scenario	Treatment scenarios
• Loss in net agricultural income caused by encroaching salinity.	• Benefit attributable to areas of agricultural land that are protected from salinity. • Direct net commercial benefit derived from treatments (eg. income from trees). • Opportunity cost of establishing treatments on agricultural land.

Modelling framework

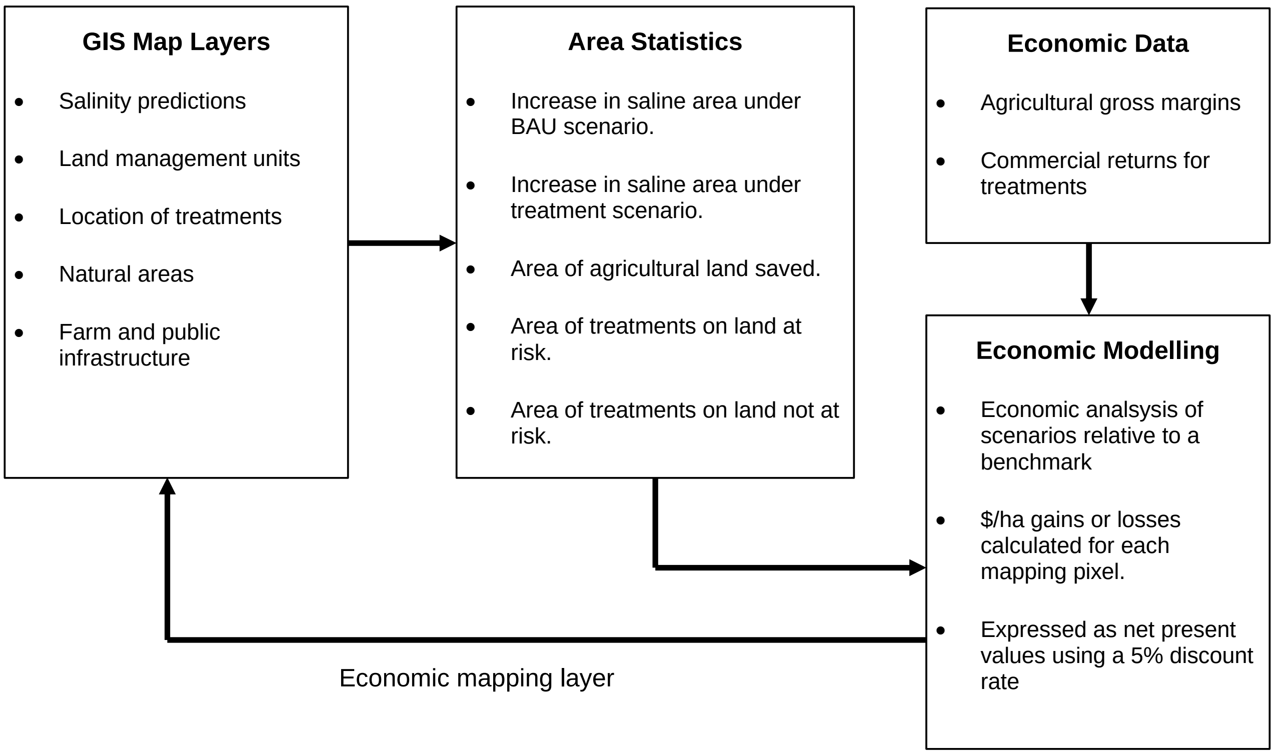
Overview

The modelling framework consisted of a temporal simulation model for estimating economic impacts and a geographic information system (GIS) which facilitated the economic analysis and allowed costs and benefits to be mapped spatially. The flow chart in Figure 1 depicts the modelling procedure. A spreadsheet was used to analyse the stream of annual costs and/or benefits associated with each scenario over a 20 year period. These calculations were based on physical information from GIS together with economic data on the profitability of agriculture and treatments on an array of land management units (or soil types). These land units were fundamental to the analysis because their underlying productivity determined the size of costs imposed by encroaching salinity and the opportunity costs incurred by planting treatments on agricultural land.

The GIS provided a record of the key physical changes to land status and man-made infrastructure that, in turn, affect economic outcomes. It served as a physical accounting tool, producing statistics on the areas of each land unit affected by salinity in the year 2020 and the areas of each land unit planted to a treatment. These statistics were calculated by combining a number of digitised overlay maps and querying the database to quantify areas of intersection. The maps included information on salinity, land management units, treatment locations, and various other layers of resource information such as remnant vegetation, main roads, and farm dams. All were generated in a raster format at a resolution of 25 by 25 metres.

The impacts estimated by the economic model were passed back to GIS for mapping as a separate layer. This was achieved by assigning "per hectare" values to each pixel, where the values represented changes in net income (present value) for that location. A five percent discount rate was used throughout the analysis. As a further aid to policy analysis, a table of the aggregate impact of a given scenario was produced by summing impacts across all land management units.

Figure 1: Flow chart of the modelling procedure



Business as usual scenario

The on-farm costs of salinity incurred under the BAU scenario were equated to future reductions in the profitability of agricultural production, using current profit levels as a benchmark. Annual losses in net income were approximated by simulating the encroachment of salinity onto a given land management unit (LMU). The cumulative nominal cost of salinity on LMU *x* up to year *t* was calculated by multiplying the cumulative area of salinity on LMU *x* at year *t* by the per hectare loss in agricultural profitability caused by salinity (Equation 1). In other words, productivity was assumed to remain unaffected until salinity encroached in year *t*, after which time economic returns were equated to those achievable on saltland. This assumption circumvented the need to specify a physical relationship between severity of salinity and production.

The unit loss caused by salinity was estimated by the difference in gross margin associated with production on unaffected land (P_x) and salt-affected land (P_s). In order to simplify the analysis, P_s was assumed to be constant, irrespective of the severity of salt or the scale of salinity. However, the model could easily be modified to relax this restriction.

The cumulative growth in salinity on LMU *x* was assumed to follow either a linear or asymptotic trend, as specified by Equations 2 and 3 respectively. A linear trend was thought to be most appropriate for regions in low rainfall zones, while an asymptotic trend was considered to represent better the situation in high rainfall areas where salinity is at more advanced state (George pers comm, 1999). The area statistics from GIS provided an estimate for the total area of salinity on LMU *x* at the end of the planning horizon (A_x) but did not supply a measure for n_x, the time lag before salinity is first predicted to encroach on LMU *x*. Instead, this parameter was assigned a subjective number by assessing the position of the LMU in the landscape.

Box 1: Equations used to calculate the cost of salinity in the BAU scenario

Cumulative cost function

$$C_{xt} = A_{xt} (P_x - P_s) \qquad (1)$$

where;

A_{xt} = the cumulative area of salinity on land management unit *x* up to year *t*,

P_x = the per hectare gross margin for agriculture on unaffected LMU *x*

P_s = the per hectare gross margin of agriculture on saltland

Linear salinity function

$$A_{xt} = \left[\frac{A_x}{T - n_x} (t - n_x) \right] \quad \text{if } t > n_x \qquad (2)$$
$$A_{xt} = \text{zero otherwise}$$

where;

A_x = the final, cumulative area of salinity on LMU *x* (at year 2020)

T = the time horizon (20 years),

n_x = the lag time till the onset of salinity on LMU *x*.

Asymptotic salinity function

$$A_{xt} = A_x \left[1 - e^{-0.2(t - n_x)} \right] \quad \text{if } t > n_x \qquad (3)$$
$$A_{xt} = \text{zero otherwise}$$

Treatment scenarios

The on-farm benefits and costs of implementing a given treatment were evaluated relative to the profitability of agriculture under the BAU scenario. Each treatment was defined as comprising one or more changes to farm management which, together, were assumed to lead to a fixed reduction in annual recharge. A hydrological “flow tube” model is currently being developed to estimate the impact of reducing recharge on the spatial extent of salinity. The predictions from this model will be used by the cost-benefit analysis.

The spatial distribution of a treatment within a study region was determined using decision criteria relating to the physical and economic suitability of areas for establishing the treatment. Mapped information on soil depth, waterlogging, and pH assisted with this task. In this initial version of the analysis, treatments were assumed to be completely effective at controlling salinity at the site where they are planted. In other words, the plantations of trees or paddocks sown to lucerne do not become "salted out" over the duration of the planning horizon. The effect of relaxing this assumption will be examined in future work.

Five different "types" of land were identified as being relevant for assessing the economic impact of a treatment. The categories cover all possible combinations of outcomes, except the salting out of treatments (see above) and the situation where saline land is rehabilitated by a treatment. Preliminary hydrological modelling suggests that there is little, if any, scope of reclaiming land that is currently saline with the proposed treatments. The five land types are:

A. Treated areas on land predicted to become saline under the BAU scenario,

B. Treated areas on land *not* predicted to become saline under the BAU scenario,

C. Standard agriculture on land that is saved from salinity by a treatment,

D. Standard agriculture on land not predicted to become saline under the BAU scenario,

E. Land that is currently affected, or untreated areas that are predicted to become saline even under the treatment scenario.

The economic impacts generated by implementing a control strategy are confined to the first three land types. That is, the stream of net income associated with these land types is expected to change relative to the BAU scenario. Land Type A may produce a net gain in profitability if the commercial benefits of a treatment are sufficiently high relative to the shadow value of saline land. Land Type B is likely to be a source of net loss because, in this case, treatments are planted on land that has a high opportunity cost. The direction of change for Land Type C is clear-cut because land saved from salinity must, by definition, be a source of benefit. The other two land types do not undergo any changes in profitability relative to the BAU scenario.

The layering capabilities of GIS were used to calculate the approximate areas of Land Types A, B, and C, by land management unit. These area statistics formed the basis of the economic analysis. Annual net returns attributable to treatments on A and B were calculated by subtracting the opportunity cost of foregone agricultural production in year t from the commercial net benefits of the treatment (Equation 4). In the case of Land Type A, opportunity costs (OC) were modelled to decline over time as the area of salinity grows (Equation 5). In the case of Land Type B, the opportunity cost is constant and equal to the shadow value of production on LMU x (Equation 6).

Land Type C describes those areas that are protected from salinity by a treatment elsewhere in the landscape. The maintenance of agricultural production on these areas is a source of indirect benefit to the treatment. Equation 7 was used to calculate annual net benefits for Land Type C.

Box 2: Equations used calculate the economic impact of a treatment scenario

Benefit function for treatments

$$B_{xt} = B_{xt} - OC_{xt} \qquad (4)$$

where;

B_{xt} = the commercial net return in year *t* from growing the treatment on LMU *x*

OC_{xt} = the opportunity cost associated with growing the treatment on LMU *x* in year *t*

Opportunity cost function for Land Type A

$$OC_{axt} = \left[A_{ax} * \frac{A_{xt}}{A_x} \right] P_S + \left[A_{ax} (1 - \frac{A_{xt}}{A_x}) \right] P_X \qquad \text{if } A_{ax} > 0 \qquad (5)$$

OC_{axt} = zero otherwise

where;

A_{ax} = the total area of Land Type A on LMU *x*,

A_{xt} = the cumulative area of salinity on LMU *x* up to year *t*,

A_x = the final area of salinity on LMU *x* at the end of the planning horizon.

P_x = the current per hectare agricultural gross margin on LMU *x*

P_s = the per hectare gross margin of agriculture on saltland

Opportunity cost function for Land Type B

$$OC_{bx} = P_x * A_{bx} \qquad (6)$$

where;

A_{bx} = the area of Land Type B on LMU *x*

P_x = the current per hectare agricultural gross margin on LMU *x*.

Benefit function for Land Type C

$$B_{cxt} = A_{cxt} * (P_x - P_s) \qquad (7)$$

where A_{cxt} is the cumulative area of land saved from salinity in year *t*, given by Equation 2 (for linear salinity trend) or Equation 3 (asymptotic trend).

Case study application

The modelling techniques developed in this paper were applied to the Woodanilling region, which is one of several case studies being examined by the Salt Scenarios 2020 Project. The region occupies 30,000 hectares and is located in the medium rainfall zone (450mm) of southern Western Australia. The predominant land-use is mixed sheep and cropping.

Digitised information on physical characteristics of the region were assembled from a number of sources. Figure 1 in the appendix contains a map which shows the distribution of four land management units, perennial vegetation, man-made infrastructure, and the extent of current salinity. Approximately seven percent of the study area is salt-affected. For the purposes of this study, land was classified as salt-affected if it has a watertable is within two metres of the surface.

Agroforestry has been proposed as one option for managing salinity in this region. Owing to low annual rainfall, the only tree crop that presently shows any commercial prospects is oil mallee. These are shrubby eucalypts that can be grown in belts and harvested for oil distillation (plus a variety of other possible products). The belts typically comprise multiple rows of trees with sufficient space between the belts to allow “alley farming” to be practiced.

Salinity predictions

At the time of writing this paper the hydrological model was still under development so it was not possible to predict the spatial distribution of salinity under each scenario. Instead, for the purposes of demonstrating the analytical technique, the spread of salinity was simulated by directly adjusting areas in GIS. The future extent of salinity under the BAU scenario was simulated by increasing proportionally the mapped area of current salinity for the study area. The area of salinity was increased from seven percent to a final level of 17 percent. Preliminary hydrological modelling has shown this to be a probable outcome for the region.

Under the treatment scenario alley farming was established on two of the land management units, with a total planted area equalling 65 percent of the region. Areas currently affected by salinity and/or subject to seasonal waterlogging were excluded. Owing to the absence of a hydrological model, it was necessary to assume that the treatment had no off-site impacts. That is, the treatments were presumed to offer no protection to adjoining agricultural land. Under this assumption the final area of salinity was calculated to be reduce from 17 to 12 percent of the study area, with all reductions occurring on treated land.

The resultant breakdown of relevant areas by LMU are summarised in Table 1. These statistics were obtained from GIS. Other key parameters for the analysis are also listed in the Table. A zero lag time lag was assumed for all land units, implying that there is no delay in the emergence of salinity. This assumption was thought to be reasonable given the low relief of Woodanilling. A linear salinity trend was adopted because the salinisation process in this region is predicted to be a long way off reaching equilibrium.

Economic data

The gross margins associated with agricultural production were assumed to range between $50 to $200 per hectare, depending upon LMU (Table 1). These estimates were based on results obtained using MIDAS (Morrison et al, 1986) which is a linear programming model designed to analyse the optimal enterprise mix for a typical farm in this region. The shadow price for salt-land was estimated by MIDAS to be $10-12/ha. This estimate was based on an assumption that 70 percent of salt-affected land has some grazing value and the remainder is non-productive. A slightly higher value of $20/ha was used in the analysis so as to allow for adaptive management. Gross margins were assumed to remain constant in nominal terms over the course of the planning horizon.

Table 1: Assumed values for key parameters, including area statistics calculated by GIS.

	Land Management Units			
	1	**2**	**3**	**4**
Total area (ha)	3250	96	1651	21906
Current salt affected (ha)	935	13	11	1025
Business As Usual Scenario				
Salt-affected area at 2020, based on linear trend (A)	1897	26	44	3057
Lag time (n)	0	0	0	0
Treatment Scenario				
% of Land Management Unit treated	0%	0%	94%	81%
Area of treatment on land at risk (Aa)	0	0	33	1610
Area of treatment on land with zero risk (Ab)	0	0	1522	16213
Area of agricultural land saved (Ac)	0	0	0	0
Salt-affected area at 2020, based on linear trend (A)	1897	26	11	1447
Economic Parameters				
Agric. gross margin for unaffected land ($/ha)	100	50	200	180
Agric. gross margin for salt-affected land ($/ha)	20	20	20	20
Commercial net return for treatment ($/ha NPV for the planning period) (B)	-	-	2204	1998

The economic return for a “treated area” was calculated by adding the commercial returns from oil mallee to the net value of agricultural production in the alleys. Returns from each enterprise were apportioned to the joint “treatment return” according to the ratio of trees to alley land, which was assumed to be approximately 1:5 (based on a planting design of 6 rows per belt and a spacing of 60m between rows). The commercial return for oil mallee was estimated using a partial budget. As this industry is still in its infancy and not currently processing mallee products, it was necessary to speculate on potential returns. For the purposes of this analysis an optimistic net present value of $800 per hectare was assumed as a return for the entire planning period. This is approximately one third of the agricultural gross margin.

Results

Under the BAU scenario, the present value of future losses in farm income over the 20 year period were estimated to be $3.6 million (Table 2). The majority of this cost (75 percent) was due to salinity damage on just one LMU which suffered a present value loss of approximately $890 per hectare over the planning period (Figure 2). In addition to production losses, a range of natural and man-made assets are calculated to be at risk from salinity.

The implementation of alley farming on a large proportion of the study area produced both gains and losses, but the net impact was a loss of $3.4 million. This implies that society would be worse off under a treatment scenario relative to doing nothing. Treated areas that were formerly at risk of becoming salt-affected produced a net gain of $1.0 million, while those areas with zero risk (and hence high opportunity costs) suffered a loss of $4.4 million. The spatial distribution of these impacts are shown in Figure 3 of the appendix. Benefits accruing in the form of "saved" assets were not quantified either in physical or economic terms. However, the magnitude of these benefits are likely to be small in this particular application because it was assumed that treatments did not offer any off-site protection against salinity.

The empirical results should be interpreted as an example of the type of information that can be produced using the methods developed in this paper. Strong conclusions for policy cannot be drawn from this preliminary investigation because the salinity predictions were not derived from a hydrological model. However, the results indicate that large-scale planting of oil mallee in recharge areas for managing salinity is unlikely to be economically attractive unless the treatment is capable of protecting substantial areas of adjoining agricultural land and assets.

Table 2: Economic and physical impacts of two salinity scenarios analysed for Woodanilling. All economic estimates are expressed as net present values.

	Business as usual scenario, assessed relative to current situation	**Treatment Scenario, assessed relative to Business as Usual Scenario**
On-farm Impacts	**Effect on net income**	
	• $3.6 mill loss	• $1.0 mill *gain* from treatments planted on land at risk • $4.4 mill *loss* from treatments planted on land with zero risk. • Net effect = $3.4 mill loss
	Effect on assets	
	• 29 farm buildings affected • 166 farm dams affected	• not estimated
Off-farm Impacts	**Effect on assets**	
	• 6.5km of main roads affected • 24ha of wetlands affected	• not estimated

Conclusion

This paper has demonstrated how a GIS framework, coupled with a cost-benefit analysis, can be used to make an initial investigation of the economic consequences of regional strategies for managing salinity. The analytical technique has a number of strengths, including:

- The economic impact maps produced by the analysis serve as a valuable communication tool for economists. The maps translate physical changes into economic outcomes and provide decision makers with an overview of how impacts are unevenly distributed across a region.

- The analysis identifies the ratio of on-farm to off-farm economic impacts, and the distribution of impacts across stakeholders. This information is valuable for devising “cost-sharing” policies once a preferred strategy has been selected.

- The analysis helps with priority setting by identifying which geographic regions are likely to yield the greatest economic returns to salinity management.

- Once the initial data are collected for a given region, the impacts of different scenarios and assumptions can be simulated quite rapidly. It allows judgements to be made about the optimal scale at which treatments should be implemented.

- The technique is readily transferable to other regions in Australia which have similar databases.

- The results force hydrologists to confront the economic implications of their recommendations for controlling salinity.

Balanced against these strengths are a number of potential weaknesses. Perhaps the greatest criticism of the method is its high demand for data. Application of the technique is limited to those regions which have a satisfactory set of digitised resource information. A second weakness is that maps tend to hide the uncertainty that underlies modelled results. GIS produces an impressive, visual product which can sometimes be misleading if the viewer does not understand the probabilistic nature of the mapped values. Quantifying and presenting risk is an important avenue for future research in economic-GIS modelling.

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