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SIGNIFICANCE OF FARMER RESPONSE FOR ESTIMATING AGRICULTURAL COSTS OF LAND SALINISATION

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ABSTRACT

In attempting to estimate the agricultural cost of land salinisation, it is important to account realistically for farmer response aimed at minimising losses of whole farm profitability. One type of farmer response involves relocating enterprises according to their salinity tolerance as the salinity status of land changes. An economic analysis of the agricultural cost of salinisation in the Murrumbidgee Irrigation Area is reported in this paper. The approach involved applying a linear programming model of regional agriculture to systematically predict on-farm response of the above kind to changed salinity conditions. The modified approach was designed to account for delays in farmer response to changes in salinity conditions, due to concerns that the previous approach unrealistically assumed immediate farmer response and thereby substantially under-estimated the agricultural cost of land salinisation.

The estimated present value of the agricultural cost of salinisation under the preferred assumption of a ten year delay in response was demonstrated to exceed that under an assumption of immediate response by 60 per cent. The estimate under an assumption of no farmer response was found to be 4.5 times greater than that under the preferred assumption. The study has thus confirmed that accounting for farmer response to salinisation is required if economic analyses are not to be responsible for excessive allocation of resources to addressing the salinisation problem. It has also demonstrated the potential for significantly reducing the agricultural cost of salinisation by providing information to farmers which assists them to respond more rapidly to worsened salinity conditions.

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1. INTRODUCTION

1.1 Background

Land salinisation is a form of land degradation caused by capillary rise of saline groundwater into the root zone of crops and pastures. Various studies have concluded that increasing areas within irrigation schemes will be affected by this problem unless remedial measures are implemented (for example, Gutteridge, Haskins and Davey 1985).

Large programs of investigations and capital works have been instigated with the aim of ameliorating this problem. Since as early as 1981, for instance, an integrated groundwater pumping/evaporation basin scheme has been operating in the Wakool and Tullakool Irrigation Districts, at a capital and operating cost since 1978 of $56 million (in 1993 values) (D. Naunton and Co. *et al.* 1993).

Proposals of such magnitude clearly warrant ex ante economic appraisal. As well as these 'big ticket items', however, there are a range of farm-level and district-level salinity management options currently being investigated as part of the process of formulating Land and Water Management Plans for various irrigated regions of New South Wales (NSW). The investigations, apart from possible future implementation of the options, also represent a considerable allocation of resources to ameliorating current and future land salinity.

Economists are concerned with identifying economically efficient responses to land salinisation, where economic efficiency involves applying all resources to their highest valued combination of end uses from the overall perspective of society (Morris *et al.* 1988). From this standpoint, resources should be committed to mitigating land salinity or its effects only to the extent that their marginal value does not exceed the marginal value of salinity-induced 'damage' to social welfare.

In this task, valuation of resources proposed for use in addressing land salinisation (eg., for constructing and operating a saline water disposal scheme) or its effects (eg., for undertaking relevant agronomic research and extension) is usually relatively easy. Estimating the value of salinity-induced damage generally requires greater thought, both because of gaps or uncertainties in technical data and because the value of damage depends on how those affected by salinity respond to it. Economists are not in a position to rectify the first of these problems, but are well equipped to consider how behavioural response by farmers to changes in land productivity should be modelled in valuing damages inflicted by land salinisation.

1.2 Study Aim and Null Hypothesis

The aim of the study reported in this paper was to develop and apply a framework for evaluating the economic impact on agriculture of land salinisation. The framework developed is presented in Section 2. Previous evaluations of damages imposed by land salinisation have differed significantly with respect to the (often implicit) framework applied. A selection of these studies are reviewed in Section 3. The way in which the framework developed was applied in this study is discussed in Section 4.

A particular aim in the study was to explore the significance for accuracy in this evaluation of accounting for farmer response to land salinisation, in terms of changes in the pattern of land use by enterprise. The null hypothesis tested was that estimates of the economic impact of land salinisation are insensitive to how farmers are assumed to respond to land salinisation. The results of the economic evaluation and of the test of the null hypothesis are presented in Section 5. Conclusions are drawn in Section 6.

1.3 Case Study Area

The null hypothesis was tested using broadacre agriculture within the Murrumbidgee Irrigation Area (MIA) in southern inland New South Wales (NSW) as a case study. The MIA comprises 477 broadacre farms which encompass 110,950 hectares and which have an aggregate irrigation allocation of 660,945 megalitres (Jones 1991).

The predominant broadacre land use is rice grown in rotation with annual pasture and winter cereals. The area of rice grown in the MIA in 1990/91 was 26,181 hectares (ha), accounting for 32 per cent of NSW rice production . Wheat was grown over 20,726 ha (Murray Darling Basin Commission 1993). The area of alternative summer crops to rice, predominantly soybeans, has been approximately 1,800 ha, lucerne 700 ha (D. McCaffery, NSW Agriculture, Griffith, pers. comm.) and vegetables 2,100 hectares (J. Salvestrin, NSW Agriculture, Griffith, pers. comm.).

Land salinity levels in the MIA have been predicted to worsen significantly over the next 30 years (van der Lely 1993a). The proportion of land not or only minimally affected by salinity[1] has been predicted to decline from 74 per cent in 1993 to 59 per cent in 2023. The proportion affected by highly saline[2] conditions has been predicted to increase from 8 per cent to 12 per cent over the same period.

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[1] That is, where electrical conductivity of soil is less than 2 decisiemens per metre (dS/m)

[2] That is, where the electrical conductivity of soil exceeds 8 dS/m

2. AN ECONOMIC FRAMEWORK FOR EVALUATING THE AGRICULTURAL IMPACT OF LAND SALINITY

2.1 Single Industry Case

In developing a framework to explore the economic impact of the agricultural effect of land salinity within a region at any time, it was initially assumed that:

(i) agriculture in the area of concern is comprised of a single industry, say the wheat industry, within which the same production function applies to all output;
(ii) demand for output from the region is infinitely price elastic;
(iii) the industry demand schedule coincides with the marginal social benefit (MSB) schedule;
(iv) the industry supply schedule coincides with the marginal social cost (MSC) schedule;
(v) in the `with salinity' scenario, all land in the area of concern is of the same salinity level; and
(vi) apart from effects of salinity, all land is of uniform quality.

The framework that was developed consistent with the above assumptions is illustrated in Figure 1.

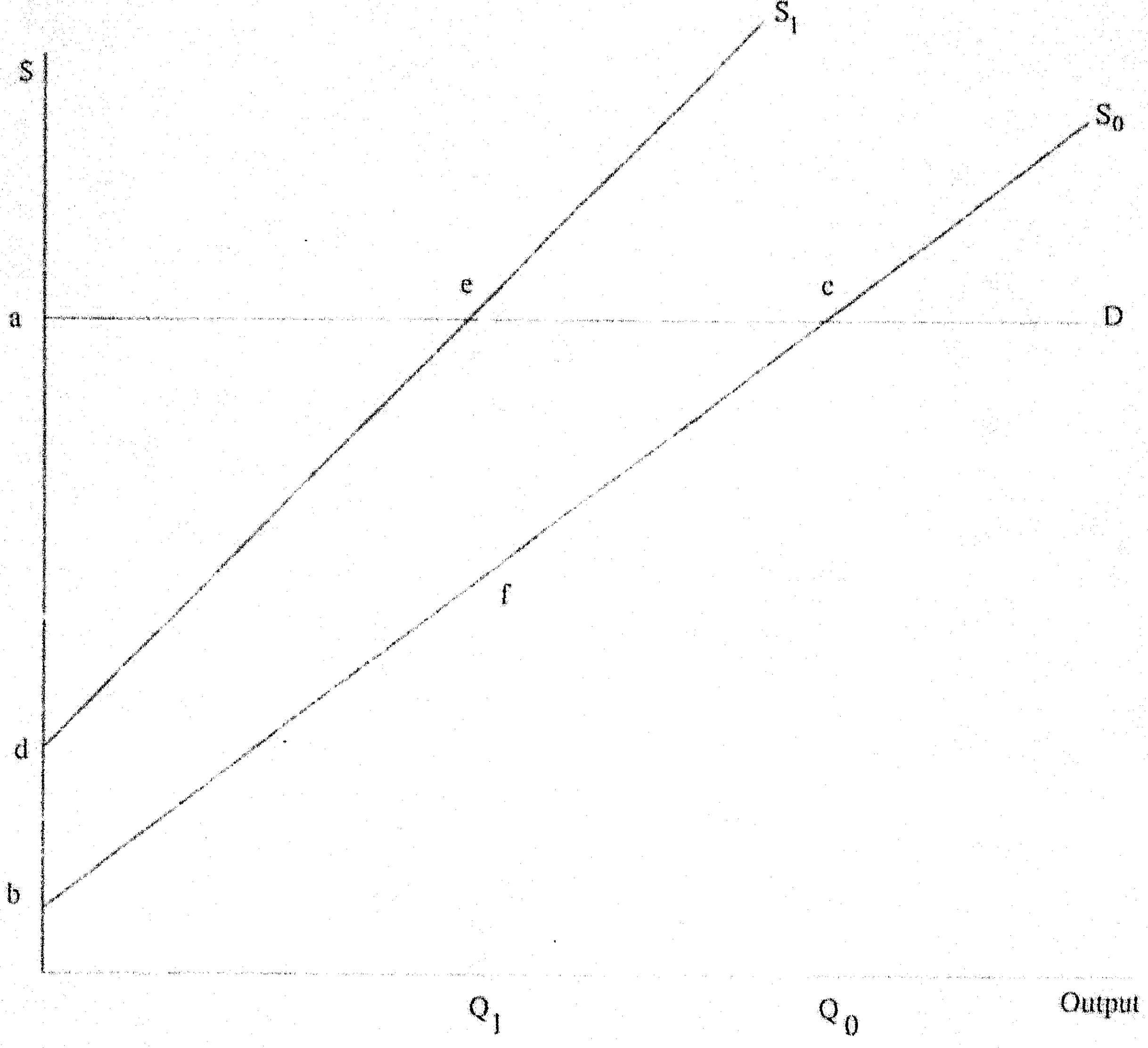
The industry supply schedule `without salinity' is denoted by S_n and represented as sloping upward to the right since diminishing returns to scale are assumed. Once land salinity has increased sufficiently, yield declines uniformly across the area of wheat grown. The consequence is a divergent upward shift in the industry supply schedule, since the cost impact of a yield reduction increases with the unit cost of the output increment. The industry supply schedule corresponding to the with salinity scenario is thus denoted by S_s

The industry demand and MSB schedules are denoted by D.

The marginal net industry benefit (MNIB) at any level of production is given by the vertical distance between the corresponding points on the industry demand and supply schedules. The marginal net social benefit (MNSB) schedule at any level of production is given by the vertical distance between the corresponding points on the MSB and MSC schedules. Given assumptions (iii) and (iv) above, the MNIB and MNSB schedules for a particular industry and salinity scenario coincide.

The industry is in equilibrium at the level of output at which net industry benefit is maximised. This occurs where the industry supply and demand schedules intersect. Equilibrium without salinity therefore occurs where S_n and D intersect. The corresponding level of output is Q_{n}, associated with an economic surplus of area abc. The equilibrium level of output with salinity is Q_s, corresponding with the intersection of S_s and D. Economic surplus at any level of production is calculated by adding the MNSB (here equivalent to the MNIB) of all intra-marginal levels of production. Economic surplus with salinity thus equals area ade. The economic impact of land salinity is given by the

Figure 1: Economic Impact of Land Salinity - Single Industry Case



reduction in economic surplus, that is, the area bced.

2.2 Multiple Industry Case

T e framework was extended to consider the implications of a situation in which land salinity occurs within only a portion of the region and there is more than a single industry suited to the region, with variation among industries in how their yields are affected by land salinity. Thus assumptions (i) and (v) above no longer apply. To simplify the exposition, it was further assumed that:

(vii) all land affected by salinity is affected uniformly; and
(viii) there are only two industries suited to the area of concern (say, carrots and wheat), the yield of only one (carrots) being affected by the level of salinity in the affected area.

The economic impact of land salinity in the affected area is illustrated in Figure 2.

Note that area cropped, rather than output, is measured on the x-axis. This is to facilitate the discussion to come in Section 3. Following from assumptions (vi) and (vii) above, yield for each industry is constant across the affected area (but depends on the salinity status of the area). The cropped area of each industry is thus directly proportional to its ou'put, so industry supply and demand schedules can be represented against cropped area similarly as against output.

The total area affected by salinity is given by the distance O^cO^w in Figures 2(a) and 2(b). The portion of this area cropped to carrots is measured by distance along the x-axis from O^c to the right, while the area cropped to 'heat is measured by distance along the x-axis from O^w to the left.

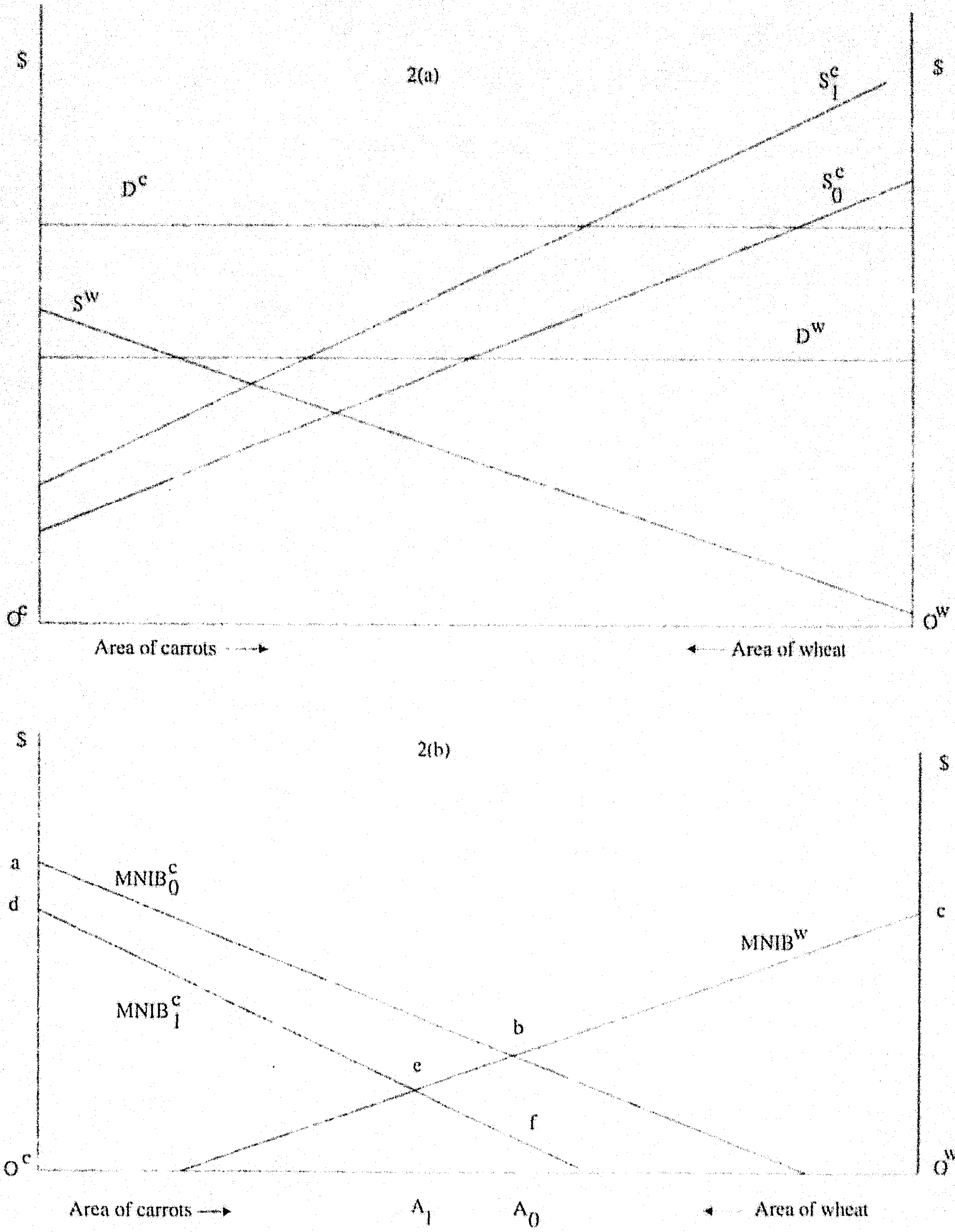
The demand schedule for the carrot industry is denoted by D^c in Figure 2(a) and the supply schedules without and with salinity by S_0^c and S_1^c respectively.

The demand schedule for the wheat industry is denoted by D^w in Figure 2(a). Since wheat yield is assumed to be unaffected by the salinity level attained in the with salinity scenario, the wheat industry supply schedules with and without salinity are both denoted by S^w.

Corresponding MNIB (a thus MNSB) schedules for each industry are derived in Figure 2(b). The above scheme is used to distinguish these schedules according to industry and to whether they refer to the with or without salinity scenario.

For a particular industry and salinity scenario, MNIB for each level of cropped area was derived by subtracting the marginal cost of production (given by the corresponding y-axis value found from the relevant industry supply schedule) from the marginal industry return (given by the corresponding y-axis value found from the relevant industry demand schedule).

Figure 2: Economic Impact of Land Salinity in the Salinised Area - Two Industry Case



Equilibrium without salinity occurs where the MNIB from carrot-cropping is equal to that from wheat-cropping (i.e., where $MNIB_0^c$ and $MNIB^w$ intersect). The equilibrium area of carrots without salinity is thus O^cA_0 and the equilibrium area of wheat is O^wA_0.

For a particular industry and a particular salinity scenario, economic surplus is given by the intra-marginal area between the x-axis and the relevant MNIB schedule. Thus economic surplus from both industries, without salinity in the affected area, is given by area O^cabcO^w.

Equilibrium with salinity occurs where $MNIB_1^c$ and $MNIB^w$ intersect. Thus the equilibrium area of carrots with salinity is O^cA_1 and the equilibrium area of wheat is O^wA_1. Thus economic surplus from both industries, with salinity in the affected area, is given by area O^cdecO^w.

The economic impact of land salinisation is measured by the difference in economic surplus between the without and with salinity scenarios. This is comprised of the reduction of economic surplus from carrots (given by area abA_0A_1ed) and the increase in economic surplus from wheat (given by area A_0beA_1). The overall economic impact is thus given by area abed.

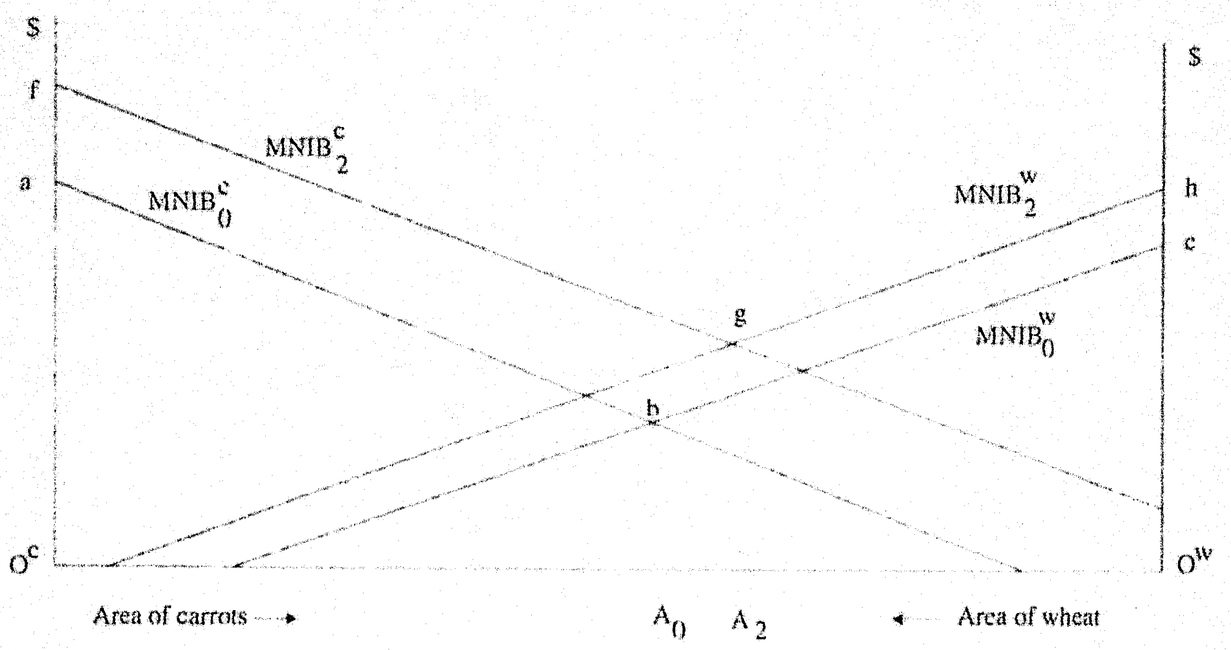
The analysis demonstrates that farmer response to land salinisation of a particular area, in the form of substituting a relatively salt-tolerant enterprise (eg., wheat) for a relatively salt-sensitive one (eg., carrots) on some of the land allocated to the salt-sensitive enterprise under the without salinity scenario, can be expected to occur.

The effect of salinity identified above is in fact likely to be only part of the total effect, however, since enterprise substitution within the area becoming salinised can be expected to affect production costs in the area remaining non-salinised. Substitution of wheat area (within which irrigation is relatively non-intensive) for carrot area (within which irrigation is relatively intensive) in the area affected by salinity, for instance, releases irrigation water (which is limited in total availability) for use in the area remaining non-salinised. The marginal opportunity cost of irrigation water therefore declines and downward shifts of the supply schedules of both industries in the non-salinised area occur. With carrots being the more intensive water-user, the downward shift of its supply schedule for the non-salinised area is greater than that for wheat. As a consequence, some land in the area remaining non-salinised will be reallocated from the relatively salt-tolerant enterprise to the relatively salt-sensitive enterprise (i.e., the reverse of the trend in the area becoming salinised). This effect is illustrated in Figure 3.

The MNIB schedules for carrots and wheat in the non-salinised area under the without salinity scenario for the salinised area are denoted by $MNIB_0^c$ and $MNIB_0^w$ respectively. The carrot schedules are located as were those denoted similarly in Figure 2(b) while the wheat schedules are located as were $MNIB^w$ and $MNSB^w$ in Figure 2(b).

In deriving Figure 3, it was assumed that the areas of the region salinised and non-salinised are equal. That is, O^cO^w represents the same number of hectares in Figures 2 and 3. It follows from the above that, for the without salinity scenario for the salinised area, economic surplus and areas of carrots and wheat in the non-salinised area are the

Figure 3: Economic Impact of Land Salinity in the Non-Salinised Area - Two Industry Case



same as in the salinised area.

The MNIB schedules for carrots and wheat in the non-salinised area, under the with salinity scenario for the salinised area, are denoted by $MNIB_2^c$ and $MNIB_2^w$ respectively.

The upward shift in the MNIB schedule for carrots in the non-salinised area due to salinity in the remaining area is greater than for the wheat MNIB schedule. This follows from the above reasoning that carrots are the more intensive user of irrigation water, the marginal opportunity cost of which has declined as a consequence of enterprise substitution in the salinised area.

The shifts in MNIB schedules for the non-salinised area arising out of salinisation in the remaining area result in a new equilibrium in the non-salinised area, such that the allocation of land to carrots increases to O^cA_2 and the allocation to wheat declines commensurately to O^wA_2. Economic surplus in the non-salinised area under the with salinity scenario for the remaining area is thus given by area O^cfghO^w. Due to upward shifts in the MNIB schedules, together with consequent enterprise substitution within the non-salinised area, economic surplus in the non-salinised area is thus higher in the with salinity scenario for the affected area than in the without salinity scenario. This increase in economic surplus is given by area abchgf.

The economic impact of salinity across both areas thus equals the decline in economic surplus in the affected area minus the increase in economic surplus in the area not affected. The overall economic impact is therefore given by area abed in Figure 2(b) minus area abchgf in Figure 3.

This analysis has demonstrated how enterprise substitution in response to salinity within the salinised area, wherein enterprises with greater tolerance to salinity displace those with lesser tolerance, leads to further enterprise substitution within the area remaining non-salinised. In the case portrayed, the direction of enterprise substitution in the area remaining non-salinised is the opposite of that occurring in the salinised area. If the relatively salt-tolerant enterprise were instead the more intensive user of water, however, the direction of enterprise substitution in the area remaining non-salinised would be the same as that occurring in the area becoming salinised.

Accurate assessment of the economic impact on agriculture of land salinity requires a modelling procedure which can account for the enterprise substitution effects identified above. Testing the null hypothesis posed in Section 1.2 will indicate, at least for MIA broadacre agriculture, the seriousness of the loss of accuracy that occurs if enterprise substitution is not accounted for.

3. REVIEW OF PREVIOUS STUDIES

A number of previous studies involving economic evaluation of the agricultural impact of land salinisation are now reviewed in light of the analytical framework presented in the previous section.

3.1 Evaluations of Impact on Farm-Gate Revenue

Studies by Gutteridge, Haskins and Davey (1985), Grieve *et al.* (1986) and van der Lely (1993b) approached economic evaluation using similar frameworks which differed from the framework presented above in a number of important respects. Firstly, the economic impact of land salinisation within the respective regions of concern was defined as equivalent to the impact on farm-gate revenue. This definition is likely to lead to considerable over-estimation of the 'true' economic impact, as can be illustrated for the single industry case with reference to Figure 1. The true economic impact was identified in Section 2.1 as given by the area bced. The impact on farm-gate revenue, given by the area Q_0ceQ_1, is appreciably larger since this measure fails to recognise that costs are also reduced as output declines. The total reduction in costs is given by area Q_0cfQ_1.

Secondly, these studies did not account for farmers responding to land salinisation by way of enterprise substitution, thereby further over-estimating the true economic impact. The error can be illustrated with reference to Figures 2 and 3. Using Figure 2(b), land salinity was shown, in the area becoming salinised, to be associated with a reduction in carrot land use from O^cA_0 to O^cA_1 and in increase in wheat land use from O^wA_0 to O^wA_1.

The approach used in the above studies, however, assumes that carrot land use in this area would remain at O^cA_0 after salinisation and wheat land use would remain at O^wA_0. It can be seen that the MNIB (and therefore MNSB) from wheat exceeds that from carrots for all of the area A_0A_1 in which wheat would be substituted for carrots. Failure to account for enterprise substitution within the area becoming salinised thus results in over-estimation of the economic impact in this area of land salinisation, the extent of the over-estimate being given by area bef. By failing to account for enterprise substitution in the salinised area, the economic consequences of this enterprise substitution for the area remaining non-salinised (as identified in Section 2.2) are also ignored. In the case portrayed in Figure 3, the economic impact of salinity would therefore be further over-estimated by area abchgf. By failing to account for enterprise substitution in the salinised area, the economic impact of land salinity is therefore over-estimated in total by area bef in Figure 2(b) plus area abchgf in Figure 3.

3.2 Murray-Darling Basin Commission Drainage Evaluation Model

In an attempt to ensure consistency in economic evaluations of capital works designed to address salinity (and waterlogging) problems, the Murray-Darling Basin Commission (MDBC) (1992) released the spreadsheet-based Drainage Evaluation Model. The model is, in one respect, more consistent with the framework presented in Section 2 than the studies just reviewed. That is, it incorporates the effect of changes in output on cash costs.

The effect on cash costs, however, is unlikely to represent the full cost effect. It is likely that there will also be significant effects on opportunity costs of resources in limited supply, such as irrigation water, irrigation channel capacity and farm family labour. Assuming that opportunity costs of these resources are not affected, as is implicitly the case with the MDBC model, is thus likely to lead to estimation error The nature of this error can be illustrated for the single industry case with reference to Figure 4, which has been modified from Figure 1. If the effect of changes in output on production costs are approximated only by effects on cash costs, the industry supply (and therefore MSC) schedules for the without salinity and with salinity scenarios are implicitly assumed to be as denoted by S_0' and S_1' respectively. Unlike the true schedules, S_0 and S_1, these schedules do not account for the phenomenon of diminishing returns to scale which, in this stylised example, manifests as soon as output expands from zero. Economic surplus without salinity would be estimated by area abmc and economic surplus with salinity by area adoe. Estimated economic impact of land salinity would thus be given by area bmceod. The true economic impact is smaller, however, given by area bced (as demonstrated in Section 2.1). This is because, by failing to recognise that MNIB (and MNSB) declines as output increases, economic losses associated with output reductions at the margin are over-estimated.

As was the case in the studies discussed above, the MDBC model also cannot account for the enterprise substitution effects of salinity as detailed in Section 2.2. The consequent estimation error is as discussed in Section 3.1.

3.3 NSW Agriculture Evaluation of a Drainage Scheme for Benerembah Irrigation District

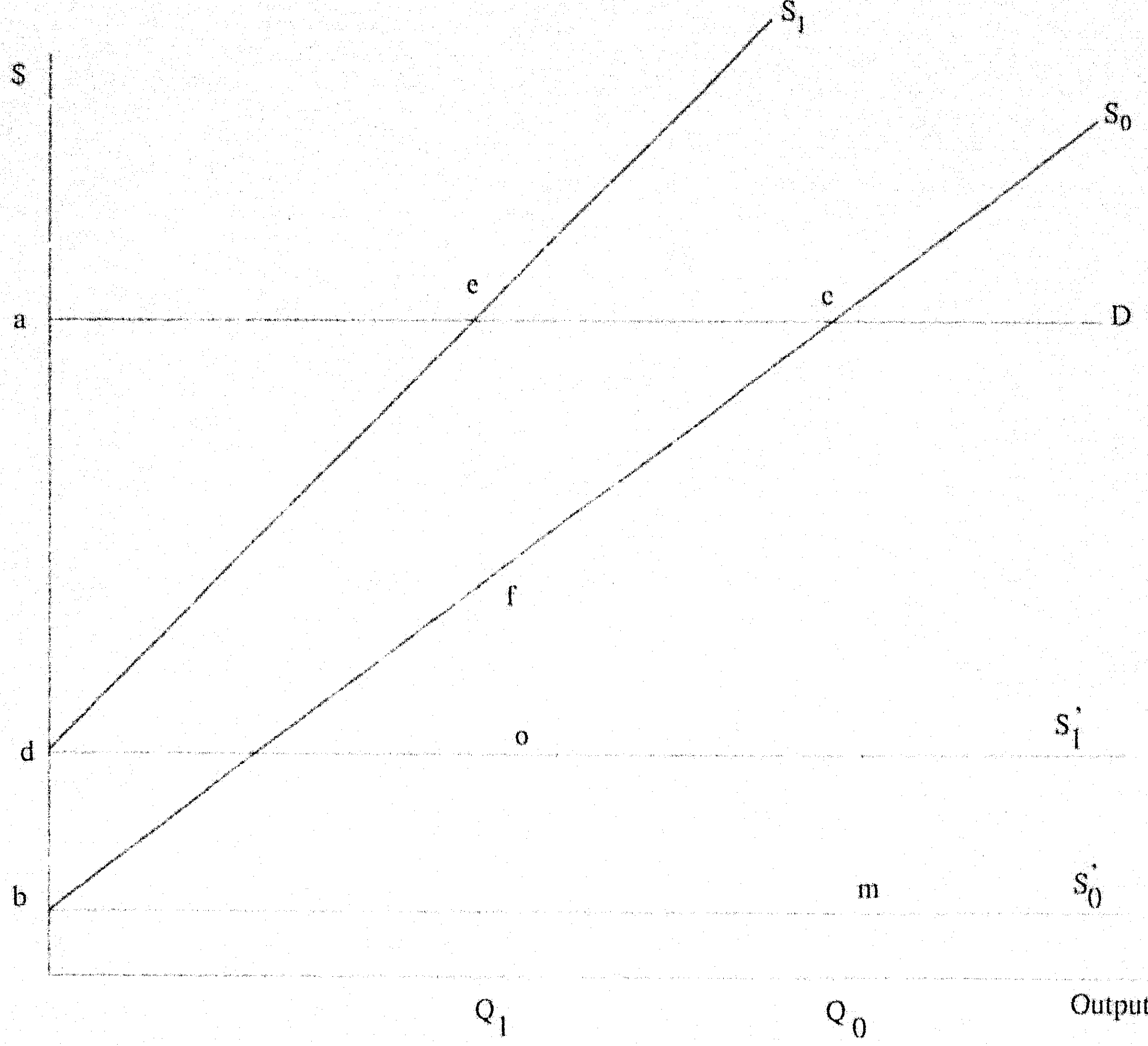
The approach used by Jones and Marshall (1992) addressed each of the concerns raised above. A single period linear programming model of broadacre agriculture in an irrigation district was developed in which:

(i) the objective function involved maximisation of district net farm income;
(ii) availability of land at different salinity levels was accounted for by incorporating separate land use constraints for a number of land categories associated with different salinity levels;
(iii) the effect of land salinity on each enterprise was accounted for by specifying, for each enterprise, a separate activity for each of these land categories, the yield of which was specified according to a yield/salinity equation for each enterprise; and
(iv) a range of additional constraints were included to account for the limited availability of various resources, such as annual irrigation supply volume, monthly irrigation channel capacity and permanent labour, thereby accounting for effects of output changes on marginal opportunity costs of these resources.

The economic impact of land salinity at a particular time was estimated by running the model twice. the first time with land use constraints set assuming zero salinity and the second time with the same constraints set according to land salinity levels predicted for that time. The loss of economic surplus was calculated as the reduction in district net farm income between the without and with salinity scenarios.

By incorporating constraints to reflect various limitations on resources availability, the method endogenously accounted for changes in the marginal opportunity costs of these resources as output levels of activities changed, thus overcoming one of the problems

Figure 4: Significance of Effects of Output Changes on Opportunity Costs



identified above with regard to the Murray-Darling Basin Commission model. The optimising nature of the method used also allowed farmer response to salinisation through enterprise substitution to be accounted for.

An assumption implicit in the method, that enterprise substitution occurs immediately following a change in land salinity levels, has been questioned by van der Lely (1993b p. 6) who suggests that "the flexibility of the choice may be subject to some rigidity, for instance the adjustment to more saline conditions over time may involve a lag and a cost (such as new paddock layouts)".

4. STUDY METHOD

4.1 Application of the Framework Presented in Section 2

The framework presented in Section 2 was used in this study as a basis for quantifying the economic impact of land salinity in the MIA over the period 1993 until 2023. However, given that:

(a) assumption (iii) in Section 2.1 is unrealistic in the case of the rice industry[3];
(b) assumption (iv) is unrealistic as a result of regulated marketing of water[4]; and therefore
(c) economic surplus (net social benefit) at equilibrium differs from net industry benefit;

it was necessary to develop a method whereby the impact of salinity on economic surplus, rather than on net industry benefit, could be estimated. The method of accounting for the difference between these two measures is discussed in Section 4.5.

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[3] Under the regulated marketing arrangements for rice grown in NSW, returns from higher and lower returning markets are pooled and an equalised price paid to farmers. With farmers basing production decisions on the equalised price rather than the (lower) marginal return to society, the MSB schedule is therefore located below the industry demand schedule.

[4] Regulated marketing arrangements by which water is allocated to irrigation, as well as externalities associated with supplying water to irrigators, mean that the price paid by irrigators for water is likely to diverge significantly from its marginal social cost (which can be estimated by applying the opportunity cost principle). Individual farmers also generate external costs as a result of their irrigation practices and their replacement of deep-rooted perennial vegetation with shallow-rooted annual vegetation, resulting in rising watertables and land salinisation. These costs appear largely to be incurred internally within the MIA, however, and therefore should not in themselves be responsible for significant divergence between industry supply and MSC schedules. Other external costs relating to drainage leaving the MIA (for example, contribution to downstream flooding), however, may be responsible for some such divergence. As these external costs are yet to be valued, it was not possible to account for them in this study. Exclusion of downstream costs from the analysis will lead to the economic impact of land salinisation during the period of interest to be over-estimated, to a degree depending on the magnitude of these costs.

The assumption of infinite price elasticity of demand made in Section 2.1 was considered for output from the MIA, given the small share of each industry's output accounted for by MIA production in each case.

4.2 The Regional Linear Programming Model

Following Jones and Marshall (1992), a regional linear programming (LP) model of broadacre agriculture was developed for the MIA. The objection function involves maximisation of district gross margin (DGM) which, since fixed costs remain constant, is equivalent to maximisation of net industry benefit. Solutions of the model could thereby be used to predict changes in equilibrium supply levels given changes in salinity conditions.

Aggregate supply from individual MIA broadacre farms would of course have ideally been analysed by constructing a model for each farm and by solving these models taking into account various interdependencies between the farms. However, the research costs involved were prohibitive. A commonly used alternative is to model one or more 'representative' farm/s and to estimate supply of the group by aggregating the solutions from the representative farm models through appropriate weighting. Buckwell and Hazell (1972) demonstrated that estimates of total supply obtained using this approach will be subject to aggregation bias unless stringent conditions are satisfied.

The method used in this study, constructing a single model to represent the full group of MIA broadacre farms, is logically equivalent to constructing a single representative farm model based on an average farm and then multiplying the estimate of supply by the number of farms. The regional LP model approach can therefore be expected to lead to some degree of aggregation bias. The resulting degree of estimation error is expected to be minor, however, compared with the scale of the errors identified in Section 3 in connection with the alternative approaches reviewed.

4.3 Details of Regional LP Model

4.3.1 Activities

A range of crop, pasture and livestock activities were specified in the model, as well as hay making and hay feeding activities. Crop activities included were rice, winter cereals (represented by wheat and barley), grain legumes/oilseeds (represented by soybeans) and vegetables (represented by onions and carrots). Pasture activities were lucerne, irrigated sub-clover based pasture, non-irrigated sub-clover based pasture. A selection of sheep enterprises typical of the MIA were also included. These were first- and second cross prime lamb production and merino wethers

Agronomic factors influencing the sequencing of crops and pastures within each land class were accounted for by specification of rotational constraints. Within each land category, the following tie constraints were specified.

- the area of rice not to exceed the area of annual pasture;
- the area of winter cereals not to exceed the area of annual pasture;
- the area of soybeans not to exceed the area of winter cereals; and
- the area of vegetables not to exceed six times the area of rice.

The fact that farmers choose among enterprises on the basis of not only short-term financial considerations but also of other factors including enterprise workloads, machinery requirements and demands for management and marketing expertise was accounted for by specifying constraints on maximum areas of rice, winter cereals, grain legumes/oilseeds, vegetables and lucerne. These limits were specified according to upper levels at which each were undertaken during the ecade.

4.3.2 Resource constraints

Separate constraints were specified in the model for land categories distinguished according to (i) level of salinity (if any); (ii) whether or not predisposed to waterlogging; and (iii) whether laser landformed or not. With respect to salinity level, salinity classes were distinguished for salinity levels of 0-2 (0), 2-3 (3), 3-4 (4), 4-6 (5), 6-8 (7) and greater than 8 (8) dS/m, where the number parenthesised following a range is the precise salinity value used in estimating the salinity-induced yield reduction for that salinity class.

The progress of land salinisation in the MIA from 1993 until 2023 has been predicted at ten year intervals by van der Lely (1993a). These predictions are shown in Table 1.

Table 1: Current and Future Land Salinity in the MIA

Land Salinity (dS/m)	(% of farm area)			
	1993	2003	2013	2023
0 - 2	74.1	68.1	63.7	59.2
2 - 3	8.0	10.5	11.0	12.1
3 - 4	4.1	5.0	6.4	7.2
4 - 6	3.6	4.2	6.0	6.8
6 - 8	2.4	2.2	1.6	2.5
> 8	7.7	10.0	11.4	12.2

In order to allow increased accuracy in accounting for changes in the economic impact of land salinity over time, land salinity predictions at five year intervals were linearly interpolated from the data included in Table 2.

The proportion of MIA broadacre land predisposed to waterlogging was estimated to be 80 per cent, and predicted to remain at this level. The proportion of MIA broadacre land already laser landformed in 1993 was estimated to be 40 per cent and was predicted to increase linearly to 85 per cent in 2003 and thereafter remain constant.

All broadacre land in the MIA was assumed to be laid out for irrigation.

Given that six land classes were distinguished according to salinity level, two according to waterlogging status and two according to landformed status, specification of area constraints for 24 (= 6 x 2 x 2) distinct land categories was required.

A constraint relating to the maximum monthly capacity for delivering water to farms in the MIA was specified. The capacity was a function of the size of supply channels, the number of dethridge wheels and the flow rate of water delivered from the irrigation supply channel. A constraint was also specified with regard to the aggregate annual water allocation to the MIA.

Total operators' labour available per season, measured in hours, was also incorporated as a constraint.

4.3.3 Costs and returns

Farm-gate prices for crops were calculated as the average over the five year period from 1988 to 1992. Variable costs of crop activities were obtained from NSW Agriculture *Farm Budget Handbooks* for 1992. Gross margins for sheep activities used in the models were calculated as the average over the four year period from 1990 to 1993. These prices, gross margins and variable costs were assumed to remain constant in real terms during the 30 year planning horizon of the study.

4.3.4 Technical coefficients

Technical coefficients were derived from a variety of sources, including NSW Agriculture *Farm Budget Handbooks*. In some cases these coefficients were revised after discussions with local NSW Agriculture district agronomists.

Variation in yield levels across land categories with different salinity levels was estimated on the basis of research which indicates there is some threshold level of land salinity for each crop and pasture, beyond which yields decline linearly with increasing salinity (Maas and Hoffman 1977). For example, wheat yields are not affected until land salinity reaches 2.9 dS/m. For every 1 dS/m in excess of 2.9 dS/m, however, there is predicted to be a 13 per cent yield reduction. The threshold levels and loss factors for plant species of interest in this study are shown in Table 2.

Table 2: Yield Loss Parameters for Land Salinity

Crop / Pasture	Salinity Threshold (dS/m)	Yield Loss per dS/m (%)
Wheat[a]	2.9	13.0
Barley[b]	3.5	9.0
Sub-clover[c]	1.3	15.0
Dryland Sub-clover[c]	1.3	15.0
Tall Wheat Grass[d]	7.5	4.0
Soybeans[d]	5.0	20.0
Rice[c]	4.0	12.0
Lucerne[c]	2.0	7.3
Onions[d]	1.2	16.0
Carrots[d]	1.0	14.0

Source: [a] Grieve *et al.* (1986). [b] Slavich and Read (1984). [c] van der Lely (1993b). [d] Maas and Hoffman (1977).

Technical coefficients relating to the impacts of waterlogging and laser landforming are detailed in Marshall *et al.* (1993).

4.4 Economic Values for Inputs and Outputs

Economic values for inputs and outputs were assumed to be equivalent to financial values with the exception of rice output and irrigation water obtained through district supply infrastructure. The reasons for these exceptions were given in Section 4.1.

A marginal value of medium grain rice output over the next five years of $110 per tonne has recently been predicted (pers. comm. J. Kennedy, Ricegrowers' Co-operative Limited). This value has been used as the economic value of rice in this study. The economic value of water used by MIA irrigators has been estimated using the opportunity cost principle to be $30 per megalitre (NSW Department of Water Resources 1993).

4.5 Calculation of the Economic Impact of Land Salinity

Equilibrium supply levels under particular salinity conditions were estimated using the regional LP model, as were equilibrium supply levels under the without salinity scenario. The differences between scenarios in estimated supply levels were used to calculate the impact of the salinity conditions on economic surplus. The impact on economic surplus was calculated by deriving the value of district economic gross margin (DEGM) associated with supply levels estimated for each scenario and determining the difference. Derivation of DEGM for each scenario involved recalculating DGM using economic values for all inputs and outputs. Although DEGM exceeds economic surplus since fixed costs are not deducted, a change in DEGM will be equal to a change in economic surplus since fixed costs by definition remain constant.

With land salinity levels predicted to increase at five year intervals, the regional LP model was re-run for each interval after respecifying area constraints for each land category accordingly. DEGM was recalculated at each interval on the basis of LP solution activity levels.

The economic impact of land salinity at a particular five year interval was calculated by comparing the DEGM predicted without any land salinity with the DEGM predicted if land salinity levels are derived as explained in Section 4.3.1. The area laser landformed, increasing as predicted in Section 4.3.1 regardless of whether the with salinity or without salinity scenario was being evaluated, is the same for both scenarios at any particular time. All LP model coefficients other than those relating to salinity level or area laser landformed were assumed to remain constant throughout the 30 year planning horizon.

The economic impact of land salinity was thereby obtained at each five year interval. The economic impact in intervening years was derived by linear interpolation.

Finally, the present value of the economic impact of predicted land salinity from 1993 until 2023 was then calculated using a real discount rate of 7 per cent per year as prescribed in NSW Treasury (1990).

4.6 Accounting for Benefits and Costs of Farmer Response to Land Salinisation

As noted in Section 3.3, the regional LP approach to estimating the economic impact of land salinity has been criticised on the grounds that farmers are implicitly assumed to respond instantaneously to changes in land salinity. Response is in fact likely to be slower than this as a result of lags in farmers recognising that salinity conditions have changed, discovering an appropriate response and being able to afford to implement responses which in some cases, as noted by van der Lely (1993b), may require some modification to farm infrastructure.

D. Naunton & Co. *et al.* (1993 p. 12.1) found that a significant statistical relationship between land salinity and farm financial performance within Wakool Irrigation District could not be established and concluded that this was due to farmers tending to:

> " . . . concentrate their resources on the most productive, least saline areas of their farm. Therefore, the major production and revenue is generated from the areas of the farm which are least likely to be influenced by salinity . . Any salinity impacts are likely to have occurred on the less intensively irrigated annual pasture and/or

dryland areas which are naturally farmed less intensively and are less productive".

We concluded therefore that an assumption of farmers substituting and relocating enterprises in response to land salinisation was reasonable, but that delays and costs involved in this response need also to incorporated in an analysis so as to avoid under-estimation of the economic impact of land salinity.

In Section 3.1 it was found that failure to account for effects of enterprise substitution in an area affected by salinity results in the economic impact of the agricultural effects of land salinity being over-estimated by the sum of the areas bef in Figure 2(b) and abchgf in Figure 3. Conversely, assuming that enterprise substitution has occurred when in fact it has yet to commence results in the economic impact being under-estimated by this same area. As enterprise substitution begins to proceed, however, the size of the under-estimate diminishes until, when the process is complete, the estimate becomes accurate.

The economic significance of delays in responses by farmers was accounted for in the study by developing a spreadsheet for use in association with the regional LP model. The method assumes that response delay is caused solely by the time taken for farmers to recognise that the salinity status of their land has changed. This assumption is considered reasonable, given that (i) information regarding the relative salt-sensitivities of the various crop and pasture species has been included in extension programs, such as *Salt Action* in NSW, for a number of years and (ii) the costs to farmers of substituting and relocating enterprises are likely in general to be minor compared with the benefits.

The procedure followed in accounting for response delays is best explained by example. A description of the process of predicting the economic effects of salinisation in 1998, assuming a five year average lag in farmer response to salinisation, follows:

(a) the LP model was run for 1998 using the salinity predictions for 1993. That is, farmers were modelled as acting in 1998 as if 1993 salinity conditions still applied. The LP solution thus provided a prediction of how farmers in 1998 would *expect* crop and pasture activities to be allocated among each of the 24 land categories, not of how they would be *actually* allocated;

(b) the *expected* 1998 allocation of crop and pasture activities by land category was transferred into the spreadsheet model;

(c) the change between 1993 and 1998 in the area within each salinity class (i.e., derived as explained in Section 4.3.1) due to the change in salinity conditions was calculated within the spreadsheet model according to the land salinity predictions for these years;

(d) these changes in areas per salinity class were apportioned among crop and pasture activities in the spreadsheet model as follows:

    (i) where the area within a salinity class was calculated to decline, the decline was apportioned on a pro rata basis among crop and pasture activities according to their *expected* areas within land categories corresponding with that salinity class; and

(ii) where the area within a salinity class was calculated to increase, the increase was apportioned on a pro rata basis among crop and pasture activities according to their *expected* areas within land categories corresponding with the immediately lower salinity class. If the total area within the 4-5 dS/m salinity class was predicted to increase, for instance, the increase was apportioned among activities on a pro rata basis according to their *expected* areas within land categories corresponding with the 3-4 dS/m class;

(e) The so-derived *actual* allocation of crop and pasture activities among land categories in 1998 was transferred into the LP. Instead of re-running the model as previously (i.e., with crop and pasture activity level variables specified as decision variables), crop and pasture activity levels were now fixed at these copied values. Re-running the LP model in this way was required to predict activity levels other than for crop and pasture activities, such as for livestock, hay-making and hay-feeding activities. The actual DEGM given predicted salinity conditions was thus derived according to activity levels determined in the second LP run.

Given that there is no evidence on which to base an assumption regarding the average length of the response delay for MIA farmers, the economic effects of predicted salinisation were estimated in the base case by assuming an average delay of 10 years. This length of delay was considered reasonable given that it can be expected that the length of the delay will vary significantly among farmers, with some farmers much slower to recognise and respond to salinisation than others. In order to test the null hypothesis, however, results were also obtained for alternative assumptions of 0 and 5 year average delays and of no response at all.

In estimating the cost of farmer response, the major constraint to substituting or relocating enterprises in response to local changes in salinity conditions was identified as the flexibility afforded by existing farm infrastructure. Of particular relevance is the location of fence lines and the design and location of irrigation channels and drains (pers. comm., Irrigation Management Service, Yanco Agricultural Institute). In some cases specialised management of a salinised area will be impractical and/or excessively costly due to inconvenient design or location of existing structures and an investment will be required to rectify the situation. It is important to note, however, that many of the locations in the MIA predisposed to land salinisation have been known to farmers for some time. Hence in many cases design and location of farm structures has taken this knowledge into account.

The approach taken in predicting future impacts of on-farm response on fencing costs and on-farm channels and drains is detailed in Marshall *et al.* (1993). The present value over the 30 year period of these costs of on-farm response to land salinisation was thus predicted, using a real discount rate of 7 per cent per year, to be $0.8 million for all response delay scenarios other than that of no response.

5. RESULTS

5.1 Base Case: Ten Year Delay in Farmer Response

Estimates of district economic gross margin for selected years between 1993 and 2023, with and without salinity, are shown in Table 3. Also included is, for each selected year, the loss of economic surplus due to salinity, calculated by subtracting DEGM with salinity from that without salinity. The present values of DEGM without and with salinity between 1993 and 2023 are also presented, together with the present value of annual losses of economic surplus over the period. Note that the estimated loss of $25.1 million in the present value of economic surplus is equal to the $24.3 million loss of present value of DEGM plus the $0.8 million present value cost of on-farm response.

Table 3: Economic Impacts of Salinity Assuming a 10 Year Delay in Farmer Response to Salinity ($m)

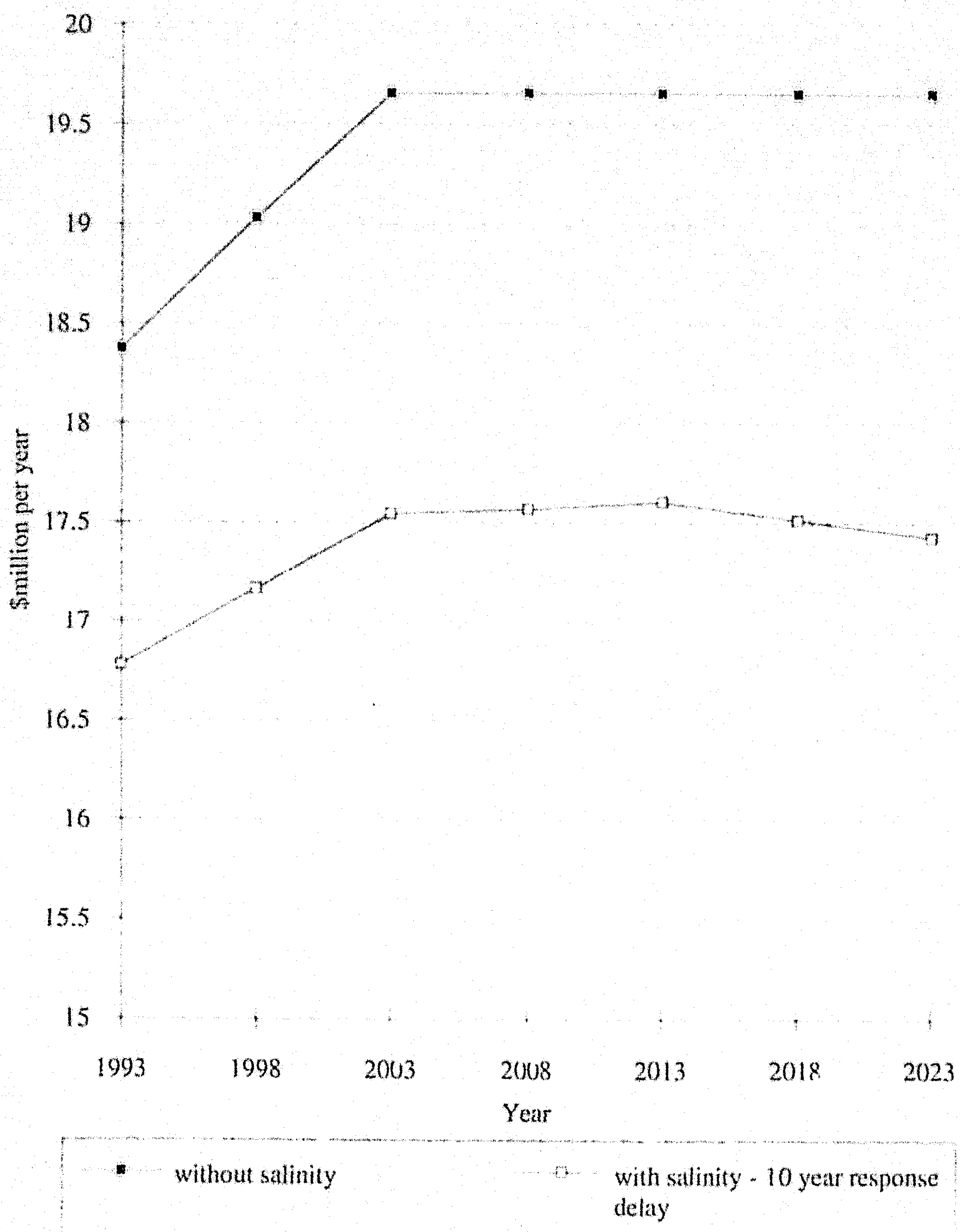
Year	DEGM Without Salinity	DEGM With Salinity	Loss of Economic Surplus Due to Salinity
1993	18.4	16.8	1.6
2003	19.7	17.5	2.1
2013	19.7	17.6	2.1
2023	19.7	17.4	2.2
Present value	240.9	216.6	25.1

Trends in DEGM over the 30 year period under the with and without salinity scenarios are illustrated in Figure 5.

The annual loss of economic surplus in 30 years time due to land salinity is thus predicted to be $0.6 million greater than the current loss.

The increase in DEGM under both scenarios between 1993 and 2003 is attributable to the effects of landforming assumed to take place during this period. The stability of DEGM after 2003 in the with salinity scenario is due to the cost of salinity-induced reductions in productivity being offset by the benefit of farmers lowering aggregate water use in response to salinisation, which represents a significant cost reduction with the economic value of water assumed to be $30 per ML.

Figure 5: District Economic Gross Margin With and Without Salinity - 10 Year Response Delay Assumed



5.2 Alternative Assumptions Regarding Length of Response Delay

A comparison of the above estimates of annual losses of economic surplus for the base case with estimates derived using alternative assumptions of response delay is presented in Table 4. Also included is a comparison of estimates of the present value (PV) of losses of economic surplus over the 30 year period derived using the various assumptions of response delay. Note that the present value estimates corresponding with all but the `no response' assumption incorporate the $0.8 million present value cost of on-farm response.

Table 4: Estimated Losses of Economic Surplus Given Alternative Assumptions Regarding Farmer Response to Salinity ($m)

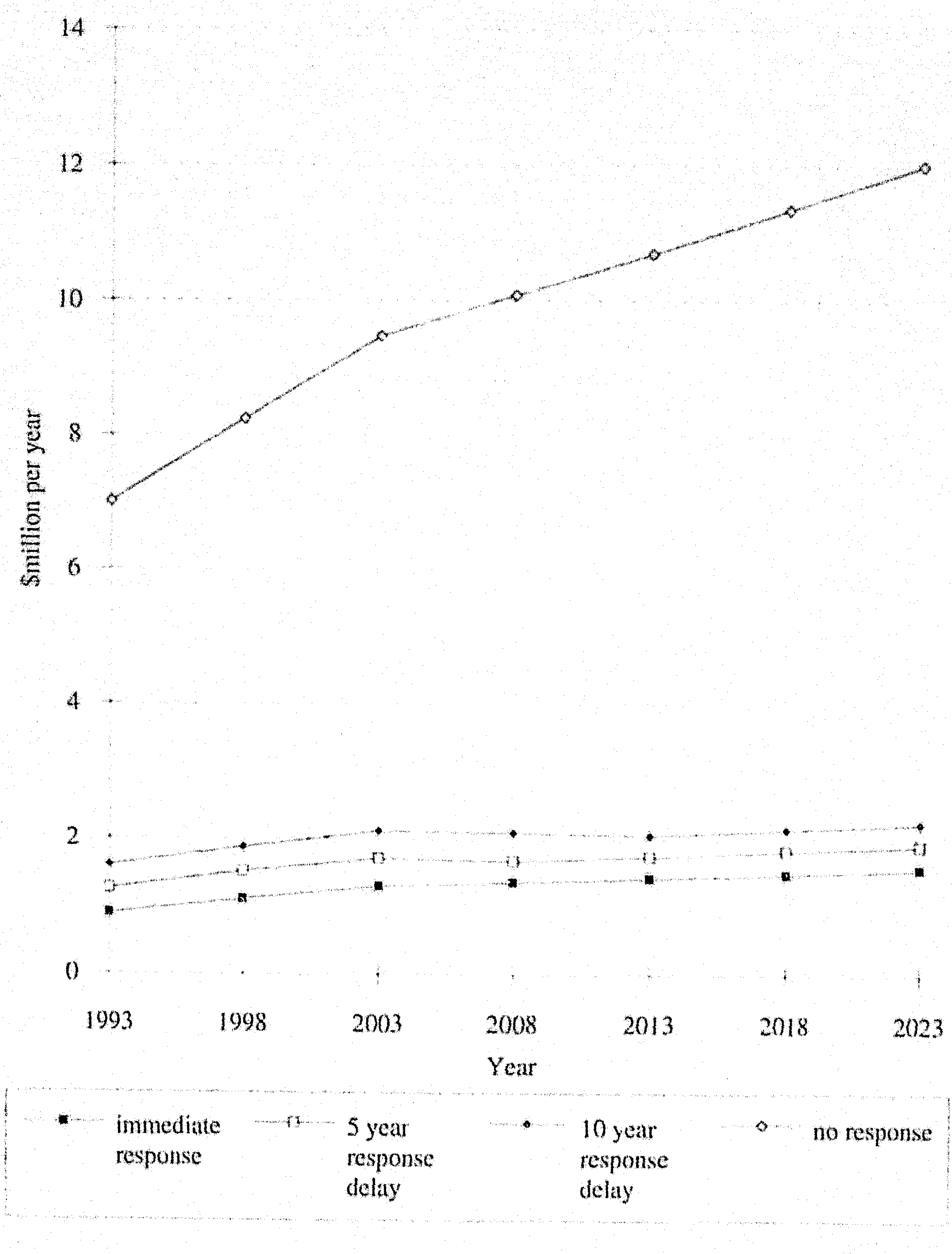
Year	Assumed Length of Response Delay			
	Immediate Response	5 Year Response Delay	10 Year Response Delay	No Response
1993	0.9	1.3	1.6	7.0
2003	1.3	1.7	2.1	9.5
2013	1.4	1.7	2.1	10.7
2023	1.6	1.9	2.2	12.0
PV	15.8	20.5	25.1	113.4

The significance for the predicted trend of losses of economic surplus over the 30 year period of the assumption used with regard to farmer response is illustrated in Figure 6.

It is evident that the assumption made regarding farmer response has a significant effect on the size of estimated loss of economic surplus in any year. If an assumption of no farmer response is used, for example, the resulting estimate of loss of economic surplus in 1993 is $5.4 million (or more than four times) greater than obtained using the base case assumption. If the assumption of farmer response after a ten year delay is accepted as reasonably accurate, this $5.4 million difference can be taken as a measure of the over-estimate of the economic impact of land salinity in a single year due to ignoring farmer response. This over-estimate corresponds with that identified conceptually in Section 2 2 as being given by the sum of the areas bef in Figure 2(b) and abchgf in Figure 3.

The assumption made regarding farmer response is clearly also critical for estimating the size of the present value of losses of economic surplus over the 30 year period. If an assumption of no farmer response is used, for example, the resulting estimate of the present value of salinity-induced losses of economic surplus over the period is 4.5 times greater than obtained using the base case assumption. Alternatively, if the assumption of immediate farmer response is used, the resulting estimate of the present value of losses of economic surplus is only 63 per cent of that obtained using the base case assumption.

Figure 6: Estimated Losses of Economic Surplus Under Alternative Farmer Response Assumptions



The results also indicate the potential in the MIA for significantly reducing the economic impact of land salinisation by undertaking steps to reduce the average delay in farmer response to changed land salinity conditions. The results above indicate that the present value of the economic impact of salinisation could be reduced by $4.6 million (18 per cent) by reducing average response delay from 10 years to 5 years and by $9.3 million (37 per cent) by reducing the response delay from 10 years to 0 years.

6. CONCLUSIONS

In the case of the MIA, estimates of the economic impact of land salinity have been demonstrated to be sensitive to the assumption made with respect to average delay in farmer response to changed salinity conditions, particularly with regard to the choice of whether to assume that farmers do or do not respond. Within the range of response lags considered "reasonable", from five to ten years, the estimate of the present value of the economic impact ranged from $20.5 million to $25.1 million. This degree of discrepancy is probably not serious given the extent of errors in some of the technical parameters used, particularly in relation to the effects of land salinity on crops and pastures in practice rather than under experimental conditions.

If farmers are assumed to not respond at all to salinisation of their land, however, the estimate of the present value of the economic impact was $113.4 million. This must be considered a serious discrepancy compared with estimates obtained when "reasonable" farmer response is assumed. The null hypothesis is thus rejected and the alternative hypothesis, that estimates of the economic impact of land salinisation are sensitive to how farmers are assumed to respond, accepted. We therefore conclude that evaluations of the economic impact of land salinity need to explicitly account for how farmers may be expected to adjust in response to the problem.

The degree of sensitivity, however, can be expected to vary across districts. The magnitude of the discrepancy between estimates in the MIA, for instance, would be expected to be relatively high because the region includes a vegetable industry in which unit returns are generally substantially greater than obtained from other broadacre enterprises. Assuming that vegetable crops, which are highly salt sensitive, would not be relocated from salinised land to non-saline land, or at least land of low salinity, obviously leads to the economic impact of salinisation on vegetable growing being substantially over-estimated.

The results also indicate there is potential for high pay-offs to be obtained from assisting farmers to recognise changes in the salinity status of their land, thereby allowing them to more promptly reallocate their land among enterprises so as to minimise the damage to profits and reduce the economic impact. Options include educating farmers to identify symptoms of land salinity or arranging for them to have greater access to salinity meters. Pay-offs from options such as these should therefore be considered against those from options involving capital expenditure, such as sub-surface drainage works, when deciding how to allocate limited resources so as to minimise the economic impact of land salinisation.

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