

Spatio-economic Assessment of Salinity Scenarios and Control Treatments

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Executive Summary

The economic component of SS2020 used a geographic information system (GIS) to facilitate the estimation and mapping of the economic consequences of two alternative scenarios. The situations examined were a "**business as usual**" scenario (which assumed minimal adaptive management), and a "**treatment**" scenario. The latter involved a variety of different strategies for controlling recharge, all of which comprised deep rooted perennials. Strategies for rehabilitating discharge areas with salt-adapted plants were not examined. Three case study areas were selected for the purposes of making an *ex ante* assessment of the economic impacts associated with each scenario. Impacts to both on and off-farm values were evaluated.

The costs incurred under the "business as usual" scenario were equated to future losses predicted to be suffered as a result of expanding salinity. That is, the costs already imposed by salinity up to this point in time were considered as "sunk costs" and netted out of the calculation. This was done because the treatments examined by this study are not expected to be capable of reclaiming land that is currently saline. Production losses were calculated by over-laying salinity predictions onto a map of land management units that have different economic values. Estimates of these values were obtained from a whole-farm optimisation model known as MIDAS (Model of an Integrated Dryland Agricultural System). A similar over-laying procedure was used to estimate the extent of losses imposed on natural assets and man-made infrastructure.

One of the objectives of SS2020 was to quantify the economic gains and losses associated with implementing particular treatments, relative to the "business as usual" alternative. In accordance with this aim, a number of treatments were devised in consultation with hydrologists, agronomists, foresters and farmers. This consultative process produced a set of criteria that were used to select and locate treatments for each case study area. The criteria included land capability, distance to markets, and availability of yield data.

A method was developed for evaluating the treatments. It used GIS and an accompanying spreadsheet-based model to simulate economic impacts. In brief, GIS was used to calculate the area of different categories of land that are expected to undergo a change in profitability following implementation of a control strategy. These statistics were then passed onto a spreadsheet that consolidated the impacts into discounted values. The summation of these impacts provided a measure of the aggregate net benefits attributable to a treatment. The potential benefits to natural areas and man-made infrastructure were also examined within this framework.

Several simplifying assumptions had to be made before the analytical method could be applied. Treatments were assumed to be completely effective at controlling salinity on the site where they were located, and off-site control was assumed to be zero. These restrictions were necessary because of the difficulties that were encountered in modelling the responsiveness of groundwater to specific treatments. With better hydrological information these assumptions could be relaxed because the economic model is capable of dealing more complex situations.

Key findings

For the three case study areas that were examined, the discounted present value of production losses under the “business as usual” scenario ranged between \$800 and \$1090 per hectare of land that becomes saline, or between \$70 and \$200 per hectare when averaged over every hectare within a case study area. When expressed in terms of equivalent annual values, the losses were between \$25 and \$33 per hectare of newly salinised land or between \$4.50 and \$6.15 per hectare averaged over the whole area. The approximate distribution of costs are shown by maps included in Appendix C. In aggregate terms, new losses for each of the two smaller case study regions (30,000 hectare each) ranged between \$4.5 to \$6.1 million. The larger of the three case study areas (comprising 107,000 ha) was estimated to suffer new losses of approximately \$8 million. In addition to these production losses, a significant amount of new damage is expected to be inflicted on infrastructure and remnant vegetation. Across the three study areas, approximately 28km of sealed roads are likely to be lost in the next 20 years, together with 54 buildings, 540 farm dams, and 10,050 hectares of perennial vegetation.

The economic impacts associated with the “business as usual” scenario have no direct usefulness for decision making, other than to provide an upper-bound of the size of future economic benefits from salinity treatments. A more important guide for policy is the extent to which these losses can actually be avoided with particular treatments, and the net benefits of implementing these treatments. The methodology that is outlined in this report for estimating net benefits requires the separation of land in several categories:

- Agricultural land adjacent to a treated area that is prevented from becoming saline.
- Land that is prevented from becoming saline and supports man-made or natural assets.
- Land prevented from becoming saline because of a treatment implemented on that land.
- Land planted to a treatment that was predicted to never be at risk from salinity.

The first three categories represent land for which profitability is expected to increase under a treatment. The fourth category describes land for which profitability is likely to decline. This is a consequence of agricultural enterprises being replaced with lower-value forestry enterprises (an exception is bluegums in areas receiving greater than 650mm annual rainfall).

Hydrological modelling conducted by SS2020 indicates that, in many instances, a very small proportion of the benefits from a treatment strategy are likely to be generated by the first two categories. That is, most strategies do not offer a great deal of off-site control. Hence, if a strategy is to produce a net benefit, most of the benefits will need to come from land belonging to the third category, meaning that treatments will need to be commercially profitable in their own right if they are to be attractive to farmers and desirable even from a community-wide perspective. A priority for future work will be to determine the extent to which this general conclusion applies to the SS2020 region, and to identify geographic areas where there is potential to realise off-site benefits from treatments.

1. Introduction

The objective of this section of the SS2020 Project was to develop and apply a methodology for evaluating the economic impacts of alternative salinity treatments in different scenarios. From the outset, the Project offered an exciting opportunity to produce maps at a scale of 1:50,000 showing the spatial distribution of costs and/or benefits associated with a variety of scenarios. Economic maps are potentially useful tools for identifying areas in need of priority attention and for gaining a better understanding of the relative magnitude of on-farm and off-farm impacts. The goal of the economics component of SS2020 was to construct these maps using salinity predictions that were to be developed by hydrologists on the research team. Particular attention was paid to developing a methodology that could be applied to other geographic regions in Australia that have similar data sets.

A review of the literature revealed that many previous 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 deciding how much to invest in treating the problem. 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 analyses of the costs and benefits of salinity treatments, rather than costs of non-treatment.

The methods developed by this study facilitate an initial appraisal of the costs and benefits of treating salinity. The analytical framework builds upon work by Smyth and Young (1997) and Walpole and Sinden (1996) who used an economic model in combination with GIS 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 potential 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 contents of this report are organised as follows: **Section 2** contains an outline of the scenarios that were examined and the types of impacts that are associated with each scenario. It also describes the framework that was developed for estimating the size of impacts. **Section 3** documents how the methodology was applied to three case study areas within the SS2020 region. Details are given of the types of treatments examined, the commercial returns for these treatments, and the information sources that were used to conduct the analysis. **Section 4** contains the results of the analysis and in **Section 5** some conclusions are made about the insights that were gained from undertaking this study.

2. Methods

2.1 Scenarios

Two types of scenarios were examined. They were a "**business as usual**" scenario, which assumed minimal changes in farm management from current practices, and a number of "**treatment**" scenarios. The treatments constituted a variety of different agroforestry strategies for reducing recharge to the ground water table. The analysis did not examine the benefits and costs 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.

Three case study areas were selected for the purposes of making an *ex ante* assessment of the economic impacts associated with each scenario. The study areas were chosen on the basis of:

- the amount of existing hydrological, economic, and soil-type information available,
- the representativeness of the area of landscapes within the SS2020 region,
- the suitability of the area for supporting one of the types of treatments under examination (where suitability took into consideration land capability and distance to markets).

The treatments were developed and designated to each study area in consultation with hydrologists, agronomists, foresters, and farmers. This consultative process also produced a set of criteria that were used to map the location of treatments within each study area. The agroforestry treatments selected for analysis were:

- Plantations of bluegums
- Belts of bluegums with conventional agriculture in the alleys
- Belts of Maritime pines with conventional agriculture in the alleys
- Belts of oil mallee with conventional agriculture in the alleys.

2.2 Impacts of scenarios

Business as usual scenario

The costs incurred under the "business as usual" scenario were equated to *future* losses predicted to be suffered as a result of expanding salinity, not including ongoing losses from land that is already saline in 2000. The analysis examined both economic costs to production and the extent of physical damage to farm buildings, farm dams, roads, and perennial vegetation. Costs imposed by the current level of salinity were considered to be "sunk costs" and netted out of the calculation. This was done because the treatments examined by this analysis are thought to be incapable of reclaiming land that is currently saline. Therefore, it would be incorrect to suggest that the costs on currently saline land could be reduced by implementing these control treatments.

In calculating production losses, the analysis allowed for the possibility of some adaptive management by assuming that salt-affected land has some grazing value. This was considered important because it is reasonable to expect that ways will be developed to use salt-land more efficiently as the scale of affected land increases.

Treatment scenarios

The net benefits of controlling salinity under each of the treatment scenarios were examined by estimating production benefits and the extent to which infrastructure and off-farm assets were protected. The gains and losses from implementing a treatment were measured *relative to* the outcomes predicted to eventuate under "business as usual". The direct costs of

treatments were included in the analysis but other costs such as administration and extension of the programs were excluded. Furthermore, it was assumed that all treatments were implemented in the first year of the planning horizon.

The impacts of each treatment were estimated by quantifying the changes in profitability associated with each of the following categories of land:

- A. Land planted to a treatment that is prevented from becoming saline because of the treatment.
- B. Land planted to a treatment that is predicted to never be at risk from salinity.
- C. Agricultural land adjacent to a treated area that is prevented from becoming saline.
- D. Land adjacent to a treated area that is prevented from becoming saline and supports infrastructure or natural assets.

Profitability is expected to increase for land categories C and D, and possibly A, when a treatment is implemented. In most cases, profits for category B are expected to fall because forestry returns are generally less than those of agriculture⁴. The aggregate impact of a particular treatment scenario was calculated by estimating the per hectare change in profitability associated with each category of land, together with the area of each category within a case study. The next section describes how these calculations were performed.

2.3 Modelling framework

Overview

The modelling framework consisted of a spreadsheet simulation model for estimating economic impacts and a geographic information system (GIS) which served as a physical accounting tool. It supplied the area statistics required by the economic analysis. GIS was also used as a means of mapping the distribution of economic impacts across a study area once the impacts had been calculated.

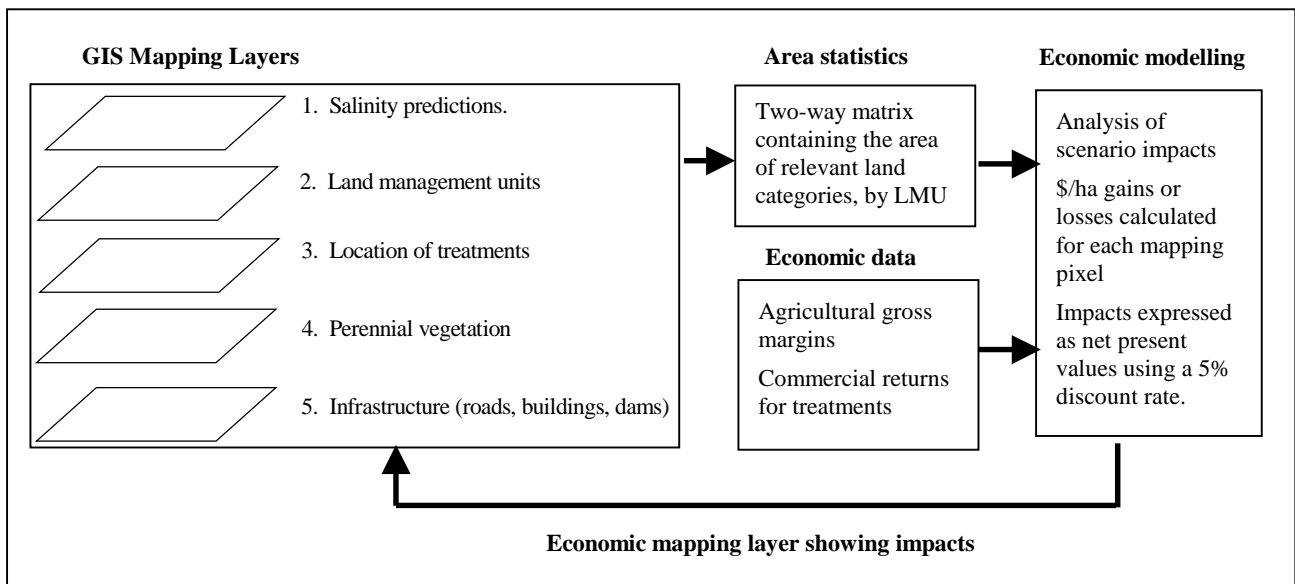
The flow chart in Figure 1 depicts the modelling procedure. A spreadsheet was used to analyse the stream of annual costs and/or benefits associated with each scenario over a 20-year period. These calculations were based on physical information from GIS together with economic data on the profitability 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, the opportunity costs incurred by planting treatments on agricultural land, and the benefits from preserving land in a productive state.

The overlaying capabilities of GIS were used to produce a two-way matrix containing estimates of the area of each land category that fall within each land management unit. The overlay maps included digitised maps of salinity (current and predicted), land management

⁴ The possible exception being bluegum plantations in areas with annual rainfall exceeding 650mm.

units, treatment locations, and various other layers of resource information such as perennial vegetation, main roads, and farm dams.

Figure 1: Flow chart of the modelling procedure.



Business as usual analysis

Annual future losses in net income under this scenario were approximated by simulating the encroachment of salinity onto a given land management unit (LMU). Box 1 contains the equations that were used to calculate salinity costs. 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 simplifying assumption avoided 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 an asymptotic trend, as specified by Equation 2. An asymptotic trend was considered to be appropriate for the study areas that were examined because in these areas salinity is expected to reach equilibrium within the next 20 years. The area statistics from GIS provided an estimate of 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

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

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

Asymptotic salinity function

$$A_{xt} = A_x \left[1 - e^{-0.2(t-n_x)} \right] \quad \text{if } t > n_x \quad (2)$$

$$A_{xt} = \text{zero otherwise}$$

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 .

Treatments analysis

The layering capabilities of GIS were used to calculate, by land management unit, the approximate areas of land belonging to each of the categories below:

- Land planted to a treatment that is prevented from becoming saline because of the treatment (Category A)
- Land planted to a treatment that is predicted to never be at risk from salinity (Category B)
- Agricultural land adjacent to a treated area that is prevented from becoming saline (Category C)

These area statistics formed the basis of the economic analysis. The equations in Box 2 show how the area statistics were used to calculate the economic impact of a treatment. Annual net returns attributable to treatments on Category 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 3). In the case of Category A land, opportunity costs (OC) were modelled to decline over time as the area of salinity grows (Equation 4). In the case of Category B land, the opportunity cost is constant and equal to the shadow value of production on LMU x (Equation 5).

Land belonging to Category C represents 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 6 was used to calculate annual net benefits for this category of land.

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

Benefit function for treatments

$$NB_{xt} = B_{xt} - OC_{xt} \quad (3)$$

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 Category A land

$$OC_{axt} = \left[A_{ax} * \frac{A_{xt}}{A_x} \right] P_s + \left[A_{ax} \left(1 - \frac{A_{xt}}{A_x} \right) \right] P_x \quad \text{if } A_{ax} > 0 \quad (4)$$

OC_{axt} = zero otherwise

where;

A_{ax} = the total area of Category 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 Category B land

$$OC_{bx} = P_x * A_{bx} \quad (5)$$

where;

A_{bx} = the area of Category B on LMU x

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

Benefit function for Category C land

$$NB_{cxt} = A_{cxt} * (P_x - P_s) \quad (6)$$

where A_{cxt} is the cumulative area of land saved from salinity in year t , given by Equation 2.

3. Case study applications

3.1 The study areas

Three study areas were selected. The southern-most study area was the Upper Kent catchment, comprising an area of 107,000 hectares. The other areas, each comprising 30,000 hectares, were located in the Woodanilling and Boscabel districts (Figure S, Appendix C). Each study area has different hydrological characteristics.

Boscabel has two distinct systems, the western sediments and eastern rocky hills. The Beaufort River flats run north-west through the middle of the region. Much of the study area is underlain by a regional aquifer, meaning that the ground water table is unlikely to be responsive to control treatments. Approximately 12 percent of the study area is already salt-affected. The region has a mean annual rainfall of 500mm.

The Woodanilling case study area lies just 10km east of the Boscabel site but the landscapes are quite different. Whilst Boscabel has a high potential for increase in salinised area, the equilibrium level of salinity in Woodanilling is not expected to exceed 20 percent of the landscape (approximately 7 percent is currently salt-affected). Furthermore, the aquifers in this area tend to be localised, implying that groundwater levels could be more responsive to recharge control. The region receives 450mm of rainfall annually.

The Upper Kent catchment was chosen as a study site principally due to the large amount of salinity mapping and hydrological investigation that has already been undertaken by previous studies. This work indicates that approximately 18 percent of the catchment is affected by salinity. The catchment is a potential future source of water for towns on the south coast of Western Australia. The aquifer underlying this area is predominantly regional. Rainfall in this region ranges from 750mm in the south to 500mm in the northern part of the catchment.

3.2 The treatments

The treatments corresponding to each study area are summarised in Table 1. Originally it was intended to analyse the impact of these treatments at two scales of implementation. However, in the absence of a hydrological model this could not be achieved. Instead, the "high-scale" of treatment was adopted for each area as shown in Table 1. In Woodanilling and Boscabel, treatments were planted on two land management units considered to be suitable for deep-rooted perennials (the sandy loams and sandy gravels). This resulted in 65 percent of the Woodanilling study area being planted to oil mallee belts and 50 percent of Boscabel being planted to Maritime pine belts.

In the Upper Kent, all the gravel slopes north of the Muirs Highway were planted with bluegum belts, while bluegum plantations were selected for areas south of the Highway where rainfall exceeds 650mm. The total area treated amounted to 30 percent of the case study area. A more sophisticated method for locating each treatment was devised based on decision criteria that included physical attributes. However, there was insufficient data to support its use.

Table 1: The treatments examined in each case study area.

Case study	Treatment name	Treatments details	
		High scale	Very high scale
Upper Kent	Bluegums	Bluegum belts and plantations on gravel slopes	Bluegum belts and blocks on gravel slopes plus non-saline waterlogged soils
Woodanilling	Oil mallee	Oil mallee belts on suitable soils with annual crop:pasture rotation in alleys	Oil mallee on suitable soils with lucerne phase-farming in alleys
Boscabel	Maritime Pines	Pine belts on suitable soils with annual crop:pasture rotation in alleys	Pine belts on suitable soils with lucerne phase-farming in alleys

3.3 Commercial returns for the treatments

The economic returns for each treatment were estimated using partial budgets for the "forestry enterprise" and gross margins for the agricultural component of the treatment⁵. With the exception of the bluegum plantations (where there is no agricultural component), a joint treatment return was calculated by combining returns from the "forestry enterprise" with the agricultural gross margins according to the ratio of trees to alley land. These joint treatment returns are itemised in Appendix A.

Table 2 contains a summary of the economic returns that were assumed for the "forestry component" of each treatment. In order to reflect the uncertainty associated with the performance of these enterprises, two sets of returns were calculated based on a standard and optimistic outlook. The specific assumptions underlying each scenario are summarised in Appendix B. The outlooks were based on yield, price, and cost information obtained from the West Australian Department of Conservation and Land Management (CALM).

Table 2: Summary of commercial returns for forestry enterprises. Returns are expressed in terms of net present values (NPV) for the 20 year planning horizon and annuities. A 5% discount rate was used.

Case study	Tree enterprise	Standard		Optimistic	
		NPV \$/ha	Annuity \$/ha	NPV \$/ha	Annuity \$/ha
Upper Kent	Bluegum blocks	3904	305	7248	565
	Bluegum belts	3400	273	6199	497
South Stirling	Maritime Pine blocks	2222	143	3529	226
Woodanilling	Oil mallee	65	5	2480	193
Boscabel	Maritime Pine belts	2026	130	3811	244

In the course of evaluating the profitability of farm forestry, attention was paid to the

⁵ Whilst it would have been desirable to evaluate the forestry enterprises within a whole farm context, MIDAS is not capable of analysing enterprises that have costs and benefits dispersed over many years. Partial budgeting provides a reasonable indication of returns to agroforestry but it does not take account of changes in fixed costs that may ensue following a large shift into forestry.

following points:

- The two component activities carried out under agroforestry (agricultural production and forestry), were assumed to be separable with no interactions between them. Hence, the total returns to an integrated treatment were calculated by adding timber returns to agricultural gross margins. In order to account for competition between trees and crop/pasture growth, a two metre gap was assumed between the tree belt and agriculture in the alley (one metre for oil mallee).
- Owing to the bulkiness of tree products, haulage costs have a major bearing on the profitability farm forestry. For the purposes of this analysis, it was assumed that all forestry operations were situated 50km from a mill. The calculated returns are therefore somewhat speculative because, for most of the sites examined, there is presently no milling infrastructure within this proximity.
- The costs assumed for tree establishment were conservative because it was assumed that all forestry operations are coordinated and funded by the farmer, thereby minimising overheads and labour costs. Insurance and fencing costs were not included and fertiliser was not applied until late in the plantation's life.
- The planning horizon of 20 years was too short for a complete rotation of Maritime Pines, which have a rotation length of 30. Hence, returns were calculated on the basis of a "standing value".
- Oil mallee is currently not a commercially proven enterprise because the technology required for oil distillation and residue processing is still under development. The product prices and production cost estimates contained in this report are based on a study by Cooper (1999).

The optimistic outcome is highly speculative as yields are dependent upon genetic improvements and the scenario includes returns from carbon sequestration. There is still a great deal of uncertainty about the eventual functioning of a carbon-credit scheme. Nevertheless, it is apparent that industries responsible for emitting greenhouse gases are making early investments in tree plantations in return for carbon credits that may materialise in the future (Australian Greenhouse Office 1999).

The analysis incorporated the potential benefits of carbon trading in a very simplistic way, by assuming a constant annual rate of carbon sequestration and a fixed price for carbon credits. The tree grower is assigned credits on an annual basis and the sale of these credits serve as an additional source of income. However, consistent with the Kyoto Protocol, at the end of the planning horizon it is assumed that the grower must purchase an emission permit to offset CO₂ that is released at harvest. For simplicity, the amount of carbon released is assumed to equal the amount sequestered (i.e. the carbon stored in timber products is not considered).

Sequestration rates were based on those documented in Hassall & Associates Pty Ltd (1999) and Shea, et al. (1998). Carbon credit prices are uncertain because a market is yet to be established for credits. A price of \$20 per tonne of carbon (\$5.45/tonne of CO₂) was assumed, which is consistent the price used by a recent ABARE study (Burns et al. 1999).

3.4 Salinity maps

Current Salinity

For a variety of reasons, the hydrological modelling techniques employed by the SS2020 Project were unable to produce realistic hydraulic head surfaces (and hence predicting salinity). Therefore, another source of data had to be found for conducting the economic analysis. In the case of Woodanilling and Boscabel, maps of current salinity were obtained from the Land Monitor Project (see Appendix C). These maps were produced by integrating Landsat imagery with landform information derived from height data, ground truthing and other existing mapped data sets. Originally, groundwater surfaces were used to define saline discharge areas. However, the lack of confidence in those surfaces meant the next best available data had to be used.

The Land Monitor salinity maps were under-predictive by design. That is, they failed to capture the full extent of salt-affected land but accurately mapped areas where salt could be identified via this technique. Another shortcoming of using the Land Monitor maps for this type of assessment is that roads, perennial vegetation and lakes were all excluded from areas mapped as salt affected. Thus, it was difficult to establish a base-line estimate of the extent to which these features are currently affected.

For the Upper Kent study area, a salinity map from a previous study by Evans, et al. (1996) was used. This map was generated using a similar technique to that described below for predicting the equilibrium level of salinity. This technique is free of the limitations of the Land Monitor salinity maps.

Salinity at 2020 under "business as usual"

Without a reliable hydraulic head surface, it was not possible predict future levels of salinity for geographic areas. Instead, the analysis drew on work done by Evans (2000) as part of the Land Monitor Project. This work uses variables derived from digital elevation models and ground-truthed areas of shallow groundwater to predict the final extent of shallow groundwater when the system comes into equilibrium with the rainfall (i.e.: discharge = recharge). For all three of the case study areas it was assumed that this equilibrium would be achieved by 2020 and shallow groundwater was saline.

Salinity at 2020 under the treatment scenarios

In the absence of a hydrological model for predicting responsiveness of groundwater to treatments, two simplifying assumptions were made. They were:

- Treatments are 100% effective at controlling salinity at the site where they are planted.
- The treatments do not have any off-site control. That is, land adjacent to treatments is not protected.

These assumptions allowed the economic analysis to proceed, but future work is required to determine their validity.

3.5 Land management unit maps

The land management units selected for the analysis coincided with those that had been previously defined for a whole-farm economic model known as MIDAS (Model of an Interactive Dryland Agricultural System; Morrison et al. (1986)). This enabled MIDAS to be used as a means of estimating economic values for production on each LMU. The agricultural gross margins assumed for each LMU are listed in Appendix A.⁶

Maps of the spatial distribution of LMUs were developed using digitised soil-landscape maps that were supplied by the state's agricultural agency, Agriculture Western Australia. The soil mapping information was more detailed than the LMUs used by MIDAS. Consequently, some interpretation work was needed to produce LMU maps from corresponding soil-landscape maps. This was done by assigning an LMU to each soil unit. Where more than one LMU was represented within a soil unit, the dominant LMU was used. Appendix C contains LMU maps for each study area.

3.6 Other mapped features

Features including buildings, dams, roads, and wetlands were obtained from the West Australian Department of Lands and Administration (DOLA) in the form of digital topographic map sheets (Microstation design files). Files were imported into the GIS and merged to cover the case study areas. Buildings and dams were extracted according to the coding used by DOLA for these features. It should be noted that these data are constantly being updated and therefore some areas are likely to be more accurate than others and some areas may not contain information at all. For example, the buildings class was completely absent for the datafiles covering four 1:50,000 map sheets at the top of the Mt Barker 1:250,000 map sheet. These regions should be re-assessed once mapping in these areas is completed. None of the case study areas were affected by this lack of data.

Data for the distribution of perennial vegetation was obtained from the Bureau of Resource Sciences. It does not differentiate between native remnant vegetation or forest plantations.

3.7 GIS overlay process

The GIS overlaying process enabled the areas of relevant land categories to be calculated, by LMU. A summary of these areas, together with economic parameters, is contained in Appendix A. The GIS analysis was performed using ESRI[®] Software. Arcview[®] was used primarily for raster processing, using the Spatial Analyst extension, and final map production. Some processing was done using Arc/Info[®] due to greater processing power and/or functions not readily available in the Arcview[®] software.

Due to the number of different inputs and sources of data there was a need to convert data sets into a common data format. Salinity data, perennial vegetation and digital elevation data were provided in raster format whilst soil landscape maps and digital topographic data were in vector format. The overlay process to compute intersections between land management units, perennial vegetation and salinity maps was performed using data in raster format to minimise

⁶ A suitable version of MIDAS was not available for the Upper Kent study area. Gross margin estimates for this area were sourced from Burdass Grieve Robinson (1998).

processing time. A standard raster cell size of 25m x 25m was used which was the highest resolution of input data sets. Wherever possible, re-sampling of data was avoided due to errors associated with such processes. The rasterising of soils data did introduce some small errors, where complex features could not be adequately represented by cells. However, at the scale of mapping undertaken for this project, these errors are unlikely to be significant. Digital topographic data (roads, buildings, etc) was retained in vector format and intersections with salinity grids computed.

The area statistics were calculated by combining raster layers for LMUs and salinity scenarios using a unique value matrix and reclassified into final land categories. This produced two main classes that corresponded to salt-affected LMUs and unaffected LMUs. Area statistics were calculated from the numbers of cells in each class. Each cell = 25m x 25m = 625m² = 0.0625 ha.

4. Analytical results

4.1 Business as usual scenario

A summary of the impacts of this scenario is provided by Table 3. For the three case study areas that were examined, the discounted present value of total production losses over the 21 years ranged between \$70/ha and \$200/ha. These losses are averaged over every hectare within a case study area. Consequently, some localised areas suffer much greater losses whilst other parts of the study area remain unaffected. When expressed per hectare of newly salinised land, the losses are between \$800 and \$1090 per hectare. When expressed in terms of equivalent annual values, the losses were between \$25 and \$33 per hectare of newly salinised land or between \$4.50 and \$6.15 per hectare averaged over the whole area. The approximate distribution of costs are shown by maps included in Appendix C.

In aggregate terms, losses for each of the two 30,000 hectare case studies ranged between \$4.5 to \$6.1 million. The larger of the three case study areas was estimated to suffer losses of approximately \$8 million. The analysis also produced some estimates of the extent to which infrastructure and remnant vegetation is predicted to become salt-affected. Across the three study areas, approximately 28 km of sealed roads are at risk, together with 54 buildings, 540 farm dams, and 10,050 hectares of perennial vegetation.

Table 3: Estimated future impacts of salinity for each of the case study areas. Impacts are additional to the damage already caused by the current level of salinity. A 5% discount rate was used.

	Woodanilling	Boscabel	Upper Kent
<i>Percent of study area salt affected</i>			
Current (2000)	7%	12%	18%
Predicted (2020)	17%	35%	33%
<i>Size of study area</i>	30,000 ha	30,000 ha	107,250 ha
<i>On-farm impacts</i>			
Cost of lost production (present values)			
Aggregate for study area	\$4.45 mill	\$6.10 mill	\$7.86 mill
Per hectare of study area	\$150/ha	\$200/ha	\$73/ha
Per hectare of newly salinised land	\$1090	\$897	\$816
Number of farm buildings at risk	16	1	37
Number of farm dams at risk	150	60	330
<i>Off-farm impacts</i>			
Length of sealed roads at risk	13 km	8 km	7 km
Area of perennial vegetation at risk	970 ha	3256 ha	5820 ha

4.2 Treatment scenarios

The results from the analysis of treatments indicate the scale of economic and physical impacts that could be attributable to implementing a large-scale agroforestry program. However, the results are entirely conditional upon the simplifying assumptions that we were forced to make in the absence of a satisfactory hydrological model. As such, the results may be best regarded as a demonstration of how the spatio-economic modelling developed by this project could be applied in future, when better data are available.

Table 4 contains a summary of the key results that were calculated using a standard outlook for treatment returns. For Woodanilling, planting 65 percent of the study area to oil mallee belts caused a net loss of \$4.0 million in production (present value). This loss is mainly attributable to the result that oil mallees were largely planted on land with zero risk of becoming saline. The loss is due to oil mallee being less profitable than conventional agriculture on this land⁷. In the case of Boscabel, belts of Maritime pine belts were estimated to be sufficiently profitable so as to produce a net gain of \$1.6 million relative to “business as usual”. Whilst losses are incurred by treating land that is not at risk from salinity, these losses are outweighed by the gains from planting pines on land at risk.

The net benefits from treating salinity were found to be greatest in Upper Kent. The strategy of planting bluegums belts and plantations was calculated to yield a net gain of \$15 million (present value) for the region over the planning horizon. When this result is broken down into its component impacts, bluegums were estimated to be profitable even on land that has zero risk of becoming saline in the absence of a treatment. This is due to the competitive returns that were assumed for bluegum belts and plantations (relative to conventional agriculture).

The lower half of Table 4 contains estimates of the extent of protection offered by the treatments to infrastructure. Whilst no effort was made to convert these physical measures

⁷ Under the optimistic outlook, oil mallee belts with alley cropping is competitive with conventional agriculture.

into economic benefits, one could use a technique of “threshold value analysis”. For instance, in the case of Woodanilling, if the collective value of these protected assets are perceived to exceed \$4.0 million in present value terms, then the control program would more than break-even.

Table 4: Economic and physical impacts of treating salinity in three case study areas. The impacts are measured relative to "business as usual" outcomes. All economic impacts are expressed as net present values, using a 5 percent discount rate. Standard outlooks were used for forestry returns.

	Woodanilling	Boscabel	Upper Kent
On-farm impacts			
<i>Production benefits or costs</i>			
-Treatments on land at risk	\$2.3 mill gain	\$2.6 mill gain	\$5.7 mill gain
-Treatments on land not at risk	\$6.3 mill loss	\$1.0 mill loss	\$9.3 mill gain
-Agric. land saved adjacent to treated land	\$0	\$0	\$0
Net impact on production	\$4.0 mill loss	\$1.6 mill gain	\$15.0 mill gain
<i>Protection of farm infrastructure *</i>			
Number of farm buildings protected	20	0	14
Number of farm dams protected	144	33	134
Off-farm impacts			
Length of roads protected (km)	2km	2km	2km
Area of perennial vegetation protected (ha)	0	0	0

* Infrastructure located within treated areas was assumed to be protected. The assumption that treatments have no off-site control means that no protection is offered to perennial vegetation and infrastructure that is located outside treatment areas.

5. Conclusions

Whilst insufficient hydrological information was available to undertake a complete economic assessment of the scenarios, the economic component of SS2020 has progressed our knowledge of the strengths and limitations of using spatial data sets to facilitate cost-benefit analysis. In addition, it has provided some foundations for future economic studies of salinity. It has done this by developing a systematic way of categorising the economic impacts of salinity across different land types. A discussion of these conclusions is presented below.

Methodological approach

This report has demonstrated how a GIS framework, coupled with cost-benefit analyses, can be used to investigate 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 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.

Foundations for future work

The methodology outlined in this report provides a systematic basis for categorising the types of economic impacts associated with a treatment strategy. Hydrological modelling conducted by SS2020 suggests that, in many instances, a very small proportion of the benefits from a treatment strategy are likely to be generated by the protection of land and assets “downstream” of the treatment site. Hence, if a strategy is to produce a net benefit, most of the benefits will need to come from the direct protection of land on a treatment site. This implies that treatments will need to be commercially profitable in their own right. Indeed, to be attractive for adoption before salinity has become an imminent threat, the treatments will need to be almost as profitable as existing agricultural land uses. A priority for future work will be to determine the extent to which this general conclusion applies to the SS2020 region, and to identify geographic areas where there is potential to realise off-site benefits from treatments.

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7. Appendices

Appendix A: Values for key parameters in the analysis of scenarios.

Table 1: Woodanilling study area.

	<u>Land Management Units</u>			
	Water logged	Deep sands	Sandy gravel	Sandy loam
Total area (ha)	3250	96	1651	21906
Current salt affected (ha)	935	13	11	1025
<i>Business As Usual Scenario</i>				
Salt-affected area at 2020 (A)	2871	23	27	3146
Lag time (n)	0	0	0	0
<i>Treatment Scenario</i>				
Percentage of Land Management Unit treated *	0	0	94%	81%
Area of treatment on land at risk (Aa)	0	0	16	2121
Area of treatment on land with zero risk (Ab)	0	0	1539	15702
Area of agricultural land saved (Ac)	0	0	0	0
Salt-affected area at 2020 (A)	2871	23	11	1025
<i>Economic Parameters</i>				
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)	-	-	2087	1880

* Areas currently saline and/or subject to waterlogging were not treated. The treatment for Woodanilling was oil mallee belts with conventional crop rotations in the alley.

Table 2: Upper Kent study area.

	Land Management Units	
	Water logged	Gravel slopes
Total area (ha)	20741	43419
Current salt affected (ha)	4106	2806
<i>Business As Usual Scenario</i>		
Salt-affected area at 2020 (A)	10375	6171
Lag time (n)	0	5
<i>Treatment Scenario</i>		
Percentage of Land Management Unit treated *	0	69%
Salt-affected area at 2020 (A)	10375	2806
<u>Bluegum block plantation:</u>		
Total area of treatment	0	3531
Area of treatment on land at risk (Aa)	0	445
Area of treatment on land with zero risk (Ab)	0	3086
<u>Bluegum belts and alley farming</u>		
Total area of treatment	0	26563
Area of treatment on land at risk (Aa)	0	3813
Area of treatment on land with zero risk (Ab)	0	22750
Area of agricultural land saved (Ac)	0	0
<i>Economic Parameters</i>		
Agric. gross margin for unaffected land (\$/ha)	100	205
Agric. gross margin for salt-affected land (\$/ha)	20	20
Commercial net return for bluegum blocks (\$/ha NPV)	-	3900
Commercial net return for bluegum belts (\$/ha NPV)	-	2780

* Areas currently saline and/or subject to waterlogging were not treated.

Table 3: Boscabel study area.

	Land Management Units			
	Water logged	Deep sands	Sandy gravel	Sandy loam
Total area (ha)	6938	1633	8084	6684
Current salt affected (ha)	2099	269	396	312
<i>Business As Usual Scenario</i>				
Salt-affected area at 2020 (A)	6603	791	1440	1044
Lag time (n)	0	0	0	0
<i>Treatment Scenario</i>				
Percentage of Land Management Unit treated *	0	0	95%	95%
Area of treatment on land at risk (Aa)	0	0	1044	737
Area of treatment on land with zero risk (Ab)	0	0	6644	5635
Area of agricultural land saved (Ac)	0	0	0	0
Salt-affected area at 2020 (A)	6603	791	396	312
<i>Economic Parameters</i>				
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)	-	-	2382	2192

* Areas currently saline and/or subject to waterlogging were not treated. The treatment for Boscabel was pine belts with conventional crop rotations in the alley.

Appendix B: Assumptions used to evaluate the economic performance of forestry enterprises

	Standard	Optimistic
<i>Bluegum block plantation</i>		
establishment costs (\$/ha)	\$635	\$635
annual growth rate (m ³ /ha)		
1st rotation	20m ³	23m ³
2nd rotation	22m ³	25m ³
pulpwood stumpage price (\$/m ³)	\$25	\$35
carbon sequestration rate (t/ha/yr)	2.5t	2.5t
carbon credit price (\$/t)	\$0	\$20
<i>Bluegum belts</i>		
establishment costs (\$/ha)	\$633	\$633
annual growth rate (m ³ /ha)		
1st rotation	18m ³	20m ³
2nd rotation	20m ³	22m ³
pulpwood stumpage price (\$/m ³)	\$25	\$35
carbon sequestration rate (t/ha/yr)	2.5t	2.5t
carbon credit price (\$/t)	\$0	\$20
<i>Pine block plantation</i>		
establishment costs (\$/ha)	\$745	\$745
annual growth rate (m ³ /ha)	12m ³	14m ³
stumpage prices (\$/m ³)		
industrial	\$12	\$15
pine rounds	\$25	\$30
small sawlogs	\$20	\$25
sawlogs	\$33	\$37
carbon sequestration rate (t/ha/yr)	2.5t	2.5t
carbon credit price (\$/t)	\$0	\$20
<i>Pine belts</i>		
establishment costs (\$/ha)	\$750	\$750
annual growth rate (m ³ /ha)	9m ³	10m ³
stumpage price (\$/m ³)		
industrial	\$12	\$15
sawlogs	\$60	\$80
carbon sequestration rate (t/ha/yr)	2.5t	2.5t
carbon credit price (\$/t)	\$0	\$20
<i>Oil mallee</i>		
establishment costs (\$/ha)	\$1663	\$1663
biomass yield at harvest (kg/tree)	15kg	15kg
harvest regime		
first harvest	year 5	year 4
subsequent harvests	every third year	every second year
oil price ex still (\$/kg)	\$2.00	\$2.50
oil content of leaf (%)	3%	3%
wood residue delivered price (\$/t)	\$30	\$30
carbon sequestration rate (t/ha/yr)	1.0	1.0
carbon credit price (\$/t)	\$0	\$20