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THE ECONOMICS OF SALINITY, WATERLOGGING AND SURFACE DRAINAGE IN BENEREMBAH IRRIGATION DISTRICT

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ABSTRACT

Land degradation, in the form of soil salinity and waterlogging, is a significant problem in the Irrigation Areas and Districts of southern New South Wales. It has been estimated that the economic costs associated with these problems amount to $50 million annually in southern New South Wales, of which $30 million is due to lost irrigated agricultural production and the remainder due to dryland salinity, river salinisation and damage to capital structures. A number of actions can be taken at either a regional or farm level. District surface drainage, sub-surface drainage, pumping from deep aquifers and changes to water pricing policies are regional options, while possible on-farm options include laser landforming, recycling drainage water, changes to crops and rotations and the adoption of improved irrigation systems.

The purpose of this particular study is to analyse an Irrigation District in the Murrumbidgee Valley for which a surface drainage scheme has been proposed. The objective of the analysis is to determine over a 30 year period changes in the net present value of district gross margin with and without the surface drainage scheme. The study differs from previous ones which determine the losses due to salinity and waterlogging in that it accounts for farmers' adjustment processes. This is done by using a regional linear programming approach which determines the optimal mix of agricultural activities, subject to the level of soil salinity and waterlogging. The results of this analysis are to be incorporated in a more general benefit-cost study of the proposed surface drainage scheme.

1. INTRODUCTION

1.1 Background

Benerembah Irrigation District (BID) occupies an area of 44,200 hectares and is located west of Griffith. In 1936 the "Benerembah Domestic and Stock Water Supply Irrigation District" was gazetted to make use of surface drainage water from the Murrumbidgee Irrigation District. Prime lambs, wool and cereal production were envisaged as the major farming enterprises.

Land use changed with time. Rice growing was commenced in the District during 1942, intended only for the duration of World War Two. It has continued since that time and has now become the dominant land use in the District. Irrigated summer and winter cereal crops have also developed into important enterprises in the District, as has broad scale vegetable growing.

Many of the original holdings have been subdivided and additional water entitlements have been allocated to the new holdings.

The original concept of BID was to provide only sufficient water for limited irrigation to stabilise production on existing relatively large holdings. Because of the low irrigation intensity drainage was not considered of great importance and no surface drainage scheme was constructed.

The total area of BID is 44,200 hectares and in 1986-87 37,000 hectares, or 83 per cent of the total area, was irrigated. Since the 1950's the total irrigated area has doubled whilst the water delivery has increased four times. A substantial increase in rice cropping contributed to the increased demand for water.

The irrigation methods are contour flood, border check and furrow irrigation. Furrow irrigation is restricted to vegetables and some summer crops. The predominant method is contour flood irrigation on natural grades. Laser levelling has allowed conversion of contour layouts to terraced systems over large parts of the District. This has provided the opportunity for border check layouts where slopes, soil types and activities have been suitable.

1.2 Salinity and Waterlogging in Benerembah Irrigation District

Regional pressure levels in the deeper aquifers were about 27 metres below the ground surface in 1956 but have steadily risen since and in 1983 averaged only 10 metres in depth. The average rate of rise has been almost 0.5 metres per year in recent years. In 1987 watertables were within two metres of the surface over roughly two-thirds of the District and were within one metre of the surface over a significant area. Plots of the rates of rise of aquifer pressures indicate that within 30 years the pressure levels in the deeper aquifers will rise to within two metres of the surface over virtually the whole of BID.

About 70 percent of Benerembah District contains clay soils and has the potential for transient waterlogging. In addition the District is flat and has a poorly defined natural drainage system. Hence, after heavy rainfall large areas remain inundated until water either percolates into the soil or evaporates. The construction of channels, roads and farm dams has also impeded the natural flow of drainage, thereby increasing the waterlogging problem. Waterlogging problems are further exacerbated in the areas of the District in which pressure levels in the deeper aquifers are within two metres of the surface.

Soil salinity levels have been measured throughout the District. A survey in 1981 indicated EC_e[1] values of 2 decisiemens per metre (dS/m) or greater in 50 per cent of the sites. At 20 per cent of the sites the EC_e values exceeded 4 dS/m. A comparison with previous results showed that salinity levels had increased by about 30 per cent between 1966 and 1981, equivalent to an increase of about 0.05 dS/m per year.

1.3 Causes and effects of salinity and waterlogging

There are a variety of factors which contribute to the development of shallow watertables in irrigated areas:

(i) Clearing trees and replacing them with shallow rooted crops and pastures, and use of annual plants in place of perennials, results in less rainwater being used and more percolating into the watertable causing it to rise.

(ii) Development of the countryside such as roads, railways, channels, flood control banks, and on-farm earthworks has changed the surface drainage pattern over the years. As noted above, this exacerbates surface waterlogging which increases the amount of water percolating into the watertable.

(iii) Leakage from on-farm and district supply channels.

(iv) Inaccurate matching of irrigation application to plant water requirements. Apart from laxity on the part of irrigators, this can be due to limitations of irrigation layout such as lack of adequate slope, uneven paddock surfaces, inadequate water supply structures and poor on-farm drainage. Inadequacies in on-farm water supply and surface drainage often limit the speed with which paddocks can be watered and drained, so that excessive duration of water on paddocks leads to percolation into the watertable.

(v) An excess of irrigation water over plant requirements must be applied to provide a net downward flow and hence prevent accumulation of salt in the rootzone.

(vi) Poor off-farm surface drainage.

As noted above the soil types and topography of BID predispose much of its area to surface waterlogging irrespective of watertable depths. The development of shallow watertables, however, can increase the tendency of overlying soil to become waterlogged and to remain saturated for longer periods due to the watertable further restricting the capacity for subsoil drainage.

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[1] An EC_e is the electrical conductivity of a soil-water extract, and this is usually measured in dS/m.

The main effects of waterlogging on plant growth are from reduced soil aeration and from chemical and nutritional changes in the soil. Prolonged waterlogging reduces soil oxygen concentration by up to 90 percent, inhibiting root respiration, root density and depth. Access to paddocks for cultivation or harvesting may also be disrupted due to waterlogging, with consequent yield penalties.

Once a watertable rises to within a critical depth from the soil surface, which in the Murray Basin is generally considered to be two metres, upward movement of salt into the rootzone can occur due to capillary rise[2] of saline moisture from the watertable. Hence the salt can accumulate unless leached downwards by rainfall or irrigation.

Plant species differ considerably in their tolerance to salinisation of the rootzone. The primary effect of soil salinity on plant growth is to decrease the availability of soil water to plant roots by increasing the osmotic potential of the soil solution. Yields can be reduced by up to 30 percent before the symptoms become visible.

1.4 Proposed district surface drainage scheme for BID

A district surface drainage scheme (hereafter referred to as district drainage) has been proposed for BID as an option for improving the situation regarding waterlogging and salinisation.

The benefits from such a scheme are:

(i) the drains permit the removal of excess water during and after periods of high water; and
(ii) surface drains encourage better farm management by allowing the removal of excess water during irrigation, particularly by border check or furrow methods.

To be effective, it is considered that the district drainage scheme would have to be accompanied by on-farm drainage works and landforming.

An estimated 34,286 hectares of BID, or 76 per cent of the total area, is proposed for district drainage. The remaining area already has access to drainage lines. This particular study confines further discussion and analysis to the area proposed in BID for district drainage.

2. STUDY DESIGN

2.1 Objectives

Poor off-farm surface drainage was identified in section 1.3 as contributing to the development of shallow watertables in BID and thereby leading to increasing problems of soil salinisation and waterlogging.

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[2] Capillary rise is the upward movement of water through the soil profile, and when this water evaporates it can leave salts lying on the surface.

A surface drainage scheme for the BID has been proposed to ameliorate the development of these problems. The primary objective of the project reported in this paper is to estimate the value of the agricultural benefits of this amelioration; specifically, the benefits from reducing the economic losses associated with the impact of these problems upon agriculture in BID below the losses that would occur in the absence of a district surface drainage scheme. This information is to be incorporated into a social benefit-cost appraisal of the drainage scheme conducted by the NSW Department of Water Resources (DWR).

Two scenarios for BID are analysed:

(i) with a district surface drainage scheme;
(ii) without a district surface drainage scheme (i.e. the status quo)

A secondary objective of the project has been to develop an approach for valuing the economic effects of salinity and waterlogging which is more consistent with economic principles than the approaches employed hitherto (see Gutteridge, Haskins and Davey (GHD), 1985, and Grieve et al, 1986).

2.2 Measurement of economic losses from soil salinisation and waterlogging

2.2.1 Approaches taken by previous studies

Economic losses from soil salinisation and waterlogging have been estimated in a number of studies. Gutteridge, Haskins and Davey (1985) used subjective assessments by experts of yield depressions resulting from soil salinisation and waterlogging due to shallow watertables to estimate reductions in regional gross value of agricultural production.

Grieve et al (1986) argued that waterlogging is a general phenomenon in irrigated lands and included estimates of losses due to waterlogging outside of shallow watertable areas in the calculation of total losses. This study also used a more objective approach to estimating economic effects. Soil and meteorological data were used to predict frequency of waterlogging, and soil salinity surveys identified the range of salinity conditions in the region. Co-efficients derived from experimental data were used in combination with the information referred to above to estimate production losses due to both waterlogging and soil salinity.

Despite their differences, the above studies share a number of features in their approaches to estimating economic losses from soil salinisation and waterlogging:

1. Economic losses for the year in which each study was undertaken were evaluated in comparison with a base situation in which the incidence of soil salinity and waterlogging is low enough that no production losses result.

   Such an approach, which implicitly assumes that it would have been economically efficient to preserve this base situation, would tend to overstate economic losses if the socially optimal rate of soil salinisation and waterlogging is indeed positive as would be expected.

2. It is implicitly assumed in these studies that the change from the base situation to the existing salinised and waterlogged situation involved no change in the levels at which various agricultural activities have been undertaken.

It is reasonable to hypothesise, however, that the development of salinisation and waterlogging have affected levels at which activities are undertaken as farmers have adjusted to preserve their viability. Farmers have the possibility of changing to crop and pasture species more tolerant of soil salinity and/or waterlogging and of using alternative production and irrigation techniques which can ameliorate the incidence of these problems. Alternative techniques may involve redesign of farm layout to improve drainage and adoption of more efficient irrigation systems or of varied rotations, among many other options.

To the extent that activity levels change with the shift from the base situation to the existing one, a simple application of production loss co-efficients to existing activity levels will result in underestimation of the economic loss due to development of salinity and waterlogging. Quiggin (1988) showed that the extent of underestimation can be significant.

3. Economic loss is implicitly assumed to be equal to the reduction in gross value of agricultural production attributable to salinity and waterlogging.

This approach assumes that the reduction in gross value of production occurs without any reduction in aggregate cost of production and that consumer welfare is not reduced as a result of lower levels of agricultural production.

2.2.2 The approach taken in this study

The studies referred to previously represent ex poste estimations of economic losses occurring due to salinity and waterlogging conditions that have already arisen. In contrast, the project reported in this paper represents an ex ante estimation of future economic effects on agriculture occurring because of continued non-availability of a district drainage system.

The project sought to improve upon previous studies of the economic effects of soil salinity and waterlogging by taking into account on-farm adjustments to changes in salinity and waterlogging problems and to off-farm developments, in this case the provision of district drainage, and the effect of these adjustments on supply from the various activities undertaken.

Provision of district drainage for BID is expected to influence shifts in activity supply schedules over time by:

(i) reducing production losses on land prone to waterlogging;
(ii) reducing the rate of soil salinisation;
(iii) increasing rates of adoption of on-farm technologies made more profitable by provision of district drainage, and by decreasing

rates of adoption of on-farm technologies made less profitable by the provision of district drainage; and by

(iv) changing the productivity of technologies already adopted, including farm layouts and irrigation systems.

Laser controlled landforming (hereafter referred to as landforming) represents an on-farm technology with the potential to substantially improve on-farm drainage. District drainage better allows this potential to be realised by increasing the capacity to dispose of on-farm drainage water. Hence the provision of district drainage has a substantial immediate effect on the productivity of land already landformed. Moreover, the increased productivity of landformed land is expected to lead to an increase in the rate of landforming.

Since landforming already has a considerable level of adoption in BID (approximately 20 per cent of the total area), these two effects of district drainage are likely to significantly influence shifts in activity supply schedules over time. Hence predictions of the rates of landforming under the alternative scenarios were incorporated into the modelling of the agricultural effects of district drainage.

In the absence of district drainage, on-farm drainage recycling provides an alternative means of drainage disposal (although this may not necessarily be the major reason for installing a recycling system). It is possible the provision of district drainage may reduce the adoption rate of recycling systems or even lead to non-use of existing systems. However, in contrast to landforming the current level of adoption of on-farm drainage recycling in BID is very low. Hence even a substantial decrease in its rate of adoption due to the provision of district drainage is unlikely to appreciably influence shifts in supply in the foreseeable future.

Predictions of the effects of district drainage provision and of landforming upon yield losses from waterlogging and upon the areas of land at different salinity levels were also incorporated into the modelling of the agricultural effects of district drainage.

For each combination of year and drainage scenario the corresponding predictions of the area landformed and of areas subject to different salinity levels were incorporated as additional constraints in a linear programming model of BID. The model was developed to predict the levels at which agricultural activities would be undertaken. The model also determined the district gross margin for each year and drainage scenario combination.

The gain in the net present value of BID gross margin attributable to the provision of district drainage was estimated by deducting the value for the "without district drainage" scenario from that for the "with district drainage" scenario.

This gain represents one aspect of the economic effect associated with BID agriculture of the provision of district drainage. Gross margin analysis does not consider changes in fixed costs. It is likely that aggregate fixed costs would vary at different rates under each scenario. In particular, the greater rate of landforming development under the "with district drainage" scenario suggests that increases in fixed costs will be greater under this scenario. The difference in the net present value of aggregate fixed costs between the two scenarios needs to be incorporated into the benefit-cost appraisal of district drainage in BID. The current study has not generated this data.

The effect of district drainage on the welfare of consumers of agricultural commodities (measured by consumer surplus) needs to be considered for a complete analysis of the economic effects. However, BID production of agricultural commodities represents a small proportion of the respective Australian totals. Furthermore, Australia is generally a price-taker for those exportable agricultural commodities produced in BID (with the possible exception of wool). Consequently, the demand for BID agricultural production is expected to be highly price elastic. Hence changes in commodity production levels from BID are likely to lead to insignificant changes in the value of consumer surplus.

Accordingly, change in the net present value of producer surplus from BID agricultural production attributable to district drainage (which can be estimated by incorporation into the analysis of the changes in the net present value of aggregate fixed costs) would provide an adequate approximation of the economic effect of district drainage associated with BID agriculture.

A complete benefit-cost appraisal will, however, also consider the secondary economic effects associated with industries and amenities other than agriculture.

2.3 Estimation of the effects of soil salinity and waterlogging on yields

Yield of crops and pastures have been shown to decline in response to soil salinisation only after a threshold level of soil salinity specific to each species is exceeded. The effect of soil salinisation and waterlogging upon crop and pasture yields is presented in Table 1. Salinity loss relationships assume a threshold value for soil salinity below which losses do not occur, with losses increasing linearly in proportion to the excess above the threshold level where that level is exceeded. This principle is illustrated in Figure 1. For example, wheat yields are not affected until soil salinity reaches 2.9 ds/m. Once salinity exceeds this level, for every 1 dS/m increase there is a 13 per cent reduction in yield.

Where waterlogging occurs the percentage yield reduction for a particular crop or pasture species is assumed to be constant regardless of the duration or severity of waterlogging. Waterlogging losses are a fixed percentage reduction in yield, there being no published research data to suggest whether differing magnitudes of waterlogging have different loss factors for the crops studied.

Figure 1 : The salinity/yield relationship

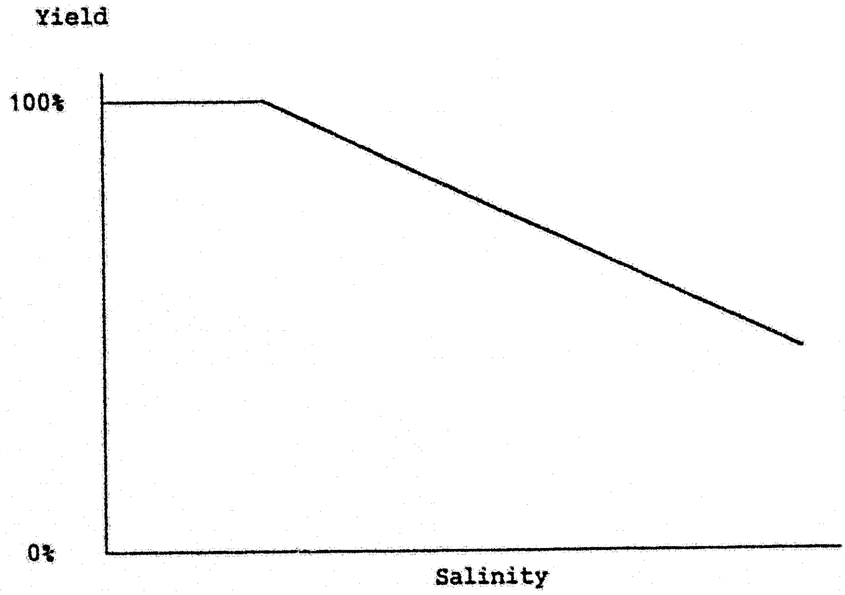

Table 1: Yield reductions due to salinity and waterlogging

Crop/Pasture	Salinity Yield Threshold (dS/m)	Salinity Loss Factor (%)	Waterlogging Loss Factor (%)
Winter cereals	2.9	13	20
Summer cereals	1.7-4.0	7-20	20
Rice	3.0	12	20
Lucerne	1.6	9	16
Perennial pasture	1.3	15	16
Annual pasture	1.6	9	8

Source: DWR, 1988.

2.4 The effects of control strategies on yield losses from waterlogging

Landforming, drainage recycling and district drainage interact with each other with regard to reducing the losses due to waterlogging. Estimates of the benefits from a reduction in waterlogging are presented in Table 2. This data, as stated by its authors, "is open to criticism as it makes very broad assumptions without hard evidence. Therefore the nature of the interaction between the strategies should be considered to be the worthwhile content rather than the actual figures, which are best estimates in some cases or simply gradational increases in others" (DWR 1988, p54). Due to the uncertain nature of this information sensitivity analysis shall be used to test the importance in any deviations in the data.

The rationale behind district drainage increasing the benefit from landforming is that getting water off the paddocks more rapidly will be of limited value if there is nowhere for it to go. District drainage should remove all runoff from landformed areas and therefore landforming associated with district drainage will be more effective than landforming alone. For the purpose of this study, coefficients used for the percentage reduction in waterlogging losses are 75 per cent for landforming plus district drainage, 40 per cent for landforming by itself, 25 per cent for district drainage by itself, and no reduction in losses if there is neither landforming or district drainage.

Table 2: Percentage reduction in waterlogging losses due to different strategies

Strategy Package	Individual Strategy (%)	Total (%)
1. Landforming by itself	40	40
2. Landforming plus on-farm drainage and recycling	45 15	60
3. Landforming plus district drainage	50 25	75
4. Landforming plus on-farm drainage and recycling plus district drainage	55 15 10	80

Source: DWR, 1988.

3. METHOD OF ANALYSIS

3.1 Methodology

The approach taken in this study was to use a static linear programming model to determine the value of agricultural production and levels of activities, subject to a range of pre-determined salinity and waterlogging constraints. Although the model is of a static single period specification, it is solved for a number of individual years over a 30 year time period. These are 0, 5, 10, 15, 20, 25, and 30 years.

Linear programming is considered an appropriate technique due to its optimising nature. As the effects of salinity and waterlogging increase over time, it is likely that farmers will adjust their on-farm activities and rotations in an attempt to maintain farm incomes. Linear programming is well suited to this application where there is a range of possible activities and restrictions applied to certain resources. In addition, research results indicate that there is a linear relationship between crop and pasture yields and salinity and waterlogging, which negates the need to consider non-linear optimising techniques.

The limitations of linear programming have been well discussed by Hardaker (1971). Principle among these are the problems of linearity, additivity, divisibility and non-certainty. The objective function of this analysis is the maximisation of district gross margin subject to a set of technical constraints. Data for the model is based on average production and perfect information regarding the prices of production inputs and product outputs. However, farmers are not all a homogenous species in the studied area, with a variety of farm sizes and types being in existence, and perfect knowledge of prices is obviously not possible.

In the presence of an externality, the maximisation of district gross margin may not be consistent with the aggregation of maximised individual gross margins. However, the technical constraints in this study include the soil salinisation and waterlogging situation for each year, of which the exogenous prediction incorporates the external effects of individuals' behaviour in previous time periods. The actions of any individual is unlikely to have any significant further effect upon these variables within that year. Consequently, given the soil salinisation and waterlogging conditions within a year, the maximisation of individual gross margins is consistent with the maximisation of district gross margin.

Not all farmers are solely profit maximisers, which is the underlying assumption of the objective function, with other objectives being the improvement of the capital value of the land, increased leisure and quality of life, creation of a viable asset for following generations and so on. No allowance is made for the allowance of uncertainty in either prices or yields within the model. Such stochastic influences can be incorporated by using techniques such as the Minimisation of Total Absolute Deviations (MOTAD) or quadratic risk programming.

3.2 Data used

The study relies significantly upon data which is determined exogenously to the linear programming model. Most important among these are the areas affected by soil salinisation and waterlogging, and within these areas the amount that has been laser-controlled landformed and that which is non landformed. The salinised areas are further broken down into various Ec_e categories.

The area under investigation comprises a total of 34,286 hectares. According to soils data (DWR, 1988) there are three separate land types, sandy ridge soils which are not affected by salinity or waterlogging (1,449 hectares), land with high watertables and affected by permanent or transient waterlogging (23,087 hectares), and non-waterlogged land that is underlain by high watertables of which 9,750 hectares is affected by soil salinisation.

The current level of laser controlled landforming is estimated to be around 20 per cent of the total district area (DWR, 1988). It is further estimated that a maximum of 80 per cent of the total area could be landformed. This is because there will be some areas which would prove uneconomic to be landformed due to the large amounts of earth required to be moved to meet a specified slope. Landforming on such areas which require such a heavy cut of soil results in a breakdown of soil structure. Hence there is farmer resistance to landforming on these areas.

The introduction of district drainage is expected to increase the likely adoption of this technology, due to the benefits which have been discussed in section 1.4. For the purposes of this analysis, the assumption has been taken that with district drainage the maximum possible landformed area of 80 per cent of the total would be reached by year 20, whereas without district drainage 70 per cent of the total area will be landformed by year 30.

It is obvious that a great deal of uncertainty surrounds the estimates of the likely rates of adoption of landforming. This factor is a critical component of the analysis and it is proposed to subject the values to sensitivity analysis.

Soil salinity estimates for the current salinised areas range from 4 to 5 dS/m, depending on the basin (DWR, 1988). These rates of soil salinisation are expected to increase over time, regardless of whether a district drainage scheme is present or not, with the annual rate of increase ranging from 0.04 to 0.06 dS/m per year, again depending upon the basin involved. It is estimated that a district drainage scheme will act to decrease the annual increase in area affected by high watertables by 25 per cent, and the annual increase in soil salinity by 25 per cent as well (Source: DWR, personal communication).

The above information is used to calculate the areas of waterlogging and salinity for five year intervals from year 0 to year 30. This information is then inserted into the linear program model to derive the solutions for the years of 0, 5, 10, 15, 20, 25 and 30. A 30 year time horizon and discount rate of 7 per cent have been used to remain consistent with the DWR benefit-cost study.

The output prices used in the activities are based on market prices for the past five years.

3.3 Model specification

A single period linear programming model was constructed for the portion of BID for which district drainage is proposed. Although being a static model, it is solved for a number of time periods over a 30 year period as discussed in section 3.1. Data for the exogenous variables are inserted in the model for the time period for which it is being solved and the solution obtained enables the determination of the annual district gross margin and the level of each individual activity for the area under investigation. It is then possible to determine the change in the discounted district gross margin which is due to the introduction of district drainage.

The model incorporates a wide range of land, water and labour constraints, and activities which include rotations at different salinity levels and waterlogging, pasture, livestock and casual labour.

There are four broad categories of land; landformed border check, landformed contour bay, non landformed contour bay and waterlogged land. For the landformed and non landformed areas, there is a range of soil salinities. Landformed border check does not experience any salinity problems in this analysis due to these areas being located on sandy ridge soils, which do not suffer from high watertables. Landformed and non landformed contour bay areas are segregated into soil salinity categories of 0, 3, 4, 5, and 6 dS/m. There are four waterlogged land categories, depending on whether district drainage exists, and if the land has been landformed.

Other land constraints relate to the area that is dryland, and vegetable and rice area restrictions.

Water constraints are specified monthly for potential water delivery capacity, and annually for the water allocation to the area from DWR. Monthly channel capacity is a function of the size of channels, number of dethridge wheels and flow rates measured in megalitres.

Labour constraints represent the total operators labour available per month, measured in hours.

Crop and pasture rotations represent the major activities in the model. These rotations are separated into sub groups depending on whether they are landformed, non landformed, waterlogged, and the salinity level. Crop and pasture rotations supply grain into crop selling pools and feed values into pasture pools which can be utilised by livestock. As can be expected, as salinity levels increase the yield values of these rotations decline. No allowance has been made for reduced harvesting costs due to lower yields, but it is expected that these differences would only be minor. Waterlogged land rotations are distinguished on the basis of whether the area is landformed and/or has district drainage.

Rice, wheat, barley, millet, irrigated pasture and salt tolerant pasture species are the major crop/pasture activities specified in the rotations. A number of sheep and cattle activities are incorporated in the model which are typical for irrigation areas. These are first and second cross prime lamb production, merino wethers and vealer production.

3.4 Model validation

In model validation we are concerned with determining whether the model structure is sufficiently realistic to be providing useful answers to the questions posed and whether the results appear reasonable in relation to expectations (Dent, Harrison and Woodford, 1986). The ability of the model to simulate the system under study has been assessed by comparing the model output with actual data.

The results of the model for the current situation was compared to unpublished DWR survey data for the area under investigation in 1988 (Table 3). This indicates that the model gives a reasonably good approximation of current production patterns in BID. The main differences in these results are that the model includes rice up to the maximum permissible area whereas actual plantings are below this, and the modelled area planted to wheat is higher than actual plantings.

Reasons for these discrepancies include the fact that the model assumes profit maximisation by individuals, whereas actually they also have a range of additional objectives, and the usual qualifications regarding the accuracy of survey data, particularly biases occurring in the completion of questionnaires.

The actual production figures of crops and livestock from the model could not be compared to actual data. This information is only derived from the Australian Bureau of Statistics statistical division data, and these cannot be broken down to such a small regional level. Furthermore, this data does not distinguish between irrigated and dryland output.

Table 3: Comparison of model results to actual results - 1988 (ha)

	Model	Actual
Rice	7,957	6,431
Summer cereals	667	607
Wheat	6,366	4,589
Other winter crops	0	584
Vegetables	449	449
Lucerne	0	306
Pasture	16,451	16,749
Fallow	3,063	2,323

Source: DWR, 1988.

4. RESULTS AND SENSITIVITY ANALYSIS

The model is used to answer a number of important questions. Firstly, what is the effect of current salinity and waterlogging levels upon district gross margin and the area and types of activities in BID. Secondly, what is the impact of the introduction of surface drainage into this area in terms changes in district gross margin and activity levels over a 30 year period. Finally, variations in some of the more uncertain and important variables are tested to determine their effect upon the analysis. This step is considered important as it will highlight where further technical research is required.

The results presented in this paper primarily relate to changes in the net present value of district gross margin. However, changes in the gross value of agricultural production and production costs are required for the benefit cost analysis of the BID district drainage scheme and these are also calculated and presented in the paper. Changes in fixed costs have not been calculated in this particular analysis but would also be required for the benefit-cost appraisal.

4.1 Current effect of salinity and waterlogging in BID

The annual district gross margin and level of activities for BID without any salinity or waterlogging influences are compared to the current level of salinity and waterlogging in Table 4. This indicates that there is a potential loss in annual district gross margin of $3.0m. This represents a 33.0 per cent reduction gross margin from the base at $9.1m. The contribution toward the total loss was determined to be $2.3m due to the influence of waterlogging and $0.4m due to soil salinisation (Table 5). The combination of salinity and waterlogging losses when calculated separately does not meet the total reduction in district gross margin.

This is due to the interaction of these two problems resulting in an increase in the cumulative economic effect, than when they occur singularly.

The above result reinforces the conclusion drawn by Grieve et al (1986), who assessed annual losses due to soil salinity and waterlogging to exceed $13m for the Murray Valley, or 16 per cent of the Districts gross agricultural production, with losses due to waterlogging ($10m) being more serious than those due to soil salinity (nearly $4m).

There is not a significant change in the areas of crops and pastures due to salinity or waterlogging, with the major differences being in the area of wheat and annual pasture. There is a significant decline in the number of wethers carried in the two scenarios from 142,187 head when there are no problems to 109,501 for the current situation. This is due to a reduction in pasture productivity which lowers possible stocking rates, despite the fact that the area of annual pasture actually increased.

Although there was little change in the levels of activities due to the introduction of salinity and waterlogging, there was a more substantial shift in the rotations used. When there is no salinity or waterlogging, the predominant rotation on landformed areas is rice-rice-wheat-wheat-pasture-pasture, and on non landformed country it is rice-rice-fallow-wheat-wheat-pasture. Given the situation of current salinity and waterlogging, the dominant rotation on landformed country is rice-wheat-wheat-pasture, while on non landformed areas it is a combination of the previous rice-rice-fallow-wheat-wheat-pasture and at high salinity rice-fallow-wheat-pasture. As soil salinity increases the rotations shorten, with a single year of rice being grown. On waterlogged land, the rotations remain the same as the original situation, however there are significant reductions in yield.

These results indicate that on land suffering soil salinity farmers will adjust their rotations to maintain production. On waterlogged land there appears to be fewer options and farmers will stick with the same rotations. This is because there are different responses amongst crops and pastures when salinity increases, however the reduction in yield due to waterlogging is of a single magnitude, despite the severity. Therefore there is a lower incentive to adjust amongst crops suffering from waterlogging.

Table 4: Gross margin, levels of activities and rotations chosen with and without salinity and waterlogging in BID

	No salinity or waterlogging	Current salinity and waterlogging
Gross margin ($m)	9.1	6.1
Rice (ha)	7,957	7,957
Sunflowers (ha)	365	667
Wheat (ha)	8,505	6,366
Lucerne (ha)	452	0
Irrigated pasture (ha)	5,293	8,849
Dryland pasture (ha)	8,470	7,602
Fallow (ha)	3,160	3,063
Vegetables (ha)	449	449
Wethers	142,187	109,501
Rotation:		
Landformed	RRWWPP	RWWP
Non landformed -	RRFWWP	RRFWWP
-	-	RFWP

R = rice; W = wheat; F = fallow; and P = pasture.

Table 5: Losses in gross value and gross margin due to salinity and waterlogging ($m)

	Gross value	Gross margin
Loss due to salinity and waterlogging	3.5	3.0
Loss due to waterlogging only	2.9	2.3
Loss due to salinity only	0.6	0.4

4.2 Impact of district surface drainage

The model is solved for seven time periods, years 0, 5, 10, 15, 20, 25 and 30, for the two scenarios of with and without district drainage. The values for the land constraints relating to landforming, salinity, waterlogging and surface drainage are determined exogenously to the model and are incorporated into the model for these separate time periods. Output from the model is used to determine the gross value of production, total variable costs, district gross margin and activity levels for the individual time periods over the 30 year time horizon. The gross value of production of the two scenarios, with and without surface drainage, are discounted at a rate of 7 per cent.

If a surface drainage scheme is introduced into BID the discounted gross value of agricultural production is $219.7m, whereas without the scheme the discounted gross value is $205.3m (Table 6). However, there is a corresponding increase in variable costs of $3.0m which results in an increase in the discounted gross margin of $11.4m due to the provision of district drainage in BID. This represents a net benefit to farmers of district drainage (excluding fixed costs). Obviously other factors would need to be considered to determine the worth of such a scheme such as the capital costs of installing drainage and landforming, operation and maintenance costs of the scheme, and environmental and secondary benefits and costs, all of which are outside the scope of this particular study.

There is no major change in the areas of crops grown between the two scenarios, however the number of livestock carried is significantly higher when there is district drainage (Tables 7 and 8). This reflects the fact that production output for both crops and pastures is higher under this scenario than without district drainage. There are two reasons to explain this result. Firstly, with the introduction of district drainage in year 0, there is a reduction in both the areas affected by salinity and the salinity level of these areas, as well as a 25 per cent reduction in the losses associated with waterlogging as discussed in section 3.4. Secondly, it is estimated that there is an increased adoption in the level of landforming due to the introduction of district drainage which has two influences. On laser levelled layouts higher yielding crops can be grown and there is not the need to follow rice crops with a fallow period, thus increasing returns from landformed rotations. Landforming on its own reduces waterlogging by 40 per cent and when combined with surface drainage, there is a 75 per cent reduction in waterlogging losses.

Over the 30 year period there was a significant increase in the level of soil salinisation and areas affected. This caused significant changes to the crops and pastures grown on this area, however there was little change in the waterlogged area over this period. There is a substantial shift towards dryland based pasture on the salinised areas, whether district drainage commenced or not. However, due to the salt affected area representing only 28 per cent of the total area, this does not affect the results to a great extent.

Table 6: Discounted gross value, variable costs and gross margin due to district drainage in BID ($m)

	Gross value	Variable costs	Gross margin
With district drainage	219.7	129.4	90.2
Without district drainage	205.3	126.4	78.8
Net effect	14.4	3.0	11.4

Table 7: Levels of activities with district drainage in BID

	Year						
	0	5	10	15	20	25	30
Rice (ha)	7,957	7,957	7,957	7,957	7,957	7,957	7,957
Sunflowers (ha)	667	647	619	664	658	658	658
Wheat (ha)	6,336	6,630	7,186	7,905	8,616	8,616	8,616
Barley (ha)	0	275	145	0	0	0	0
Lucerne (ha)	0	30	72	0	14	0	0
Irrigated pasture (ha)	8,672	8,298	7,608	7,060	6,238	6,238	6,238
Salt tolerant pasture (ha)	0	0	0	0	0	0	0
Dryland pasture (ha)	7,839	8,311	9,169	9,750	9,750	9,750	9,750
Millet (ha)	0	0	0	0	0	0	0
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	3,033	2,336	1,699	1,049	325	325	325
Unused (ha)	0	0	0	113	935	935	935
Wethers (hd)	113,087	118,255	122,264	119,902	121,268	121,268	121,268

Table 8: Levels of activities without district drainage in BID

	Year						
	0	5	10	15	20	25	30
Rice (ha)	7,957	7,957	7,957	7,957	7,957	7,957	7,957
Sunflowers (ha)	667	667	667	667	667	666	667
Wheat (ha)	6,366	6,386	6,742	6,944	7,346	7,746	8,149
Barley (ha)	0	401	0	0	0	0	0
Lucerne (ha)	0	0	0	0	0	1	0
Irrigated pasture (ha)	8,849	8,599	7,888	7,173	7,173	7,173	6,798
Salt tolerant pasture (ha)	0	0	295	565	303	0	0
Dryland pasture (ha)	7,602	7,893	8,506	9,186	9,446	9,722	9,750
Millet (ha)	0	0	0	0	0	28	0
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	3,063	2,603	2,453	2,013	1,611	1,209	808
Unused (ha)	0	0	0	0	0	0	375
Wethers (hd)	109,501	111,910	106,368	107,713	110,405	113,038	108,888

4.3 Sensitivity analysis

An important component of any economic analysis is to test what happens to the earning capacity of the project if events differ from guesses made about them in planning. The reworking of analysis to see what happens under changed circumstances is called sensitivity analysis (Gittinger, 1982). Sensitivity analysis is useful for determining how marginal a project is, illustrating the riskiness of a project, and it can be used as a method for dealing with unquantified values. However, care must be taken not to abuse sensitivity analysis by using it as an excuse to quantify things that might have been quantified, or if a complicated set of interrelated switching values are presented which do not assist the decision maker in choosing among alternatives.

For the purposes of this study it was deemed necessary to test the effect of changes in the discount rate, the level of adoption of landforming, and the reduction in waterlogging losses due to the strategies of landforming and district drainage. The latter data was considered important for testing because of the uncertain nature of the information and the importance of waterlogging losses in the analysis. The initial level and adoption of landforming is also considered an important component of the study and a fair degree of uncertainty surrounds this information.

Rates of 0, 5, 10, 15 and 20 per cent were used to determine the sensitivity of the difference in discounted gross margin due to the drainage scheme to the discount rate (Table 9). This indicates that the difference in the district gross margin due to the project is sensitive to the discount rate used.

Two scenarios were used for testing changes in the initial level and adoption of landforming. In the base analysis the best estimates of the current level of landforming is 20 per cent of the total, with 80 per cent of total area landformed in year 20 with the district drainage, and 70 per cent in year 30 without district drainage to represent a lower rate of adoption. It was decided to test two extremes. First, the same level of initial landforming but with no further landforming to represent an extremely low adoption rate of landforming. Second, a high current level of landforming of 70 per cent of the total area and final levels of 80 per cent of the total in year 20 for district drainage and 70 per cent without drainage. Although the estimate of the current area landformed in BID is considered reasonably accurate, it is considered worthwhile to test the effect of a high current landformed area in an irrigation district upon the net benefits of providing district drainage.

As can be expected, the level of landforming has an impact on the magnitude of discounted district gross margins (Table 10). However the differences in discounted gross margins with different landforming levels were not as great as expected. It would appear that either a high initial level of landforming or a reasonable rate of adoption are required for district drainage to be feasible.

The reduction in waterlogging losses due to landforming and district drainage are a result of a subjective assessment. There is little information to suggest how much this may vary so an arbitrary 10 per cent variation in the reduction in waterlogging losses, as discussed in section 3.2, was used to test the sensitivity of the results to this factor. This resulted in a change in discounted net benefit due to the scheme of $3.3m, or 29 per cent. This is a significant result and draws attention to the fact that little technical research is currently being undertaken in this area (ie reduction in waterlogging loss coefficients due to district drainage and landforming).

Table 9: Effect of discount rate on discounted project net benefits ($m)

Rate (%)	Net benefit
0	42.4
5	18.8
10	10.1
15	6.2
20	4.3

Table 10: Effect of changes in level or adoption of landforming on analysis ($m)

Scenario 1: Low level of landforming adoption	
With district drainage	208.2
Without district drainage	198.9
Net benefit	9.3
Scenario 2. High level of current landformed area	
With district drainage	232.9
Without district drainage	219.1
Net benefit	13.8

5. SUMMARY AND CONCLUSION

The study determined that soil salinisation and waterlogging are significant problems in BID, resulting in a $3m per annum reduction in district gross margin compared to a situation where no salinity or waterlogging problems exist for the same area. These estimates allow for farmers having adjusted activity mixes due to the development of these problems. Waterlogging was shown to currently be the major contributor toward agricultural losses, resulting in a reduced district gross margin of $2.3m, whereas soil salinisation accounts for a loss of $0.4m in gross margin. This finding supports the conclusion drawn by Grieve et al (1986) that the impact of waterlogging in the Murray Valley far exceeded that of soil salinisation.

The major focus of this study was to determine the net agricultural benefit of a proposed surface drainage scheme to ameliorate future effects of salinity and waterlogging in BID. Two scenarios were considered, "with district drainage" and "without district drainage". The net benefit of $11.4m was determined by calculating the change in discounted district gross margin due to the scheme. This measure does not consider any differences in fixed costs between the scenarios. The results of this study are to be incorporated into a comprehensive benefit-cost analysis of the scheme, which would include changes in the gross value of production, and in variable and fixed costs, as well as environmental and secondary effects.

The analysis indicates that the net agricultural benefits of district drainage are sensitive to the initial level of landforming, and the rate of adoption of this technology over time. Although the 20 per cent of total area estimate of the current level of landforming in BID is considered reasonably accurate, the analysis shows that the net benefit of any surface drainage proposal will be positively related to the initial level of this technology.

Another variable determined to have a significant impact upon the net agricultural benefit due to district drainage was the reduction in waterlogging losses due to the strategies of landforming and district drainage. The current estimates of the coefficients are a subjective assessment (DWR, 1988) rather than being based on technical research. Varying each of these coefficients by 10 per cent resulted in a 29 per cent change in net benefit. This result emphasises the need for improved technical research regarding waterlogging losses and the benefits from reducing these losses by landforming, district drainage, and on-farm drainage and water recycling.

The study reported herein used a regional linear programming model of BID to determine the structure of agricultural activities in individual years subject to constraints including the soil salinity and waterlogging conditions. Changes to these conditions were determined exogenously to the model. At the present stage there is little information regarding the relationship between individual activities, landforming and district drainage upon rising watertables, soil salinisation and waterlogging. This is a key requirement before a more dynamic approach can be applied to this problem. Such an approach could be used to endogenously determine the optimum rate of landforming in areas such as BID.

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