Land Salinisation, Waterlogging and the Agricultural Benefits of a Surface Drainage Scheme in Benerembah Irrigation District

Randall Jones and Graham Marshall*

Soil salinisation and waterlogging are significant problems in the Irrigation Areas and Districts of southern New South Wales. Various actions can be taken at either a regional or farm level to alleviate these problems. 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 controlled landforming, pumping groundwater from shallow aquifers, recycling drainage water, changes to crops and rotations and the adoption of improved irrigation systems.

The purpose of this study was to analyse the agricultural benefits of a surface drainage scheme proposed for an Irrigation District in the Murrumbidgee Valley. The objective of the analysis was to determine over a 30 year period the change in present value of district net farm income attributable to the surface drainage scheme. The study differed from other economic assessments of the losses due to salinity and waterlogging in that it accounted for farmers' adjustment processes. A regional linear programming model was developed which determined the optimal mix of agricultural activities in any year, subject to the level of soil salinity and waterlogging.

1. Introduction

1.1 Background

Benerembah Irrigation District (BID), located adjacent to the Murrumbidgee Irrigation Area (MIA) in southern New South Wales (NSW), is experiencing significant problems of rising watertables and the associated land degradation problems of waterlogging and land salinisation.

Watertable 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 (van der Lelij 1988). The average rate of rise has been almost 0.5 metres per year in recent years. Watertables were within two metres of the surface over roughly two-thirds of BID in 1987 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 levels in the deeper aquifers will rise to within two metres of the surface over virtually the whole of BID. High watertables are considered to be those within two metres of the soil surface.

Widening of the area underlain by high watertables is expected to increase agricultural losses attributable to waterlogging and soil salinisation. Provision of surface drainage infrastructure (i.e. district drainage) to the area of BID currently lacking access to an off-farm drainage network (i.e. the study area) was proposed as a means of slowing the onset of these problems and their effects on agricultural productivity.

The benefits from providing district drainage are that the drains permit the removal of excess water during and after irrigation and periods of high rainfall. This reduces the potential for inundation and deep percolation of water into the watertable, lowering agronomic losses from soil salinisation and waterlogging.

The study area, for which provision of district drainage was proposed, accounts for approximately 34,286 hectares of BID, or 78 per cent of its total area. The remaining area already has access to drainage lines. Construction of a district drainage network by the NSW Department of Water Resources (DWR) for the study area began in 1990, on the basis of its own benefit-cost appraisal which indicated that the project would generate a positive net social benefit (Graham 1990). The DWR valuation of the benefits of the drainage proposal focussed largely on the agricultural benefits within

* NSW Agriculture, Orange and Yanco Agricultural Institute respectively.
The authors gratefully acknowledge the comments of the anonymous referees and the Editor on a previous draft.
Review coordinated by Bob Batterham.

the study area, in terms of reduced yield losses attributable to soil salinisation and waterlogging, which were estimated at $11.1 million in present value terms.

1.2 Study objectives

The primary objective of the study was to estimate the value of the agricultural benefits of providing district drainage to the study area. The study specifically values the benefits of district drainage in terms of reducing economic losses associated with soil salinisation and waterlogging. Accordingly, the effects of two drainage scenarios for the study area were compared; (i) with a district surface drainage scheme; and (ii) without a district surface drainage scheme (i.e. the status quo).

A secondary objective of the study was to estimate, in a manner more consistent with economic principles than previous studies of the effects of salinity and waterlogging in the Murray-Darling Basin, the annual value of agricultural losses attributable to existing levels of these problems.

In this analysis an optimising model was developed to determine the agricultural benefit of district drainage, whereas the DWR benefit-cost analysis of the drainage proposal adopted a static crop mix approach.

This study did not aim to estimate the net social benefit of the district drainage scheme. This was the purpose of the DWR benefit-cost analysis which also took into account the costs of the drains, pumps and on-farm landforming. The benefit-cost analysis considered, but did not quantify, the benefits of reduced road damage, maintenance of visual amenity, the value of water for reuse, and the prevention of deterioration of remaining natural vegetation. This study's aim was to improve the basis for estimating the agricultural benefits from district drainage.

The results reported in this study represent a revision of an earlier analysis (Jones and Marshall 1990), incorporating farm overhead costs and more reliable estimates of waterlogging yield loss coefficients.

1.3 Problems of high watertables

Pope and Solomon (1989, p.1) list various factors which contribute to the development of high 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 infrastructure in the surrounding countryside, such as roads, railways, channels, flood control banks, and on-farm earthworks, has changed the surface drainage pattern over the years. This change 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 root zone[1]; and
(vi) poor off-farm surface drainage.

High watertables can lead to soil salinisation and increased problems with waterlogging. The approach taken in this study is that an area of land can suffer from either salinity or waterlogging, but not both in conjunction. This is consistent with the approach of Grieve, Dunford, Marston, Martin and Slavich (1986) who noted, however, that the underlying assumption that the effects of the two

[1] Irrigation water naturally contains salts and, to maintain a salt balance in the root zone, there is a need for a proportion of water applied to drain below this zone (Ayers and Westcot 1989).

problems are simply additive may lead to an underestimation of the effects of soil salinity where waterlogged conditions also exist. Despite its limitation, this approach is necessary given the lack of available information of the combined effects of salinity and waterlogging on agricultural production.

Waterlogging

Of the 34,286 hectares within the study area, 23,087 hectares (67 per cent) is assessed as prone to permanent or transient waterlogging (van der Lelij 1988). The heavy clay subsoils have poor internal drainage. Furthermore, the waterlogging prone area is flat and has a poorly defined natural surface drainage system. Hence, after heavy rainfall large areas remain inundated until water either eventually percolates into the soil or evaporates.

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 per cent, 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.

Plant species vary considerably in their tolerance to waterlogging. Rice is highly tolerant but other crops are affected to varying degrees. The deep rooted winter cereals are more likely to be affected by waterlogging from shallow watertables than shallow rooted perennial and annual pastures which have their root zone in only the top 300 millimetres. Pasture, on the other hand, is particularly affected by surface inundation as growth stops whilst the plants are flooded. Waterlogging losses are calculated as a fixed percentage reduction in achievable yield for each crop or pasture activity (Table 1).

Soil salinisation

Once a watertable rises to within a critical depth from the soil surface, which in the Murray-Darling Basin is generally considered to be two metres (Pope and Marston 1988), upward movement of salt into the root zone can occur due to capillary rise[2] of saline moisture from the watertable. This

[2] Capillary rise involves the upward movement of water and dissolved salts through the soil profile due to evaporation at the surface.

Table 1: Yield reductions due to salinity and waterlogging

Crop/Pasture	Salinity Yield Threshold (dS/m)	Salinity Loss Factor[f] (%)	Waterlogging Loss Factor[g] (%)
Wheat	2.9[a]	13.0[a]	20.0[a]
Barley	3.5[b]	9.0[b]	20.0[a]
Rice	3.0[c]	12.0[c]	4.0[c]
Sorghum	6.8[d]	16.6[d]	5.0[c]
Maize	1.7[c]	12.0[c]	5.0[c]
Soybeans	5.0[c]	20.0[c]	5.0[c]
Lucerne	2.0[d]	7.1[d]	8.0[c]
Perennial pasture	1.6[a]	9.0[a]	25.0[a]
Annual pasture	1.3[a]	27.0[a]	12.5[a]
Vegetables	1.0[d]	14.0[d]	5.0[c]

Source: [a] Grieve *et al* (1986). [b] Slavich and Read (1985). [c] Maas and Hoffman (1977). [d] Ayers and Westcot (1989). [e] van der Lelij (1988). [f] This factor represents the additional loss in yield for each 1 dS/m increase in soil salinity. [g] This represents a once-for-all reduction in yield when waterlogged conditions are present.

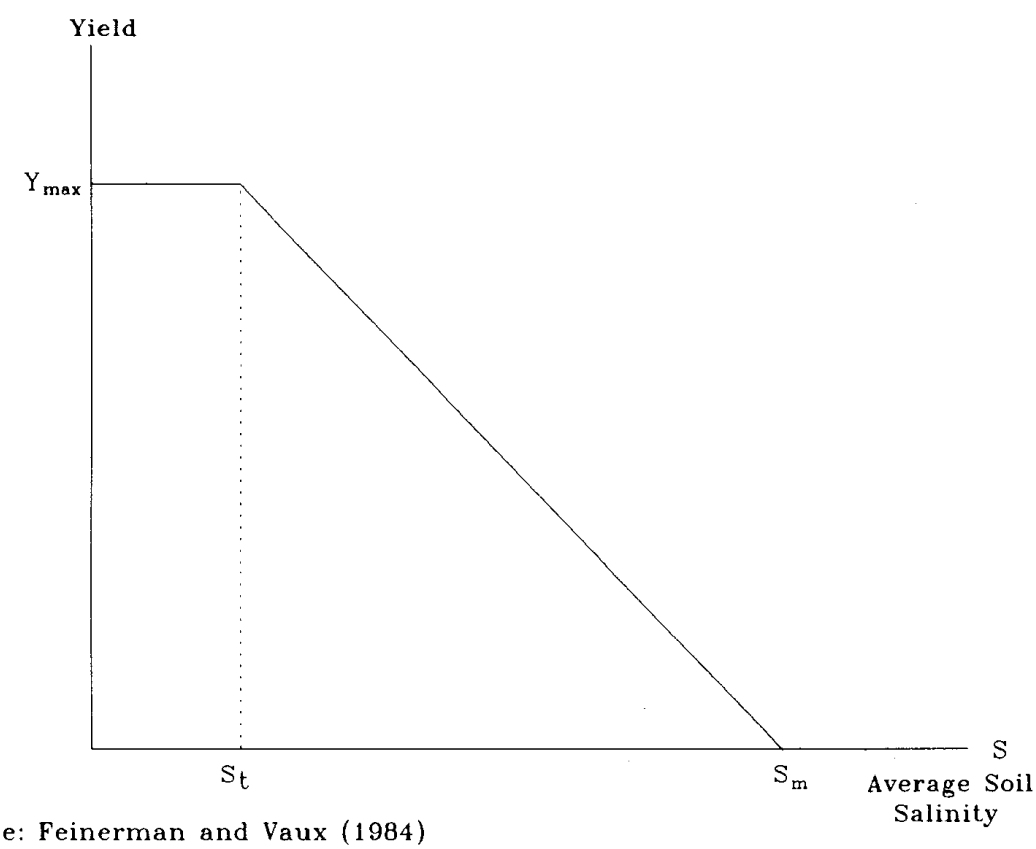
salt accumulates unless leached downwards by rainfall or irrigation. Within the study area, 9,750 hectares (28 per cent) are assessed as currently affected by soil salinisation. Although this area is underlain by shallow watertables it is assumed in this analysis that the area is not subjected to waterlogging losses in addition to those incurred due to salinisation.

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. Salinity may reduce crop yields by as much as 25 per cent without crop plants revealing visible symptoms (Rhoades and Ingvalson 1971).

The general relationship between soil salinity and yield is illustrated in Figure 1. Research indicates that there is some threshold level of soil salinity, S_t, beyond which crop and pasture yields decline linearly with increasing salinity (Maas and Hoffman 1977). The threshold levels and loss factors for the plant species of interest in this study are shown in Table 1. For example, wheat yields are not affected until soil salinity reaches 2.9 decisiemens per metre (dS/m). Once salinity exceeds this level, for every 1 dS/m increase there is a 13 per cent reduction in yield. It is apparent from Table 1 that plant species differ considerably in their tolerance to salinisation of the root zone. Feinerman and Vaux (1984) present a production function which describes this relationship:

$$Y = \begin{bmatrix} a + b\left(\frac{S_0 + S_1}{2}\right) & \text{if } S_m \geq \left(\frac{S_0 + S_1}{2}\right) > S_t \\ Y_{max} & \text{if } \left(\frac{S_0 + S_1}{2}\right) \leq S_t \end{bmatrix}$$

Figure 1: Relationship Between Yield and Salinity



Source: Feinerman and Vaux (1984)

where

Y = yield
Y_{max} = maximum yield with no salinity losses
S_0 = soil salinity prior to growing season
S_1 = soil salinity at end of growing season
S = $(S_0 + S_1)/2$ average soil salinity
S_m = S where $Y = 0$

$a > 0$, $b < 0$ are known parameters.

EC_e values of 2 dS/m and greater can lead to significant economic losses of crops and pastures. An EC_e is the electrical conductivity of a soil-water extract, and this is usually measured in dS/m. Soil salinity levels have been measured throughout BID, with a 1981 survey by the Water Resources Commission indicating EC_e values of 2 dS/m or greater in 50 per cent of the sites (van der Lelij 1988). At 20 per cent of the sites the EC_e values exceeded 4 dS/m. A comparison with previous results showed that soil 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.

2. Estimation of Economic Losses

2.1 Previous studies

The costs of soil salinisation and waterlogging in the irrigated areas of southern NSW in terms of reduced agricultural yields have been estimated in a number of previous studies. Gutteridge, Haskins and Davey (1985) used subjective assessments by experts of yield depressions resulting from soil salinisation and waterlogging due to high watertables.

Grieve, Dunford, Marston, Martin and Slavich (1986) argued that waterlogging is a general phenomenon in irrigated lands and included estimates of losses due to waterlogging outside high watertable areas in the calculation of total losses. Grieve *et al* used a more objective approach to estimating yield losses than the Gutteridge *et al* study. Soil and meteorological data were used to predict frequency of waterlogging. Soil salinity surveys identified the range of salinity conditions in the region. Yield loss coefficients derived from experimental data were also used in combination with the previous information to estimate average annual production losses due to both waterlogging and soil salinity.

Despite their differences in arriving at yield loss coefficients, the two studies share a number of features in their approaches to estimating economic losses from soil salinisation and waterlogging.

Firstly, annual economic losses were evaluated with reference to a hypothetical 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, is likely to overstate economic losses as some portion of the worsening of soil salinisation and waterlogging may be economically efficient.

Secondly, 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 that the development of soil salinisation and waterlogging has affected the types of activities undertaken and the levels at which they are undertaken, as farmers adjust 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. To the extent that activity levels do change with the shift from the base situation to the existing one, a simple application of production loss coefficients to existing activity levels may underestimate the reduction of economic welfare due to the shift to the existing degraded situation. Quiggin (1988) showed that the extent of underestimation can be significant.

Finally, economic loss was implicitly assumed in those states to equal 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 change in the aggregate cost of production and that consumer welfare is not reduced as a result of lower levels of agricultural production.

The determination of the agricultural benefits from the provision of district drainage in BID by Graham (1990) shared a number of features of the above studies. First, it was assumed that no change in the levels of activities would occur, regardless of the severity of the land degradation problems. Second, the study used gross value of agricultural production to measure economic losses from salinity and waterlogging. The study did, however, attempt to value over time the economic impact of these two problems.

2.2 Approach taken

With the exception of the study by Graham (1990), the studies referred to previously have been of an ex post nature. That is, they estimated economic losses occuring due to salinity and waterlogging conditions that have already arisen. In contrast, the primary emphasis of this study is an ex ante analysis of the economic benefits of district drainage in terms of reduced future agricultural production losses within the study area. However, an ex post evaluation is also reported, which aimed to estimate the relative contributions of soil salinity and waterlogging to aggregate economic losses. The study does not attempt to indicate the economically efficient rate of soil salinisation and waterlogging.

Farmer reaction to changing waterlogging and soil salinity conditions is systematically accounted for in this study by respecifying land quality constraints in a regional linear programming model according to exogenously predicted changes in the levels of these conditions during a 30 year planning horizon.

The study has assumed perfect price elasticity of demand for the production of agricultural activities in BID. Of the major commodities produced (rice, wool and wheat) wool and wheat represent infinitesimal proportions of Australia's total production so there is little likelihood of price impacts from changes in production. Approximately 85 to 90 per cent of Australian rice production is exported. As Australian rice exports only represent 5 per cent of total world trade, Australia is generally a price taker for this commodity. Therefore, there are unlikely to be price impacts from changes in BID rice production. As a result, changes in levels of agricultural production from the study area will have an insignificant effect on the value of consumers' surplus. Hence this study has focussed only on changes in producers' surplus, with the justification that these changes account for virtually all of the economic effect of changing levels of soil salinity and waterlogging within the study area.

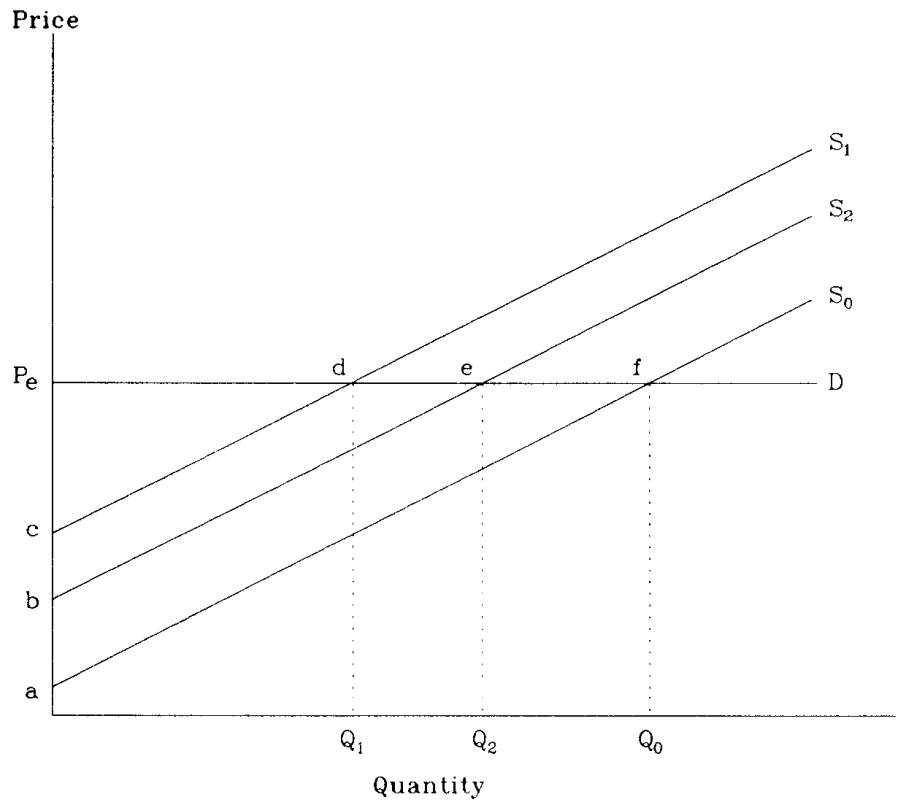
The method of estimating the agricultural losses associated with soil salinisation and waterlogging is illustrated in Figure 2. Without district drainage, the supply curve for agricultural commodities is S_0. Increasing salinisation and waterlogging results in a shift of the supply curve[3] to the left, to S_1. Producers' surplus declines from the area $\mathbf{P_e fa}$ to $\mathbf{P_e dc}$, and the economic loss is represented by the area **cdfa**. With the provision of district drainage, the supply curve shifts to S_2 and producers' surplus becomes $\mathbf{P_e eb}$. Therefore, the agricultural benefit of the provision of district drainage is the area **cdeb**, while the economic loss from salinity and waterlogging is the area **befa**.

3. Accounting for the Effects of District Drainage

This study attempts to systematically account for future shifts in commodity supply schedules for the study area under both the with and without district drainage scenarios. Provision of district drainage is expected to influence shifts in commodity supply schedules over time by (i) reducing production losses on land prone to waterlogging; (ii) reducing the rate of soil salinisation and thereby reducing production losses; (iii) changing the productivity of technologies already adopted, including farm layouts and irrigation systems; and (iv) increasing rates of adoption of on-farm technologies made more profitable by the provision of district drainage, and by decreasing rates of adoption of on-farm technologies made less profitable by the provision of district drainage.

[3] It is assumed for illustrative clarity that supply curve shifts are attributable only to worsening soil salinisation and waterlogging. In reality, technological advances can be expected to lessen leftward shifts or even result in rightward shifts. The crucial point, however, is that S_1 can be expected to lie to the left of S_2 in future periods.

Figure 2: Change in Producer Surplus Due to the Provision of District Drainage



The methods of incorporating these effects in the analysis are discussed in turn.

3.1 Reducing production losses from waterlogging

Provision of district drainage increases the potential to considerably reduce production losses from waterlogging, by complementing on-farm measures which assist in the removal of excess water from agricultural land. Laser-controlled landforming[4] (hereafter referred to as landforming) can improve drainage of surface water from individual paddocks. Drainage recycling and reuse assists in the disposal of drainage water accumulating in low-lying areas of farms. District drainage enables the increased runoff from landformed areas, and drainage volumes in excess of that which can be handled by a recycling system, to be disposed of off-farm, thereby avoiding waterlogging losses due to lack of a drainage 'escape' from farms.

Estimates of the benefits of various combinations of these measures, in terms of the reduction in average annual waterlogging-induced production losses, are presented in Table 2. For example, the waterlogging loss factor for wheat without any ameliorative action is 20 per cent (Table 1), while with landforming the loss is reduced by a factor of 40 per cent to a value of 12 per cent. With landforming plus on-farm drainage and recycling the loss factor becomes 8 per cent due to a 60 per cent reduction in the waterlogging loss. The modified waterlogging loss factors were included in the regional linear programming model in order to

[4] Laser controlled landforming is a technique for accurately modifying the microtopography of a farm landscape to improve the productivity of farm resources.

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	45	
on-farm drainage and recycling	15	60
3.Landforming plus	50	
district drainage	25	75
4.Landforming plus	55	
on-farm drainage and recycling plus	15	
district drainage	10	80

Source: van der Lelij (1988).

incorporate the effects of district drainage, including the rate of landforming adoption, on waterlogging-induced production losses. Although the data are all that is available, van der Lelij (1988, p.54) noted:

> it 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.

3.2 Reducing production losses from soil salinisation

Without provision of district drainage, the annual rate of increase in soil salinity in the study area is predicted to be 0.04 to 0.06 dS/m per year (van der Lelij 1988). Provision of district drainage and the associated increase in rate of landforming adoption (see below) is predicted to reduce the rate of increase of the area affected by high watertables, as well as the rate of soil salinisation, by 25 per cent (van der Lelij 1988). The effect of this on production losses was determined using coefficients from Table 1.

3.3 Changing the productivity of technologies already adopted

By complementing landforming in improving on-farm drainage, provision of district drainage is expected to increase the productivity of land within the study area already landformed. The benefits of this are accounted for by the reduced waterlogging loss coefficients for landformed land specified in the regional linear programming model for the with district drainage scenario. The area that has been landformed in the study area has been estimated at around 20 per cent of the total area (Storrie, NSW Agriculture & Fisheries, personal communication, 1989). Increasing the productivity of landformed land would, therefore, have a significant immediate impact on producers' surplus in the study area.

Since drainage reuse and recycling is partly an alternative to district drainage as a disposal method for drainage, provision of district drainage may reduce utilisation of recycling systems on farms where they already exist. Nevertheless, it is shown in Table 2 that provision of district drainage is expected to reduce waterlogging-induced production losses on these farms by a further 10 per cent. However, as the current level of adoption of drain-

age recycling in the study area is negligible, it has been assumed to be zero to simplify modelling.

3.4 Affecting rates of adoption of on-farm technologies

By increasing returns from landforming, provision of district drainage is expected to increase the rate of adoption (i.e. hectares treated per year) of landforming within the study area. It has been estimated that a maximum of 80 per cent of the study area could be landformed (Solomon, NSW Agriculture & Fisheries, personal communication, 1989). There are areas for which landforming is expected to be uneconomic for farmers due to the large amounts of earth required to be moved to meet a desired slope. Apart from the greater cost of shifting more earth, landforming these areas would have significant detrimental effects on soil structure and fertility.

With provision of district drainage, it is estimated that this maximum level of landformed area would be reached by year 20, whereas without district drainage it is estimated that only 70 per cent of the study area would be landformed by year 30 (Solomon, NSW Agriculture & Fisheries, personal communication, 1989).

Provision of district drainage may reduce the incentive for farmers to adopt drainage recycling as a way of disposing of drainage that would otherwise inundate part of a farm area. However, since current adoption of this technique in the study area is negligible, even a substantial reduction in its future rate of adoption because of access to district drainage is unlikely to have a significant effect on shifts in study area supply schedules.

4. Method of Analysis

4.1 Regional linear programming model

A linear programming model was developed to predict annual aggregate net farm income in the study area over a 30 year time horizon under both the with and without district drainage scenarios. Linear programming allows for systematic incorporation of effects of farmer reaction to changes in salinity conditions and waterlogging loss coefficients. This is dependent on specification of an objective function, which in this case represents maximisation of district (i.e. study area) net farm income. Research results indicating that yields vary linearly with changes in salinity and waterlogging parameters (Maas and Hoffman 1977) support the use of a linear optimising technique.

The objective function was chosen so that the model could be used to predict the aggregate behaviour of individual producers within the study area, each of which is assumed to aim for profit-maximisation on an annual basis. The question arises, however, of whether individual farmers annually maximising their net farm income is synonymous with annual maximisation of regional net farm income, particularly where actions by individual farmers have off-site costs such as is the case with the watertable/soil salinisation problem (wherein the sub-surface drainage capacity of a soil profile has characteristics of open access). This problem has been circumvented in this study by considering the external effects of individuals' behaviour in previous years in the exogenous prediction of soil salinity levels in any given year. The actions of any individual is unlikely to have any significant effect upon soil salinity levels within that year. Consequently, given a prediction of the soil salinity conditions applying within a year, the annual maximisation of individual net farm income is consistent with the objective function of annual maximisation of district net farm income.

The study is concerned with the effect that introduction of district drainage can be expected to have on farmer behaviour and in this context it was assumed that property rights to sub-surface drainage remain characterised by open access during the 30 year study horizon. Farmers are thus assumed to continue to ignore the costs they impose, through their current sub-surface drainage, on future users of sub-surface drainage capacity. Therefore, the predicted patterns of behaviour are distinct from those that would maximise, for each scenario, the present value of district net farm income over this time horizon.

To simplify analysis the model was run for year 0 then every 5 years thereafter, with the regional net farm income assumed to remain constant for the

four years following each run of the model. The values of constraints at the time of each model run regarding the area landformed and areas of land in various salinity level categories were predicted exogenously as discussed above. The present value of regional net farm income under the with and without district drainage scenarios could then be estimated. The present value of agricultural production benefits from providing district drainage could then be estimated as the difference between the present values of the two scenarios. Note that this measure does not account for the difference in capital costs, both private (landforming) and public (district drainage), associated with the two scenarios. These costs, along with other costs and benefits including those occurring outside of the study area, would need to be considered in a complete benefit-cost analysis of the district drainage proposal. The model is deterministic with constant prices and costs used.

4.2 Model details

Land is distinguished in the model according to whether it is subject to salinity, to waterlogging, or to neither problem. For salinised land, separate constraints apply to land associated with different irrigation layouts. These are the layouts of landformed border-check, landformed contour bay and non-landformed contour bay.

For the salinised contour bay categories of land, further categorisation according to soil salinity levels of 0, 3, 4, 5 and 6 dS/m applies. The landformed border-check category is assumed not to experience soil salinity problems since these areas are located on sandy ridge soils which are not susceptible to the occurrence of high watertables. Four waterlogged land sub-categories are distinguished in the model, according to whether district drainage is provided and if the land has been landformed or not.

An additional land constraint relates to the maximum area that can be planted to rice. This has been set by the DWR and Rice Industry Consultative Committee for environmental reasons. Although all available land in the study area is assumed to be irrigable, it is possible in any year for dryland pasture production to occur on irrigable land.

A constraint relating to the maximum monthly capacity for delivering water to farms in the study area is specified. This capacity is a function of the size of supply channels, the number of dethridge wheels, and the flow rate of irrigation water delivered from the supply channel measured in megalitres. A further water-related constraint concerns the aggregate annual water allocation by DWR to the study area.

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

Rotations of crops with pastures represent the major activities in the model. The rotations are distinguished depending on the land sub-category to which they are applied. Crop and pasture rotations supply grain into crop selling pools and feed into pasture pools which can then be utilised by livestock activities. Hay making and hay feeding activities are also included in the model.

Rice, wheat, barley, millet, irrigated sub-clover pasture and dryland salt tolerant pasture species represent the major crops and pastures specified in the rotations. A number of livestock activities which are typical for irrigation areas are included in the model. These are first- and second-cross prime lamb production and merino wethers.

Farm-gate commodity prices and input costs were assumed to remain constant over the 30 year study horizon and were calculated as equal to average levels for the period 1985-86 to 1989-90. In reality, farm-level terms of trade are expected to decline, with the impact of this upon farm incomes offset to some extent by technological innovation and farm structural adjustment. In any year the gain in producer surplus from district drainage, as a result of reduced yield losses from waterlogging and land salinisation, will depend on how these socio-economic factors have influenced the positions of commodity demand and supply schedules. Given the uncertainty associated with predicting these factors, the simplifying device of constant real prices and costs was used. This corresponds with a world in which demand schedules remain fixed over time and shifts in supply schedules result only from changes in waterlogging and soil salinity

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

	Model (ha)	Actual (ha)
Rice	7,957	6,431
Summer cereals	667	607
Winter cereals	5,743	5,161
Vegetables	449	449
Pastures	16,841	17,055
Fallow	3,296	2,323

conditions.

A discount rate of 7 per cent was used to calculate present values. This rate has been used to maintain consistency with the DWR benefit-cost analysis of the drainage scheme (Graham 1990).

4.3 Model validation

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

The 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, these data do not distinguish between irrigated and dryland output.

5. Impact of District Drainage, Salinity and Waterlogging in the Study Area

5.1 Present value of providing district drainage to the study area

With district drainage provided for the study area, the present value of regional net farm income was estimated at $44.7 million. Without district drainage, the present value of regional net farm income was estimated at $38.8 million. Hence the benefit to agriculture of providing district drainage in the study area was estimated at $5.9 million.

Other factors would need to be considered to determine the economic worth of providing district drainage, such as the capital costs of installing district drainage and landforming, operation and maintenance costs of the scheme, possible waterlogging to farms outside Benerembah Irrigation District due to increased drainage volumes, and environmental and secondary benefits and costs. These issues are of relevance to the benefit-cost analysis conducted by DWR and have not been addressed in this study.

There was little overall change in the total areas of crops and pastures throughout the study area between the two scenarios (Table 4). There was, however, significant adjustment on the salinised areas as dryland pasture replaced rice, wheat and irrigated pasture as salinity levels increased for both scenarios (Table 5). An interesting observation was that the original area of rice, and to a lesser extent the area of irrigated pasture, on salinised land were phased out of production with increasing salinity. On waterlogged land there were slight increases in the areas of rice and wheat for both scenarios, while there were declines in the area of irrigated pasture and fallow (Table 6).

There is an offset on rice area on the waterlogged

Table 4: Levels of Activities with District Drainage in the Total Study Area

	Year						
	0	5	10	15	20	25	30
With District Drainage							
Rice (ha)	7,957	7,957	7,957	7,957	7,957	7,957	7,957
Sunflowers (ha)	667	667	649	620	581	581	581
Wheat (ha)	5,743	6,345	6,922	7,566	8,256	8,256	8,256
Lucerne (ha)	0	0	26	69	128	128	128
Irrigated pasture (ha)	8,807	8,149	7,461	6,668	5,789	5,789	5,789
Dryland pasture (ha)	8,034	8,736	9,461	9,750	9,750	9,750	9,750
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	3,296	2,650	2,009	1,322	573	573	572
Unused (ha)	0	0	0	505	1,384	1,384	1,384
Wethers (hd)	117,942	123,185	128,350	128,545	130,682	130,682	130,682
Without District Drainage							
Rice (ha)	7,957	7,957	7,957	7,957	7,957	7,957	7,957
Sunflowers (ha)	667	667	667	667	667	667	663
Wheat (ha)	5,743	6,078	6,412	6,747	7,082	7,455	7,859
Lucerne (ha)	0	0	0	0	0	0	6
Irrigated pasture (ha)	8,807	8,437	8,070	7,709	7,347	6,945	6,495
Dryland pasture (ha)	8,034	8,454	8,854	9,215	9,575	9,750	9,750
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	3,296	2,911	2,545	2,210	1,875	1,502	1,092
Unused (ha)	0	0	0	0	0	228	678
Wethers (hd)	112,600	115,048	113,630	115,794	118,485	120,428	118,414

land for the reduction on salinised areas, as it is profitable to increase rice areas on waterlogged land and remain within the overall rice area restriction. The rationale for increasing rice production on waterlogged land is that this crop is the least affected by waterlogging. On the waterlogged land, wheat replaced areas of irrigated pasture and fallow. The model suggests that it would be rational by landholders in the study area to retire some areas of waterlogged land and devote remaining resources to the more productive areas.

The number of wethers carried was slightly higher when district drainage was provided (Table 4), reflecting the fact that pasture production is higher under this scenario than under the without district drainage scenario. The reasons for this are that with district drainage provided, the pasture losses from waterlogging are reduced and that with the greater adoption of landforming more intensive pasture production occurs.

5.2 Current financial impact of soil salinity and waterlogging in the study area

The annual district net farm income and levels of activities for the study area that would hypothetically result from the absence of any soil salinity or waterlogging conditions are compared to the current estimated levels of salinity and waterlogging in Table 7. This was determined by solving the model separately for the hypothetical situation of no salinity or waterlogging and for the current levels of these phenomena as established by van der

Table 5: Levels of Activities with District Drainage in the Salinised Areas of the Study Area

	Year						
	0	5	10	15	20	25	30
With District Drainage							
Rice (ha)	203	120	0	0	0	0	0
Sunflowers (ha)	667	667	649	620	581	581	581
Wheat (ha)	1,203	1,120	974	931	872	872	872
Lucerne (ha)	0	0	26	69	128	128	128
Irrigated pasture (ha)	1,228	737	228	0	0	0	0
Dryland pasture (ha)	8,034	8,736	9,461	9,750	9,750	9,750	9,750
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	82	38	0	0	0	0	0
Without District Drainage							
Rice (ha)	203	89	0	0	0	0	0
Sunflowers (ha)	667	667	667	667	667	667	663
Wheat (ha)	1,203	1,089	1,000	1,000	1,000	1,000	994
Lucerne (ha)	0	0	0	0	0	0	6
Irrigated pasture (ha)	1,228	1,086	897	536	174	0	0
Dryland pasture (ha)	8,034	8,454	8,854	9,215	9,575	9,750	9,750
Vegetables (ha)	449	449	449	449	449	449	449
Fallow (ha)	82	32	0	0	0	0	0

Lelij (1988). The model was also separately solved to determine the losses which were attributable to salinity only, or to waterlogging. This indicates that an annual reduction in district net farm income of $1.7 million is incurred when contrasted with the hypothetical situation. The contribution toward the total loss was determined to be $1.5 million due to the influence of waterlogging and $0.2 million due to soil salinisation.

The above result reinforces the conclusion drawn by Grieve *et al* (1986), who assessed annual losses due to soil salinity and waterlogging to exceed $13 million for Berriquin and Wakool Irrigation Districts of the Murray Valley. Losses due to waterlogging (nearly $10 million) were determined in that study to be more serious than those due to soil salinity (nearly $4 million).

The estimated losses differed to that of Graham (1990), who determined the contributions to the loss of gross value of agricultural production from salinity ($1.4 million) and waterlogging ($1.5 million) to be almost equal. The divergence in the results is accounted for by the on-farm adjustment on salinised areas as illustrated in the previous section. This supports the stated objective that an optimising approach to estimate losses is more consistent with economic principles than a static one which implies that no change in the activities chosen will occur regardless of the severity of the problem.

6. Sensitivity Analysis

Changes in a number of parameters were evaluated to determine the impact upon the agricultural benefit of providing district drainage to the study area. The parameters tested were the discount rate, water prices, rates of adoption of landforming,

Table 6: Levels of Activities with District Drainage in the Waterlogged Areas of the Study Area

	Year 0	5	10	15	20	25	30
With District Drainage							
Rice (ha)	7,754	7,837	7,957	7,957	7,957	7,957	7,957
Wheat (ha)	4,540	5,226	5,948	6,635	7,384	7,384	7,384
Irrigated pasture (ha)	7,579	7,412	7,173	6,668	5,789	5,789	5,789
Fallow (ha)	3,214	2,612	2,009	1,322	573	573	573
Unused (ha)	0	0	0	505	1,384	1,384	1,384
Without District Drainage							
Rice (ha)	7,754	7,868	7,957	7,957	7,957	7,957	7,957
Wheat (ha)	4,540	4,989	5,413	5,747	6,082	6,455	6,865
Irrigated pasture (ha)	7,579	7,351	7,173	7,173	7,173	6,945	6,945
Fallow (ha)	3,214	2,879	2,545	2,210	1,875	1,502	1,092
Unused (ha)	0	0	0	0	0	228	678

Table 7: Losses in Annual District Net Farm Income due to Salinity and Waterlogging

	Study area net farm income ($million p.a.)
No salinity or waterlogging	4.7
Current salinity and waterlogging levels	3.0
Loss due to salinity and waterlogging	1.7
Loss due to waterlogging only	1.5
Loss due to salinity only	0.2

waterlogging loss coefficients and the coefficients for reduction in waterlogging losses due to landforming and district drainage. The results of this analysis are presented in Table 8.

One component of the NSW Government's micro-economic reform process is the elimination of subsidies on the supply of irrigation water. Presently charges apply only to the direct costs of operating and maintaining irrigation and drainage systems, with no contribution toward the operation and maintenance of storage structures. A charge which reflects all supply and drainage costs for BID has been estimated at $13.98 per megalitre (Yates, Department of Water Resources, personal communication, 1990), which represents approximately a 50 per cent increase on the water charge used in the study. Even though the regional net farm income was significantly reduced by an increase in water charge of this magnitude, the effect of the net benefit of the scheme was negligible with only a $0.1 million decrease.

The level of landforming was tested by assuming a

Table 8: Sensitivity Analysis

	Agricultural benefit of district drainage ($ million)
Full cost recovery of water charges	5.8
Zero landforming adoption rate	3.7
10 per cent increase in waterlogging loss coefficients	6.2
10 per cent decline in the percentage reduction in waterlogging losses due to landforming and district drainage	5.4
Discount rate:	
2 per cent	12.2
5 per cent	7.7
7 per cent	5.9
10 per cent	4.1
12 per cent	3.4

zero rate of adoption over the 30 year horizon. In the base analysis, the best estimate of the current level of landforming was 20 per cent of the total, with 80 per cent of total area landformed in year 20 with district drainage, and 70 per cent in year 30 without district drainage. The significance of landforming adoption assumptions was tested by assuming the same level of initial landforming but with no further areas landformed. This resulted in a decline in the net benefit of district drainage from $5.9 million to $3.7 million. This illustrates that the future rate of adoption of landforming is a significant factor in determining the value of agricultural benefits from providing district drainage to the study area. Therefore, there is a need for landholders to contribute to the scheme by providing private capital, via adopting landforming, to realise the full agricultural benefits of the drainage proposal.

As illustrated in Section 5.2, waterlogging losses are the largest component of total economic losses from salinity and waterlogging in the study area. Research data regarding yield losses under differing degrees of waterlogging are not available. Waterlogging loss coefficients for all crops and pastures were increased by 10 per cent to test the impact upon the analysis. This increase in waterlogging loss coefficients resulted in a $0.3 million (or 5.7 per cent) increase to $6.2 million in the agricultural benefit of providing district drainage to the study area.

As discussed in Section 3.1, the values attached to the reduction in waterlogging losses due to landforming and district drainage were the result of a subjective assessment. There is little information to suggest how much this may vary, so the effects of an arbitrary 10 per cent decline in the percentage reduction in waterlogging losses due to landforming and the provision of district drainage was tested. This resulted in a 7.7 per cent decline in the agricultural benefit due to the scheme to $5.4 million.

A range of discount rates was used to test the sensitivity of the results to this variable. As indicated in Table 8, the net benefit of district drainage remains positive at rates up to 12 per cent, even though it is substantially reduced.

7. Summary and Conclusions

The major focus of this study was the estimation of the agricultural benefit of a surface drainage scheme proposed to ameliorate the effects of salinity and waterlogging in an area of Benerembah Irrigation District. The present value of net farm income in this area during the 30 year study horizon was estimated to be increased by $5.9 million due to the

completion of the scheme. Sensitivity analysis demonstrated, however, that realisation of this level of benefit is dependent upon farmers in the area undertaking substantial on-farm investment in laser-controlled landforming so as to be able to efficiently move surface drainage from farms into the drainage network.

The analysis endogenously accounted for farmers adjusting their activity mixes over time in order to continue maximising profits in the face of changing levels of soil salinity and waterlogging. To have assumed that farmers would not attempt to minimise the impact upon their net farm incomes would have resulted in the financial impact of future salinity and waterlogging, and therefore of district drainage, being substantially overestimated. This is evident from the study by Graham (1990) which estimated the agricultural benefits of the scheme to be $11.4 million, based on the difference in gross value of production between the two scenarios with a static crop mix, and annual losses due to salinity and waterlogging to be similar. This study, however, demonstrated that there was significant adjustment on the salinised areas and consequently a much lower loss value and agricultural benefit due to district drainage.

Estimation of the agricultural benefit from district drainage represents one part of the complete benefit-cost analysis required to justify such a scheme. This benefit needs to be compared with the costs associated with the scheme, including the cost of construction and landforming. District drainage is also likely to generate external costs. These costs include those resulting from flooding due to increased drainage flows, possible increases in salinity levels in the lower Lachlan, Murrumbidgee and Murray Rivers, and those resulting from permanent inundation of otherwise transient wetlands.

The construction cost of the scheme has been estimated at between $4.5 million (van der Lelij 1988) and $5.5 million (ACIL 1990). The discounted capital cost of the additional landforming associated with the district drainage scheme has been estimated at a minimum value of $2.8 million. This has been calculated using the lowest landforming contract rate of $260 per hectare, which does not include any allowance for the redesign of farm layouts, additional fencing and so on (Marshall and Jones 1991). In addition, operating and maintenance costs of the scheme have been estimated at 2 per cent of the construction cost (i.e. $90,000 to $110,000 annually). Therefore, given the magnitude of the capital costs, both private and public, it is questionable that the scheme can be judged an economic use of the community's resources.

Variations in the discount rate, irrigation water charges, the waterlogging loss coefficients and the waterlogging yield loss reduction coefficients relating to the adoption of landforming and district drainage did not significantly affect the results. Whereas the waterlogging loss coefficients were obtained from limited research results, the current estimates of the reduction coefficients are based only on a subjective assessment rather than on technical research. There is a need for greater accuracy in this information, however, for the purposes of this analysis errors within 10 per cent do not significantly affect the results.

The study indicates that current levels of soil salinisation and waterlogging result in a $1.7 million per annum reduction in the study area net farm income compared to a situation where salinity and waterlogging problems are absent. These estimates allow for farmers having adjusted activity mixes in response to the development of these land degradation problems. The findings of Grieve *et al* (1986), that waterlogging losses had a much greater impact than soil salinisation on the gross value of agricultural production in two Murray Valley irrigation districts, were supported by this investigation.

In this study, rates of soil salinisation and landforming under the alternative drainage scenarios were predicted exogenously. The additional modelling complexity required in order to endogenise these variables was not considered given the lack of reliable data linking farmer choice regarding activity mixes and landforming investment with ensuing soil salinity and waterlogging conditions. Given improved data, however, future analyses of proposed drainage schemes could profitably utilise a more dynamic framework. In such a framework, the rate of soil salinisation at any time would be endogenously predicted as a function of

previous choices made by farmers regarding activity mixes and landforming investment. The rate of landforming investment at any time would also be modelled as a function of the soil salinity conditions predicted for that time.

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