



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

**SAGWAMS: Resource Policy and Optimal Management
of an Irrigated Farm**

by

Nick Milham¹

Mike Bryant

Warren Musgrave

Randall Jones²

**Centre for Water Policy Research
University of New England, Armidale**

**Paper presented to the 37th Annual Conference of the Australian
Agricultural Economics Society, University of Sydney, Sydney,
9–11 February 1993.**

Abstract

A study was conducted in the Benerembah Irrigation District to determine the possible responses of irrigators to selected water management policies, and to investigate the potential effects of these policies on their economic viability and water-use efficiency. The approach was to develop an integer programming model of a representative farm (SAGWAMS) and simulate the economically optimal patterns of resource use and production under assumed policy scenarios. The policy options modelled included relaxing the constraints on farm size and rice production, and introducing tradeable permits in licensed allocation. Some of the results, which are preliminary in nature, are presented here.

¹Current location: NSW Agriculture, AGCOST Unit, Parkes.

²NSW Agriculture, ESU, Orange.

Introduction

Irrigation farmers in the Murrumbidgee region of New South Wales are being increasingly confronted with problems associated with rising watertables, waterlogging and land salinisation. For example, prior to irrigation, groundwater levels in the Murrumbidgee Irrigation Area were 20 to 30 metres below the ground surface. Now, more than 200000 hectares of shallow watertables (less than two metres from the soil surface) occur in the Murrumbidgee and Murray regions of New South Wales. This is forecast to double by 1995 (Grieve et al. 1986). Watertables are rising primarily due to increased groundwater accessions through percolation of water from irrigation of crops and pastures, and seepage from irrigation supply and drainage channels (Irrigation Farm Working Group 1986).

Waterlogging and salinisation lead to lower productivity of horticultural, cereal and pasture crops. Waterlogging can cause yield losses of up to 50 per cent in cereal crops, and a significant reduction in growth of pastures. And, although comprehensive analyses have not been completed, it appears that salinisation can have similar detrimental effects (Grieve et al. 1986). Waterlogging in paddocks also interferes with the execution of management activities such as cultivation and crop spraying (GHD 1985). The potential losses from waterlogging and salinisation have been estimated as amounting to over \$14 million per annum in the Benerambah, Berriquin and Wakool Irrigation Districts alone (Grieve et al. 1986).

There is considerable pressure for water resources to be supplied and allocated on more of a cost-recovery, economic efficiency, basis. Managers of public irrigation facilities are having to deal with rising maintenance costs and the questions of whether or not to restore, upgrade, abandon or privatise sections of the now aging irrigation infrastructure. Off-site costs and degradation of environmental resources are important elements in this debate.

There are a variety of alternative resource management policies that managers of irrigation schemes can implement to address the above problems. These include, for example, user/polluter pays, transferable water entitlements, and deregulation of land-use and commodity output constraints. The proposed policies tend to focus on changing water-use by irrigation farmers. Under some circumstances, some of these policies may lead to reductions in the extent of some agricultural enterprises and declines in farm incomes. In turn, these could lead to financial stress

and reduced employment opportunities for both urban and rural workers throughout the region. There is thus a need to evaluate the likely responses of irrigators to alternative water management policies and to investigate the potential flow-on effects to the local and regional communities.

The objectives of the study underpinning this paper were to examine the possible impacts on irrigators, and likely environmental implications, of alternative institutional arrangements for irrigation areas and districts in the Murrumbidgee Region of New South Wales. These arrangements included the use of transferable water entitlements, changing water allocation entitlements and the price of those entitlements, and changes in land control measures, such as rice area quotas. This paper describes the structure and operation of a model that was developed to examine these impacts, and discusses the results obtained when some existing institutional constraints were relaxed. The implications of imposing new constraints or increasing water prices are not discussed. The Benerembah Irrigation District was selected for the study site as it encompassed the salinity and waterlogging problems mentioned above.¹

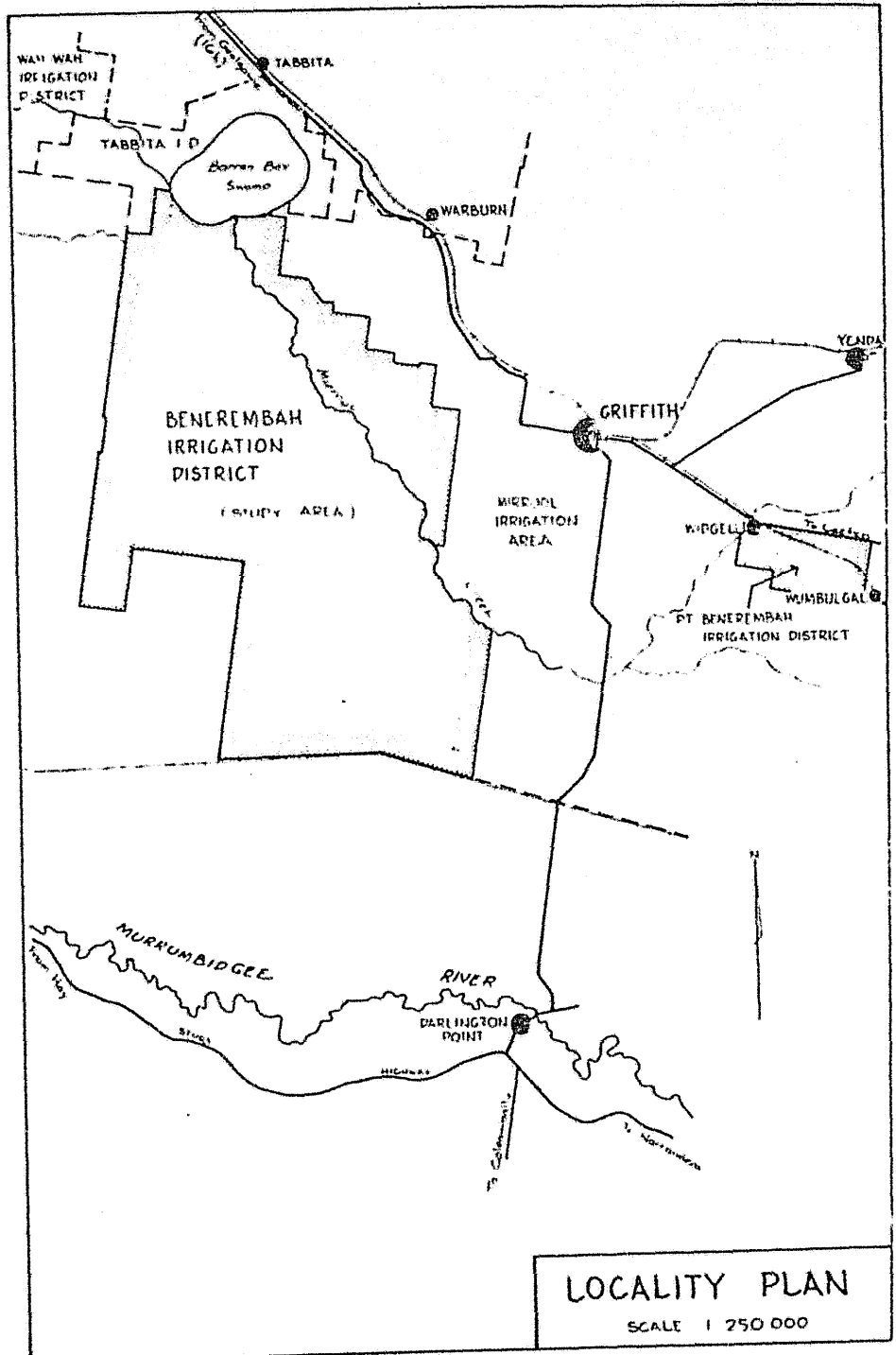
The Benerembah Irrigation District

The Benerembah Irrigation District (BID), located to the south-west of Griffith in southern New South Wales (see Figure 1), is 44225 hectares in area, of which 39830 hectares have been developed for irrigation. A minor portion, some 2428 hectares in area, is located to the east of Griffith. There are 135 individual holdings in the BID, with a 'standard' farm comprising approximately 435 hectares (Jones 1991a). The major agricultural activities are rice and wheat cropping, vegetable growing, and sheep enterprises based on annual pasture rotations.

The original concept of the Benerembah District was to utilise surface drainage from the Murrumbidgee Irrigation Area, to provide only sufficient water for limited irrigation to stabilise production on existing, relatively large holdings. Because of the intended low

¹ The study was conducted by the Centre for Water Policy Research, with the principal researchers being Mike Bryant, Nick Milham and Vol Norris. Randall Jones, of NSW Agriculture, who was conducting complementary research, acted in a collaborative capacity. Financial support was provided by the Australian Water Research Advisory Council of the Commonwealth Department of Primary Industries and Energy.

Figure 1
 Benerembah Irrigation District Locality Plan



Source: WRC (1986, p.22)

irrigation intensity, drainage of the land was not considered of great importance and no surface drains were constructed. However, since the BID was gazetted in 1936, the original holdings have been extensively subdivided, additional water entitlements have been allocated to the new holdings, and irrigation intensity has increased substantially.

In 1986, the Water Resources Commission (now the Department of Water Resources) reported that, due to the intensity and extent of irrigation in the BID, the watertable was rising rapidly (0.5m/yr), and that waterlogging and land salinisation were affecting 20–25 farms in the District (WRC 1986). By 1988, the watertable was within two metres of the surface on 27000 hectares within the BID (WRC 1988) and, by early 1991, some 2000 hectares were reported as being significantly affected by waterlogging and salinisation (Department of Water Resources 1991). It has been estimated that the consequent decline in productivity has caused a loss in farm income, on average, of \$9000 per farm (Grieve *et al.* 1986). Furthermore, unless remedial action is taken, it is forecast that as much as 25 per cent of the District could become totally useless for agricultural purposes within 30 years (Department of Water Resources 1991).

Data

Primary information and data on farm enterprises and management practices in this District were collected during the course of several meetings with local farmers. The major secondary sources of information and data for this study were Crean (1991) and Jones (1991). This information covered the areas of:

- * commodity production and land-use constraints within the BID;
- * District regulations on the supply and use of irrigation water, and physical capacity constraints;
- * the cost of irrigation allocation;
- * monthly percentage allocation available on average;
- * the cost of upgrading undeveloped land;
- * standard production enterprises and practices (e.g., livestock, crops, crop and pasture rotations, water requirements etc);
- * variable production costs and farm-gate returns;
- * per cent of rainfall and irrigation water lost as surface run-off; and,
- * monthly rainfall and evaporation.

The numeric data were current in the 1990 calendar year.

The SAGWAMS Model

Mathematical programming was selected as the analytical technique because of its ability to generate economically optimal patterns of resource use in response to changed institutional, economic and physical constraints. This technique enables determination of the likely impacts on input requirements, i.e., land, water, labour and capital, as well as providing estimates of agricultural output. The approach taken was to develop a model of a representative farm on which to simulate farmer responses to a range of scenarios.

The management objective assumed throughout this study was that of maximisation of net farm income over the short to medium-term. Dumsday and Edwards (1990) identified this as an objective widespread amongst Australian farmers.

In its current form, the Surface and Groundwater Modelling System (SAGWAMS)² is a mixed-integer linear programming model. It is designed to select the combination of resources and activities that maximise annual net farm income within the constraints that could be imposed by the physical and regulatory environment. It has been coded for solution by the Generalised Algebraic Modelling System (GAMS) software package, which is available for both mainframe computers and DOS-based personal computers.

The data input file for the model comprises a text file that can be edited using any word-processing package. It contains 335 variables and 383 functional relationships and constraints. SAGWAMS is extremely flexible and versatile in form and its parameters and constraints are easily adapted to suit required specifications. Verification and validation (Mihram 1972; Naylor 1971) of these relationships and constraints were integral, on-going aspects of the development process.

A major component of the model concerns water availability, usage and storage. In particular, the model can optimise storage design in terms of volume and surface area and associated

²The enterprise options used in SAGWAMS were derived from an earlier model developed by Jones (Jones 1991a;b). So far, SAGWAMS only encompasses surface water modelling. Extension of the model to incorporate groundwater will be dependent on the availability of research funding.

pumping infrastructure. Allocation is received and utilised on a monthly basis. Accommodated here are options for the construction of an on-farm storage facility, together with the costs incurred, storing allocation water and storing and recycling rainfall and irrigation run-off.³ Transfer of water between months is also allowed. Evaporation from the storage is taken into account and depends on the time of year, and the area and depth of the water in the storage. Construction costs vary with the capacity of the storage and the height of the embankment. The selection of the size and number of pumps associated with the storage is endogenous to the model and depends on the maximum volume of water to be pumped in any one period and the costs of purchase and installation.

SAGWAMS has been designed and developed in this fashion to allow the investigation of the question of what farms in the BID might be like under alternative regulatory and management conditions. It was thus necessary to provide maximum flexibility in water management and to allow the potential for on-farm water management systems not currently evidenced in the District. In practice, a lack of suitable, impermeable, soils may rule out the option of an on-farm storage for some farmers.

The quantity and quality (productive capacity and suitability for irrigation) of the land asset is also dealt with in some detail. Land is divided into four primary categories being dryland area, non-landformed contour bay area, landformed contour bay area and rice land. Rice can only be grown on areas categorised as rice land. The rice land category, which is also landformed contour bay area, is an artifice to account for the restrictions placed on rice production. It can also be used for purposes other than rice production.

Experimental Design

The initial resource allocation and constraints on the representative farm are shown below:

- * 435 hectares of land, being 50 hectares of undeveloped dryland, 290 hectares of landformed contour bay area, of which 70 hectares could be used to produce rice, and 95 hectares of non-landformed contour bay area. Land can be neither traded nor upgraded. The constraints on the maximum permissible area of rice production and on

³An important aspect of these provisions in the model is that total surface run-off exiting the farm is explicitly calculated in the model. Thus, if required, quotas or charges on this discharge could be easily incorporated in the optimisation process.

land trading and upgrading can be relaxed as required;

- * 2120 megalitres of allocation water, which cost \$13–98 per megalitre and could not be traded. There were no off-allocation flows. There was a monthly channel capacity constraint of 480 megalitres and there was no on-farm water storage. There is provision in SAGWAMS to relax the constraints on trading in allocation and on-farm water storage. If trading in allocation is permitted, purchase and sale prices of water licenses are assumed to be \$350.10 and \$350 per megalitre, respectively. When water storage is permitted, the options of constructing a storage, pumping allocation direct to storage and intercepting rainfall run-off and irrigation tail water then become available. Construction of the storage and pump station, and the cost of the additional pumps required, are capital costs. The per litre cost of pumping water into the storage and the time taken, i.e., the monthly maximum that can be pumped, both vary depending on the size of the pumps used. Water in the storage is subject to evaporation. The storage competes for land with the dryland production activities: the trade-off between storage area and crop area is optimised in the model;
- * 600 hours per quarter of operator labour. Unlimited casual labour was available at a cost of \$10–00 per hour;
- * It was assumed that the business had \$50000–00 liquid capital (cash), which could be invested in either on-farm capital or off-farm financial assets. Off-farm assets yielded a real return 4.5 per cent per annum. No borrowing was allowed. The constraint on borrowing can be relaxed as required. Loans attract a real interest rate of 11.5 per cent per annum. Loan capital forms part of the liquid capital pool and can only be expended on capital investment;
- * \$200000–00 of farm machinery and equipment. Excess machinery and equipment can be sold to provide additional liquid capital, but none can be sold. The constraints on sales and purchases can be relaxed as required;

Operating surpluses are not available for expenditure on capital items or for financial investment. That is, they do not contribute to the pool of liquid capital.

Possible agronomic activities on the farm are limited to various pre-specified rotations of irrigated rice, wheat and pastures, or dryland pastures. There are 38 alternative crop rotations accommodated in the model (see Jones 1991a). Pasture, which is produced on a seasonal basis,

can be carried forward in the form of hay, and hay can be bought and sold if required. Possible animal production activities include a self-replacing Merino flock, Merino wethers, two first-cross activities (Merino x Dorset Horn and Merino x Border Leicester), and a second-cross prime lamb activity. The variable costs of production, grain tonnage produced and the number of head in each flock, for the selected combination of cropping and livestock activities, are each calculated for a total rotation.

Wheat and rice are assumed to yield market returns of \$111 and \$130 per tonne, respectively. The per head net income from the sheep activities are:

- * \$41.00 for the Merino breeding flock;
- * \$23.34 for the Merino wether flock;
- * \$29.82 for the Merino x Dorset Horn flock;
- * \$33.36 for the Merino x Border Leicester flock; and,
- * \$27.20 for the second-cross prime lamb flock.

Water Trading:

One option available to the managers of the BID is to allow farmers to trade in water allocation. That is, permit farmers to buy and sell allocation at a market-determined price. Individual farmers would set their buying price at, or below, the marginal return generated from the additional volume purchased (Jones 1991b). Thus, allocation would have a capital value independent of the land and would tend to be reallocated to the most profitable and water-efficient enterprises. This would facilitate industry adjustment and benefit both the farmers and the economy as a whole.

Restricting Water Allocations:

A further policy option is to simply reduce the total volume of water allocated to irrigation farming. A reduction in allocation would force farmers to use the available water more efficiently⁴, either through different irrigation methods or improved timing and control of water applications, or to switch production to commodities requiring less irrigation. This could be

⁴Economic efficiency means that the highest possible profit per unit of input is being obtained at the margin. Technical efficiency means that the highest possible output per unit of input is being achieved at the margin. Economic efficiency thus subsumes technical efficiency.

expected to lead to a reduction in total accessions to the watertable across the District, and to mitigation of many of the current drainage and waterlogging problems.

A related option, to be evaluated in a subsequent study, is only seasonal adjustments of water allocations to farmers in response to changing water table levels. Farmers who are producing crops that lead to high water tables or those who are suffering higher than usual water tables as a result of seasonal conditions could expect temporary restrictions to subsequent water allocations.

Rice Area Constraints:

The control of rice area also leads to some inefficiencies in resource use, including licensed allocation. Farmers whose holdings have substantial areas of the better rice growing soils are prevented from increasing the area under rice production above 71 hectares, while other farmers may be growing rice on land that is only marginally suitable. Relaxing this control in conjunction with the introduction of more appropriate allocation pricing or quota arrangements, could lead to aggregate rice production in the BID being more water-efficient (IAC 1987).

Water Pricing:

An alternative to the quota-type regulations proposed above is to increase the price of water allocation to a level that reflects the total cost of delivery to the farm or, at least, the variable costs of irrigation plan management.⁵ It has been suggested that total cost recovery, including social and environmental costs, would make most irrigation farming in the MIA uneconomic (Watson and Rose 1980; WRC 1988). However, the lesser penalty of increasing allocation prices to reflect the marginal cost of delivery, and/or some component of environmental costs, would still induce more economically efficient water use in a social sense. Total use of water for irrigation purposes could be expected to decline (IAC 1987).

⁵These costs are generally not fully covered by standard charges for irrigation water (IAC 1987).

Home Maintenance Areas:

Relinquishing the Home Maintenance Areas policy, which restricts maximum farm size, is a further policy initiative. This allows some farmers to take advantage of economies of size to improve water-use efficiency and their prospects for long-term economic viability. It also allows those farmers who are unable to maintain economic viability to more readily realise their land asset and adjust out of the industry. Removing these restrictions thus appears to have substantial potential benefits in terms of more efficient water use, and economic and social adjustment and growth (IAC 1987).

From a farm management perspective, introduction of some of these options may require significant adjustments to management practices and to the mix of commodities produced. Possible physical changes to the farm layout could include landforming of suitable areas to improve irrigation efficiency and drainage, construction of an on-farm water storage to enable recycling of surface run-off, or the installation of more efficient irrigation equipment.

In light of the alternative policies described above, a range of experiments were designed and conducted with the SAGWAMS model. The design and outcomes of four of these experiments are discussed below.

Scenario 1:

The first experiment, reported as Scenario 1, related to the initial resource allocation and constraints specified for the representative farm. In brief, this involved a given land area of 435 hectares, which could be neither traded nor upgraded, licensed allocation of 2120 megalitres, which could neither be traded or stored, a \$200000 stock of machinery and equipment, which could be sold if in excess of requirements, and \$50000 in liquid capital. Investment of up to \$50000 in financial assets was accommodated, but no borrowing was allowed. This model was the most constrained and the results obtained from it served as a benchmark, or control, against which to compare the outcomes of the other scenarios.

Scenario 2:

In the second scenario, upgrading and trading of land was permitted but the maximum area was still constrained to be 435 hectares. The model was specified such that any unused land would be sold. That is, the optimal farm plan could not include any extra land. The assumed per hectare purchase prices of the various categories of land were: \$1400 for non-landformed contour bay; \$1800 for landformed contour bay; \$1800 for rice land; and, \$1700 for dryland. Thus, in effect, it cost \$400 per hectare to landform contour bay area and \$500 per hectare to upgrade dryland to landformed contour bay area. Trading in licensed allocation was also allowed, with the maximum additional supply being 1000 megalitres. Allocation was assumed to cost \$350 per megalitre. Additional machinery and equipment up to \$100000 in value could be purchased. This experiment was designed to provide insights into the optimal combination of land types and the optimal consumption of allocation under conditions of transferable water entitlements.

Scenario 3:

The third scenario was basically the same as the second but with the restriction on on-farm water storage removed. That is, under this scenario, water storage and recycling were allowed and the temporal efficiency of water use could also be maximised. Only if the opportunity costs of obtaining additional allocation were high, or if the desired level of supply was unavailable at certain times of the year, would it be economic to construct a storage. It should be noted that, other than the pumping cost involved, recycled water is free.

The analysis of this scenario included an estimate of the break-even rate of interest on financial investments. This break-even interest rate was, in effect, an estimate of the real rate of return on capital.

Scenario 4:

The final policy scenario was one in which the restriction on the maximum size of the farm was removed. In effect, this was equivalent to removing the regulations pertaining to the Home Maintenance Areas. In all other respects, this scenario was the same as Scenario 3. The results of

this case indicated the optimum farm size, and maximum net farm income, under completely deregulated conditions.

Results

Before reporting and discussing the results obtained from these experiments it is important to note that these results are preliminary only. The information and data used in the model are now two years old and would require some revision to reflect existing economic conditions in the BID. Thus, these results are best regarded as being indicative of the power of the SAGWAMS model for investigating the potential farm-level effects of alternative management policies. Notwithstanding this, some interesting and enlightening conclusions can be drawn from the results.

The four charts on the following pages comprise a summary of the results obtained under each of the four alternative policy scenarios posed above. Figure 2 contains details of the optimal mix and physical output of agricultural commodities, and the consequent level of net farm income. In Figure 3, the optimal use of licensed allocation and stored water, together with the volume of drainage discharged from the farm, is shown. Total farm area, the area under rice production and the area of non-landformed land, are shown in Figure 4. Figure 5 depicts the optimal level of off-farm financial investment under each of the scenarios modelled.

From Figure 2, it can be seen that net farm income rises by almost 30 per cent following relaxation of the constraints on land upgrading and trading in water licences (Scenario 2). Marginal increases in net income are also achieved with the progressive deregulation represented by Scenarios 3 and 4. Underlying these changes are adjustments in the level of off-farm investment and the mix of commodities produced.

Rice production rises by about 10 per cent from Scenario 1 to Scenario 2. This is enabled primarily by increasing the intensity of irrigation (see Figure 3), with the optimal area of land under rice increasing by just two hectares to 72 hectares (Figure 4). Water application rises from 4.9 ML/ha under Scenario 1, to 5.0 ML/ha under Scenario 2 and 6.3 ML/ha under Scenarios 3 and 4. Closer analysis of this result reveals that further expansion of irrigation effort is prevented by the limited supply of licensed allocation in the summer months. However, as

constraints on management are reduced, the optimal area of rice production declines and stabilises at 65 hectares, a lower level than is optimal under the initial scenario. This implies that, in a deregulated operating environment, rice production would not be likely to exceed the maximum level currently enforced by regulation.

Net farm income per megalitre of water applied closely tracks the area of rice production, rising from \$38/ML (Scenario 1) to \$47/ML (Scenario 2) but stabilising at the lower level of \$43/ML under Scenarios 3 and 4.

Due to the large proportion of non-landformed contour bay and dryland, there is a large sheep activity under Scenario 1 (Figure 2). As the restrictions on land and water use are relaxed, it is profitable to landform more and more of the farm area (Figure 3) and shift production away from sheep into irrigated wheat (Figure 2). For Scenarios 3 and 4, under which the entire farm area is landformed, the optimal sheep activity is some 32 per cent smaller, and the optimal wheat activity almost 200 per cent larger, than for Scenario 1.

The increase in the profitability of the farm enterprise is such that off-farm investment, which is optimised at its constrained maximum of \$50000 under Scenario 1, declines to \$37000 in Scenario 2 and to zero in Scenarios 3 and 4 (Figure 5). That is, under deregulated conditions it appears to be at least as profitable, if not more so, to invest on-farm than off-farm.⁶

Environmental concerns also appear to be addressed more successfully in the scenarios representing a less regulated operating environment. In Scenarios 3 and 4, the total use of licensed allocation is about 3 per cent lower than in either of Scenarios 1 or 2. (About 30–40 megalitres are sold.) Drainage discharge from the farm is also substantially reduced. (See Figure 3.) These benefits are attributable to increased temporal efficiency in water use made possible by the construction of an on-farm water storage facility.⁷ The optimal capacity of this reservoir is estimated as being about 150 megalitres. Offsetting this is the increased intensity of irrigation noted earlier.

⁶Of course, off-farm investment is often a risk management activity. This analysis is based on optimising a point estimate of net farm income and hence implicitly assumes risk neutrality (Anderson 1976).

⁷An issue that arises here that warrants further investigation is that of accessions to groundwater from the reservoir.

Figure 2
Commodity Output and Net Farm Income under Four Policy Scenarios

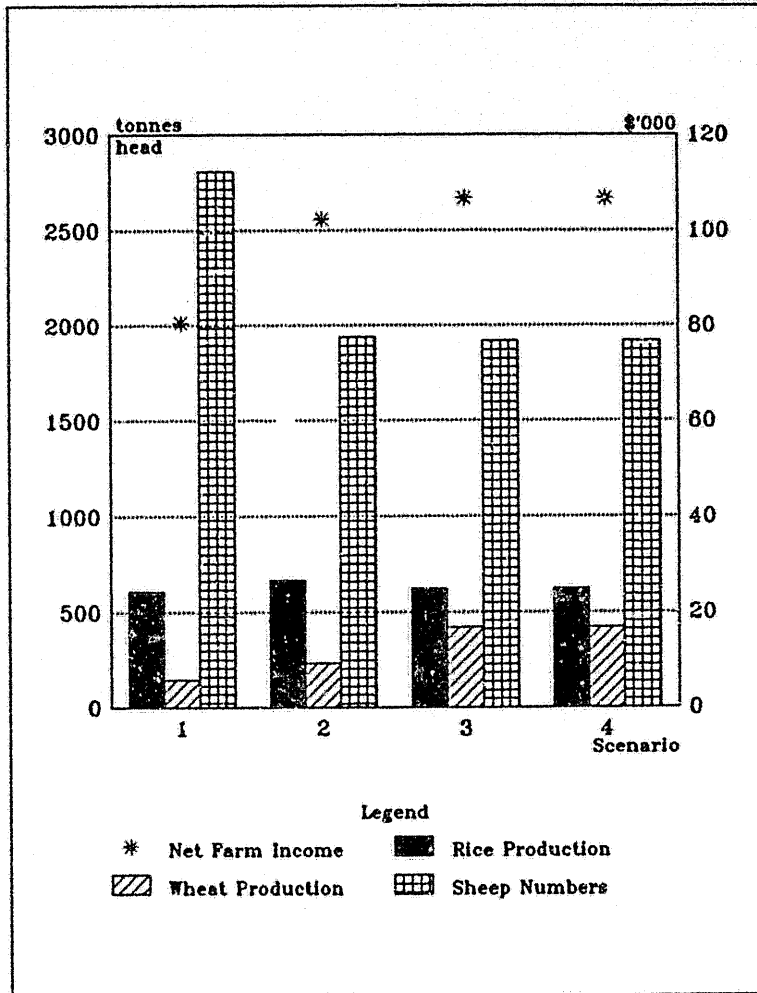


Figure 3
Optimal Water Management under Four Policy Scenarios

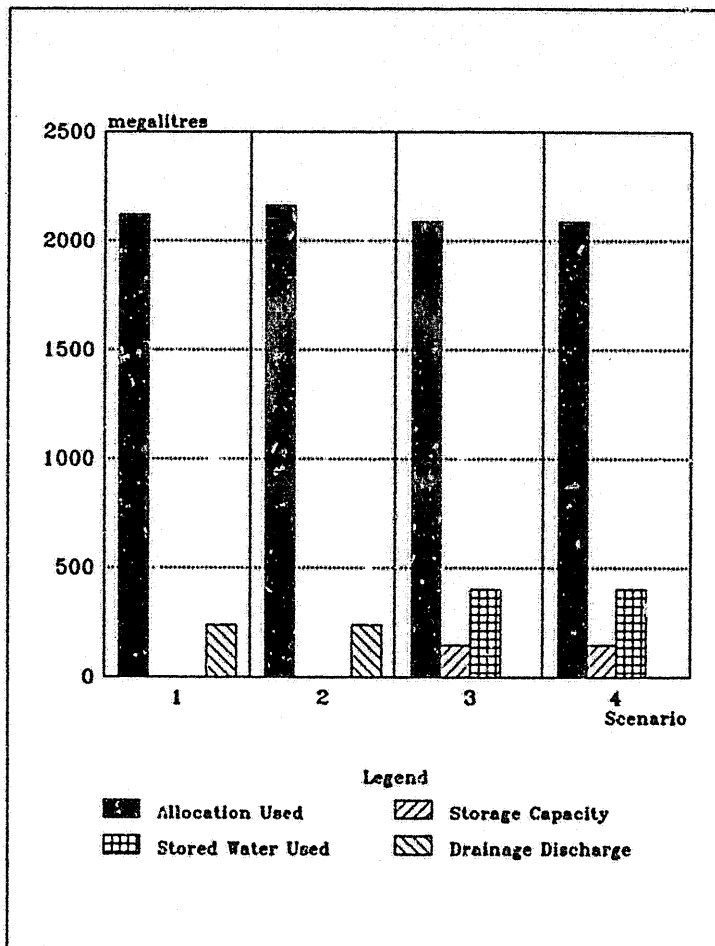


Figure 4
Optimal Land Management under Four Policy Scenarios

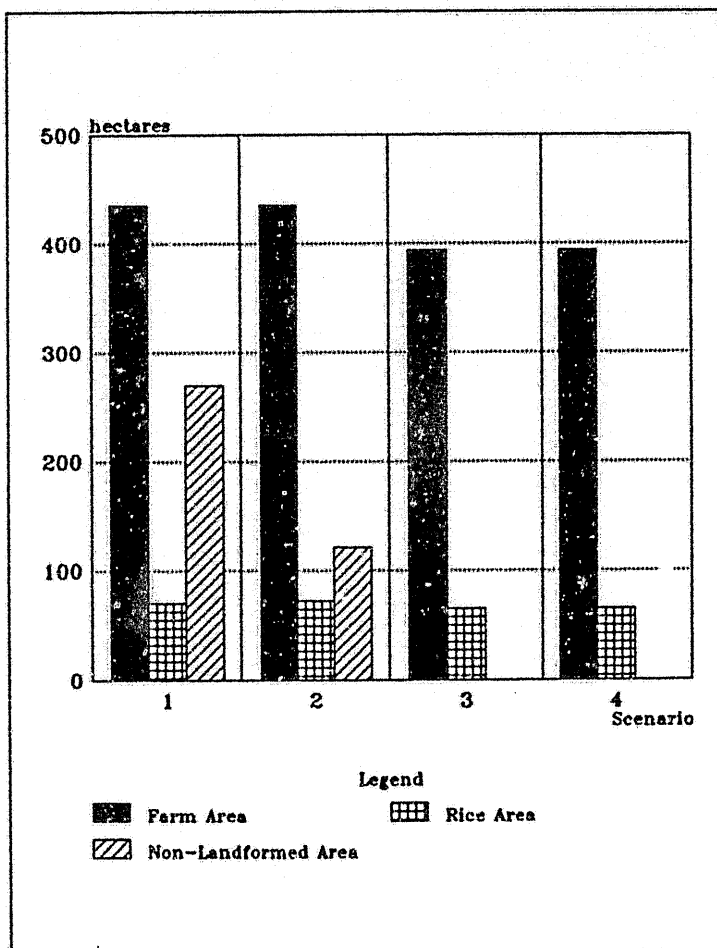
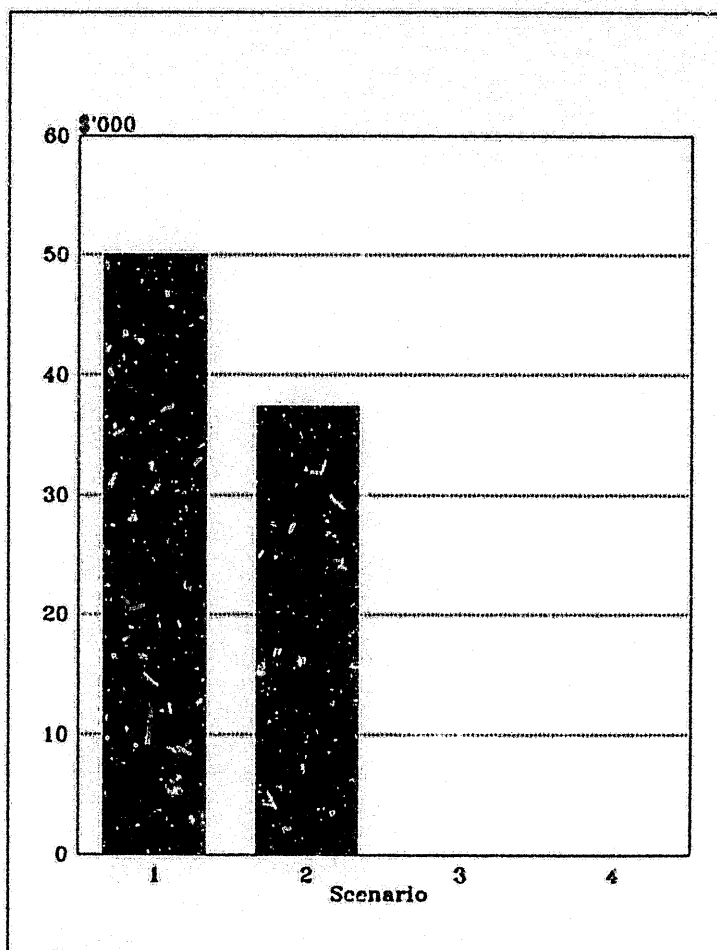


Figure 5
Off-farm Financial Investment under Four Policy Scenarios



It is noteworthy that the optimal farm plan is exactly the same under both Scenarios 3 and 4. The only difference between these policy scenarios is that in Scenario 4 the constraint on the maximum size of the farm is removed. The optimal farm size under these scenarios is about 400 hectares, marginally less than that in Scenarios 1 and 2. Thus, under relaxed institutional arrangements, economies of size do not appear to exist in the BID. Rather, land quality and temporal efficiency of water use seem to be the major influences on farm profitability. This result suggests that the Home Maintenance Areas regulations are having little effect and that the purpose for which the regulations were instituted would, in any case, be achieved without them.

Conclusions

The major implications of removing existing institutional constraints on irrigation farming in the BID are:

- (i) Farmers will direct more financial resources into farm investments, such as upgrading land and water harvesting;
- (ii) Farm profitability will rise significantly;
- (iii) Use of allocation water will not change significantly on a per hectare basis;
- (iv) Water harvesting will provide a significant addition to total farm water supplies; and
- (v) Where water harvesting facilities are used, substantial volumes of surface run-off water, previously discharged into surface drains, will be held on-farm for irrigation.

In the short term, farmers will be better off financially but there will be little impact on the total use of allocation water. Other policies will need to be considered if it is found that the

amount of allocation water used must be reduced to relieve pressure on rising water tables.⁸

Future Applications

The SAGWAMS model, and the methodology underlying its development, is already a powerful tool for analysing the potential impacts of water management and environmental policies in irrigation farming areas. However, if research funding became available, this research could be readily extended to encompass a much wider range of resource management issues.

Specific areas identified for further research using the SAGWAMS approach include:

- Generalising SAGWAMS to other irrigation areas.
- Incorporating groundwater components and soil properties in SAGWAMS.
- Investigating the potential responses to quotas/charges on drainage discharge from irrigation farms.
- Investigating the potential responses to quotas/charges on groundwater accessions from irrigation farms.
- Determining the farm-level impacts of alternative irrigation technologies and management practices.
- Further analyses of the economic and environmental impacts of on-farm water storage.
- Scaling up the research to investigate regional socio-economic impacts.

References

- Anderson, J.R. (1976), 'Essential probabilistics in modelling', *Agricultural Systems* 1(3), 219-31.
- CAC (1991), *Development and Adjustment in the Murray-Darling Basin: A Monograph*, Community Advisory Committee, Murray-Darling Basin Ministerial Council, Canberra, June. Ministerial Council, Canberra, June.

⁸ A complimentary study is currently being undertaken by the Centre to assess the impacts on watertable depth and farm performance, of farmers' responses to alternative institutional arrangement. A model, similar to SAGWAMS, is being developed that includes interactions between water applications and watertable depth.

- Crean, J.J. (1991), *Farm Budget Handbook: Winter Irrigation Cropping and Livestock Murray Valley 1991*, Division of Rural and Resource Economics, NSW Agriculture and Fisheries, Yanco.
- Department of Water Resources (1991), *Benerembah Surface Drainage Scheme: Brief Summary and Field Inspection Itinerary*, Technical Services Unit, NSW Department of Water Resources, Leeton, February.
- Dumsday, R.G. and Edwards, G.W. (1990), Recent uncertainty about land degradation policies – economists views, paper presented to the Fifth Australian Soil Conservation Conference, Perth, 21–23 March.
- Grieve, A.M., Dunford, E., Marston, D., Martin, R.E. and Slavich, P. (1986), 'Effects of waterlogging and soil salinity on irrigated agriculture in the Murray Valley: a review', *Australian Journal of Experimental Agriculture* 26, 761–77.
- GHD (1985), *Waterlogging and Land Salinisation in Irrigated Areas of NSW: Volume 1 – The Problems*, Gutteridge, Haskins Davey, Sydney.
- IAC (1987), *Report on the Rice Industry*, Report No. 407/1987, AGPS, Canberra.
- Irrigation Farm Working Group (1986), *The Profitability of Large Area Irrigation Farms in the Murrumbidgee and Murray Valleys of NSW*, Report to the NSW Minister for Agriculture, Lands and Forests, New South Wales Department of Agriculture, December.
- Jones, R. (1991a), Optimal Irrigation Water Allocation and Supply Reliability in the Murrumbidgee Valley, unpublished MEc Thesis, University of New England, Armidale.
- Jones, R. (1991b), The farm level benefits of an annual water transfer scheme in the Murrumbidgee Irrigation Area, paper presented to the 35th Annual Conference of the Australian Agricultural Economics Society, University of New England, Armidale, February.

- Mihram, G.A. (1972), 'Some practical aspects of the verification and validation of simulation models', *Operational research Quarterly* 23(1), 17-29.
- Naylor, T.H. (1971), *Computer Simulation Experiments with Models of Economic Systems*, Wiley, New York.
- Watson, W.D. and Rose, R.N. (1980), Irrigation issues for the eighties: focusing on efficiency and equity in management of agricultural water supplies, paper presented to the 24th Annual Conference of the Australian Agricultural Economics Society, University of Adelaide, Adelaide, February.
- WRC (1986), *An Integrated Survey of Land Use Hydrology and Soils of the Benerembah Irrigation District*, NSW Water Resources Commission, Sydney.
- WRC (1988), *Benerembah Irrigation District: Options for Management of Waterlogging and Salinisation, Working Papers 1988*, NSW Water Resources Commission, Griffith.