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The Market for Irrigation Water

A Modelling Approach

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A model of irrigation farming in the Murrumbidgee Valley is described and applied to three policy issues with output prices held constant. The model was used to explore the potential supply and demand for saleable water allocations within and between Irrigation Areas and Districts with output prices held constant; the effects of higher water prices on farm incomes, tax revenue and income of water supply authorities; and the effects of rising groundwater and salinisation on farm values.

Introduction

Irrigation in the Murray–Darling Basin (MDB) presents the economic problem of balancing the benefits of irrigation against the costs of salting and of rising water tables, as well as of water supply itself, so as to maximise the net benefits from both land and water resources over time. A mathematical programming modelling system has been designed to address this concern, and has been used to explore issues of water pricing and trading of water allocations, including effects on salinity and responses to it.

The approach adopted is to use a system of mathematical programming models to analyse the economic responses of farms in the Irrigation Areas and Districts, and to explore the effects of different policy settings on farm profitability, output mix and water use. This approach is not unique. Mathematical programming models are particularly suited to the study of new situations where past experience will be only a limited guide and major structural changes are being explored. In Australia the economics of irrigation has been explored with programming models by Flynn (1969); Briggs Clark, Menz, Collins and Firth (1986); Bureau of Agricultural Economics (BAE) (1987); Alouze and Fitzpatrick (1988); Chewings and Pascoe (1988); and Jones and Marshall (1990). Overseas, the technique has been used by Griffin (1990) to measure the impacts of urban water demand on irrigators; by Long (1990) to study competition between power generation and irrigation; and by Martin, Cox, Nakamoto and Halloran (1990) who examined the interaction of agricultural support and electricity demand for irrigation pumping. Knapp, Dinat and Nash (1990) carried out a study with a similar focus to the one reported here, examining the trade-offs between salinity control in drainage and farm incomes in Colorado.

Background

Irrigation farming in the Murrumbidgee Valley

The Murrumbidgee Valley is one of the major irrigated areas of the MDB and accounts for half of the irrigated area in New South Wales. The area was chosen for study because it is an important component of Australian irrigation farming and contains both horticultural and broadacre irrigated farming, as well as two types of irrigation organisation: Irrigation Areas and Irrigation Districts (distinguished below). The area began to be developed for irrigation in the early years of this century, and the newest Irrigation Area, Coleambally, was opened in the 1960s. The system has been characterised by water charges which do not cover the full costs of supplying the water for irrigation, and a high degree of control of land use and ownership.

Intensification of farming was achieved largely through the home maintenance area[1] concept, which has been integral to the Irrigation Areas since their inception. Thus, the present structure of the industry is based on subsidisation of a major input together with legal impediments to autonomous adjustment (BAE 1987; Langford-Smith and Rutherford 1965).

Farming in the Murrumbidgee Valley Irrigation Areas and Districts falls into three main types: broadacre in the **Irrigation Areas**, broadacre in the **Irrigation Districts**, and **horticultural** (defined as growing tree crops and vines) in the Irrigation Areas. Other activities include vegetable production and dryland farming. The origins of these categories are partly historical and partly agronomic. Originally the Areas were set up for intensive irrigation, with drainage systems. The Districts were subsequently set up to use surplus and drainage water from the Areas for stock and domestic purposes, to give landholders some protection against drought (BAE 1987). They were not designed with drainage infrastructure because only limited water use was envisaged. Hence the Areas are more intensively cropped, with rice, other crops and irrigated pasture, while the District farms are mainly larger farms with lower intensity of irrigation. Specific parts of the Irrigation Areas were set aside for horticulture, and these were the only areas on which horticultural crops were permitted to be grown.

The situation in the Areas and Districts is now being changed. Land holding rules are being changed by an increase in home maintenance areas and relaxation of restrictions on land use to allow more flexibility for structural adjustment. The centralised control of water supply is being replaced by the introduction of boards of producers who have responsibility for water management and transfer of water allocations between farmers. All these changes can be expected to permit increased economic efficiency.

Irrigation has had a major effect on groundwater tables, which have risen locally because of excess water percolating down from the root zone. Higher water tables have led to increased levels of surface salinity both on- and off-farm (Department of Water Resources 1989a).

Pricing issues

Currently, water allocations are delivered at prices below average cost. Farmers are therefore subsidised and water authorities make a loss. This is the case in Victoria as well as in New South Wales (Verdich and Amos 1984; Department of Water Resources 1990). It has been

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[1] This is the farm size defined in the New South Wales *Crown Land Consolidation Act 1913* as 'an area which, when used for the purpose for which it is reasonably fitted, would be sufficient for the maintenance in average season and circumstances of an average family' (Woodlands and Penman 1981).

estimated that water prices would have to approximately double to cover costs of operation and maintenance of the system.

In neither state has it been proposed that water prices should be set to recover the costs of the main storage dams. In this study, accordingly, the latter are regarded as sunk costs. It is possible that at current prices and interest rates they would not all have been constructed, but at the time of construction the cost was considered justified by the social and development benefits expected from the irrigation system (Langford-Smith and Rutherford 1965).

The loss to the irrigation authority and subsidy to farmers from supply of water at below its cost are illustrated in Figure 1. *AQ* represents the quantity of water demanded by farmers at different prices, and *ES* represents the authority's supply costs per unit. (For simplicity, the average cost is here assumed constant, in which case it equals the marginal cost.) The current water price is *B*, and the price at which the authority would cover all its costs is *E*. The triangle *ACB* represents the farmers' surplus, and BCQ_1O is the current revenue of the water authority. The authority's loss is *EGCB*. Changing the price to *E* would give a new distribution, with farmers' surplus now *AFE* and the authority's water revenue EFQ_2O. In the present situation there is a 'deadweight' loss to society, represented by the area *FGC*, caused by farmers using more water than they would do if they paid the marginal cost of supply.

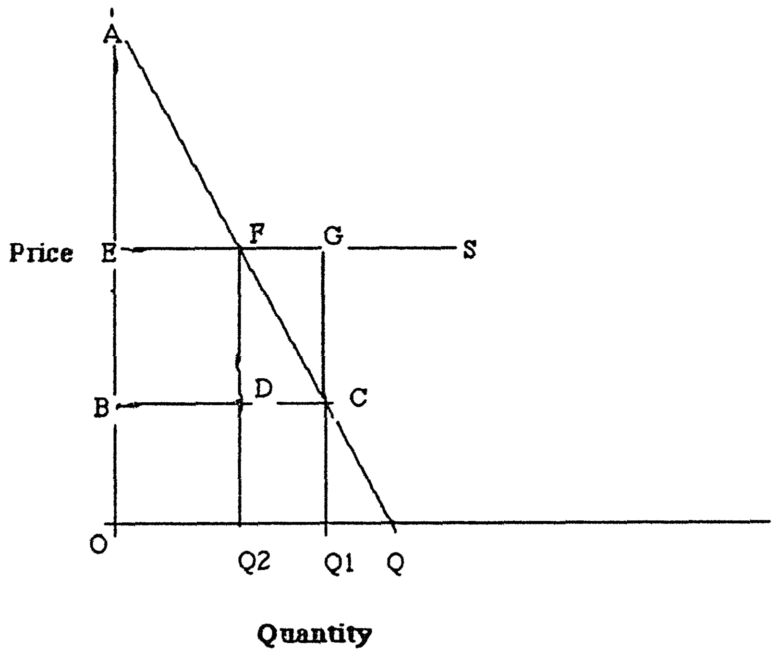

FIGURE 1 – *Water pricing*

In reality, the marginal and average costs of water are unlikely to be the same. Water supply costs are considered further below, but at first sight it appears probable that increasing water supplies come at increasing unit cost, whereas the marginal saving from reducing water use would be small, at least in the medium term, because the delivery systems are already in place. That is, in relation to reductions in use of water, the supply curve is likely to be almost flat like *ES* in Figure 1. To the extent that average cost differs from marginal cost, the use of average cost pricing (as considered in Verdich and Amos 1984) would introduce a further deadweight loss due to allocative inefficiency, because farmers will make optimal decisions on water use from the societal standpoint only if they pay the marginal cost of water. Howitt and Vaux (1990), in a simulation of Californian irrigation, have shown that water systems using average and marginal cost pricing differ greatly in the quantities of water traded and in their economic efficiency.

The extent of the deadweight losses resulting from undercharging and average cost pricing depends on the slopes of the supply curve (the marginal cost of supplying water) and the demand curve for water. Estimates of the elasticity of demand for water by irrigators suggest that it is not elastic in the Murrumbidgee region at current prices (Briggs Clark et al. 1986; BAE 1987). This is confirmed by later analysis in this paper. If this is the case, the change in water use following a change in price may be quite small, so the deadweight losses will also probably be small. There will be a transfer from the authority to farmers, but with little net loss to society. However, the form of pricing used in New South Wales is neither average cost nor marginal cost. The system involves a higher priced basic allocation of water, with excess water charged at a lower price. This will clearly encourage extra water use, and appears contrary to allocative efficiency.

It is probable that any subsidy conferred by low water prices will be capitalised into land values. If so, any increase in water price may impose a capital loss on farmers, and may also affect the security of any loans that are secured by land. Because the levels of debt in the rice industry are relatively high (ABARE 1990, pp. 9–11, 21), the latter point may be of some importance to the industry.

The cost function facing the supplying authority is currently unknown. It would be expected that costs would increase if more water were supplied than at present, because capital investment would be required – for example, new storages, or lining of channels to reduce leakage. Reducing the amounts of water supplied would not be expected to save much in the short to medium term, as the capital works required for the current level of supply would remain in place and in use. However, the Department of Water Resources (1989b) has reported that 'with substantial increases in rice production between 1968 and 1979 and the concomitant need for more water many channels are now operated at well above their original design capacities, ... causing scour erosion and downstream siltation'. (Total water use in the Murrumbidgee Valley increased from 300 000 ML in 1968 to 1 500 000 ML in 1988.) In these circumstances reductions in water use could lead to cost savings. In the longer term, reduced water use could be expected to lower variable costs as infrastructure is replaced. However, because water supply employs a spatial network, it can be expected that the cost savings from entirely closing discrete areas would differ from the savings from delivering less water to all farms. The actual costs of various levels of water supply could be obtained only by detailed technical assessment of the options facing the authority.

On-farm costs of salinity

Salinity is a major issue in the economics of irrigation. In the Murray–Darling Basin it has two aspects. The first is the surface effects of rising ground water, which has two main causes: clearing of trees over a long period, which affects the water table over wide areas, and 'mounding' of excess irrigation water under irrigated areas, which is more localised. Of these, it is the local raising of the water table which has the more serious consequences for irrigated farming and is discussed in this paper. The second aspect is the external cost of saline drainage water to other water users – both other farmers and urban users.

Within Irrigation Areas, water applied to crops has several destinations. Besides being taken up by plants as intended, water is lost by evaporation from the soil surface, through drainage and by deep percolation into the subsoil. It is necessary for some water to pass through the soil profile to wash out salts. If the net movement of water is upward, salt from below will be deposited when the water evaporates. Hansen, Israelson and Stringham (1984) suggest that up to 30 per cent of water applied needs to penetrate below the root zone to prevent long term salt build-up in the soil.

In the Murrumbidgee Valley the groundwater tables were originally very deep. For example, in Benerembah Irrigation District in 1956 the groundwater level was 27 m deep, but had risen to an average of 10 m in 1983 because of additions from irrigation water applied and lost into the subsoil (Department of Water Resources 1990).

The consequence of rising groundwater in itself is that eventually the rooting depth is restricted; and where the groundwater is saline, plant growth is affected by the salt. In addition, waterlogging can be a problem where water tables are high. Salt and waterlogging together can reduce yields by 30–40 per cent (Jones and Marshall 1990) and eventually salt pans can be formed on which no production is possible. The degree of these effects depends on the individual site and in particular on the structure of the underground aquifers. Some well drained sites will remain productive when other sites are completely useless. Investment in surface or underground drainage or pumping from the watertable can reduce the costs of rising groundwater, but only at the cost of adding more salt water to the drainage system and increasing the external costs of salting.

External costs of salinity

The external costs of salting come from saline drainage from irrigation farms, and also from channel leakage. The downstream irrigation areas such as the Riverland are affected by the drainage of up-river areas such as the MIA. Irrigation water passes down through the soil on the way to the drainage and so picks up soluble salts. The effect is enhanced if the soil is already saline, or if the local groundwater table is high enough to slow down the drainage and the groundwater is also saline. In any case, some increase in water salt content will occur as irrigation water passes through into drainage.

Salt in water affects crop growth, although some crops are more susceptible than others to high levels of salts. The impact of salt on down-river irrigation was estimated by Peck, Thomas and Williamson (1983) as $4 million for the Riverland on the basis of reduced yields alone. Quiggin (1985), using an approach which took account of reduced capacity to grow salt-sensitive crops, made a much higher estimate of about $20 million for all irrigation areas on the Murray and Murrumbidgee. This was equivalent to a cost of $18/ML above the delivery charge (then $7/ML). Apart from the costs to other irrigators, excessive salt in the water imposes costs on urban and industrial users through damage to machinery and boilers and unpleasant water flavour. These effects can be reduced only by the costly mixing in of higher quality water supplies or by processing the water to reduce its salinity. Quiggin's estimates suggested that, taking account of these costs, the total cost of salinity came to about $25 million.

Alouze and Fitzpatrick (1988) worked with an integer programming model to assess the benefits of various salt control schemes. Based on their work, it can be estimated that the net benefits of schemes designed to produce a 78 EC (about 50 per cent) drop in salinity in the Murray–Darling Basin would be about $14 million each year, and the gross benefits $31 million each year. The Murray–Darling Basin Ministerial Council (1987) estimated losses of $39 million a year from salinity and waterlogging in irrigation areas. This estimate includes the costs of the internal losses in areas originating salt as well as the external costs. Young, Cocks and Humphries (1990) have estimated that the cost of lost production through all salting in the Murray–Darling Basin is $65 million each year, with an additional downstream cost to urban industrial and agricultural water users of $37 million which by 2015 is expected to rise to $57 million in real terms.

Description of the Model

The general principle on which this model system is based is to represent irrigated agriculture in the Murrumbidgee Valley by a set of mathematical programming models, in which the present value of a future consumption stream is maximised by choices among possible cropping, management, investment and financial 'activities'. The modelling system is based around a single matrix implemented in the WINGZ spreadsheet system. Individual representative farms are produced from this matrix using different 'right hand sides', which represent resource endowments of individual farms.

Sources

The data sources from which the matrix is being developed include publications, personal communications and unpublished material from ABARE and elsewhere. The main published source for technical coefficients is the series of Farm Budget Handbooks published by the New South Wales Department of Agriculture and Fisheries (Jones 1989a,b; Jones and Young 1988). Other important sources of information are previous ABARE work (Briggs Clark et al. 1986; BAE 1987), and unpublished documentation of the ABARE's Regional Irrigated Agriculture Model.

Model building

The WINGZ spreadsheet from which the operating matrices are derived is in five parts. In the first part, the raw technical information from Farm Budget Handbooks and other sources is recorded in the form in which it was obtained. In the second, these data are combined and manipulated to give resource requirements for each individual activity, and for a series of rotation packages representing combinations of individual activities. The resource constraints are derived from a third part of the spreadsheet in which farm survey data from ABARE's industry surveys are recorded. Input prices are recorded in a fourth section of the spreadsheet. Finally, the linear programming (LP) matrix itself is built up from the rotation packages, individual activities, capital and trading activities and resource constraints.

The advantage of using spreadsheets in this way is that any changes to technical coefficients or to the structure of rotations will automatically flow through to the LP matrix, as will any change in prices. In a similar way the information from the Farm Budget Handbooks can be modified in the light of technical progress and farm practice as and when new data become available. This is facilitated by the fact that the information in that part of the spreadsheet is recorded in basically the form in which it is provided in the Handbooks.

A system of programs in FORTRAN has been developed to take the LP matrix on the spreadsheet and convert it into the standard format in which it can be optimised by mathematical programming systems. The system used to optimise these models is MINOS (Murtagh and Saunders 1980), which permits linear, nonlinear and integer programming within a single framework. All the modelling is being done on Apple Macintosh computers.

Representative farms

Representing a population of farms by mathematical programming models involves a degree of aggregation (unless all the farms are modelled individually, which is seldom practicable). In this region the population exceeds 2000 farms. The errors which can be caused by aggregation in modelling have been extensively discussed. Initial work by Day (1963) established rules for the effective elimination of aggregation bias, but as Buckwell and Hazell (1972) pointed out these are so restrictive as to be of limited applicability. These authors suggested that greater levels of aggregation would be associated with an upward bias in optimal output. However, an exploration of aggregation error by Hall (1977) showed that the direction of error could be either output increasing or decreasing, and that aggregation error could be small over a wide range of levels of aggregation provided that the model's specifications were appropriate.

On this basis it was decided that the best compromise between model complexity and excessive aggregation was to have five representative farms, each representing a discrete area or farm type: namely, the Irrigation Areas of Yanco, Mirrool and Coleambally, the Irrigation District of Benerembah, and the horticultural farms. The structure of the model would allow other representative farms to be created for particular needs Other options for model aggregation would have been a single farm, which would have been too aggregated, or the modelling of all the 30 farms in the survey sample, which would have been too complex a task.

Agronomic specifications

Soil types are of major importance to this region because of the very different agronomic requirements of rice and horticultural crops. Horticultural and tree crops generally require freely drained soils, whereas rice requires shallow soils with an an impervious layer which can be kept continually wet. These soil types are represented in the models, which also distinguish laser levelled soils from other soils. Data on use of laser levelling are taken from Young (1989), which is based on a joint survey by ABARE and the New South Wales Department of Agriculture and Fisheries.

The growing of crops in rotations is of considerable agronomic importance. It can be represented in a mathematical programming model by developing representations of individual activities and tying them together using constraint rows. A more sophisticated approach by El-Nazer and McCarl (1986) involves estimating the impact of different crop combinations on yields, but this was rejected because of data limitations. A third approach, used here, is to combine the individual activities into rotation packages (Heady and Candler 1958). For example, a typical activity package of the matrix is a combination of two years of rice, no wheat and three years of pasture. The necessary calculation of resource requirements for each package is easily done in the spreadsheet framework.

The rotations are based on combinations of pasture and cropping. In this simplified development the crops represented are sod-sown rice (which is often used as the first rice crop because it is high yielding), aerial sown rice, winter wheat (representing all cereals) and winter pasture. Rice is commonly grown for up to two years, but three years is relatively rare and is not an option included in this model specification. Cereals may be grown for up to two years. Pasture, which has a regenerative effect on the soil, is grown as an integral part of the cropping system.

The level of water use can also be varied in the model. It is assumed that the response of crop yield to water use is linear between the dryland yield and that yield achieved at the normal level of water use given in the Farm Budget Handbook. A set of low water-use activities was developed by interpolating water use at half the normal level. It was here assumed that rice could not be grown at any but the normal water use because of the practice of keeping fields flooded during the growing season.

In addition to the crop rotations – various possible rotations for irrigated land, and one dryland crop rotation – farms can also be modelled as growing dryland pasture and irrigated summer pasture outside a rotation. There are two livestock activities represented, which use the fodder from the pasture: the production of prime lambs from a self contained flock, and the production of vealers.

Four horticultural activities are provided – two citrus activities (namely, with and without drip irrigation) and two grape activities (with and without drip irrigation). Further development of this part of the model will need to take explicit account of the time dimension in tree cropping.

The constraint rows of the model include capital use, cash costs, water activities and the water allocation, seasonal labour use activities, machinery use and harvesting activities. There are also constraint rows for the four types of land, for the dryland rotation on each soil type, for areas of irrigated land on each soil type and for the feed activities (in which four seasons are distinguished). In addition, there are a number of accounting rows which provide information about production and areas of crops. There are also a series of constraints and activities which allow for income tax and the consumption/investment decision.

Objective function

The structure of the objective function is designed to maximise the present value of an infinite stream of after-tax consumption – that is, the capital value of the farm, less the net debt position. Farm income and off-farm income (from investments and off-farm work) together with cash costs generate net pre-tax income. This income is then fed through a submatrix which simulates the progressive income tax system. The after-tax income is then split between consumption and investment. The annual consumption return is fed to the objective function through an activity which compounds it by the real rate of interest to obtain the capitalised value of an infinite stream of consumption expenditure at that rate.

The other financial activities in the model are borrowing and investment activities, land transactions and the purchase of capital equipment.

Depreciation of plant and machinery is charged on the basis of the survey data. The estimates represent the rate of depreciation on a current cost basis – a higher rate than that actually allowed for tax purposes, which is on an historic cost basis. Adjustments are made to the pre- and post-tax income rows to compensate for this difference. On the basis of the survey data, the taxation rate of depreciation is set at 60 per cent of the current cost rate.

Borrowing is in the form of an annual overdraft which adds to opening cash for investment and to cash costs of interest, and is a cost in the objective function. Interest is charged at the real interest rate as a cash cost, but the inflation component is added back into costs before taxation is calculated to account for the effect of actual payments on taxation rates. The after-tax income is correspondingly adjusted to return to a real interest rate basis.

There are activities for buying general-purpose machinery (defined as a package of tractors and associated equipment) and for buying harvesting equipment. Other investment options include laser levelling of land and conversion to drip irrigation for tree crops and vines. The return from capital purchases is in increased future income flows, which are capitalised in the objective function. Thus capital spending is compared with the capitalised value of the benefits from the investment.

Modelling the effects of salinity

The principle used in modelling the effects of salinity is to treat the proportion of farm area which is saline as a function of the amount of groundwater supplied in past periods.

Each activity which uses water also supplies water to a soil water pool which receives the net additions of water to the subsoil from each activity in each year. Some activities such as lucerne, trees or pumping and draining activities may draw from this pool. Water enters the soil from the top through irrigation, and from below if the regional groundwater is rising independently of irrigation; it is lost through evaporation and drainage. The saline water reaches the surface (or near surface) sooner in some areas than in others. Net additions increase the area which is saline, .ccording to the hydrologic nature of the region.

The saline areas have a set of soil types and rotations corresponding to those of the non-saline areas but with lower yields. Each year the sum of the soil water pool from the previous year and the current year's additions is used to apportion soils between saline and non-saline. Thus, optimisation takes account of the past and current water use on the farm. The model does not optimise salinity over time, but responds to the current situation as a farmer would. This allows the testing of the consequences of various policies.

Insufficient data are presently available to confidently calibrate the model for all regions. The estimates used in this paper will be refined in the course of further development.

Analysis

Three areas are explored in this paper: the market for water allocations; the effects of changing water prices; and the impact of the freedom to trade water allocations on the costs of salinity. The system of models described above is still under development, so the main focus of this analysis is on exploration of the capacity of the models to contribute to analysis of these issues. The emphasis is thus on the implications of the direction of model response and on its general consistency with theoretical and practical knowledge of the irrigation industry.

The market for water allocations

The first set of experiments is intended to explore the market for water allocation and the effects of different levels of water prices on allocation values and farm incomes. Water price is defined as the charges paid by irrigators per unit of water. Allocation price is in the nature of a capital value: it is the sum paid for a permanent right to buy water at a specified water price. For each representative farm a set of single-year experiments was carried out using varying water prices and allocation prices according to a central composite design (Hall, Fraser and Purtill 1988). The prices used are presented in Table 1, and the results for allocation sales in Table 3.

The base level (code 1) was based on marginal (that is, second-tier) water prices in 1988-89. These prices do not meet all the costs of supplying water (Department of Water Resources 1989a), and in fact are below those charged in earlier years in real terms. Verdich and Amos (1984) presented a framework for estimating the costs of water delivered to farms in the

TABLE 1

Water and Allocation Prices Used

	Water price			
Price code	Yanco, Mirrool Horticulture	Benerembah	Coleambally	Allocation price
	$/ML	$/ML	$/ML	$/ML
1	10.0	6.0	7.0	20.0
2	11.5	6.9	8.0	31.0
3	15.0	9.0	10.5	60.0
4	18.5	11.1	13,0	89.0
5	20.0	12.0	14.0	100.0

Murrumbidgee Valley. Table 2 is based on their work, using updated cost estimates which take account of the changed basis of costing recommended by consultants (Department of Water Resources 1989b). On the basis of the approximate calculation in the table, water charges in the Irrigation Areas and Districts would have had to almost double to meet the level of costs for supply and distribution of irrigation water. There may be scope for savings from more economical operation under the new system of local management, but there appears to be a possibility of a very large increase in water prices if full cost pricing were adopted.

In this paper, the intention is not to recommend the appropriate levels of water prices to farmers, but rather to explore the effects of a range of possible prices. The expectation is that prices will rise over time, and hence current prices are used as the lowest level. A price which would cover delivery and supply cost (code 5, in Table 1) is used as a theoretical benchmark. Prices are set as follows. The water prices shown in Table 1 are assumed to comprise a supply price of $2.05/ML and a distribution price. For each price code, the distribution prices to all regions are increased in the same proportion. For simplicity in modelling, a flat rate for all water is used rather than the two-tier pricing currently in use for all water prices except code 1.

In Table 3, it can be seen that the effect of increasing the price of water allocation is to increase the amount of allocation that the representative farms are willing to sell at a given water price. A rise in the water price reduces the value of saleable allocation to the farmer and hence increases the quantity that the farmer is willing to sell at any given allocation price. The negative values indicate purchases of water allocation, which occur at lower water and allocation prices. (The purchasers or sellers, respectively, can be thought of as users other than the irrigation farms specifically modelled.)

TABLE 2

Costing of Rural Water Use 1988-89

Water user group	Cost category	Expenditure	Revenue	Shortfall	Current price	Full-cost price
		$m	$m	$m	$/ML	$/ML
Licensed pumpers	Supply	6.2	6.2	–	2.1	2.1
	Distribution	–	–	–	–	–
Areas and Districts	Supply	5.0	–	5.0	–	–
	Distribution	37.0	21.5	15.5	–	–
	Total	42.0	21.5	20.5	11.7	22.7
Town and industry	Supply	0.6	–	0.6	–	–
Total		48.8	27.7	21.1	–	–

TABLE 3

Sales of Water Allocation by Representative Farms

Run	Water price	Allocation price	Allocation sales (per farm)				
			Yanco	Mirrool	Benerembah	Coleambally	Horticulture
	$/ML	$/ML	ML	ML	ML	ML	ML
1	1	3	253	–168	–238	44	121
2	2	2	65	–396	–266	22	79
3	2	4	619	891	406	528	198
4	3	1	65	–396	–266	527	79
5	3	3	472	326	15	528	121
6	3	5	900	963	527	552	198
7	4	2	252	–168	–266	22	121
8	4	4	900	963	552	528	198
9	5	3	619	891	224	342	198

In Figure 2, the allocation price at which sales of allocation are zero is the equilibrium price in a situation where water allocation cannot be transferred across regional boundaries, and the prices of water itself are at the base levels. The equilibrium price ranges from about $35/ML in Yanco up to $65/ML in Benerembah. The horticultural farms have an excess of water for sale even at the lowest allocation price of $20/ML, apparently because the allocation exceeds the needs of the crops they can grow.

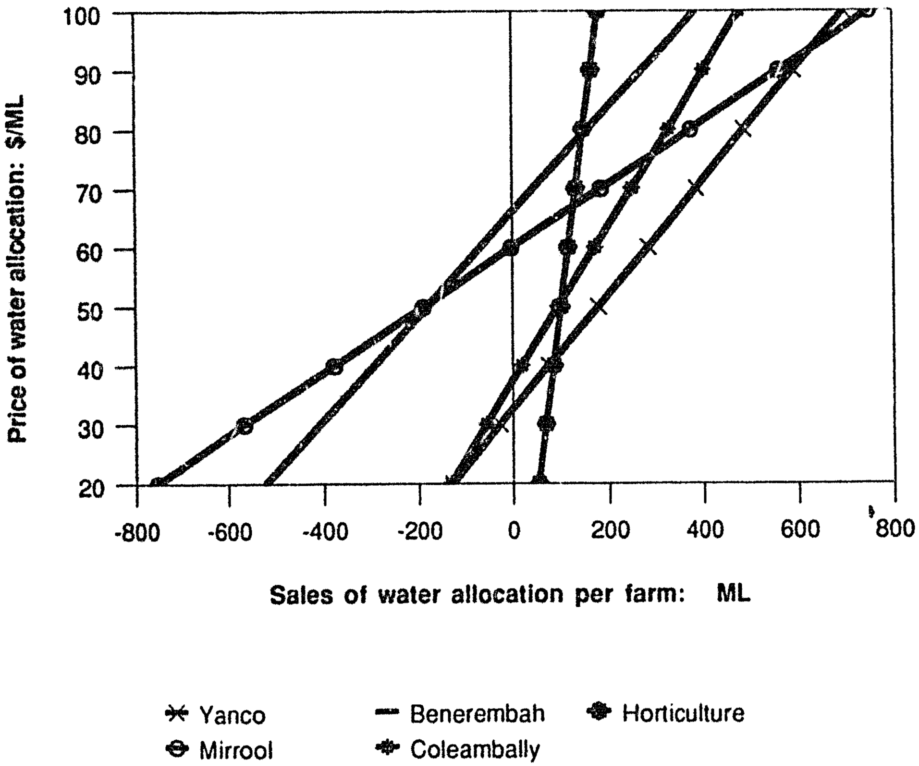

FIGURE 2 – *Allocation sales by representative farms*

The prices at which water allocations would trade would be different from the no-trade equilibrium if allocation could be transferred between regions and farm types and to or from the irrigation area as a whole. (Non-irrigation users could place a value on water either for industrial purposes, to ensure stream flow and thus control salinity, or for urban use.) Figure 3 shows the allocation sales at two water prices taking all five groups of farms together. At the current water prices, the equilibrium allocation price at which no water allocation would be sold for the whole system would be about $40/ML. At the much higher water prices which would cover the costs of supply and distribution of water, the equilibrium price would be below $20/ML. Non-irrigation uses could have a high marginal value and could raise the price of allocations above the equilibrium level, in which case there would be a net sale of water allocation from the Murrumbidgee Valley.

Effect of water prices on farm incomes

The level of water pricing affects farm incomes. A set of experiments was carried out to estimate this effect by running the models recursively for ten years with different water supply prices. Water allocations could not be traded. The effect on incomes was calculated as the present value of the ten years stream of (after tax) consumption expenditure, less initial debts, plus the present value of terminal net worth. Terminal net worth is the value of the objective

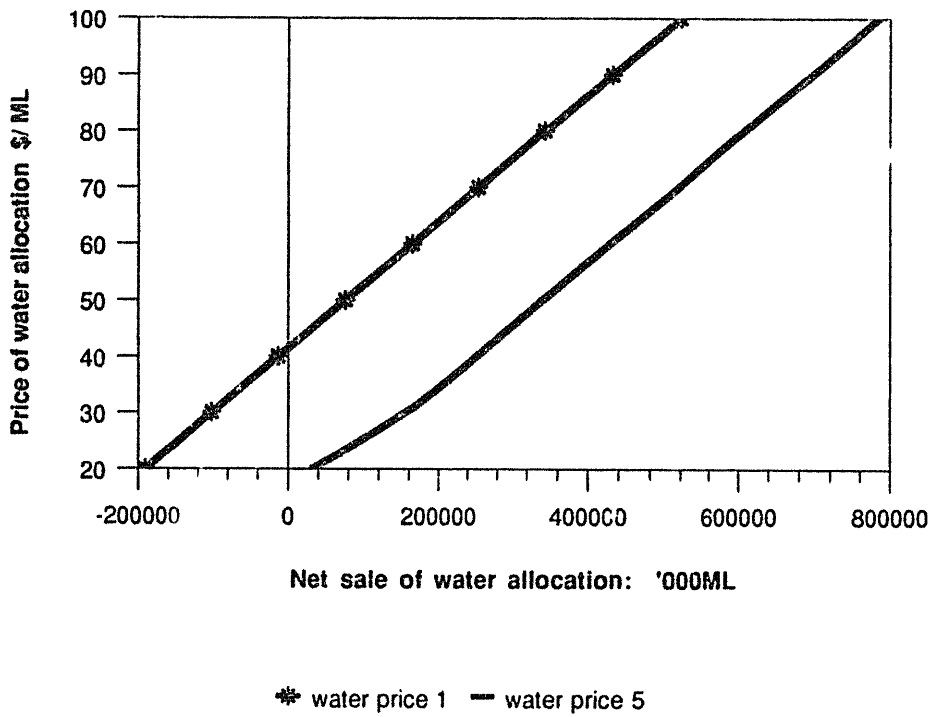

FIGURE 3 - *Total allocation sales - Murrumbidgee*

row, that is, the present value of an infinite future stream of consumption expenditure less net indebtedness in year ten.

Each model was run for ten years. The annual income equivalent of the net present value is tabulated in Table 4, with the average water use as an indication of adjustment.

The charging of full costs of water supply and delivery would have a significant effect on farmers. In the model, their consumable incomes fall by an average of ten per cent. Water use falls by three per cent. The effect of the changes is much greater on the non-horticultural farms than on the horticultural, because horticultural farms have a very high water allocation in relation to their needs and the cost of water is less in relation to their returns than on the broadacre farms.

Following a change to full cost recovery in water prices. it is estimated (Table 5) that $9m would be transferred to the supply authority and $4m would be transferred from the farmers consumption expenditure.

TABLE 4

Effects of Water Prices on Farms

Area /type	At current water prices			At full-cost prices		
	Consumption(a)	Tax	Water use	Consumption	Tax	Water use
	$/farm	$/farm	ML/farm	$/farm	$/farm	ML/farm
Yanco	25 167	14 333	1 560	19 708	7 481	1 495
Mirrool	22 893	10 770	1 560	17 419	5 111	1 560
Benerembah	22 866	9 906	1 759	18 264	5 334	1 759
Coleambally	25 622	14 640	1 538	21 625	9 094	1 538
Horticulture	29 260	22 442	146	28 473	21 602	104
	$m	$m	GL	$m	$m	GL
Valley totals	36.30	22.35	1.18	32.50	19.38	1.14

(a) After-tax consumption expenditure.

TABLE 5

Effects of Water Prices on Revenue to Water Authority and Farmers

Revenue	Current water prices	Full cost prices	Difference
	$m	$m	$m
Water charges	10.4	19.1	8.7
Farm consumption	36.3	32.5	3.8

Salinity and allocation trading

A major focus for future analysis using this model is the salting of land because of rising water tables. The analysis in this section focuses on the Benerembah Irrigation District, where this problem is particularly severe. The Department of Water Resources estimates that if no action is taken the whole of the Benerembah District will have high water tables and associated salting within 30 years. The model simulates, in a simplified way which will be refined in future developments, the effects of excess irrigation water reaching the water table and the consequent effects on yield. Four scenarios were modelled at current water prices, using ten-year recursive runs of the Benerembah representative farm model. The model was run with and without trading in allocations, and with and without the salinity effects of water supply. The price of water allocation is here set close to the equilibrium for all five groups of farms taken together. The trading provides additional income which makes a difference to the final outcomes. In Table 6, the net present values for each simulation are presented.

TABLE 6

Effects of Salinity and Trading in Water Allocations on Net Present Values – Benerembah District

Allocation trading	Salinity effect	Net present value
		$ '000 /farm
No	No	247
	Yes	226
Yes	No	267
	Yes	245

The loss of net present value because of salinity is 8.5 per cent when there is no allocation trading and 8.2 per cent when trading is allowed. These losses are those attributable to increases in salinity above the present level caused by rising groundwater levels due to excess irrigation water.

The current version of this model does not include any drainage activities. The only strategies incorporated for controlling high water tables and salting are reducing water use (particularly for rice), changing cropping or adoption of laser levelling to reduce waterlogging.

Policy Implications

The results presented indicate that farms would have an incentive to trade in allocations of water if trading were permitted between Irrigation Areas and Districts. Transfers between areas are dependent on the capacity of the infrastructure to physically supply the purchased water. Limitations of supply capacity are not currently included in the model specification.

A further consideration concerning a market for allocations of water is the possibility of outside buyers entering the market. The value of water may be less in irrigation use than in urban use (Griffin 1990) or industrial use (Long 1990). Moreover, the costs of salinity are heavily borne by Adelaide consumers and industrialists and by downstream irrigators. It is a distinct possibility that water could be bid away from these upstream irrigation areas either by cities or downstream irrigators or for environmental or recreational purposes. This would internalise one of the major externalities of the irrigation system – a major advantage, additional to the value to farmers of 'uncoupling' the land / water package.

Randall (1981) classified the cost of water into three categories, namely: the opportunity cost, the social cost and the resource cost. The transfer of allocations would allow both the opportunity cost and the social cost of water to be expressed at a farm level.

The third class of costs, the resource cost, is the cost of supplying water. In the past, water charges have not met this cost, with a consequent implicit subsidy to farmers from taxpayers. The results give an indication of the broad extent of this transfer, and of the impact of a much higher price on farmers' incomes. The model results indicate that a doubling of water charges would reduce farm incomes by 10 per cent, with a corresponding fall in capital values. In addition, the higher water charges would greatly increase the supply of water allocation for sale at any given allocation price.

The models are designed to represent, and respond to, the effects of waterlogging and salinisation accompanied by rising groundwater levels. Further work is planned to develop these aspects of the models. The preliminary analysis indicates the effects of on-farm salting on output patterns in the Benerembah District, and shows that farmers are able to make some adjustment to ameliorate salting even in the absence of drainage opportunities.

Further Development

In its current state the model is well suited to the analysis of on-farm issues. More disaggregated versions are easily made by creating new 'right hand side' resource endowments, from farm survey data or other sources, by means of the spreadsheet system. The model has some ability to represent technical change, by substituting activities with different resource requirements and by altering the soil endowment to saline soil as the groundwater accession increases. These features need to be maintained, although further validation and development work would be valuable on these technical aspects of the model.

A major current limitation of the model is its linear specification. This may be a limitation on more exact modelling of some technical changes, in particular the relationships between salinity and the rise of water tables, which may well be nonlinear. Nonlinear relationships will also be important where simulation of markets is attempted. The demand for water from downstream users is not likely to be linear, because the adverse effects are unlikely to be linear with salt content. The MINOS solution system being used can handle nonlinear relationships, and will be used to increase the power of the models to simulate the real situation.

A second major direction of development is to move from a 'representative farm' system to one which allows separate farms to be linked by trading rows into a regional matrix. This approach will initially be aimed at producing a Murrumbidgee Valley model. This model should encompass not only farms but also the water supply system and a representation of the regional hydrology. Longer term developments could encompass other irrigation regions and links between them to create a model of all irrigation farming and water use in the Murray–Darling Basin.

An extended regional model with nonlinear water markets could be used to analyse the trade-offs between regional farm incomes and incomes elsewhere, in the manner discussed by Quiggin (1985) but with a more elaborate model of the system components. Such analysis would be a significant contribution to the management of the Murray–Darling Basin.

Conclusion

This paper describes a mathematical programming approach to the modelling of irrigation farming in the Murrumbidgee Valley, and presents the results of simulations involving trading in water allocations, changes in the price at which irrigation water is sold to farmers, and the economic effects of salinity. The model appears a reasonable representation of reality in that its behaviour is in keeping with economic logic and experience.

One conclusion which can be drawn from the analysis relating to trading in water allocations is that trading would be advantageous to farmers, although this conclusion has to be qualified by the limitation that the model represents on-farm situations only and takes no account of the costs of any changes in the capacity of the supply system required to make such trading possible. It was also confirmed that the quantity of allocations traded depended on both the price of allocations and the price of water. At higher water prices more allocation would be sold, at any given allocation price, than at current water prices.

Simulations were also carried out of the effect of raising water prices to a level which might approximate that which would cover supply and distribution costs (almost double the current charges). The change was accompanied by a fall in farm incomes, but there was little change in water use, and so little change in economic efficiency, in the absence of an external market for water allocations. The finding that the price of water had a large influence on the value of allocations, however, indicated that, if increased water prices were accompanied by an external demand for water, changes in water use and cropping patterns could ensue.

The modelling of salinity relationships needs further development before strong conclusions can be drawn from the analysis. It is reasonable to suppose that salinity influences farm incomes and cropping patterns and would influence the availability of allocations for sale.

This model has been shown to be a useful tool for the analysis of water management issues and its capacity will be increased by further developments which are planned to be built incrementally into the existing modelling framework.

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