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DEMAND FOR WATER IN THE MURRAY VALLEY, NEW SOUTH WALES: AN APPLICATION OF LINEAR PROGRAMMING

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The move to decentralise and develop the inner areas of New South Wales in the first half of the century resulted in the development of several irrigation regions along the Murrumbidgee and Murray Rivers. Water was supplied to these regions at a low price, resulting in overuse of water and consequently environmental degradation.

The increasing emphasis on the user-pays principle in the 1980s and an increase in concern as to the environmental damage in the region has resulted in a review of attitudes by the water supplying authorities. The provision of subsidised water is no longer considered desirable and proposals have been put forward to increase the price of water.

In this paper, the results of a study to estimate the responsiveness of water demand to price in the Murray Valley are presented. The results indicate that a policy of cost recovery may result in a short term economic loss to the region, depending on the regime of prevailing commodity prices.

The push to decentralise and develop the inner regions of New South Wales during the first half of the century resulted in the establishment of several Irrigation Areas in the Murrumbidgee and Murray Valleys. These Areas were subdivided into small farms and provided with water supply works and drainage, along with an abundant supply of water. The size of the farms were restricted to what was considered a 'home maintenance area', an area large enough to support a family. Restrictions on ownership were also introduced to prevent large corporations buying out the land and displacing the settlements that were an integral part of the decentralisation plan.

Associated with the Irrigation Areas in the Murrumbidgee and the Murray Valleys are a group of Irrigation Districts, principally established to provide water for stock and domestic use to reduce the impact of drought in the region. These Irrigation Districts were provided with water supply systems, with much of the water in the Murrumbidgee Valley being drainage water from the Irrigation Areas. Unlike the Irrigation Areas, the Irrigation Districts were not provided with drainage works, a factor that contributed to increasing salinity in subsequent years.

In the past, as the marginal cost per megalitre to the farmer declined under the block pricing scheme, irrigators have been encouraged to use larger volumes of water. This use of water by irrigators (which is rational, given the existing charges and regulations) entails the choice of water-intensive enterprises, resulting in greater use of water than is economically desirable (Bureau of Agricultural Economics 1987).

As a consequence of this overirrigation on 'leaky' soils, the region is now experiencing environmental problems such as increased salinity and waterlogging of soils. These problems may threaten the future viability of agricultural production in the region. Further, the increased salinity of the tail water which feeds back into the Murray River may threaten productivity of irrigated agriculture further down river, as well as substantially reducing the quality of Adelaide's water supply.

In the 1980s, the attitudes towards subsidising agriculture have changed, with an increased emphasis of the 'user pays' doctrine. As a consequence, attention has been focused on the relative cheapness of water that is supplied to the Irrigation Areas and Districts (see, for example, New South Wales Water Resource Commission 1986). This can be seen as a move both to improve the economic efficiency of water use and to further reduce environmental degradation and minimise the externalities to other water users down river.

In this paper, the demand for water in the Murray Valley is investigated through the use of the Regional Irrigated Agriculture Model (RIAM), following a similar study on the demand for water in the Murrumbidgee Valley used in the Bureau of Agricultural Economics (1987) submission to the Industries Assistance Commission long term rice enquiry. The study also examines the effects of variations in the price of water on returns to producers in the regions and the implications of increased water charges for the continuing economic viability of irrigation in the region. The issue of what price should be charged is not addressed in this study.

Previous Water Demand Modelling

Although there has been research concerning the physical characteristics of the Murray Valley such as soil composition, little has been documented about water use in the region. Considerable work, however, has been

undertaken in modelling water use in the Murrumbidgee Valley. Ryan (1969) and Flinn (1976) both used a linear programming model to determine the effects of water allocation and pricing on a representative farm. Briggs-Clark, Menz, Collins and Firth (1986) used a regional linear programming model to estimate the short term demand for irrigation water in the Murrumbidgee Irrigation Area and the Coleambally Irrigation Area. However, this work neglected the subregional differences caused by different soil types and water availability, as well as neglecting the demand for water by the Irrigation Districts in the region.

Preliminary results of the Regional Irrigated Agriculture Model (RIAM), reported in the Bureau's submission to the Industries Assistance Commission inquiry, indicated that the sensitivity of water demand to price varied considerably between Irrigation Areas and Districts. A main feature of the model was the disaggregation of the Murrumbidgee Irrigation Area into two separate Irrigation Areas - Yanco and Mirrool, the inclusion of the three Irrigation Districts and the inclusion of subregional differences, basically the soil type composition of the regions. A series of demand functions for irrigation water were then derived to estimate the effect of different pricing levels on water use in the various subregions, and the own-price elasticities of demand for water were estimated. As the model was based at the regional level, however, the influence of factors such as farm size and home maintenance areas could not be incorporated into the estimation of the demand for water.

This study concentrates on extending the RIAM model to include irrigated agriculture in the Murray Valley.

Description of the Study Region

There has been irrigated agriculture in the Murray Valley since 1880 (New South Wales Water Resources Commission 1984). As in the neighbouring Murrumbidgee Valley, the predominant irrigation crop grown in the Murray Valley is rice. Unlike the Murrumbidgee Valley, however, the Murray Valley has only one Irrigation Area, Tullakool, occupying less than 1 per cent of the total irrigated area. The remainder of the region consists of five Irrigation Districts - Berriquin, Denimein, Deniboota and Wakool (Figure 1). The implications of the region having mostly Irrigation Districts is to have limited drainage and a less reliable water supply system, as well as lower water allocations than the Murrumbidgee Valley.

Farm size varies considerably in the Murray Valley. Irrigation farms in the eastern Murray Valley range from 160 ha to 200 ha while in the western Murray Valley irrigation farms are around 400 ha to 800 ha. The larger areas and the generally poorer soils in the western Murray Valley result in many of the irrigation enterprises being usually less water intensive. In contrast, more intensive irrigation does occur on the better soils in the eastern Murray Valley.

The crop yields in the Murray Valley are generally low compared to those in the adjacent Murrumbidgee Valley due to lack of irrigation water and the tendency to use fewer inputs. The lower temperatures in the Murray Valley also result in lower rice yields than in the Murrumbidgee Valley as low temperatures can cause sterility in the plant, preventing the development of the rice grains. Temperatures of 12°C or less prior to flowering have resulted in sterility in as much as 60 per cent of the crop (Currey 1984). To avoid this, more water is applied to insulate the crop against the cold, reducing the already limited amount of water available for other irrigation.

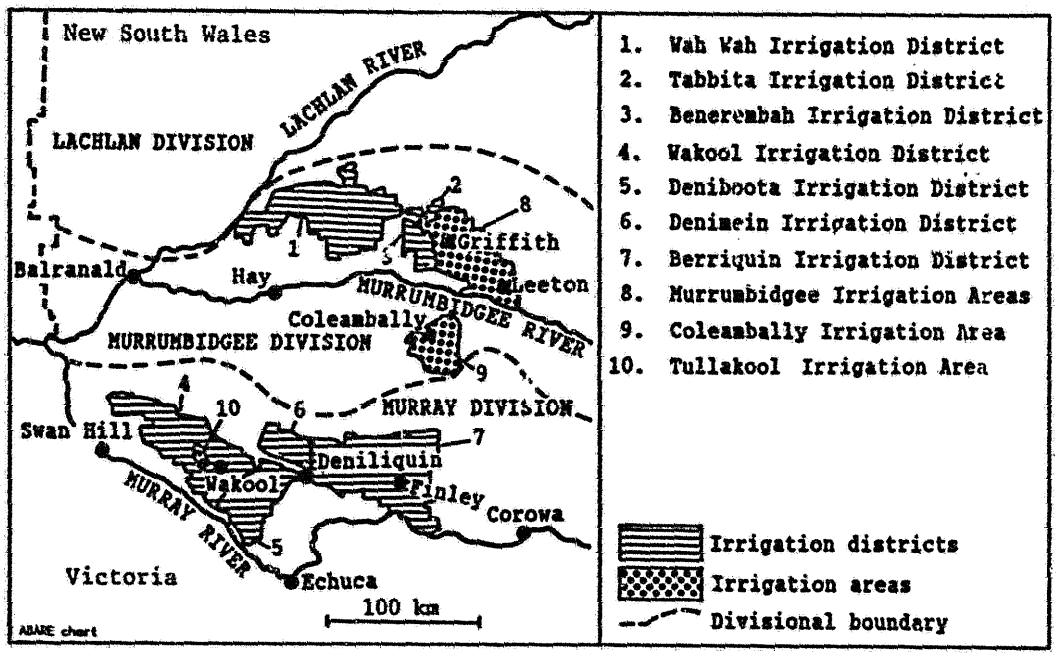


FIGURE 1 - Irrigation Regions of Southern New South Wales.

Water allocation also differs across the Murray Valley. Despite the Wakool Irrigation District having a higher water allocation than the other Districts (an average of 818 ML compared to about 670 ML), with large areas of potentially irrigable land in the western Districts, water is still a limiting resource. Water delivery is a further constraint to production in the Murray Valley due to inferior infrastructure. Most farmers in the Murray generally only have one Dethridge wheel while in the Murrumbidgee three wheels are common. This means that for crops that require large amounts of water applied in a short period, timely applications cannot be guaranteed.

Although rice is still the main crop in the Murray Valley, the limited water supply means that a decision must be made to irrigate either rice or some other crop instead, but generally not both. As a result, crops in the Murray Valley (especially in the western regions) tend to be predominantly dryland, with the exception of rice, which must be fully irrigated, with irrigation water being applied to supplement natural rainfall and only if there is water left after irrigating the rice.

A quota system which limited the area of rice that could be sown was lifted temporarily in 1987. The quota, enforced by the New South Wales Water Resources Commission, restricted the area of rice to 73 ha per farm in the Tullakool Irrigation Area and from 53 ha to 57 ha in the Irrigation Districts of the Murray. However, rice production is still constrained in the region by water availability as well as the availability of suitable soils. Rice production is also constrained by the need to rotate crops to prevent degradation of the land. The amount of water used in rice growing is now also restricted to 16 ML per hectare. Those growers who cannot meet this limit because their soils are too 'leaky' are forced either to produce alternative crops or to risk crop sterility due to the inability to insulate against low temperatures. A further complementary restriction is placed on the type of soil on which rice can be grown. For example, to avoid rising

water tables, rice cannot be grown on soils with high infiltration rates. These measures are an attempt to curb the increasing salinity problems in the Murray Darling Basin as well as an attempt to minimise the quantity of water used.

The Regional Model and Matrix Description

The approach taken in this study was to use linear programming to simulate water use in the Valley. The use of linear programming has particular advantages over, say, econometric modelling in this particular study for several reasons. Firstly, the current pricing policy has not allowed the forces of supply and demand to determine directly the price of water. Similarly, allocations of water have been linked to the area of land rather than to how much water a farmer was willing to purchase at that price. Consequently, an econometric model could not be estimated as there has been no variance in water prices or water use.

A second disadvantage of a positive model such as an econometric model is the implicit assumption of continuity of structural and institutional parameters. For example, an econometric model would be unable to predict the demand for water under a different set of institutional constraints other than those under which it was estimated. A programming model, however, can simulate these changes in institutional constraints and thereby estimate the new water demand.

The use of the programming model, however, does have some difficulties. Firstly, the model maximises gross margins to producers, given a set of technical constraints based on the 'average' producer and perfect information as to prevailing prices. However, management and foresight are not homogeneous features of farmers within any one region and farmers do not always maximise gross margins. Thus, a normative model such as a linear programming model can only provide an indication as to what should happen rather than what would happen.

In the light of the above, a regional linear programming model was constructed for the Murray Valley irrigation region for the purpose of investigating the major consequences of various water pricing policies, subject to resource availability, costs and commodity prices. The base model utilises commodity price and cost data from the 1984-85 season so that the results can be verified against actual performance data for the region. Although other stochastic factors such as climate and variations in water availability can affect the short term demand for water, these factors have not been included in the model and are considered beyond the scope of this paper.

Being a short run model, no account is taken of the capital requirements of the different management options considered. Therefore, in interpreting the results, it must be recognised that the optimal strategies as outlined by the model may not be optimal in the longer term. For example, only one form of irrigation technology, namely flood irrigation, is considered in the model as it is by far the most common method in the region. If, in the long run, water prices did increase to the degree simulated, there might be incentive for the farmers to adopt more water-efficient irrigation technology.

The activities considered in the model include cereal production (mostly rice, wheat, triticale and barley), pasture production and livestock activities. Rice and lucerne only appear as irrigated activities, whereas

the winter cereals can be either irrigated or dryland. Pasture activities can either be irrigated or dryland, with correspondingly different feed production. Also included in the model are baling, selling, buying and feeding hay activities. The livestock activities include sheep and beef cattle breeding, as well as wether growing, steer fattening and dairy production. All technical coefficients were derived from New South Wales Department of Agriculture budgets (Jones 1985) except for the dairy and hay enterprises (Martin 1986), and vegetables (Hickey undated, Jones and Salvestrin 1985). Rice prices were obtained from the Ricegrowers Co-operative Ltd and include all payments for the 1984-85 crop.

The model is constrained by water availability, land areas (both total and irrigable), areas of the various soil types and farm labour availability (although hiring casual labour is unconstrained). Rotational constraints are based on those recommended by the New South Wales Department of Agriculture for maintaining soil fertility as well as past production in the Areas and Districts. Feed pools reconcile pasture and hay availability with livestock feed demand. The area of rice grown is constrained by the quota set by the authorities, in the base model for the purpose of model validation. Estimates of irrigable land areas were derived from New South Wales Department of Water Resources (formerly the New South Wales Water Resources Commission) Annual Reports (New South Wales Water Resources Commission 1985). Maximum availability of operator labour was determined from ABARE Rice Industry Survey statistics. Water allocation was based on the maximum water delivered to the region over the last ten years.

As the model cannot take risk into consideration, the area of high return, high risk, activities such as vegetable growing was restricted to the area grown in the base year. This restriction assumes that most farmers would not move to these risky enterprises and would, instead, vary their mix of traditional enterprises in response to changes in the price of water. Similarly, most oilseed cropping requires specialist equipment. In the short term, it is assumed that the area of oilseeds cannot increase beyond the area in the base year due to the lack of appropriate equipment. In the longer term, of course, the area of the crops might expand if they were a viable alternative to traditional cropping, as farmers could purchase the necessary equipment.

An important feature of the model is the disaggregation of the Districts into subdistricts based on the soil type characteristics. Four soil types were identified as the dominant soils in the Murray Valley, each having an impact on the activities that could be undertaken. The soil type areas were determined from CSIRO soil maps of the region and are as follows:

<u>Soil 1: Sandy soils of the old river ridges and sandhills</u>. These soils have at least 0.62 m of sand on top of heavier clay subsoil which can cause perched water tables with low infiltration rates at quite shallow depths. Deeper sand horizons result in soils too permeable for efficient flood irrigation.

<u>Soil 2: Red-brown earths.</u> These soils have wide agricultural use depending on the subsoil characteristics. The lighter textured soils are suitable for horticulture, vegetables and lucerne growing. Infiltration of water is generally satisfactory although constant cropping can cause structural breakdown, giving a hard compact surface, slow absorption of water and poor seed germination. The growing of rice on this soil type is constrained to 50 per cent of

the available area, representing the estimated proportion of this soil type actually suitable for rice.

Soil 3: Transitional red-brown earths. These are soils with dense slaking surface crusts making pasture and crop establishment difficult. They are suitable for rice growing because of their dense clay subsoils, but surface crusting renders them unsuitable for row cropping or horticulture. Slow infiltration rate is also a characteristic of these soils.

Soil 4: Grey and brown soils of heavy texture. These soils generally have calcareous crumbly (self-mulching) surfaces which vary in texture and depth. They have a high clay content (approximately 60 per cent) and crack extensively on drying. These soils are generally of high fertility and can be used for most activities, becoming impermeable when very wet allowing ponding for rice as well as having a reasonable infiltration rate when less water is applied, making them also suitable for other crop and pasture production.

The model aims to maximise total gross margin for the region given the constraints outlined above. Variable costs (excluding water and labour charges) are incorporated as the enterprise objective function value, while the enterprises produce outputs which feed into the objective function through their selling enterprises. The sensitivity of the model to changes in output prices, water prices or labour costs is easily determined due to the separation of variable costs and returns.

Model Validation

A common method of assessing the ability of a normative model to accurately simulate the system under study is to compare the output from the model with the actual production (McCarl and Apland 1986). In Table 1, the results of the model, using 1984-85 costs and returns, are compared to what actually happened in the Murray in 1984-85. As can be seen, most of the model results are of the right order of magnitude with the exception of the areas of fallow or dry. This is possibly due to the substitution of other grains, which do not require periods of fallow, for wheat in some areas.

TABLE 1

Comparison of Model Results to Actual Results 1984-85

	Tullakool		Berriquin		Deniboota		Denimein		Wakool	
Activity	Model	Act.	Model	Act.	Model	Act.	Model	Act.	Model	Act.
	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Rice	1264	1148	27837	27837	9467	9162	5117	5117	13269	12925
Cereals	332	102	22512	33121	6823	5183	1629	1050	6283	2231
Pastures	2236	1565	78483	64814	14234	14403	6640	3597	25644	22819
Lucerne	0	0	1763	2146	275	399	131	135	253	217
Oilseeds	0	0	1915	2128	119	225	38	40	894	642
Vegetables	0	0	1823	1802	41	93	47	25	246	277
Fallow or dry	0	277	2251	58	0	2101	0	1194	0	2474

Source: New South Wales Water Resources Commission (1986).

Further, as rotations are based on the average or recommended rotation, in any one year it would be unlikely that the model would predict the exact combination of crop production, although the model would predict the average combination over a number of years. As a consequence, the differences between actual and estimated areas of production in Berriquin and Wakool is not considered to be a problem.

Although it would be desirable to compare the actual production of the crops with the model output, this information is not available at either the regional or subregional level. These figures can only, at best, be estimated from Australian Bureau of Statistics Statistical Division data which do not correspond to the areas modelled. Similarly, livestock numbers estimated by the model cannot be compared to actual livestock numbers in the region.

As a further test of the ability of the model to estimate the actual production of the region, the gross margin for the region as a whole was compared to estimates from the ABARE 1984-85 Rice Industry Survey. The average gross margin (excluding vegetable production) on a per farm unit basis was estimated from the model to be about $97 000. The average gross margin for the Murray Valley on a farm unit basis was estimated from survey data to be about $91 000. Given the sampling errors involved with the use of survey data, the two estimates are very close. Further, the estimate from the model would be expected to be marginally greater than actual results due to the perfect knowledge inherent in the model.

Results

In order to estimate the derived demand functions for water in the Murray Valley given current cropping activities, the price of water was parametised over the range of $4/ML to $80/ML, with no constraint on the amount of water available to the region. Both Briggs-Clark et al. (1986) and the Bureau of Agricultural Economics (1987) found that the demand for water, being a derived demand, was dependent on both the price of water and the price of the commodities produced. Consequently, the model was parametised using both 1984-85 commodity prices (representing a 'good' year) and 1986-87 commodity prices (indexed to 1984-85 values, representing a 'bad' year). The price to quantity relationships were plotted to give the derived demand functions, shown in Figure 2.

The model output for each year was also fitted to a cubic regression and point elasticities estimated, seen on Figure 2 at selected points. This regression model is:

$$\underset{\text{(millions of ML)}}{\text{Quantity of water}} = \underset{(19.4)}{1.413} - \underset{(-5.5)}{5.92E\text{-}4}\,(\text{price})^2 + \underset{(3.2)}{4.45E\text{-}7}\,(\text{price})^3.$$

Corrected $R^2 = 0.9158$.

As the data used in the regression model are themselves the output of a model, the corrected R^2 is a measure of how well the regression model fits the 'true' response surface as defined by the programming model rather than the measure of how much variation in the dependent variable is explained by variations in the independent variables. Further, the t-statistics (in parenthesis) are not relevant in this deterministic context (Candler and Cartwright 1969), the only criterion for assessment being the R^2. The t-statistics are presented, nevertheless, for the information of the reader.

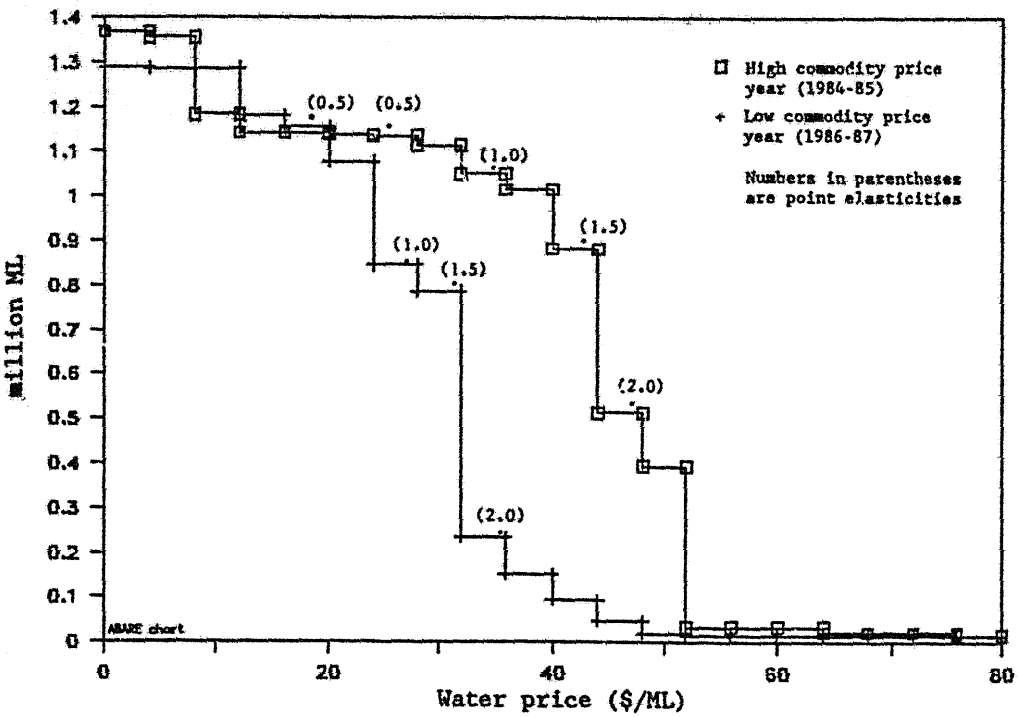
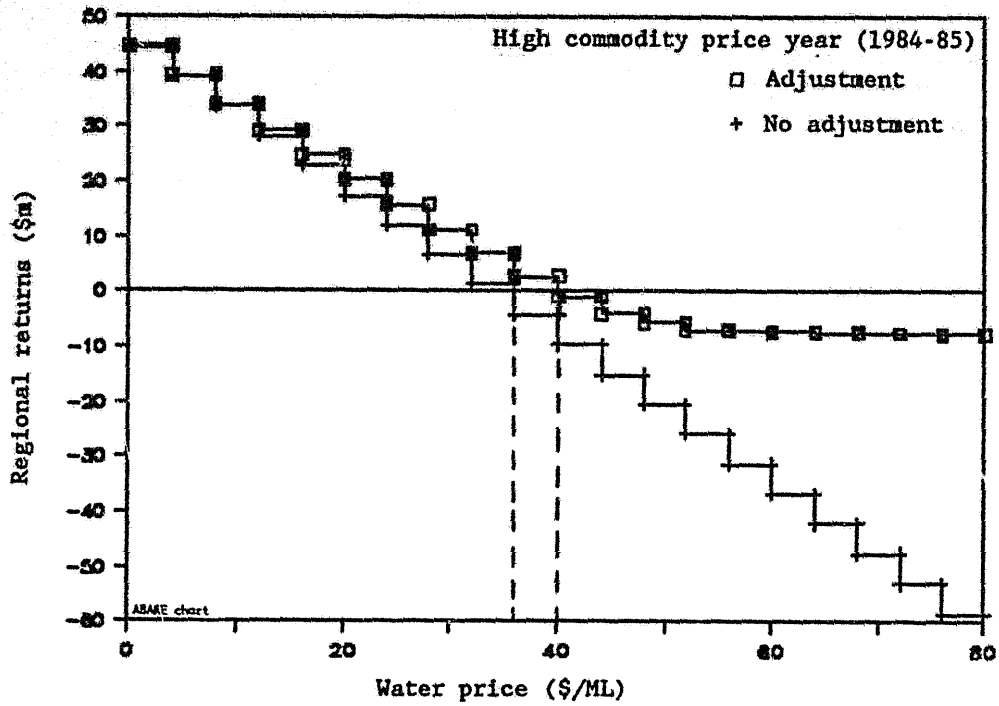


FIGURE 2 - Derived Demand for Water in the Murray Valley Irrigation Region.

With all other prices and costs held constant, the demand for water was found to be more elastic with low commodity prices (in the 'bad' year) than with high commodity prices (in the 'good' year): the function became elastic at about $26/ML under low commodity prices and at about $36/ML under conditions of high commodity prices. These results compare favorably with those presented in Bureau of Agricultural Economics (1987), where the demand for water in the Murrumbidgee Valley in total became elastic at about the same price.

The parametisation of the model also produced the total gross margins in the Murray Valley at the different water prices. Bureau survey data were used to estimate the overheads (such as interest payments, insurance, repairs and maintenance, administration costs) and the imputed value of the family labour in the region, to assess the price of water at which the operator would run at a loss in the short term. Information on overheads for vegetables was taken from Irrigation Farm Working Group (1986). As the analysis is restricted to the short term, depreciation as a measure of capital costs was ignored. Even in the absence of depreciation, it was estimated that the total costs associated with production in the region not included in the gross margin were $52.8m in 1984-85 and $53.8m in 1986-87 (in 1984-85 dollars).

In Figure 3, the total returns to the region net of the overheads and the opportunity cost of family labour (that is, short term profits) are shown for each price level parametised in the model. From this figure, it can be seen that in a year of relatively high commodity prices, producers are capable of making positive profits (excluding depreciation) with water



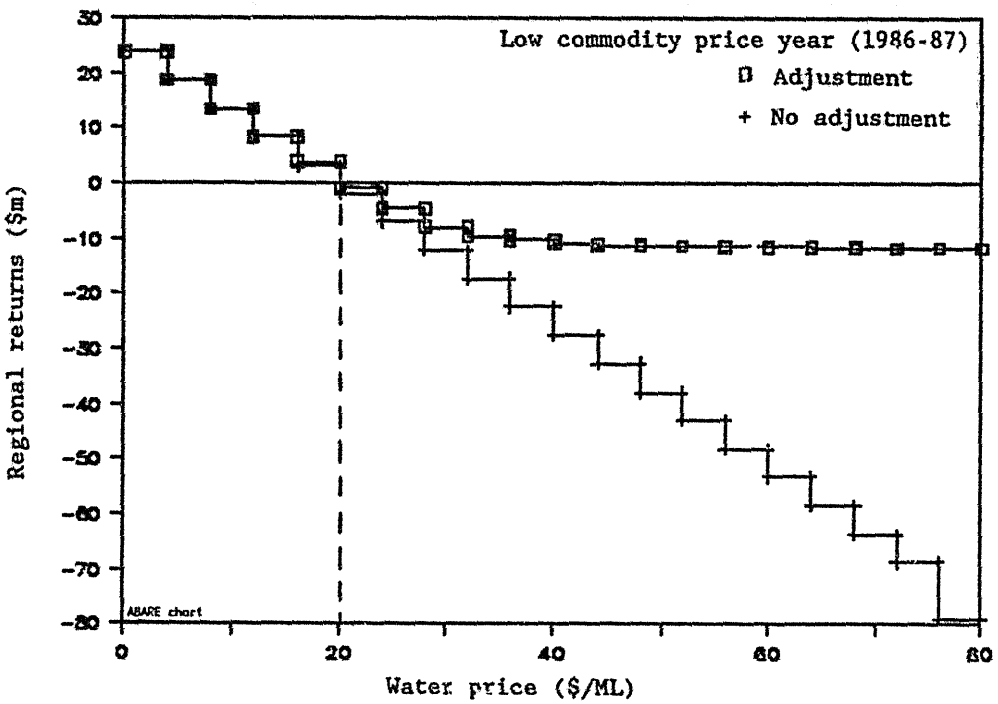


FIGURE 3 - Gross Margins Less Estimated Overhead Costs.

prices up to $40/ML. However, under conditions of low commodity prices as in1986-87, water charges above $20/ML would have resulted in a net short term loss to the region. If the farmers had not changed their enterprise mix in response to the changing water price, then the magnitude of the short term loss would have been much greater, as seen in Figure 3. The price at which this negative returns occurs, however, is not much different than if the farmer adjusts.

Discussion and Conclusions

The results presented in this paper suggest certain implications for water pricing in the Murray Valley. First, the demand for water is sensitive to other commodity prices as well as to its own price. Under conditions of relatively high commodity prices, water use may not decline significantly until the price reaches about $36/ML. Under conditions of low commodity prices, however, water use may decline more rapidly and at lower prices. The implications of this is that the imposition of higher prices may result in fluctuations in water demand as commodity prices change from year to year. This could cause supply control problems for the water supply authorities as well as complicating the issue of permanent water transfers.

The second major implication of the preliminary results of the model is that although water may still be used for irrigation when prices are relatively high, farm labour will be receiving less than its opportunity cost at prices above $40/ML in a good year, and as low as $20/ML in a poor year. The inclusion of capital depreciation in these overheads would reduce the breakeven point even further. In the Bureau's submission to the Industries Assistance Commission, the Bureau recommended that a policy of cost recovery for water would reduce water use to a more economically desirable level and reduce the buildup of groundwater. Such a policy, however, may result in short term adjustment pressure in the region.

It should be stressed, however, that these are short term results only. In the longer term, higher water prices would provide more incentive for the adoption of more efficient irrigation technology. For example, improved farm layout would lift the profitability of the region as well as reducing the demand for water. Similarly, capital restructuring might enable the expansion of the currently limited oilseed production or allow new enterprises to be introduced into the region. These changes could alleviate the short term losses to the region indicated by the model as resulting from increased water charges.

Other areas for further study using the model include quantifying the cross-price elasticities of demand for water with the major commodities, mainly rice, cereals, wool and meat production. Further, the supply responsiveness of rice to factors such as water price as well as the prices of other commodities can be examined on an industry wide basis with the incorporation of the Murrumbidgee Valley model. The effects of salinity on production in the area will also be an area of further study using the model. Other activities can also be included in the model to examine the potential for alternative enterprises.

In conclusion, although the model is currently only an annual rather than long run model, it does produce results that have implications for short term water demand. In particular, water pricing policies will need to be complemented with policies to facilitate adjustment in the region in the short term.

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