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ESTIMATED DEMAND AND SUPPLY FOR IRRIGATION WATER IN SOUTHERN NSW

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Abstract

In February 1994 the Council of Australian Governments (COAG) agreed to a number of significant reforms of the water industry One of the most important was to "implement comprehensive systems of water allocations or entitlements backed by separation of water property rights from the land title and clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality". In relation to trading in water allocations or entitlements COAG also noted that where cross-border trading is possible, that the trading arrangements be consistent and facilitate cross-border sales where this is socially, physically and ecologically possible.

The purpose of this paper is to report on the first part of a wider research program evaluating alternative water property rights structures and trade within and between NSW and Victoria. Regional linear programming models are used to determine supply and demand functions for irrigation water in nine irrigated regions in southern NSW. The results of this analysis will subsequently be incorporated into a spatial equilibrium model being co-operatively developed by NSW and Victoria.

1. Introduction

1.1 Background to water policy development

The Australian water industry has been the focus of substantial review in recent years. The Industry Commission (1992) made a number of significant recommendations relating to irrigated agriculture. These included the privatisation of irrigation areas; full cost recovery of rural water charges; the introduction of permanent transferability in all irrigation systems; allowances for the transfer of water between schemes and between uses; that entitlements of new supplies should be auctioned; and that the States should formalise water entitlements for environmental purposes and that any additional water for the environment should be purchased. The Industry Commission estimated that the gains from its proposals for pricing and institutional reform would permanently increase the level of gross domestic product by some $800 million.

In February 1994 The Council of Australian Governments (COAG) considered and agreed to a number of important reforms of the water industry. The key agreements relating to rural water included:

- the introduction of consumption-based full-cost recovery pricing of water;
- the removal, where possible, of cross-subsidies or transparency of cross-subsidies and full disclosure of community service obligations;
- implementation of comprehensive systems of water allocations or entitlements backed by separation of property rights from land title and clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality;
- declaration of formal allocations for water including allocations for the environment as a legitimate user of water. Recognition that wherever possible, environmental requirements will be based on the best scientific information available;
- that trading arrangements be instituted once entitlement arrangements have been settled. Where cross-border trading is possible, that arrangements be consistent and facilitate cross-border sales.

The COAG agreement has a key role in generating improved outcomes in terms of the sustainability of natural resource use as well as better environmental outcomes. Responsibility for the implementation of the COAG framework rests with the Agricultural Resource Management Council of Australia and New Zealand (ARMCANZ) in consultation with the Australian and New Zealand Environmental Co-ordinating Committee (ANZECC) and the Murray-Darling Basin Ministerial Council (MDBMC). The COAG framework is the Nation's major policy initiative for water resources and thus is a key focus of ARMCANZ in undertaking its natural resource management responsibilities.

The establishment of the COAG water reform framework and the further property rights reform developments by ARMCANZ has provided a much needed boost to progressive reform of the State's water industry. As a consequence, proposals outlining changes to water prices and environmental allocations have been developed in NSW by the Department of Land and Water Conservation (DLWC) and the Environment Protection Authority (EPA).

In August 1995 the NSW Government announced a package of reforms to address environmental degradation associated with the use of irrigation water. These included an interim increase in the water management charge of $1.35 per megalitre; the referral of the issue of rural pricing to the Government Pricing Tribunal, so that from July 1996 rural water prices would be set through an equitable and transparent process; establishing and maintaining existing caps on diversions from a number of western catchments; apply moratoriums on permanent transfers of portions of licensed entitlements which have not been used for the last three irrigation seasons; increased water availability to wetlands and the environment, and the establishment of two inter-departmental working groups to set minimum standards for water quality and river flows

The goal of the River Flow Objectives Working Group is to develop an environmental allocation package which halts, then reverses, the decline in the health of rivers, wetlands and estuaries from water and catchment management, and to provide equity between the environment and other water uses The Working Group is comprised of representatives from the EPA, NSW Agriculture, DLWC, National Parks and Wildlife Service, NSW Fisheries and the Department of Urban Affairs and Planning.

Although environmental benefits are likely to be generated by the reforms introduced by COAG and the NSW Government, there is likely to be a significant impact upon the existing users of irrigation water from these reforms, particularly any move to reallocate water from irrigation to environmental uses. It is possible that the reforms will significantly impact upon the optimal allocation of the water resource and the demand for water by irrigators. There is the potential that trade in water will be affected as a result.

1.2 Purpose of the paper

There are two purposes of this paper. First, to present estimated demand and supply functions for irrigation water in southern NSW. These functions have been developed as an input to general policy analysis of water resource issues. Second, to present an empirical framework, spatial equilibrium analysis, for application to emerging policy issues as a result of the water policy reforms outlined above. This methodology has significant application to issues of trade in water between regions and uses, and to the evaluation of the impact upon agriculture of the introduction of environmental allocations.

The analysis reported in this paper is part of a joint project between NSW Agriculture and Agriculture Victoria evaluating alternative property rights structures and the impact of COAG reforms on irrigated agriculture (Eigenrram, Jones, Sappideen and Stoneham 1996).

1.3 Outline of the paper

The market for water in NSW is illustrated in section 2. Presented are the concepts of excess demand and excess supply which are used to represent the demand and supply of transferable water entitlements (TWE). The alternative policy scenarios evaluated in this study are outlined in section 3 These scenarios involve the evaluation of alternative approaches to providing environmental allocations. The methodology for estimating the demand for irrigation water, parametric linear programming, is presented in section 4. The regions modelled and a basic specification of the models are discussed. Section 5 outlines the use of spatial equilibrium analysis for resource allocation issues in the water industry and presents the model specification for this study In section 6 the results of the analysis are reported. The stepped demand functions for irrigation water and the estimated linear demand, excess demand and excess supply, along with the results of the spatial equilibrium analysis of the alternative environmental allocation scenarios are presented. A brief summary of the paper is provided in section 7.

2. The Water Market in NSW

Randall (1981) noted that most Australian water resources have entered a mature phase of development. In this phase the water economy is characterised by sharply rising incremental costs of supplying water and there is greatly increased interdependencies among water users. There is more intense competition for water supplies which expand slowly and the aggregate effects of individual water use decisions include rising watertables and increasingly polluted and saline effluents.

The Murray-Darling Basin typifies this situation where in parts there is now considerable conflict between agricultural, urban, recreation and environmental uses. Also there are significant problems of water pollution and land degradation and there is a need for rehabilitation of ageing reservoirs, water delivery and drainage systems. The major issues when a water economy enters a mature phase are the optimal allocation of the water resource among competing users and methods for addressing the land degradation and environmental problems resultant from irrigation.

The principal tools for policy reform of the water industry involve supply management and demand management. Supply management tools include changes to allocation levels and supply reliability while demand management concepts involve price reform and water markets. The establishment of both permanent and TWE schemes in NSW have been a significant step towards improved efficiency of water resource use. Reform to the price system in NSW, however, has been slow with significant levels of public subsidisation of water prices remaining. A properly functioning price system would be an effective allocator of resources and direct water to its most productive use, regulate the growth of water demand and promote flexibility of water use such that it is more readily directed to new socially desirable uses which may emerge and away from lower value uses (Pigram and Musgrave 1990).

Howe (1990) argues that water markets possess a number of desirable characteristics for efficient allocation of resources. "Markets guarantee flexibility in allocation while providing security of tenure (no one has to sell). The price established in the market and the ability to sell at that price if desired force the decision maker to take the resource opportunity cost into account. Markets guarantee fairness between buyer and seller, by definition, since each must be made better off or one would refrain from trading" (Howe 1990 p.44).

The potential for an irrigation region, or individual irrigator, to participate in a TWE scheme will depend upon a number of factors. These include the size of the volumetric allocation[1] of irrigation water, the base water charge for supplies of water from the volumetric allocation and the region's, or individual's, demand function for irrigation water.

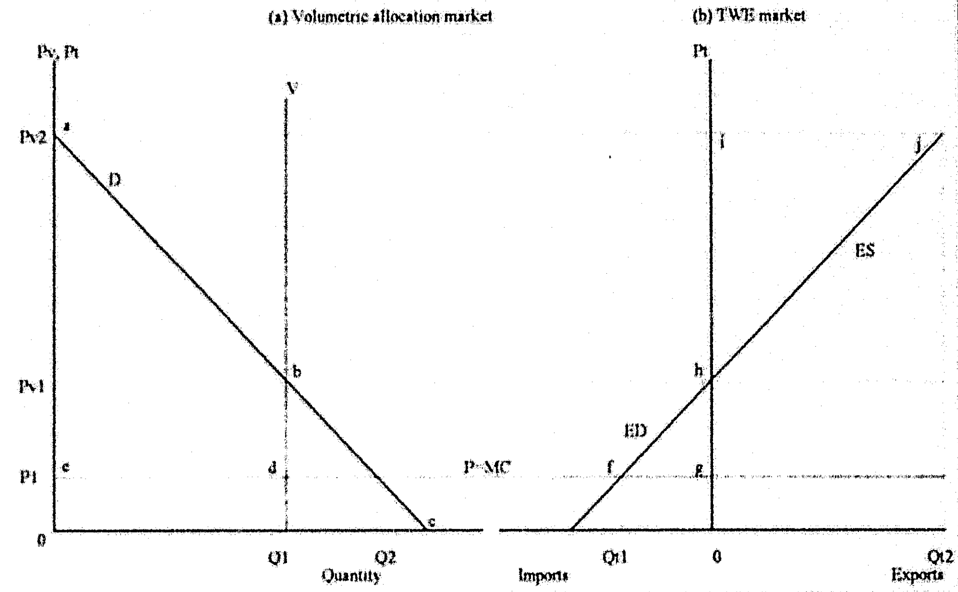
Consider Figure 1 where part (a) presents the market equilibrium's for volumetric allocation use and part (b) the equilibrium's for trade water. The right-hand section of Figure 1 illustrates the excess demand (*ED*) and excess supply (*ES*) functions for irrigation water which determine the level and flow of trade in irrigation water. On the y-axis P_v represents the price for volumetric allocation and P_t the price for trade water (where trade water, TWE and excess demand are the same commodity). D is the demand function for irrigation water, P_l is the fixed charge per unit of volumetric allocation and V is the available volumetric allocation of water for an irrigation region which can be interpreted as an annual quota on water use in the region. The true supply curve for irrigation water is unknown, with individual irrigators being faced with the administratively set artificial supply function of P with a fixed marginal cost of P_l for volumetric allocation supplies. The excess demand and excess supply functions are derived from the demand function D and the volumetric allocation constraint V.

Under the current institutional setting irrigation water consumption is at Q_l at the prevailing price P_l. If the quota constraint on volumetric allocation was relaxed, irrigation water consumption would be at Q_2 where marginal cost equals marginal revenue. The actual demand function for irrigation water from volumetric allocation supplies is the segment *ab* of the demand function D. At Q_l the marginal revenue from water consumption exceeds the marginal cost and thus it would pay to obtain additional supplies of water. The segment *bc* of the demand function D is an excess demand function and can thus be considered the demand function for TWE, or imported, water which is additional to that available from the volumetric allocation (as measured by its demand function *ab*). This same function is represented in Figure 1b by the excess demand function *ED*. At price P_{vl} the demand for TWE water is zero while at P_l, $0Q_{tl}$ (or Q_2-Q_l) is demanded. The minimum price of TWE water is unlikely to be below P_l after the costs of supply and distribution in that region, transport costs and translation factors (transmission losses) are accounted for.

It should be noted that for the purpose of simplicity Figure 1(a) has been drawn assuming the price of TWE water, P_t, equals the price of volumetric allocation water, P_l. P_t will in fact not equal P_l, but vary in a competitive market above P_l.

[1] The term allocation is used to represent the irrigation entitlement to farmers. A volumetric allocation system operates in the Murrumbidgee and Murray Valley", where the volumetric allocation relates more to shares available water than an absolute quantity.

Figure 1: The market for water



If the volumetric allocation quota, V, in Figure 1(a) intersected the curve P to the right of the function D, then the water constraint would become non-binding, there would be a surplus in the volumetric allocation which results in there being no possibility of an excess demand function for irrigation water.

The curve ES in Figure 1(b) represents an excess supply function for volumetric allocation which could be made available for sale through a TWE scheme. This excess supply function is the inverse of the demand function D for the quantity range $0Q_1$. It is therefore dependant not only upon the functional form of D but the level of volumetric allocation V. At a price of P_{v2} demand is zero, meaning OQ_1 (or $0Q_{t2}$) is excess supply at that price. At a price P_{v1} the demand function intersects V and excess supply is zero.

In this problem ES and ED are a direct function of D and V and can be algebraically determined once these two functions are known. Consider where:

(1) D is $p_w = \alpha_w - \beta q_w$
(2) ED is $p_m = \alpha_m - \beta q_m$
(3) ES is $p_x = \theta_x + \gamma q_x$
and $V = Q_1$

In this particular problem as we are dealing with a limit on supply, the slopes of D, ED and ES are equivalent except that the sign is reversed for ES i.e. γ=-β. To estimate ED and ES is simply a matter of determining the intercept when q_w is equal to Q_1. Thus

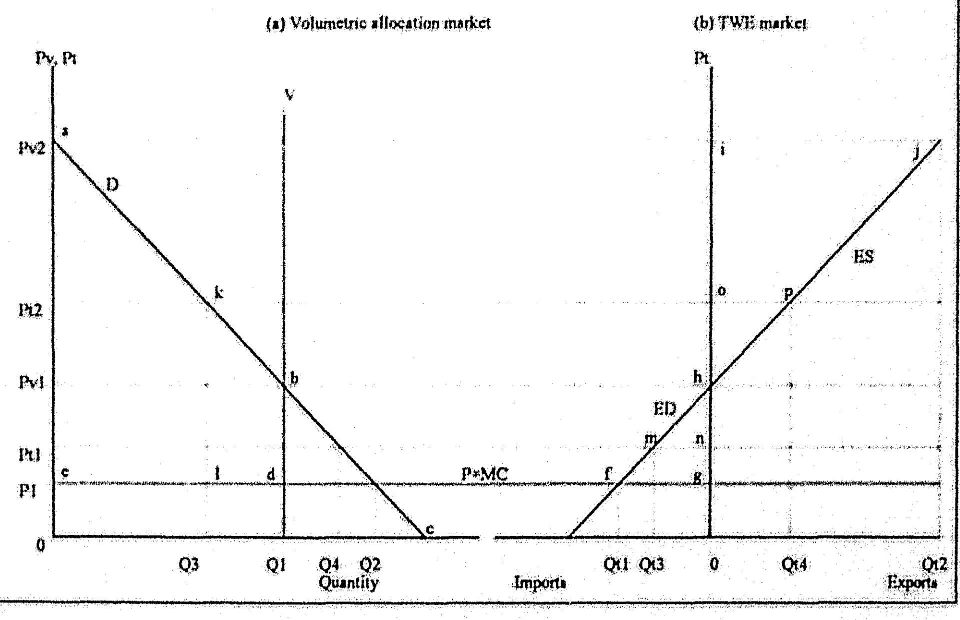
(4) $p_m = (\alpha_w - \beta Q_l) - \beta q_m$
(5) $p_x = (\alpha_w - \beta Q_l) + \gamma q_x$

The level of consumer surplus is measured by the areas *abde* + *fgh*, assuming $P_t = P_v$. In the first area the relevant price is P_v while in the latter area the relevant price is P_t. Producer surplus is measured by the area *hij*, assuming $P_t = P_v = P_{v2}$. The areas fgh and hij represent the maximum consumer surplus and producer surplus from trade in irrigation water that can be derived under alternative price scenarios.

Consider in Figure 2 two alternative water trade price scenarios, P_{t1} and P_{t2}. At the water trade price of P_{t1} all volumetric allocation is still used, Q_1 at price P_1, however an imported volume of TWE water of $0Q_{t3}$ (or Q_4-Q_1) will be consumed at the price P_{t1}. The relevant economic surplus areas are a consumer surplus measured by the areas of *abde* + *hmn* Producer surplus is zero as no water is sold from this region at P_{t1}. When water trade price becomes P_{t2} it has reached a sufficient level to attract sales of water from the region of $0Q_{t4}$ (or Q_1-Q_3). This leaves consumption of water in the region at $0Q_3$, at the fixed price P_1. The relevant economic surplus areas are now a consumer surplus area of *akle* and a producer surplus area of *hop*.

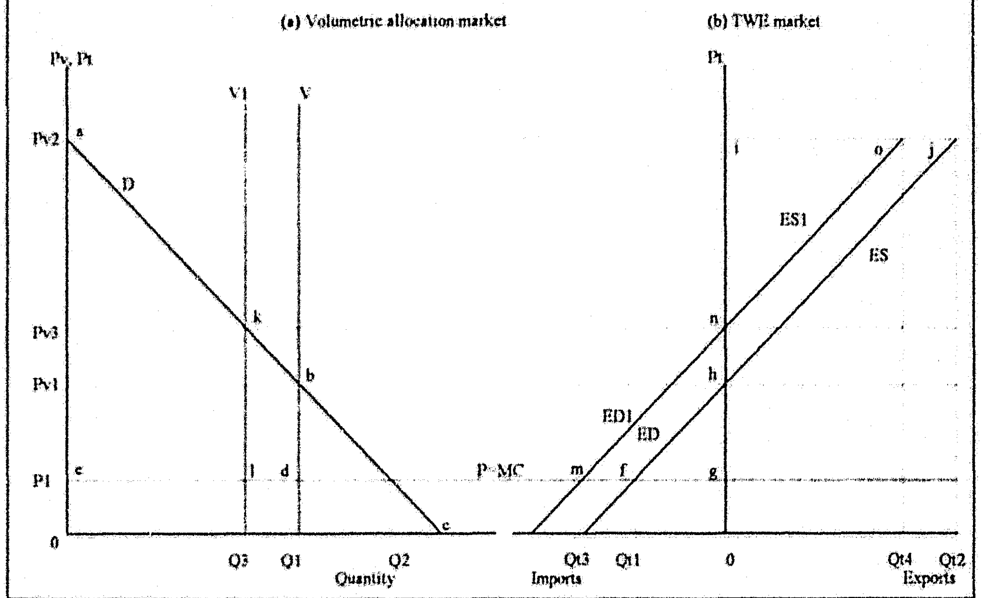
The important point from the presentation in Figure 2 is that at any one equilibrium price a region can be a net buyer or net seller of TWE water, not both. The value of the TWE water will govern whether a regions buys or sells water.

Figure 2: Water trade with differing trade prices



Consider now Figure 3 where the volumetric allocation constraint V has been shifted to the left to V_1 as a result of a particular policy change, such as the reallocation of irrigation water by a supply authority. Although the demand for water, D, remains unchanged ED and ES have been shifted to ED_1 and ES_1. The demand function for volumetric allocation is *ak* instead of the previous *ab*, and the demand function for TWE is now represented by the segment *kc* (a shift to the right). Consumer surplus is now measured by the area *akle* + *mgn* and producer surplus is *nio*.

Figure 3: Water trade with reduced volumetric allocation



3. Policy Scenarios

For the estimation of demand functions this study has followed the approach of Flinn (1969) by estimating both seasonal and intra-seasonal demands for irrigation water. Seasonal excess demand and excess supply functions only have been estimated.

Parametric linear programming is used to determine the demand functions for irrigation water. This results in stepped functions to which ordinary least squares (OLS) regression analysis is applied. The excess supply and TWE demand functions for different policy scenarios can be calculated directly from the estimated demand function for each region. These functions are then incorporated into a spatial equilibrium model of irrigation regions in southern NSW.

For the purpose of this paper the spatial equilibrium model is solved for a number of differing policy scenarios. The analysis involves some crude assumptions relating to the physical impact of environmental allocations upon irrigation water availability as the appropriate hydrological data, which is required for the River Flow Objectives Working Group process as outlined in section 1.1, is not yet available. Consequently, the results presented are for demonstrative purposes only. The objective of this analysis is to demonstrate the possible impact of environmental allocations upon irrigated agriculture and measure the opportunity cost to agriculture from alternative means of providing water to the environment

Three alternative scenarios are considered. For scenarios 2 and 3 the environmental demand could be assumed to represent the benefits from providing dilution flows or in-stream environmental requirements (e.g. fish breeding, red gum rehabilitation) for the Murray River

1. *The status quo*. There is no environmental allocation and volumetric allocations for each region are set at the annual average availability of 118 per cent of volumetric allocation in the Murrumbidgee Valley and 116 per cent in the Murray Valley This scenario reflects the position presented in Figure 1.

2. *Environmental allocation requirements are met by a uniform reduction in water availability* In this scenario it is assumed that the environment requires an annual allocation of 750,000 megalitres which is met by a uniform reduction in annual availability of volumetric allocation in all regions. This equates to a 22.6 per cent reduction in volumetric allocation availability to 95.4 per cent in the Murrumbidgee Valley and a 22.2 per cent reduction in volumetric allocation availability to 93.8 per cent in the Murray Valley. This is the traditional supply management approach adopted by water supply authorities for resource allocation problems This scenario corresponds to the situation presented in Figure 3 where the volumetric allocation quota in each region is shifted to the left, to V_1.

3. *Environmental allocation requirements are met through the market place*. In this scenario it is assumed that the environment has a fixed annual demand of 750,000 megalitres, however, this has to be met through participation in a TWE system (either from temporary or permanent transfers). This scenario corresponds with that presented in Figure 2 whereby the environment represents an additional demand region in the water market, leading to a possible increase in the value of P_t. This approach is one example of the application of a demand management tool to the resource allocation problem.

There are a number of advantages of scenario 3 over scenario 2 from a policy context. First, because the environment's demand for water is met in the market place it allows water to move from those regions which have the lowest marginal value product to those with the highest marginal value product. It will therefore incur the least opportunity cost. Second, as noted by (Howe 1990) fairness is guaranteed by the market as no-one is forced to sell. Therefore, there is unlikely to be any legal action or claims for compensation by irrigators adversely affected by the reallocation of irrigation water to satisfy environmental requirements as in scenario 2. An important issue that is required to be resolved with scenario 3 is the question of who pays for the water on behalf of the environment.

4. Regional Linear Programming Models

4.1 Parametric linear programming versus econometric analysis

A normative approach such as linear programming has a number of advantages over econometric modelling to determine demand functions for irrigation water in the study region. Current pricing policies in the region have not allowed market forces to directly determine the price and quantity consumed of irrigation water. Consequently, most historical price data observations have corresponded to point *d* in Figure 1 rather than along *ab*. Thus, it would be difficult to estimate an econometric model given the lack of data. Another advantage of a normative model over a positive one is that it can be used to estimate demand functions under different policy and institutional settings than have historically existed.

The deficiencies of linear programming have been well noted (for example Hardaker 1971, Dent, Harrison and Woodford 1986). These include the assumptions of linearity, perfect divisibility, and an objective function which maximises profit (in this case) where other objectives such as the minimisation of risk and accumulation of wealth could be equally applicable. These issues are unlikely to be of concern in this particular analysis and can be easily overcome through the adoption of techniques such as non-linear programming, mixed integer programming and various risk and stochastic methodologies.

4.2 Previous studies

Parametric linear programming has had substantial applications in the determination of demand functions for irrigation water. However, there has only been limited application of this technique to the determination of supply functions of irrigation water.

Moore and Hedges (1963) applied static linear programming to estimating individual farm demand functions for differing farm sizes in California, USA. The individual farm demand relationships were then aggregated by means of weights based on the distribution of farm sizes in the study area. A regression equation was then fitted and the aggregate demand curve and elasticties of demand were estimated. Gisser (1970) and Gisser and Mercado (1972) used parametric linear programming to estimate demand functions for imported water, as an alternative to depleting groundwater reserves in the Pecos River Basin in the USA. Gisser was able to use these functions to calculate regional incomes from various price scenarios for imported water.

There have been a number of applications of parametric linear programming to estimating the demand for water in Australia. Flinn (1969) used a similar approach to Moore and Hedges (1963) by estimating the regional demand for water by aggregating the demand functions determined from five individual farm linear programming models of Yanco Irrigation Area. An important feature of Flinn's work was the estimation of intra-seasonal as well as seasonal demand functions. Flinn argued that the elasticity of demand for water would differ between the seasons of spring, summer and autumn. More recent studies of the demand for water (Briggs Clark, Menz, Collins and Firth 1986; Chewings and Pascoe 1988; Read Sturgess and Associates 1991) differed significantly to Flinn in that they used regional linear programming models rather than aggregating the results from individual farm level models. Read Sturgess and Associates argue that a regional model, rather than models of representative farms within regions, would be able to capture the essential elements of water demand in the irrigation regions. Briggs Clark *et al* (p8) divided their regional model of the Murrumbidgee irrigated region into four sub-regions, with each sub-region being relatively homogenous. They argued that as "regional consequences are being considered, further dissagregating was not considered a worthwhile addition to model complexity and research time"

Despite the claims made by both Briggs Clark *et al* and Read Sturgess and Associates for adopting regional, as opposed to farm level models, due to the high level of aggregation there is still the very strong possibility of aggregation bias in their studies.

4.3 Study approach

This study has used parametric linear programming to determine the demand functions for irrigation water. OLS regression analysis was applied to the resulting stepped functions to estimate a linear demand function. The function estimated through this normative process is an unconstrained[2] demand function in an unregulated market. The assumption is made that this function is applicable to the condition of a regulated water market. It is difficult to test the validity of this assumption as there is no data, time series or otherwise, to econometrically determine a demand function for water in a regulated market environment

The excess supply functions and demand functions for water, as discussed in section 2, are determined from the estimated demand function for irrigation water for the alternative policy scenarios. The excess supply and demand functions are then incorporated into a spatial equilibrium model to determine the impact upon inter-region trade and economic surplus of different policy scenarios

Regional linear programming models of individual irrigation areas and districts in the Murrumbidgee and Murray Valleys have been developed for this task. Aggregation bias is minimised by using more disaggregated regional models than earlier studies such as Briggs Clark *et al* and Read Sturgess and Associates. For example, where Briggs Clark *et al* used one model of the Murrumbidgee Region this study has developed four separate models (Murrumbidgee Irrigation Area, Coleamabally Irrigation Area, Benerembah Irrigation District and Wah Wah Irrigation District). Furthermore, each of the models are further dissagregated on the basis of soil type and irrigation technology, and in some models on the basis of farming type (e.g. mixed farming versus dairy farming).

[2] The model was solved after relaxing any constraint on the supply of volumetric allocation to the region. Other production resources, such as land, labour and capital, remained constraining.

Individual regional linear programming models were developed for the following irrigation areas and districts in the Murrumbidgee and Murray Valleys:

- Murrumbidgee Irrigation Areas
- Benerembah Irrigation District
- Wah Wah Irrigation District
- Coleamabally Irrigation Area
- Murrumbidgee River private diverters
- Berriquin Irrigation District
- Denimein Irrigation District
- Cadell irrigation region
- Wakool Irrigation District

The main activities represented in the models are lucerne, rice, wheat, oats, barley, soybeans, maize, sorghum, sub-clover, perennial pasture These activities are generally specified as rotations In some models, or for some soil types, enterprises are predominately lucerne and pasture based while for others rice and winter cropping are the major rotational choices.

Other activities represented in the models include livestock, hay making for on-farm use or sale, volumetric water allocation buying and trading, pasture transfers, labour hire and reconciliation's for pasture, labour, watertable recharge and irrigation runoff.

Constraints include soil types, irrigation technologies (landformed, non-landformed, raised beds), various limits to some crops (such as rice) for environmental and administrative reasons, labour, volumetric allocation, off-allocation supplies, diversion/channel capacities, limits to watertable recharge and irrigation runoff, and various pool constraints for labour, pasture and crops, and hay selling.

Further details of the model specification and data used for each of these models can be found in Jones (1991), Wall, Marshall, Jones and Darvall (1994), Curthoys, Marshall and Jones (1994), and Gunaratne, Wall, Marshall and Jones (1995a,b,c).

5. The Spatial Equilibrium Model

There have been few applications of spatial equilibrium analysis to irrigation issues in Australia. Guise and Flinn (1970) developed a model of the Murrumbidgee Irrigation Area of NSW to evaluate pricing and allocation decisions. More recently Hall, Poulter and Curtotti (1994) developed a model of the southern Murray-Darling Basin to examine issues relating to tradable water entitlements. Despite its limited use, spatial equilibrium modelling has significant potential use for problems regarding property rights, environmental allocations, transferability of entitlements and water price reform in the rural water industry.

The spatial equilibrium model is a partial equilibrium approach and is generally solved by quadratic programming (Takayama and Judge 1964). Two alternative specifications of the spatial equilibrium model are presented by Takayama and Judge (1971), the quantity and price formulations. The approach adopted in this study is the price formulation.

The objective function of a mathematical programming model of the spatial equilibrium problem is quadratic. Two alternative specifications for the objective function are the quasi-welfare objective function (Takayama and Judge 1971) and the net social revenue objective function (MacAulay, Batterham and Fisher 1988). The latter specification has been adopted in this study.

Generally a primal-dual form is used for the net social revenue spatial equilibrium model. This simply means that to form the primal-dual objective function the dual objective function is subtracted from the primal and the constraints from both the primal and dual are used. Properly specified this ensures the value of the objective function will be zero at the optimum.

Let i, j denote the regions which compose the discrete but divisible production and consumption locations. Transport costs per unit are expressed as

$t_{ij} \geq 0$, for all i and j

The typical linear demand function will be represented is

(6) $\quad y_i = \alpha_i - \beta_i p_i$, for all i,

where y_i is the quantity demanded in the ith region, p_i is the demand price in the ith region and $\alpha_i > 0$ and $\beta_i > 0$

The typical linear supply function is

(7) $\quad x_i = \theta_i + \gamma_i p'_i$, for all i,

where x_i is the quantity supplied in the ith region, p' is the supply price in the ith region, and $\gamma_i > 0$

These functions can be more compactly expressed in matrix form as

(8) $\quad y = A - BP_y$

(9) $\quad x = \Theta + \Gamma P_x$

For each region it is assumed that the quantity actually consumed, y_i, is less than or equal to the quantity shipped into the region from all supply regions,

(10) $$y_i \leq \sum_{j=1}^{n} x_{ji}$$

where $x_{ji} \geq 0$ is the quantity shipped from the jth to the ith region.

The actual supply quantity, x_i, is assumed to be greater than or equal to the effective supply from region i to all regions

$$(11)\qquad x_i \geq \sum_{j=1}^{n} x_{ij}$$

where $x_{ij} \geq 0$. The objective is to develop a mathematical programming model which will yield a competitive spatial equilibrium and allocation solution. The resulting model is to minimise

$$(12)\qquad Z = -\alpha' p_y + \theta' p_x - p_y' B p_y + p_x' \Gamma p_x + T' X$$

subject to

$$(13)\qquad \begin{bmatrix} \alpha \\ -\theta \\ -T \end{bmatrix} - \begin{bmatrix} \mathrm{B} & & G_y \\ & \Gamma & G_x \\ -G_y' & -G_x' & \end{bmatrix} \begin{bmatrix} \rho_y \\ \rho_x \\ X \end{bmatrix} \leq 0$$

and

$$\left(\rho_y \rho_x X'\right) \geq 0,$$

where

$$\alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_n \end{bmatrix}, \qquad \theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_n \end{bmatrix}, \qquad T = \begin{bmatrix} t_{11} \\ t_{12} \\ \vdots \\ t_{nn} \end{bmatrix},$$

$$\mathrm{B} = \begin{bmatrix} \beta_1 & & & \\ & \beta_2 & & \\ & & \ddots & \\ & & & \beta_n \end{bmatrix}, \qquad \Gamma = \begin{bmatrix} \gamma_1 & & & \\ & \gamma_2 & & \\ & & \ddots & \\ & & & \gamma_n \end{bmatrix},$$

$$G_y = \begin{bmatrix} 1 & & & 1 & & & & 1 & & \\ & 1 & & & 1 & & & & 1 & \\ & & \ddots & & & \ddots & \cdots & & & \ddots \\ & & & 1 & & & 1 & & & & 1 \end{bmatrix},$$

$$G_x = \begin{bmatrix} -1 & -1 & \cdots & -1 & & & & & & & \\ & & & & -1 & -1 \cdots & -1 & & & & \\ & & & & & & & \ddots & & & \\ & & & & & & & & -1 & -1 & \cdots & -1 \end{bmatrix}.$$

In addition to the standard spatial equilibrium model specification a number of specific constraints and dual variables to the problem have been included.

For each region the actual supply from region i to all regions cannot exceed the volumetric allocation in that region,

$$(14) \quad \sum_{j=1}^{n} x_{ij} \leq V_i$$

where $x_{ij} \geq 0$ and V_i is the volumetric allocation limit for region i

As outlined in section 2, the supply commodity is the quantity of water *exported* from region i while the demand quantity is the quantity of water *imported* into region i. Therefore, as the model is dealing with excess supply and excess demand curves which cannot intersect and there is no equilibrium conditions within a region, the following constraint is included to exclude within region trade and force trade to only occur between regions[3],

$$(15) \quad \sum_{j=1}^{n} x_{ii} \leq 0$$

Ten regions are included in the model, nine irrigation and one environment region where

Region 1 = Murrumbidgee Irrigation Areas (MIA)
Region 2 = Benerembah Irrigation District
Region 3 = Wah Wah Irrigation District
Region 4 = Coleamabally Irrigation Area
Region 5 = Murrumbidgee River private diverters
Region 6 = Berriquin Irrigation District
Region 7 = Denimein Irrigation District
Region 8 = Cadell irrigation region
Region 9 = Wakool Irrigation District
Region 10 = Environment

The DLWC advised that no account of transmission losses is made for trade within the Murrumbidgee Valley, within the Murray Valley and between the Murrumbidgee and Murray Valleys. No trade is allowed to occur from the Murray to Murrumbidgee Valley for hydrological reasons.

An administrative transfer fee, at $75 per lodgement regardless of size (DLWC, personal communication), applies to permanent and temporary applications. 30 transfers (both temporary and permanent) took place in the Murrumbidgee Valley in

[3] The linear programming solutions for estimating demand for irrigation water endogenously account for within region trade that may take place.

1993-94 totalling 14,832 megalitres (Department of Water Resources 1994). This resulted in an average transfer cost of $0.15 per megalitre. In the Murray Valley 83 transfers of 24,441 megalitres took place at an average transfer cost of $0.25 per megalitre.

6. Results

The study determined seasonal and intra-seasonal demand functions for irrigation water in each irrigation region in southern NSW. Using these functions as input data in the spatial equilibrium model the impact of environmental allocation policies on irrigated agriculture in the Murrumbidgee and Murray Valley's was estimated. The results are separately reported in the following two sections.

6.1 Estimation of demand and supply functions

The seasonal and intra-seasonal stepped derived demand functions for irrigation water for the nine irrigation regions are presented in Appendix 1. The derived demand functions, almost without exception, illustrate that total seasonal demand is highly inelastic for a certain price range, as measured by the arc elasticity of demand, e.g. $0 to $25 in the Murrumbidgee Irrigation Area, $0 to $45 in Coleambally Irrigation Area and $0 to $35 in Berriquin Irrigation District. In all regions the elasticity of demand becomes progressively more elastic as the price of water increases.

The pattern to intra-seasonal demand for irrigation water and arc elasticities of demand is similar to that for total seasonal demand. Generally, demand for irrigation water is greatest in summer, followed by spring and then autumn. Wah Wah Irrigation District is the only region that differed from this pattern with autumn demand exceeding spring for prices up to $37 per megalitre.

OLS regression analysis was used to fit linear functions to the stepped derived demand functions. The resulting estimated linear demand functions, along with the adjusted R^2 and volumetric allocation for each region, are presented in Table 1. The adjusted R^2 indicates that the linear functions are a reasonable fit of the data, with the exception of the Murrumbidgee River private diverters, Wakool and Denimein. A visual observation of the data for these three regions suggests that either exponential, log or power functions would provide a better fit than a linear regression. However, a linear regression was used given the need for linear supply and demand functions at this stage in the spatial equilibrium model.

The excess demand and excess supply functions determined from the estimated linear demand functions for irrigation water are presented for two differing volumetric allocation availability scenarios in Tables 2 and 3. These functions are derived from equations (4) and (5) and correspond to policy scenarios 1 and 2 in section 3. Note that only the intercept values change for the differing policy scenarios with the slopes remaining the same (except for sign changes) as explained with equations (4) and (5).

Table 1: Estimated seasonal demand functions for irrigation water and volumetric allocation (price form)

Region	Volumetric allocation (ML)	Intercept (ML)	Slope (ML)	Adjusted R^2
MIA	660,945	937,769	-9,294	0.80
Benerembah	228,073	313,943	-3,259	0.86
Wah Wah	116,279	222,812	-3,300	0.81
CIA	446,699	632,442	-7,258	0.83
Private Diverters	600,008	1,231,885	-13,878	0.73
Berriquin	676,296	1,541,013	-17,491	0.91
Denimein	83,900	231,895	-2,222	0.58
Cadell	276,747	589,858	-9,780	0.95
Wakool	254,307	471,849	-5,802	0.77

Table 2: Estimated excess demand and excess supply functions at 118% and 116% volumetric allocation availability for the Murrumbidgee and Murray Valleys (price form)

	TWE demand function		Excess supply function	
Region	Intercept (ML)	Slope (ML)	Intercept (ML)	Slope (ML)
MIA	157,854	-9,294	-157,854	9,294
Benerembah	44,817	-3,259	-44,817	3,259
Wah Wah	85,603	-3,300	-85,603	3,300
CIA	105,337	-7,258	-105,337	7,258
Private Diverters	523,876	-13,879	-523,876	13,878
Berriquin	756,509	-17,491	-756,509	17,491
Denimein	134,571	-2,222	-134,571	2,222
Cadell	268,831	-9,780	-268,831	9,780
Wakool	176,853	-5,802	-176,853	5,802

Table 3: Estimated excess demand and excess supply functions at 95.4% and 93.8% volumetric allocation availability for the Murrumbidgee and Murray Valleys (price form)

	TWE demand function		Excess supply function	
Region	Intercept (ML)	Slope (ML)	Intercept (ML)	Slope (ML)
MIA	307,102	-9,294	-307,102	9,294
Benerembah	96,318	-3,259	-96,318	3,259
Wah Wah	111,860	-3,300	-111,860	3,300
CIA	206,206	-7,258	-206,206	7,258
Private Diverters	659,364	-13,878	-659,364	13,878
Berriquin	906,647	-17,491	-906,647	17,491
Denimein	153,197	-2,222	-153,197	2,222
Cadell	330,269	-9,780	-330,269	9,780
Wakool	233,309	-5,802	-233,309	5,802

6.2 Estimation of environmental allocation scenarios

As discussed in section 3 the results derived from the spatial equilibrium analysis must be considered as demonstrative given the assumptions made for a number of key parameters, in particular the reduction in water allocations as a consequence of environmental allocations.

The spatial equilibrium model was solved for the three policy scenarios presented in section 3 using the data presented in Tables 2 and 3. The results of this analysis is presented in Tables 4, 5 and 6. Illustrated in Table 4 is (for the i-th region where i=1, ...10) the supply price for TWE in each region (SPi), the demand price for TWE water in each region (DPi), the level of exports of water from each region (Xi), the level of imports of TWE into each region (Yi), and the volumes of TWE water traded between regions (Xij)

In the base scenario the value of TWE water is $31 per megalitre. The major exporters are the MIA, Coleambally, Benerembah, Cadell and Wah Wah. The major importers are Berriquin, private diverters and Denimein

In scenario 2, where environmental allocations are met from a uniform reduction in the availability of volumetric allocation, the value of TWE water will increase by around $10 per megalitre due to the greater scarcity of the resource. The major importers and exporters are the same, however, the volume of trade is reduced by 12 per cent from 363,630 megalitres to 319,338 megalitres.

In the third scenario where the environment has a fixed demand but has to purchase its requirements from the market place, the price of TWE water increases by $10 per megalitre from the base scenario. The pattern of trade is significantly affected with the MIA, Coleambally, Cadell, Benerembah, Wakool private diverters and Wah Wah exporting substantial volumes of water. Imports of TWE water by Berriquin is dramatically reduced as a consequence of the environment's fixed demand, while the private diverters region has moved from an importer to an exporter of water.

The economic welfare implications of each of the options for the two catchments and each of the regions is presented in Tables 5 and 6. This information indicates that there is a 12 per cent decline in economic surplus in the region (from $192.200 million to $168.505 million) associated with scenario 2. In scenario 3 if a market based system was introduced, whereby the environment was required to purchase water, the opportunity cost to irrigated agriculture is significantly less with a 4 per cent decline in economic surplus (from $192.200 million to $183.777 million).

There are, however, significant distributional consequences among the regions associated with these options. It is illustrated in Table 6 that higher losses in economic surplus are associated with scenario 2 than scenario 3 in all the regions studied.

Table 4: Results from spatial equilibrium analysis

	Scenario 1	Scenario 2	Scenario 3
SP1	31.09	41.47	41.49
SP2	31.09	41.47	41.49
SP3	31.09	41.47	41.49
SP4	31.09	41.47	41.49
SP5	-	-	41.49
SP8	31.09	41.47	41.49
SP9	31.09	41.47	41.49
DP5	31.24	41.62	-
DP6	31.34	41.72	41.74
DP7	31.34	41.72	41.74
DP10	-	-	41.49
X1	131,078	78,261	227,775
X2	56,497	38,810	90,404
X3	16,991	24,975	51,326
X4	120,310	94,750	195,826
X5	-	-	52,001
X8	35,214	75,252	136,969
X9	3,539	7,290	63,911
Y5	90,319	81,801	-
Y6	208,364	177,017	26,381
Y7	64,947	60,521	41,832
Y10	-	-	750,000
X15	-	49,405	-
X16	66,131	28,857	-
X17	64,947	-	-
X110	-	-	227,775
X25	50,497	-	-
X26	-	38,810	-
X27	-	-	10,696
X210	-	-	79,708
X35	16,991	15,282	-
X36	-	9,693	-
X310	-	-	51,326
X45	16,830	17,115	-
X46	103,479	17,115	-
X47	-	60,521	-
X410	-	-	195,826
X510	-	-	52,001
X86	35,214	75,252	26,381
X87	-	-	29,634
X810	-	-	80,954
X96	3,539	7,290	-
X97	-	-	1,501
X910	-	-	62,410

Table 5: Economic surplus results of alternative policy scenarios ($ million)			
	Scenario 1	Scenario 2	Scenario 3
Consumer surplus	189.680	166.937	175.283
Producer surplus	2.519	1.568	8.495
Total surplus	192.200	168.505	183.777
Change in surplus		-23.695	-8.422

Table 6: Economic surplus results of alternative policy scenarios for each region ($ million)			
	Consumer surplus	Producer surplus	Total surplus
Scenario 1			
MIA	34,561,848	924,376	35,486,224
Benerembah	11,591,106	489,746	12,080,852
Wah Wah	4,821,285	43,743	4,865,027
CIA	20,784,593	997,137	21,781,730
Private diverters	40,859,113	-	40,859,113
Berriquin	45,172,449	-	45,172,449
Denimein	8,034,252	-	8,034,252
Cadell	10,295,529	63,399	10,358,929
Wakool	13,559,962	1,080	13,561,041
Scenario 2			
MIA	32,291,119	329,521	32,620,640
Benerembah	10,675,511	231,099	10,906,611
Wah Wah	3,894,119	94,510	3,988,629
CIA	18,656,514	618,465	19,274,980
Private diverters	35,838,143	-	35,838,143
Berriquin	39,142,644	-	39,142,644
Denimein	6,883,321	-	6,883,321
Cadell	7,596,709	289,542	7,886,251
Wakool	11,958,838	4,582	11,963,420
Scenario 3			
MIA	32,283,504	2,791,250	35,074,754
Benerembah	10,672,513	1,253,978	11,926,491
Wah Wah	3,891,083	399,153	4,290,236
CIA	18,649,593	2,641,784	21,291,377
Private diverters	38,814,845	97,419	38,912,264
Berriquin	43,951,226	-	43,951,226
Denimein	7,478,753	-	7,478,753
Cadell	7,587,655	959,155	8,546,811
Wakool	11,953,359	351,981	12,305,341

7. Summary

This paper has outlined both theoretical and empirical frameworks for evaluating trade in irrigation water and to measure the impact of environmental allocations upon irrigated agriculture. The study first estimated a number of seasonal and intra-seasonal demand functions for irrigation water in nine regions in southern NSW. This illustrates that the demand for irrigation water is highly inelastic up to water prices of between $15 and $50 per megalitre depending upon the individual region. The study also revealed that there are differences in the intra-seasonal demand for irrigation water with demand in summer being greatest followed by spring and autumn. Although not reported in the paper the arc elasticities of demand for intra-season demand showed a similar trend to seasonal arc elasticities of demand at particular price points within a region.

OLS regression analysis was used to determine linear demand functions for irrigation water for each region. From these functions excess demand and excess supply functions were determined for various policy scenarios. The resulting functions were then incorporated into a spatial equilibrium model to determine the impact upon irrigated agriculture of various hypothetical environmental allocation policies. It was found that a policy of uniformly reducing water availability to all users to meet a 750,000 megalitre environmental allocation in the Murrumbidgee and Murray Valley's would reduce economic surplus in the region by 12 per cent. An alternative environmental allocation policy, whereby the environment purchased it requirements from a TWE market, resulted in a 4 per cent decline in economic surplus.

Despite the spatial equilibrium analysis being of a hypothetical nature a number of significant implications can be drawn. First, forcing the environment to obtain its water requirements through a market mechanism may be a more economically efficient outcome than imposing a uniform reduction in water availability to all irrigation users as it encourages the lowest value agricultural uses of water to gravitate to environmental uses. It is therefore likely to experience the least social opportunity cost. Second, such an approach automatically deals with issues of compensation given the fairness of the market. It is probable that irrigators adversely affected by a reduction in water availability so as to meet environmental allocations will seek compensation for financial losses incurred. If these actions go through the court system it may lead to a lengthy and costly resolution process. Finally, the question of who pays for the water on behalf of the environment requires resolution. In this hypothetical example the cost of obtaining the environments fixed requirement is $31.1 million (750,000 megalitres at $41.49 per megalitre). The application of scenario 2 implies that the irrigation industry pays for the introduction of environmental allocations while scenario 3 implies the general community, or more likely taxpayers, bear the financial responsibility.

In summary, the question of property rights in the NSW water industry requires to be properly addressed. Only through the introduction and application of a more comprehensive property right structure for water than currently exists can these complex resource allocation problems be addressed. It is also probable that the market has a greater role in this process than water supply authorities have yet allowed it to play.

References

Briggs Clark, J., Menz, K., Collins, D. and Firth, R. (1986), A model for determining the short term demand for irrigation water, BAE Discussion Paper 86.4. AGPS, Canberra.

Chewings, R.A. and Pascoe, S. (1988), Demand for water in the Murray Valley, New South Wales: An application of linear programming, Paper presented to the 32nd Annual Conference of the Australian Agricultural Economics Society, Melbourne, February.

Curthoys, C., Marshall, G. and Jones, R. (1994), Coleambally Land and Water Management Plan Economics of On-farm Proposals, A Report to the Community Working Group of the Coleambally Land and Water Management Plan.

Dent, J.B., Harrison, S.R. and Woodford, K.B. (1986), Farm Planning with Linear Programming: Concept and Practice, Butterworths, Sydney.

Eigenraam, M., Jones, R., Sappideen, B. and Stoneham, G. (1996), 'Water policy reform in Victoria' Paper presented at the 40th Conference of the Australian Agricultural and Resource Economics Society, University of Melbourne, February.

Flinn, J.C. (1969), 'The demand for irrigation water in an intensive irrigation area', Australian Journal of Agricultural Economics 13(2), 128-43.

Gisser, M. (1970), 'Linear programming models for estimating the agricultural demand function for imported water in the Pecos River basin', Water Resources Research 6(4), 1025-32.

______ and Mercado, M. (1972), 'Integration of the agricultural demand function for water and the hydrogeological model of the Pecos basin', Water Resources Research 8(6), 1373-84.

Guise, J.W. and Flinn, J.C. (1970), 'The allocation and pricing of water in a river basin', American Journal of Agricultural Economics 52(2), 411-421.

Gunaratne, N., Wall, L., Marshall, G. and Jones, R. (1995a), Economics of On-Farm proposals: A report to the Community Working Group of the Cadell Land and Water Management Plan, Economic Services Unit, September.

______ (1995b), Economics of On-Farm proposals: A report to the Community Working Group of the Denimein Land and Water Management Plan, Economic Services Unit, September.

______ (1995c), Economics of On-Farm proposals: A report to the Community Working Group of the Wakool Land and Water Management Plan, Economic Services Unit, September.

Hall, N., Poulter, D. and Curtotti, R. (1994), ABARE Model of Irrigation Farming in the Southern Murray-Darling Basin, ABARE Research Report 94.4, Canberra.

Hardaker, J.B. (1971), Farm Planning by Computer, Technical Bulletin 19, Ministry of Agriculture, Fisheries and Food, London.

Howe, C.W. (1990), 'An analytical framework for water transfers'. In J.J. Pigram and B.P. Hooper (ed.) Transferability of Water Entitlements, Proceedings of an international seminar and workshop, University of New England, Armidale, 4th-6th July.

Industry Commission (1992), Water Resources and Waste Water Disposal, Draft Report, Canberra.

Jones, R.E. (1991), Optimal irrigation water allocation and supply reliability in the Murrumbidgee Valley, unpublished M.Econ dissertation, Department of Agricultural Economics and Business Management, University of New England, Armidale.

MacAulay, T.G., Batterham, R.L. and Fisher, B.S. (1988), Cubic programming and the solution of spatial trading systems, Paper presented to the 32nd Annual Conference of the Australian Agricultural Economics Society, Melbourne, February.

Moore, C.V. and Hedges, T.R. (1963), 'A method for estimating the demand for irrigation water', Agricultural Economics Research Vol. 15, 131-135.

Pigram, J.J. and Musgrave, W.F. (1990), 'Transferability of water entitlements in Australia', Regulated Rivers: Research and Management Vol. 5, 391-399.

Randall, A. (1981), 'Property entitlements and pricing policies for a maturing water economy', Australian Journal of Agricultural Economics 25(3), 195-220.

Read Sturgess and Associates (1991), Derivation of economic demand schedules for irrigation water in Victoria. Executive Summary, Water Resource Management Report Series, State Water Resource Plan, Department of Conservation and Environment - Victoria, August.

Takayama, T. and Judge, G.G. (1964), 'Equilibrium among spatially separated markets: A reformulation', Econometrica 32, 510-24.

______ (1971), Spatial and Temporal Price Allocation Models, North-Holland Publishing Co., Amsterdam.

Wall, L., Marshall, G., Jones, R. and Darvall. D. (1994), Economics of on-farm proposals: Berriquin Land and Water Management Plan, A Report to the Berriquin Community Working Group.

APPENDIX

Figure 4: Derived demand schedules for irrigation water in the Murrumbidgee Irrigation Areas

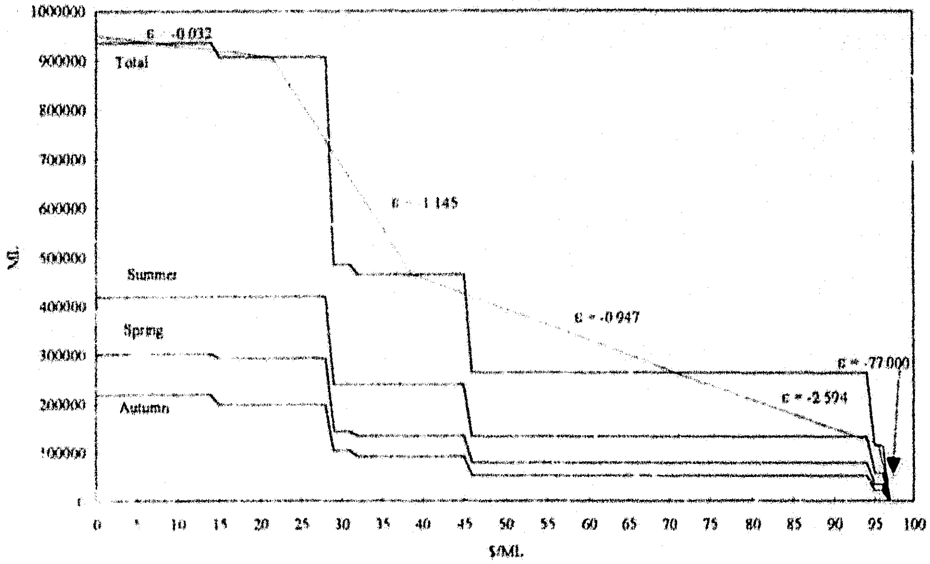


Figure 5: Derived demand schedules for irrigation water in Benerembah Irrigation District

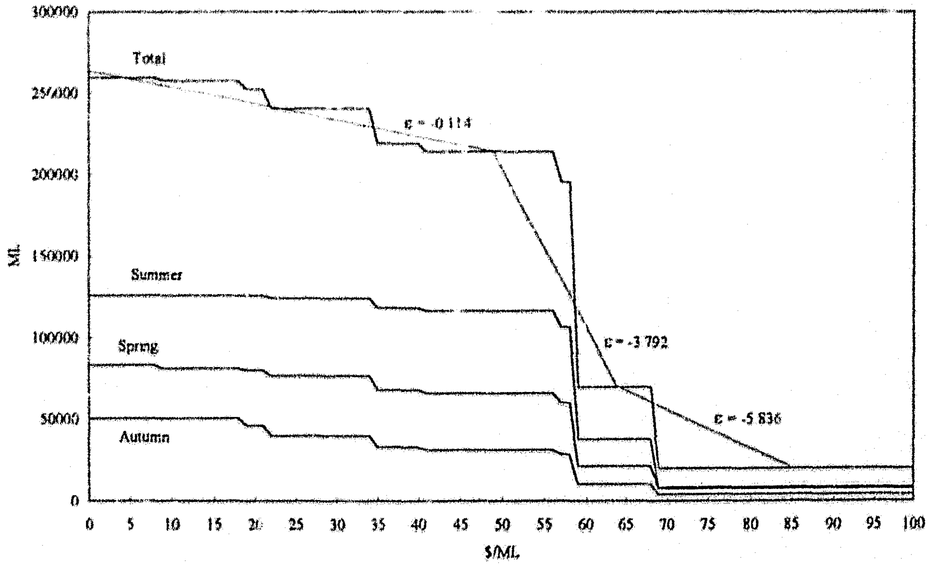


Figure 6: Derived demand schedules for irrigation water in Wah Wah Irrigation District

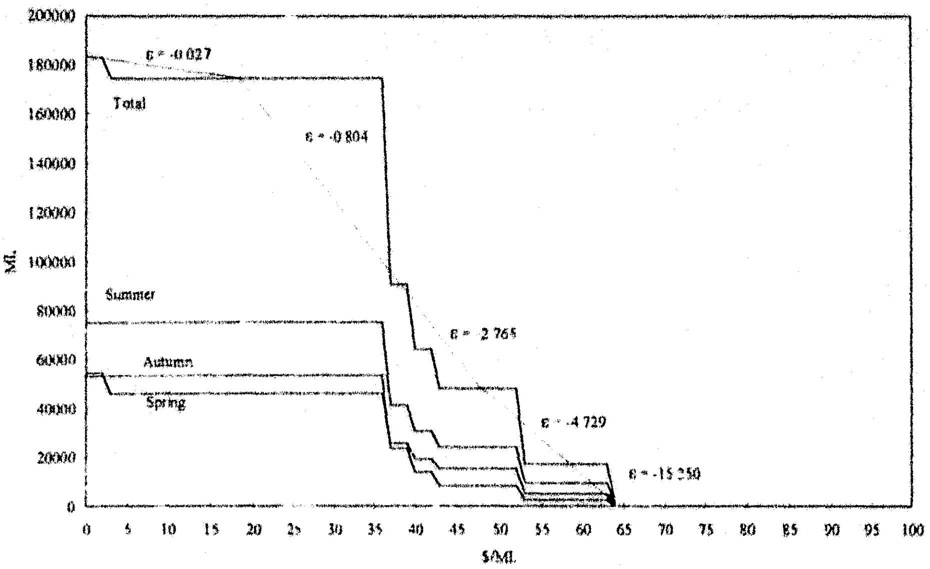


Figure 7: Derived demand schedules for irrigation water in Coleambally Irrigation Area

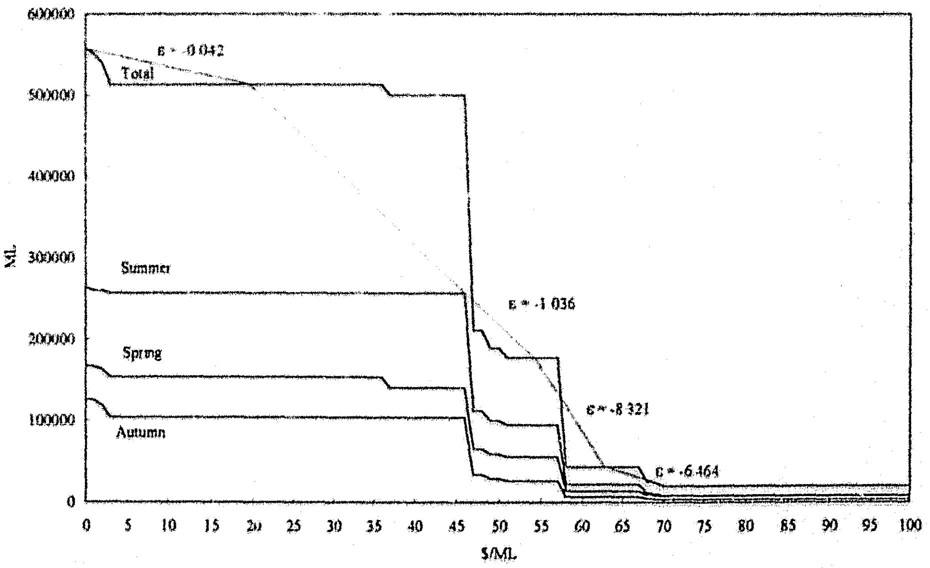


Figure 8: Derived demand schedules for irrigation water in the Murrumbidgee River private diverters

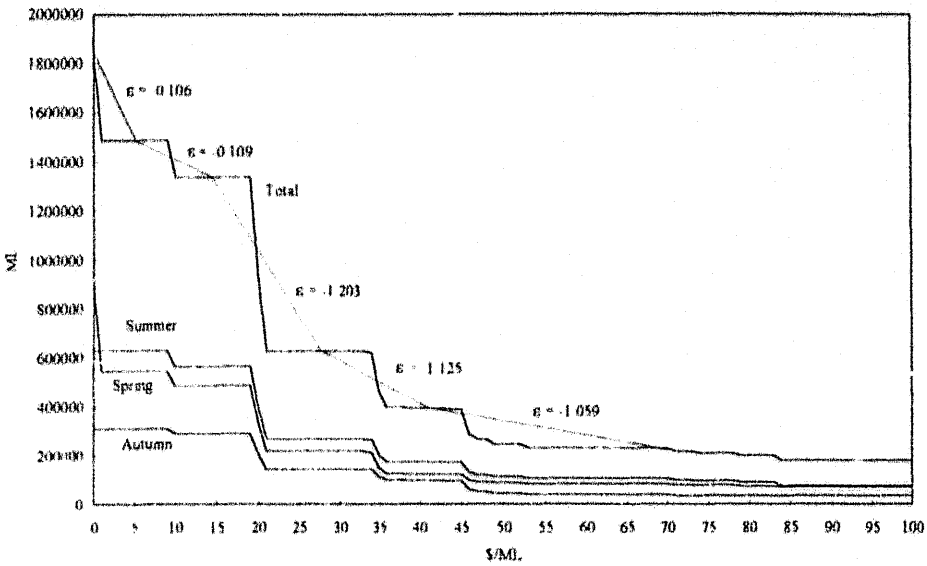


Figure 9: Derived demand schedules for irrigation water in Berriquin Irrigation District

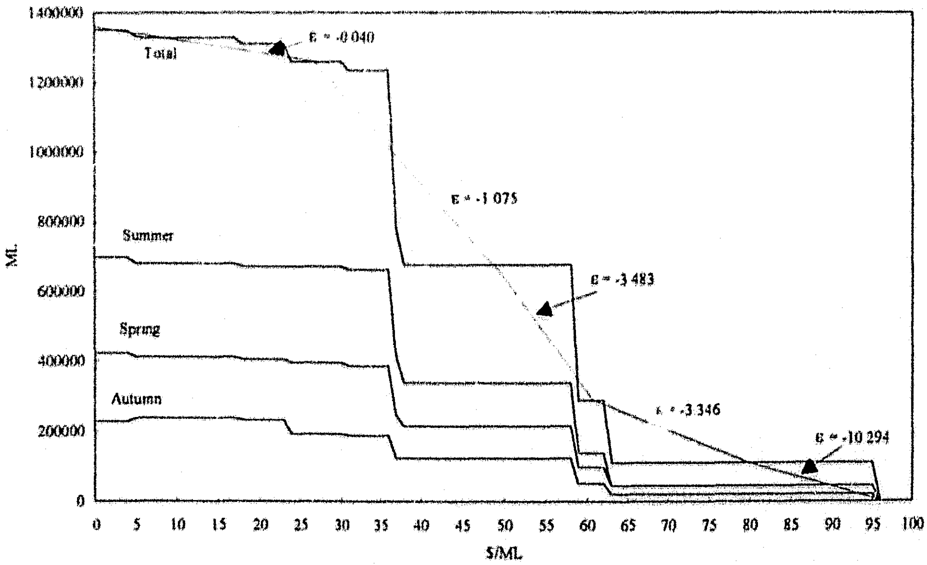


Figure 10: Derived demand schedules for irrigation water in Denimein Irrigation District

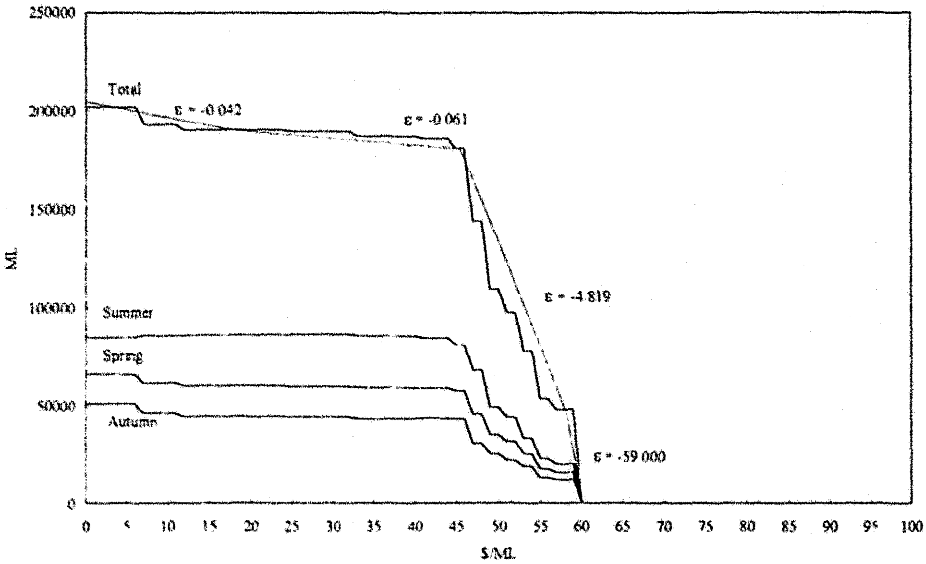


Figure 11: Derived demand schedules for irrigation water in Cadell irrigation region

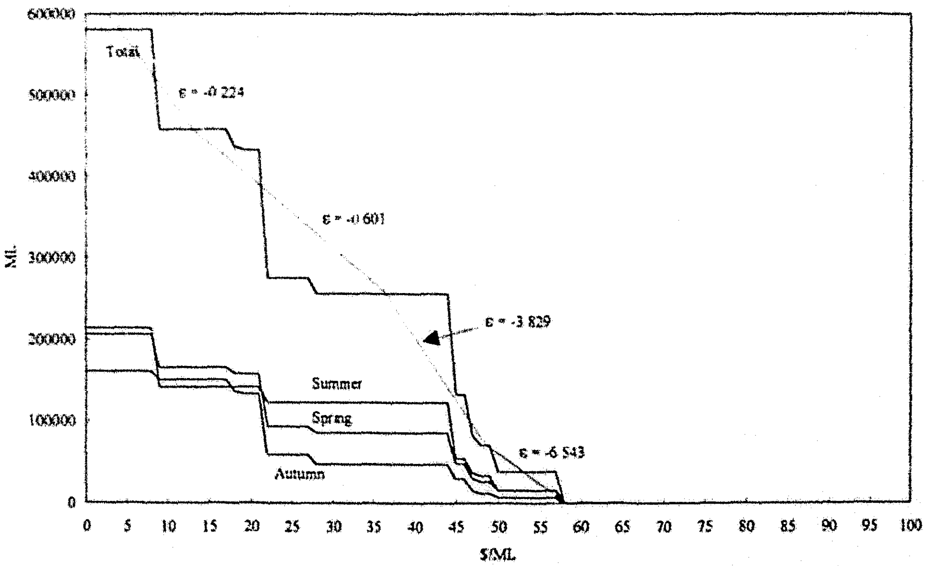


Figure 12: Derived demand schedules for irrigation water in Wakool Irrigation District